Wheat Production and Improvement in the Sudan

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Foreword

Demand for wheat in the Sudan was low in the past because the diet of the majority of the Sudanese population was based mainly on sorghum. Over time, wheat consumption increased considerably due to urbanization and the rising population, while wheat yields remained considerably low. The country's strive for self-sufficiency has been associated with area expansion and productivity enhancement through the development and transfer of technology to farmers.

To solve the constraints facing wheat production and to transfer technology to the farmers, the Nile Valley Regional Program (NVRP) has been established in 1988/89 as a collaborative program involving the Agricultural Research Corporation (ARC) and the International Center for Agricultural Research in the Dry Areas (ICARDA) with financial support from the Netherlands through the Directorate General for International Cooperation (DGIS) of the Ministry of Foreign Affairs. Because of its impact, NVRP was extended for a second three-year phase (1991/92–1993/94) after the conclusion of its first phase in 1990/91. An external review mission, organized by the donor, the Netherlands, in 1993, highly commended the impact of NVRP on technology development and transfer to the farmers, in addition to institutional development and capacity building in the Sudan. As a result of the Review Mission Report, NVRP was extended to 1994/95. Regional cooperation with the other partners in the program, Egypt and Ethiopia, to solve common problems through complementary research, has also been effectively developed through NVRP to utilize the scarce human and physical resources available to the national programs.

The Wheat Program has the overall objective of developing improved technologies and transferring them to the farmers to enhance productivity and yield stability of wheat, with due consideration to the sustainability of the farming systems under which this crop is produced. As partners, ICARDA and CIMMYT/ICARDA program collaborate with the Sudan in the development of research workplans, technical backstopping, the provision of germplasm and training opportunities, and contribute to research coordination at national and regional levels. CIMMYT-Mexico also provides adapted wheat germplasm and technical backstopping, particularly in heat tolerance research. The direct program implementation, leadership and reporting are undertaken by the national scientists.

The NVRP is considered a major milestone in wheat improvement and technology transfer to farmers in the Sudan. High and profitable wheat yields of demonstration fields have encouraged pursuing the endeavors for self-sufficiency. The 1991/92 crop season witnessed high vertical expansion when production was enough to cover domestic needs for the first time. Adoption levels of improved wheat technology components in various production areas were substantial, resulting in a rising trend of wheat production. These and other achievements within the NVRP were documented in this publication.

Based on its positive impact and output, NVRP is considered a highly successful model for tripartite cooperation involving the ARC, representing the Sudan's national agricultural research system; ICARDA as an international center; and the Netherlands as the donor. This document clearly illustrates the fruits of this effective cooperation and the substantial payoff of the investment in agricultural research. The financial support of the Netherlands Government is greatly acknowledged. Without such support, the impact on technology development and transfer in the Sudan would have been rather limited.

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Preface

Wheat production in the Sudan started thousands of years ago on the fertile soils of the banks of the River Nile in an area which now administratively falls in the Northern and Nile River states. Since the early 1960s, wheat production started to spread southwards and the crop is now also cultivated in the central plains of the country at lat. 14–15°N, where there is plenty of land and water available. This expansion of wheat cultivation into areas beyond its general adaptation has been necessitated by the ever-increasing demand for wheat arising from changes in the eating habits of the Sudanese people.

Before 1965, there was little research on wheat in these nontraditional areas except for some yield trials and agronomic experiments at the Gezira Research Station of the Agricultural Research Corporation (ARC). During the period 1965–1985, research work expanded to include disciplines such as entomology. However, the work was still confined to the research station. The success achieved through on-farm research in the Nile Valley Project on Faba Beans in the period 1979–1985 encouraged the wheat researchers to expand the scope of their work by going out to farmers' fields. The resources made available under the ARC/ICARDA/OPEC Fund Pilot Project permitted them to start some on-farm research to develop wheat production technology for different production conditions. With the beginning of the Nile Valley Regional Program (NVRP) on Cool-Season Food Legumes and Wheat, funded by the Netherlands Government, on-farm research on wheat was intensified following a multidisciplinary approach. Back-up research, technology transfer and capacity building were other components of the NVRP, which operated from 1988/89 to 1994/95. The on-farm and back-up research done during the NVRP period are considered a landmark in wheat research in the Sudan, as they were instrumental in resolving constraints to wheat production not only in the traditional but also in nontraditional areas, leading to substantial improvement in the production of this important crop.

Although the wheat research carried out under the NVRP during the period 1988/89–1994/95 has been reported in the annual reports of the Program, a collective review and documentation of the results will serve as a reference and base for any future research. Accordingly, a National Research Review Workshop was organized at the ARC in Wad Medani, from 27 to 30 August 1995, to review the research accomplishments of the Program and to develop guidelines for future research.

This volume presents the proceedings of that Review Workshop. We would like to thank the ARC scientists and the administration for their dedicated efforts in the Program.

The Workshop and the publication of these Proceedings have been generously funded by the Netherlands Government, to whom we are greatly indebted. We thank Dr. Hala Hafez, the production editor of this publication, for her long hours of work inputting the material together and seeing it through to publication.

The Editors

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Introduction

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Wheat is the second most important cereal crop in the Sudan after sorghum. As a single crop, it occupies the largest area in irrigated schemes. Wheat consumption in the Sudan has been sharply increasing, from about 220,000 tons in 1970/71 to over 800,000 tons in 1990/91, both due to population growth and rising per capita consumption. The bulk of wheat consumption is in urban areas, though the rate is lower.

Average yields are generally low as affected by many production and environmental factors. However, with continual research and technology transfer, notable improvements have been achieved. Wheat yields increased from an average of 1.2 t/ha in 1975/76–1985/86 to 1.5 t/ha in 1986/87–1993/94. Due to both area expansion and yield improvement, annual wheat production increased from an average of 200,000 tons in 1986/87–1988/89 to an average of about 600,000 tons in 1991/92–1993/94.

Many factors are known to affect the productivity of wheat in its main growing areas in the Sudan. Generally classified, these factors include weather, cultivars and sowing dates; crop establishment practices; crop nutrition and irrigation; harvesting practices; and biological factors. The short wheat growing season (90–100 days) and the excessively high temperatures at early and late crop growth stages contribute greatly to the low wheat productivity. Thus, developing heat-tolerant wheat cultivars and optimizing the sowing date are of paramount importance in determining the final productivity of the crop.

Wheat is a crop of temperate origin but its cultivation in the Sudan has recently expanded into latitudes lower than 15°N as a winter crop. The minimum temperature for wheat growth is about 3–4°C, the optimum about 25°C and the maximum about 30–32°C. Thus, producing wheat in the Sudan, where relatively high temperatures prevail at critical growth stages, poses a challenge to agricultural research.

Wheat production in the Sudan is fully mechanized. For farmers to obtain high yields and make profits, machinery has to be efficiently used and managed. Irrigation water and irrigation practices are factors which have always limited wheat productivity. The adoption of fertilizer recommendations is variable and moderate mainly due to the limited availability of inputs and their high costs. The recommended number of waterings and irrigation regimes at the vegetative and reproductive stages need to be applied for better yield.

Besides the abiotic stresses, wheat is attacked annually by a number of insect pests. The severity of the attacks is governed mainly by the prevailing climatic conditions, most importantly temperature. Disease surveys revealed that the only important diseases on wheat in the Sudan are rust diseases, prevalent in New Halfa. Weather conditions during the wheat season, particularly temperature and humidity, are conducive to stem rust disease development. Studies on weed competition showed that unrestricted weed growth and delayed weeding reduced wheat yield.

The Nile Valley Regional Program (NVRP) has been established as a collaborative program involving the Agricultural Research Corporation (ARC) in the Sudan and the International Center for Agricultural Research in the Dry Areas (ICARDA) with financial support from the Netherlands Government. The NVRP Wheat Program in the Sudan has the overall objective of developing improved technologies and transferring them to the farmers to enhance productivity and yield stability of wheat with due consideration to the sustainability of the farming systems under which this crop is produced.

NVRP research workplans are jointly prepared by the ARC and ICARDA while program implementation, leadership and reporting are done by the ARC scientists. ICARDA provides technical backstopping, germplasm, provisions for training and capacity building, and contributes to research management and coordination at the national and regional levels. The CIMMYT/ICARDA program and CIMMYT-Mexico also provide technical backstopping and germplasm. The NVRP methodology is implemented in three overlapping research phases. Under the first—back-up research—activities cover gaps in applied research knowledge. New areas of research are explored as well as research to resolve constraints facing the adoption of new technologies by farmers. In the second—on-farm researcher-managed trials—experiment station research findings are evaluated under actual farm conditions. The organization and management of these trials remain with the national scientists, while the supervision is shared between scientists and extension workers. Treatments that provide larger economic returns than those traditionally obtained by farmers are included in the third phase—farmer-managed demonstrations. In this phase, the technologies tested successfully on farms are demonstrated to farmers in large pilot production fields which the farmers lay out with advice from researchers and extensionists.

Because of its impact, the NVRP has extended for seven years between 1988/89 to 1994/95 through the continuous support of the Netherlands. This document presents a review of the research conducted in the Sudan within the NVRP during the last decade on the production and improvement of wheat and the transfer of the recommended technologies to farmers. Achievements and some future directions and strategies for further work are also highlighted.

Chapter 1
Wheat Production in the Sudan

Production Situation and Economic Aspects

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Abstract

The Sudan's wheat situation is characterized by rapid growth in consumption, continuous and variable deficit between domestic needs and local production, uncertain estimates of actual wheat demand due to quota and price controls, continuous efforts for attaining self-sufficiency through a policy-driven production strategy, and intensive research for better crop adaptation and higher productivity. Technology development and government support have notably enhanced wheat production and improved self-sufficiency since the mid-eighties. Coverage of domestic needs in 1992, though not sustainable in subsequent years, was yet a big achievement. Despite its generally lower financial profitability than other rotational crops, wheat efficiently utilizes winter resources of land, water and labor. Yet, its yields need to be raised for a better comparative advantage in the use of domestic resources, if its area is to be expanded. Current average wheat yields are quite variable and are substantially lower than the potential. Space variability, induced by confounded effects of location, management and farmers' preferences, calls for some level of specialization and vertical increase in production in contrast to the current area expansion strategies. If augmented with appropriate policy and institutional incentives, the high economic potential that wheat enjoys in the irrigated sector would be better exploited.

Status of Wheat Consumption and Production

Wheat demand was limited prior to the 1960s, being mostly in northern Sudan and largely met by sustained domestic production in that traditional consumption area. Demand has, however, increased over time in urban areas to magnitudes that could no longer be satisfied by local production. Moreover, wheat consumption has gradually shifted to many rural areas, induced by a substantial shift in consumption habits away from the traditionally used sorghum. The sharp trend in wheat consumption is depicted in Fig. 1 which shows the expansion of consumption from a little over 220,000 tons in 1970/71 to over 800,000 tons in 1990/91. Although population growth is partly responsible for that increase, much of the increase, which was encouraged by highly subsidized bread prices, is attributable to rising per capita demand, especially in urban areas. Average per capita consumption per year rose from 10.5 kg in 1960 to about 33 kg in 1993 (Fig. 2).

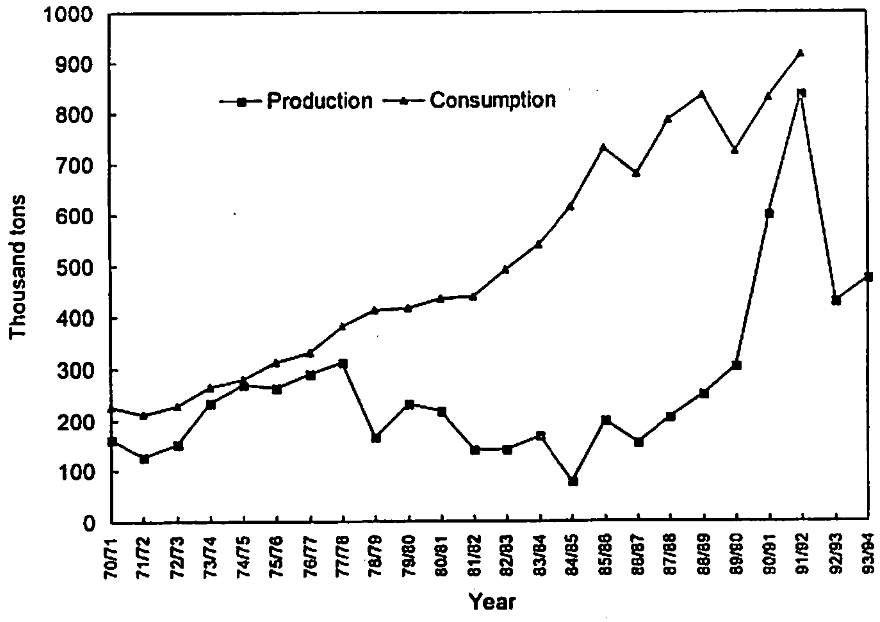

Fig. 1. Wheat production and consumption in the Sudan, 1970/71-1993/94 (Ministry of Finance and Economic Planning, Economic Survey; Statistics of the Ministry of Agriculture).

Quantitative restrictions and rationing of consumption have slowed growth in demand in the past, thus improving self-sufficiency (Hassan *et al.* 1994). During the 1980s, high growth in wheat consumption was maintained through low consumer prices induced by food aid, overvalued currency and direct subsidies (Hassan *et al.* 1991; Damous 1986; Hassan and Faki 1993). Removal of consumer subsidies on wheat bread in later years has also worked in a similar direction to reduce the quantities demanded in the face of increasing bread prices.

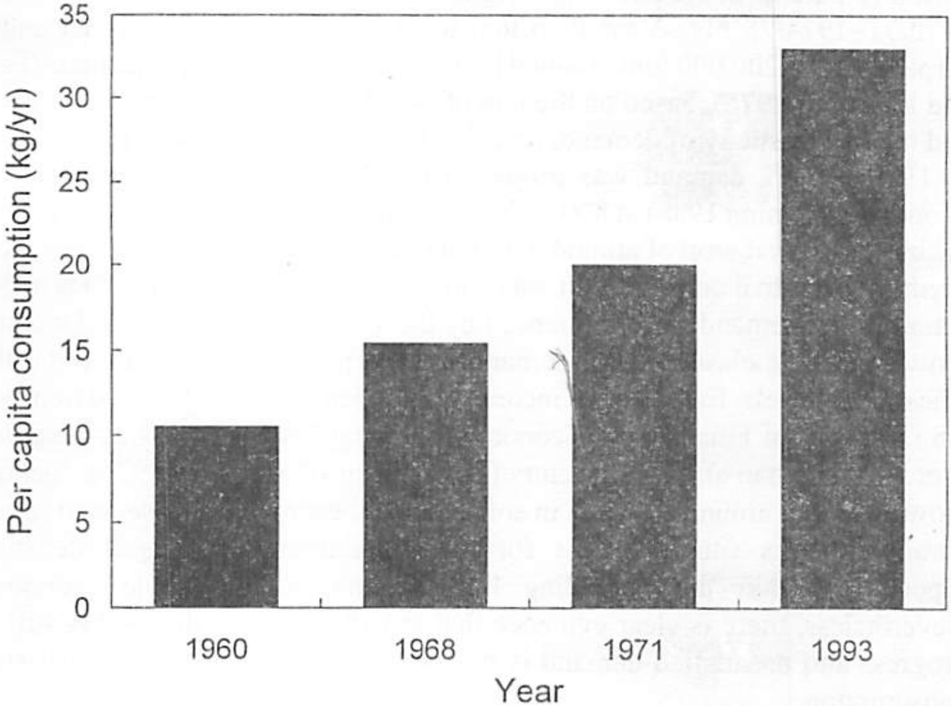

Fig. 2. Per capita annual wheat consumption in the Sudan in selected years (Faki and Hadari 1976; Faki *et al.* 1995).

Both consumption directions have resulted in a continuous and variable deficit between domestic needs and local production (Fig. 1) which has necessitated the exertion of efforts to bridge the gap through imports. The country has had to import, in most years, about three quarters of its annual needs that currently range between 0.8 and 1.0 million tons. This has exerted a heavy burden on the Sudan's limited foreign exchange earnings. The Sudan's wheat imports were already 596,000, 679,000 and 978,000 tons in the years 1986, 1987 and 1991, respectively, valued at 94, 101 and 129 million US dollars. The country's total foreign exchange earnings were only 333 million US dollars in 1986, compared to 628 in 1983 (FAO 1993), indicating the high wheat-import burden on an already worsening trade balance.

Estimates of actual wheat demand are uncertain as induced by short wheat supplies and price fixation of wheat flour and grain. Wheat self-sufficiency was envisaged in the 1960/61–1969/70 Ten-Year Plan, but this was not achieved although actual production exceeded planned targets early during the Plan's period (Faki and El Hadari 1976). Again, ambitions were so high within the 1970/71–1974/75 Five-Year Plan that local needs would be covered and a surplus of over 200,000 tons attained by 1975. Earlier demand projections (Faki and El Hadari 1976), based on the rate of population increase, income growth and income elasticity of demand, revealed local needs of 868,000 tons already in 1980. Again, demand was projected in 1988 (Ministry of Finance and Economic Planning 1988) at 800,000 tons by the mid-nineties. Already in 1992, the bumper wheat crop of around 850,000 tons was about enough to meet local needs when actual consumption was about 900,000 tons. Uncertainties about actual wheat demand were influenced by the levels of population and income growth, income-elasticities of demand used in projection estimates, and the wheat price levels. Estimates of income elasticities of demand ranged between 0.8 (Ministry of Finance and Economic Planning 1988) and 1.4 as weighted averages of urban and rural sectors (Department of Statistics 1970). Income growth rates of around 5% used in some demand estimates also seemed rather ambitious. This situation calls for reliable estimates of wheat demand, especially within the prevailing liberalization in the whole economy. Nevertheless, there is clear evidence that growth in wheat demand is still in progress and unsatisfied demand is prevalent as reflected by the ever-rising consumption.

Expansion of policy-induced production involving high subsidies in a continual race to realize self-sufficiency has long been in effect. In addition to past efforts, a crash program was launched in 1989 to achieve wheat self-sufficiency by 1992 (Government of Sudan 1990). The instruments used were area expansion in existing irrigation schemes, exploitation of productivity gains from improved wheat production technology and various policy measures to encourage wheat production. Area expansion, which implied a considerable change in crop rotations in irrigation schemes, has been enormous. The area under wheat reached an all-time high of over 400,000 ha in 1990/91 (Fig. 3). This was about three times the average area in the period 1980/81–1989/90. Wheat production has increased to 600,000 tons in that period; about 72% of total wheat consumption. The increase in production by 3.1-fold was over-proportional to that of the area, reflecting noticeable yield improvement levels. Still more production was realized in 1991/92 when more than 850,000 tons of wheat were harvested in that climatically favorable cool season. In later seasons, production levels were, however, substantially lower, being affected by bad weather (excessively high temperatures) and suboptimal availability of some strategic inputs. Despite the considerable annual yield fluctuations, the trend is towards more productivity and production (Fig. 3).

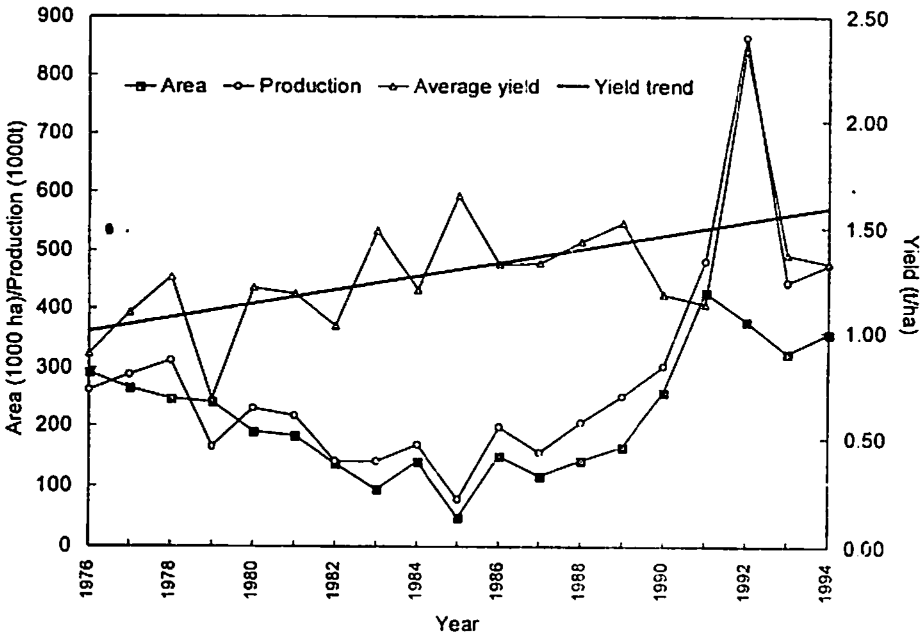

Fig. 3. Development of wheat areas, production and average yields in the Sudan, 1976–1994.

Intensive research has been conducted to adapt the crop to new areas targeted for its production expansion with the objective of improving yields to levels that ensure profitability to producers and at the same time render the crop competitive within the farming systems that characterize these new areas. The technology developed by the Agricultural Research Corporation (ARC) has been independently verified in farmers' fields since the mid-eighties by the ARC in collaboration with ICARDA through OPEC financial support and later through the Nile Valley Regional Program (NVRP), supported by the Netherlands Government. Sasakawa-Global 2000 (SG 2000)[1] and national production corporations, especially the Gezira Scheme, have also demonstrated the technologies developed by the ARC. Encouraging, though highly variable, yield improvements were achieved which, together with area increases, have resulted in improved self-sufficiency as compared with its sharp decline since the mid-seventies (Fig. 4).

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[1] Agricultural projects established by Sasakawa African Association and Global 2000, Inc., in various African countries to develop programs for demonstrating technologies to farmers in cooperation with national extension services.

Financial Benefits to Producers

Being essentially a cash crop in most of its growing areas, wheat should be remunerative to its growers and its production should be in harmony with the existing cropping systems so that its production is maintained and expanded. Profitability represents a major indicator which is probably reflected by the considerable wheat area fluctuations in northern Sudan. Farmers' high response to the market there outweighs their need to produce their own consumption requirements. Wheat profitability was examined by a comparison of its net returns and its contribution to total farm income with those of other main crops in three major producing schemes over the period 1981/82–1991/92. This is shown in Table 1 in which net returns were calculated at constant 1981/82 level of prices by deflating actual values by the official exchange rate of the Sudanese pound to the US dollar (Faki and Ismail 1994c).

Table 1. Average 1981/82–1991/92 net returns from major crops in irrigation schemes and their relative share in farm income at 1981/82 constant prices.

Scheme	Cotton	Wheat	Groundnut	Sorghum
		Net returns† (LS/ha)		
Gezira	256 (78)	173 (97)	391 (96)	158 (81)
New Halfa	304 (52)	206 (77)	421 (76)	128 (96)
Rahad	220 (34)	153 (70)	383 (108)	220 (125)
Average	260 (55)	177 (81)	398 (93)	169 (101)
		% of total farm income		
Gezira	39	21	29	11
New Halfa	45	24	26	5
Rahad‡	50	7	35	18
Average	45	17	30	11

† Figures in parentheses are standard deviations.
‡ Wheat averages for Rahad were for the last two seasons.
Source: Computed based on records of Gezira, New Halfa and Rahad schemes.

With average net returns of LS 177 per ha, wheat ranked third among the four field crops. Its contribution to total farm net returns averaged 17% which was only higher than that of sorghum. Humble returns from wheat were mainly related to the low yields obtained which are in turn a function of location and many management factors. Low returns denote low incentives to farmers who usually manage resources at their disposal to achieve maximum net benefits. This was evident from analyses within the former crop-sharing systems in Gezira prior to 1981. Farmers then tended to shift resources away from cotton to other crops, particularly wheat, in contrast to national efficiency criteria of high cotton profitability (Faki 1982).

Wheat Competitiveness

Despite its relatively low returns, wheat is an important winter crop with limited substitutes in the large irrigation schemes south of Khartoum. It utilizes land and water during a slack period and, on account of its low labor requirements, it hardly poses any competition for labor at its peak demand during harvest time of summer crops (Faki and Ismail 1994a). It nevertheless competes for land and irrigation water if its area is to be expanded. Cotton represents the main competitor to wheat for irrigation water and inputs to be procured from abroad. Its area, in turn, depends on the extent of cultivation of summer crops (groundnut and sorghum) which may themselves compete for water with wheat if their sowing is delayed. Such competition arises when irrigation of these crops extends beyond October, the time when their irrigation should stop and water is released for wheat planting.

Nevertheless, the interdependencies between cotton, other summer crops and wheat imply that cotton will not fully utilize the available water during winter. The degree of competitiveness between wheat and cotton was analyzed by a simplified linear programming model which maximizes total real net returns with water and land constraints only under the assumption of no overlap between summer crops and wheat (Faki and Ismail 1994c). The resulting wheat and cotton area combinations, delineated by varying the areas of summer crops, were analyzed by a quadratic regression model in the following form:

$$W = 12855 + 0.991\, C - 0.0000012\, C^2$$

where W and C denote wheat and cotton areas (in ha), respectively.

The model revealed complementarity between the two crops up to 181,000 ha of cotton after which its expansion would result in a nearly proportional decrease in wheat area. This indicates good opportunities for wheat production up to about 200,000 ha, provided that it is economically feasible.

Further, the competitiveness of wheat and cotton was evaluated by comparison of their gross margins to scarce production factors at the 1993 costs and prices. The results are summarized in Table 2 in which wheat was represented by three technology levels that differ in fertilizer dose, number of irrigations and land preparation practices.

Table 2. Gross margins to scarce production factors of long-staple cotton and wheat, grown at low, medium and high technology levels.

Gross margin	Cotton	Wheat (technology level)		
		Low	Medium	High
Land (LS/ha)				
Including labor	16,786	4,598	9,850	21,854
Excluding labor	23,212	5,740	11,420	23,901
Water (LS/m^3)	1.94	0.96	1.43	2.99
Labor (LS/man day)	139	402	600	1,004
Cash (LS/LS/month)	0.051	0.053	0.094	0.171

Source: Faki and Ismail (1994c).

Despite its lower gross margins per unit of land and irrigation water, wheat returns to labor and cash capital outlays were higher. This provides the opportunity for wheat expansion with labor and finance scarcity. Use of high technology in wheat will nevertheless be conducive to its competitiveness with respect to all factors including land and irrigation water for which cotton is usually more competitive. With respect to foreign exchange earnings, cotton has a greater advantage over wheat. Assuming no imperfections in the input and output markets, their respective values added were $899 and $350 per ha. However, with high wheat technology, its value added would rise to $604 per ha.

Many studies addressed wheat competitiveness in the use of domestic resources using Domestic Resource Cost (DRC) analysis under various policy and technological scenarios. Emphasis in these studies was on the Gezira Scheme which accommodates over 60% of the Sudan's wheat area and assumes high similarities to other important producing areas. The most important determinants of wheat comparative advantage are its yields, international prices of inputs, international prices of wheat, exchange rates and the levels at which domestic resources are valued. Despite their different empirical results, these studies shared a common inference that the use of yield-improving technology is indispensable for wheat production at competitive levels.

Detailed analysis for 1991 and 1992 in the Gezira (Hassan and Faki 1993) revealed that a full technological package has to be applied and world wheat prices have to increase by 11% above their 1992 trend levels so that wheat becomes as competitive as cotton in the use of domestic and foreign resources. Priority needs to be given to promoting faster adoption of efficient production methods to close the gap between potential and current farmers' wheat yields. Otherwise, it would be inefficient to expand wheat cultivation at the expense of cotton.

Analysis in the 1993/94 season (Faki and Ismail 1994b) revealed that a break-even wheat yield of 1.48 t/ha would be necessary to attain a comparative advantage level. However, yields should be raised to 1.9 t/ha for wheat to reach the same level of competitiveness as cotton (cultivar Barakat). Higher levels of subsidies for wheat and taxation for cotton were computed, as reflected by effective rates of protection[2] of 2.84 and 0.85 for the two crops, respectively. The required yield levels, although possible to attain, need large efforts in the areas of extension and provision of inputs and finance. This is shown by the fact that the average yield in that season was 1.25 t/ha, while a yield level of 1.9 t/ha was realized in only 18% of the wheat area. Confinement of wheat to high potential areas and for interested farmers, together with encouragement of some level of specialization in the production of various crops, including wheat, could represent a suitable alternative strategy for wheat production. Different short rotations would then be designed subject to location-specific factors and comparative advantage of producing various crops.

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[2] Effective rate of protection is a ratio of value added at market price to that at world price equivalent. Values greater than unity denote subsidy, while those less than one denote taxation of the commodity under investigation.

Potential in the Irrigated Sector

The potential for grain production (wheat and sorghum) in the irrigated sector is highly related to policy considerations and the prevailing farm constraints due to their impact on farmers' incentives. A linear programming sector model was developed using the 1991/92 costs and prices, involving considerable wheat subsidies, to examine optimum cropping patterns in the irrigated sector with and without government intervention in area allocations and input provision (Faki *et al.* 1995). Land, irrigation water, labor, rotations and subsistence needs of sorghum were the main scheme-level constraints while fertilizer was constrained at the sector level. Three technology levels were tested for each crop depending on water and fertilizer amounts applied. Optimum areas of wheat and the production and technology levels under different policy scenarios are depicted in Table 3.

Table 3. Optimum wheat areas, production and technology use in the irrigated sector under different policy scenarios.

Policy option	Area (1000 ha)	Production (1000 t)	Technology level (% of area)	
			High	Low
Free cropping pattern	528	758	70	30
Approx. of current pattern, relaxed input availability	371	653	75	25
Cereal production targets, fixed cotton area	302	600	90	10
Cereal and cotton production targets, 25% more water	489	770	80	20
More cotton production targets, relaxed input levels	261	600	100	00

Under free farmer decisions and with existing input levels, the cropping pattern would include the cultivation of 528,000 ha of wheat, representing 43% of the cultivated area in the irrigated sector and producing 758,000 tons. About 51% of this areas would be in the Gezira Scheme. However, with constraints on water and fertilizers, 30% of the wheat area would be under low technology.

With policy interventions to produce certain amounts of grain, high technology use would be necessary at the expense of input use in other crops. This particularly applies to schemes in which extremely poor yields are obtained in the absence of adequate water and fertilizers.

Depending on the nature of the policy option, wheat area would generally decrease as cotton area is increased. If the water supply could be raised by 25%, wheat area and its production would be enhanced. Further increases in cotton area would lead to a reduction in wheat area even if full relaxation of inputs is achieved. However, a shift to high wheat technology use would result in attaining the same level of production. This study strongly supports the argument that the vertical increase in production through the adoption of improved technology with high inputs will release land to other important crops like cotton and eliminate competition. With increased input costs and crop prices, a situation that simulates later changes of subsidy removal, both wheat area and its production would decrease by about 20%. Cotton would in contrast expand considerably. This implies that subsidy removal would induce a shift of emphasis towards more cotton and less wheat.

The effect of wheat price change on its supply was considerable. This was examined in the model together with variation in sorghum prices since the two crops are close consumption substitutes. From supply response of the two crops, arc supply elasticities of 2.03 and 1.43 were computed for sorghum and wheat, respectively. Although the response of sorghum to its own price was higher, wheat was nevertheless substantially elastic. The high substitutability of the two crops was shown by their considerable supply elasticities of 1.69 for wheat in response to sorghum price change and 1.19 for sorghum in response to wheat price change. These figures indicate that national production needs could be geared effectively through appropriate pricing policies.

Wheat Yields

Wheat yields in all producing areas have been characterized by high variability and generally low levels relative to the potential revealed by research results since earlier times. Yield variation of the main field crops is computed for Gezira and New Halfa over a 12-year period (Faki and Ismail 1994a). Average yields and their coefficients of variation are shown in Table 4.

Table 4. Crop yield variability in Gezira and New Halfa, 1980/81–1991/92.

Crop	Gezira		New Halfa	
	Average yield (t/ha)	CV (%)	Average yield (t/ha)	CV (%)
Cotton	1.50	24	1.44	26
Wheat	1.26	35	1.17	24
Groundnut	1.38	21	1.69	19
Sorghum	1.07	28	1.00	23

Source: Faki and Ismail (1994a), based on records of Gezira and New Halfa schemes.

Wheat yield variability was especially high in Gezira. It is more or less comparable to other crops in New Halfa but still slightly higher than those of groundnut and sorghum. Since wheat receives considerable attention and enjoys continual uniform supply of many inputs as compared with sorghum and groundnut, its variability levels should be lower. Part of the wheat yield variability is explained by yield improvement over time which could be discerned in two areas, namely, Gezira and northern Sudan (Fig. 5). Wheat yields in the north are noticeably higher but still quite variable. Despite the effect of many management factors on wheat yields within and across seasons, time-related variability is largely explained by the variation in the level of winter temperatures and availability of major inputs such as irrigation water and fertilizers. Analysis of time-series data for Gezira (Faki and Ismail 1994a) showed significant correlation between average wheat yield and the mean temperatures in December, January and February. Although the highest correlation ($r = -0.75$) was recorded for the mean temperature in February, canonical correlation of the yield with mean temperature in these months was high ($r = 0.87$).

The persistent wheat yield variability in irrigation schemes should have implications on the strategy of producing the crop at profitable levels. While, in addition to temperatures, irrigation also contributes to time variability, many other natural and management factors should be responsible for a major portion of yield variability among farmers and sites. Analysis of wheat yields in the Gezira from 1988/89 to 1992/93 (Faki and Ismail 1994a) reveals high space variability as reflected by high coefficients of variation in individual seasons (Table 5).

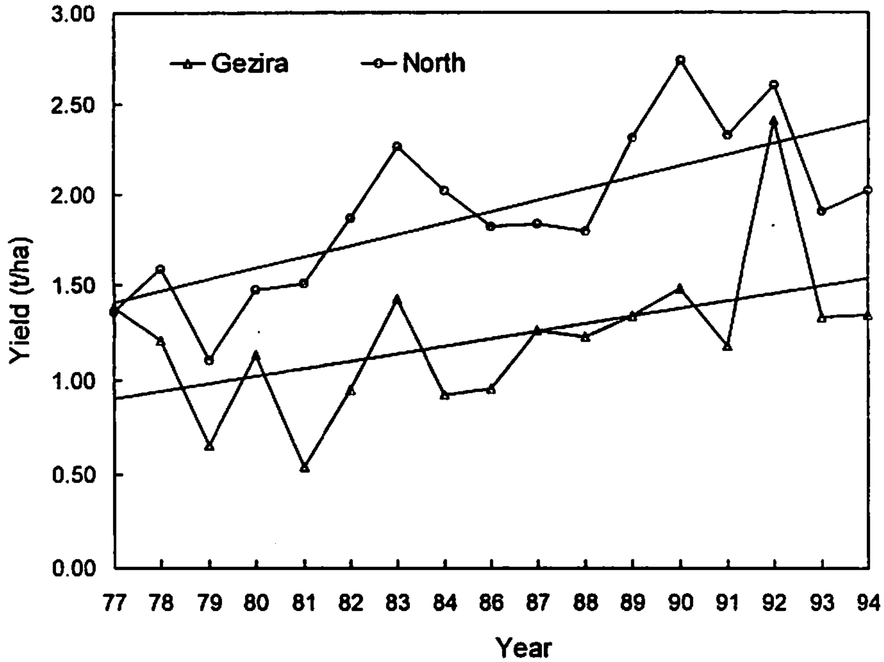

Fig. 5. Wheat yields and their trends in two producing areas (Gezira and north Sudan), 1976/77–1993/94.

Table 5. Wheat interseasonal yield variability in Gezira in the period 1988/89–1992/93 (based on average yields of all Gezira administrative blocks).

Season	Average yield (t/ha)	SD (t/ha)	CV (%)	Minimum (t/ha)	Maximum (t/ha)	Yield gap (t/ha)
1988/89	1.34	0.45	34	0.16	2.48	2.09
1989/90	1.44	0.42	29	0.23	2.56	2.02
1990/91	1.05	0.29	28	0.17	2.12	1.71
1991/92	2.23	0.45	20	0.58	2.91	1.54
1992/93	1.25	0.47	37	0.11	2.63	2.37

While the figures reflect variability among block means, variability among individual farmers is expected to be much higher. Analysis of yields over seven seasons from 1985/86 to 1991/92 (Faki and Ismail 1993) depict a consistent trend in relative yields of certain blocks with high, medium and low yields (Fig. 6). The magnitude of spatial yield variability can be illustrated by the results of yield data analysis in two seasons, namely, 1991/92 (a very favorable season) and 1992/93 (a moderate season). Despite the lower variability and the exceptionally good weather of 1991/92, almost one third of the area had lower productivity than the Scheme's average. In moderate seasons, represented by 1992/93 which has fair representation of weather conditions, variability was high between and within the two parts of the Scheme (Gezira and Managil). About 80% of the area in Managil did not exceed the average yield of the Scheme while the figure for the Main Gezira was 30%. For the whole Scheme, about 50% of the area attained less than the average yield.

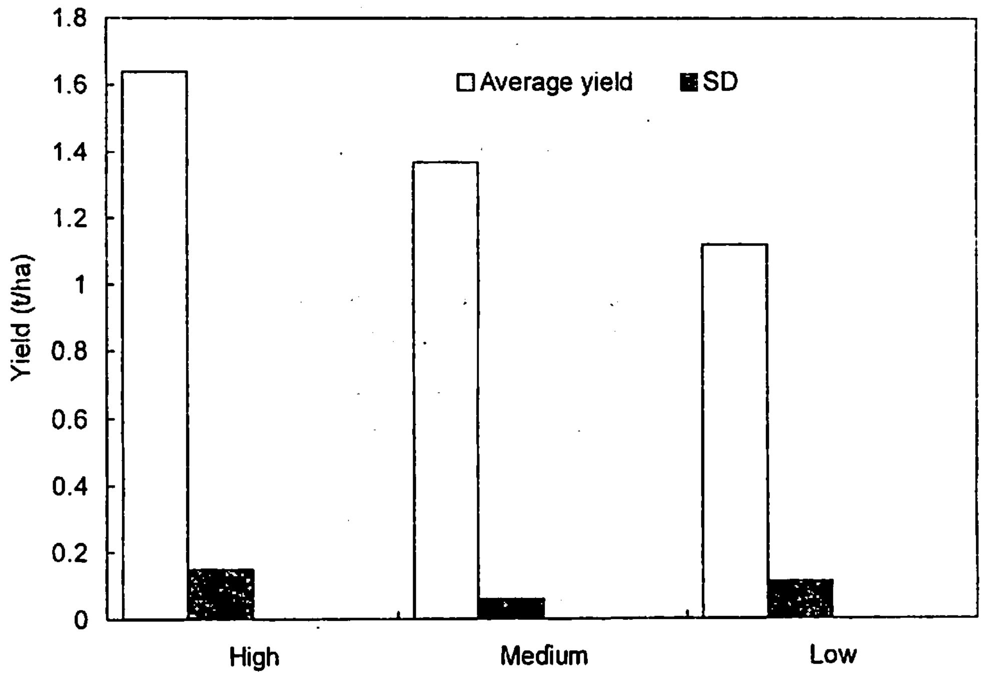

Fig. 6. Average wheat yields of high-, medium- and low-yield blocks in Gezira.

As mentioned earlier, many factors interact to cause yield variability. Adoption of technological improvements would be conducive to increasing the yield level in general and reducing both space and time variability. Questions, however, arise whether all areas designated for wheat production could be managed to maintain target yields on account of some location factors, input availability and farmers' interests. This may require serious reconsideration of area allocation to wheat in response to those factors. Again, the issue of some level of specialization in the production of wheat comes into consideration where farmers with comparative advantage would be allowed to expand their wheat areas within crop rotations that sustain the land resource.

Farmers' Attitudes

Farmers' interests and preferences, as induced by their socioeconomic circumstances, are important in directing their attitudes towards crop management and adoption of improved technology. It has been the understanding among workers in the field of wheat production that farmers' close engagement in wheat practices are important factors in productivity enhancement. Yield-gap analysis in the Gezira (Faki and Ismail 1993) has confirmed such an understanding. The impact of farmers' attitudes was evaluated for wheat in Rahad Scheme in the 1993/94 season (Babiker and Faki 1984) by comparisons between two farmer groups; keen (committed) farmers towards wheat production versus those with low interest (non-committed). The required information was collected through a field survey using a purposive sampling procedure for selection from the two groups, depending on knowledge of the Scheme's extension staff.

The results showed that non-committed farmers were less experienced in wheat production and much less enthusiastic to its production than committed farmers. This was attributed to their social background, being livestock herders, and their continued preference for livestock production. Their interest in wheat was mainly for its fodder contribution, secured water availability in the winter season and benefits from residual soil nutrients of wheat to succeeding crops. Most of the non-committed farmers were not satisfied with the recent introduction of wheat in the Rahad rotation. Their management practices were generally poor as depicted by delayed sowing, poor water management associated with water-logged conditions, poor crop emergence and severe weed infestation. These farmers hardly engage in the supervision of various wheat cultural practices themselves, but leave that to a family member. Moreover, they did not acknowledge the importance of supervision in the field of some important wheat management practices.

Yields realized by this group of farmers averaged 0.86 t/ha over the 4-year period 1990/91–1993/94 as compared with 2.71 t/ha for committed farmers; implying 68% lower yields. This has the consequence of misuse of scarce inputs in wheat production, taking into consideration that all wheat areas in the scheme receive uniform input levels and services. Such inputs could otherwise be more efficiently used in other crops. Available alternatives include reconsideration of wheat cultivation by those farmers or adjustment of the levels of inputs and services to the obtained yield levels. In both cases, extension services should be intensified. Crop specialization by committed farmers could form a feasible alternative to the current fixed crop areas, as mentioned earlier. This should be based on location differences, farmer objectives, and their knowledge and attitudes.

Policy and Institutional Issues

Policy and institutional factors have long been decisive components of wheat production in the Sudan. Wheat production relations in government irrigation schemes were based on a controlled and considerably subsidized system. Controls were related to wheat area allocations, provision of inputs, wheat prices and its disposal. Input subsidies were primarily related to an officially over-valued exchange rate. The whole set-up was geared towards encouragement of wheat production that thrives to ensure a margin of profit to the average producer. Although such profit margins were quite variable and often low, their trend was increasing in nominal terms.

The magnitude of effects that policy and institutional changes would inflict on the wheat production situation was monitored for the Gezira Scheme through the changes that took place following the adoption of structural adjustment programs in the whole economy (Faki *et al.* 1993). The shift towards a market economy under such program has induced drastic subsidy reduction, restriction in interventions in prices and formulation of finance policies according to Islamic terms. These changes had, in their transitional stage, reflected on producers' choice and their production decisions, despite the fact that part of the controls in areas, input supply and input and product prices have remained. The major effect on producers was a high increase in production costs by 91%, largely due to an increase in the tradables component of those costs by 110% (Table 6).

Table 6. Comparison of production-influencing indicators of wheat in the Gezira Scheme in response to policy changes, 1992/93.

Item	Past†	1992/93	% change
Production, yields and prices			
Total production costs (LS/ha)	10,739•	20,563	91
Tradables (LS/ha)	5,924	12,959	119
Non-tradables (LS/ha)	4,815	7,604	58
Ratio: tradables/non-tradables	1.23	1.70	38
Break-even yield (t/ha)	1.23	1.71	40
Wheat price (LS/t)	8,750	12,000	37
Important input/wheat price ratios			
Urea (LS/kg)	0.86	2.30	167
Fuel (LS/gallon : LS/kg)	4.68	9.17	96
Labor (LS/man day : LS/kg)	10.6	11.4	8

† Average of the five seasons preceding 1992/93.
Source: Faki *et al.* (1993).

The increase in the cost of tradables relative to that of domestic resources goes in line with the objectives of the reform program when their ratio increased from 1.23 to 1.7; by 38%. However, wheat prices that only increased by 37% largely lagged behind, resulting in deteriorating and often negative monetary returns at average yields of the five years preceding 1992/93 of 1.52 t/ha. Wheat prices offered by flour mills and those prevailing in the free market were 50 and 67% higher than the predetermined wheat delivery price, respectively. Break-even yields under that situation would be 1.7 t/ha which were difficult to realize in light of past trends. Input/output price ratios worsened as depicted by increases of 167, 96 and 8% for urea, fuel and labor, respectively, implying that producers would operate at low portions of production functions and apply lower input levels. That discrepancy was a reflection of the cost of finance and a general inflationary component. In addition, delay in finance and low fertilizer availability (75% of the recommendation) contributed to low management levels, exposed by the sowing date, machinery use and levels of fertilizer application.

Average sowing dates in five wheat producing areas (Gezira, Managil, Rahad, New Halfa and the White Nile) were in 40% of the cases delayed beyond the recommended November sowing. Farmers in some areas planted wheat only when its prices started to rise late after the optimum sowing date.

Tillage costs increased by 100 to 230%, depending on the type of tillage. A high proportional increase was recorded for the cost of the traditional ridging tillage system. However, its absolute costs were lower than the recommended disc harrowing and it is additionally more easily accessible by farmers, being supplied by private tractor owners in farmers' villages on credit arrangements within the limited finance situation. Its use had therefore expanded and would probably do so in the future.

Despite the lower than usual supply of fertilizers, there was strong evidence that the provided dose was not fully applied. Fertilizer sales by farmers outside the official channels prevailed in many areas at very low prices which were 50% of the purchase price. This was a response to farmers' need for cash and the unfavorable production relations which outweighed encouraging returns, had economically optimum fertilizer doses been applied. This is shown by Table 7 in which fertilizer response and marginal revenues were estimated using on-station and on-farm data (Faki *et al.* 1993).

Table 7. Regression coefficients and profitability indicators of wheat-yield response to urea in irrigation schemes, 1992/93.

Scheme	Coefficient (kg wheat/kg urea)	Marginal revenue†
Managil	5.5	66
South Gezira	4.2	50
Rahad	3.7	44
White Nile	7.4	89
Average	5.2	62

† At the predetermined wheat delivery price.

The wheat yield response was high, averaging 5.2 kg/kg urea. The average marginal revenue, even at the low wheat predetermined price, amounted to LS 62 per kg urea, which was almost double the marginal cost of fertilizer of LS 32 per kg of urea. This was indicative of higher profitability with higher than the applied doses. It reflects subjective irrational farmers' behavior induced by low morale in response to the whole set of policy and institutional measures.

As an important aspect in institutional development for wheat improvement, national efforts in wheat research have been intensified since the mid-eighties by strengthening collaborative efforts with ICARDA and CIMMYT with the support of the Sudanese Government, OPEC funds and the Netherlands Government from 1988/89 to 1994/95 (the NVRP). This aspect has been achieved through developing a delivery system involving researchers, extensionists and farmers in a multidisciplinary team. Staff education, training and professional visits in the last seven years contributed greatly to institutional development in wheat research. This is fully covered under technology transfer and human resource development papers in this volume.

References

Babiker, E.A. and Faki, H. 1984. Farmers attitudes towards wheat production in Rahad Scheme. ARC/ICARDA Annual Coordination Meeting, September, 1993, Agricultural Research Corporation, Wad Medani, Sudan.

Damous, E.M. 1986. Economic analysis of government policies with respect to supply and demand for wheat and wheat production in Sudan. Ph.D. dissertation. Washington State University, Seattle, Washington.

Department of Statistics. 1970. Household sample survey 1967/68. Ministry of Planning, Khartoum.

Faki, H. 1982. Disparities in the management of resources between farm and national levels: Example of the Sudan Gezira Scheme. Agricultural Administration, 9, 1982.

Faki, H., Ahmed, A.T. and Dawelbeit, M. 1993. Some implications of free-market policy on technology use and production of wheat in large irrigation schemes. Pages 50–59 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual Coordination Meeting, 29 August–2 September 1993, Agricultural Research Corporation, Wad Medani, Sudan.

Faki, H. and El Hadari, A.M. 1976. Some economic aspects of wheat consumption in the Sudan. Eastern Africa Journal of Rural Development 9: 139–149.

Faki, H., Gumaa, Y.T. and Ismail, M.A. 1995. Potential of the Sudan's irrigated sector in cereals grain production: analysis of various policy options. Agricultural Systems 48: 457–483.

Faki, H. and Ismail, M.A. 1993. Wheat yield gaps: results of analysis in Gezira. Pages 41–50 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual Coordination Meeting, 29 August–2 September 1993, Agricultural Research Corporation, Wad Medani, Sudan.

Faki, H. and Ismail, M.A. 1994a. Wheat yield gaps in the Gezira Scheme. Pages 40–54 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual Coordination Meeting, 28 August–1 September 1994, Agricultural Research Corporation, Wad Medani, Sudan.

Faki, H. and Ismail, M.A. 1994b. Wheat competitiveness in the Gezira Scheme. Pages 55–60 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual Coordination Meeting, 28 August–1 September 1994, Agricultural Research Corporation, Wad Medani, Sudan.

Faki, H. and Ismail, M.A. 1994c. Some economic indicators for wheat production prospects in the Sudan. Pages 96–104 *in* Wheat in Heat Stressed Environments: Irrigated, Dry Areas and Rice-Wheat Farming Systems (D.A. Saunders and G.P. Hettel, eds.), 1994. Mexico, D.F., CIMMYT.

Food and Agriculture Organization (FAO). 1993. Agrostat, 1993.

Government of the Sudan. 1990. The Three Year Economic Salvation Program 1990–1993. The Economic Committee of the Revolutionary Council, Khartoum.

Hassan, R.M. and Faki, H. 1993. Economic policy and technology determinants of the comparative advantage of wheat production in Sudan. CIMMYT Economics Paper No. 6. Bangkok, Thailand, CIMMYT.

Hassan, R.M., Faki, H. and Byerlee, D. 1994. Improved wheat production practices and the question of economic efficiency in the Gezira Irrigation Scheme. Pages 78–93 *in* Wheat in Heat Stressed Environments: Irrigated, Dry Areas and Rice-Wheat Farming Systems (D.A. Saunders and G.P. Hettel, eds.), 1994. Mexico, D.F., CIMMYT.

Hassan, R.M., Mwangi, W. and D'Silva, B. 1991. Multi-market analysis of Sudan's wheat policies: Implications for fiscal deficits, self-sufficiency and the external balance. Pages 212–219 *in* Issues in Agricultural Development: Sustainability and Cooperation (M. Bellamy and B. Greenshields, eds.). Dartmouth Publishing, UK.

Ministry of Finance and Economic Planning 1988. Food Security Study. Khartoum, Sudan: Ministry of Finance and Economic Planning.

Discussion

Q: Prof. Mohamed Ahmed Khalifa

Is the classification of wheat production zones geographic, and if so, what is its bearing on the supposition that the production of wheat in Gezira should be confined to certain areas of higher potential and that lower-yielding areas should be excluded?

A: Hamid Faki

This is an important point. Yield classification in this specific case was not geographically oriented. But work in the past has shown that wheat productivity conforms with the geographic location to a considerable extent. Based on time-series data on cotton and wheat yields, 11 'farm types' were delineated in Gezira/Managil where, in many cases, the farm types depicted contiguous areas although of course there were some pockets. Both geography and farmers' preferences should be used as criteria for locating productive wheat areas. Wheat should be confined to those areas which ensure high productivity due to technology use rather than expanding in poor-yielding areas.

Comment: Prof. Ali E. Kambal

Please comment on the following points: (1) No analysis of wheat production in the north has been carried out, and (2) there is a need for a detailed analysis of why some farmers get high yields and others in the same Number get low yields, i.e., both geography and farmers' performance are important in determining yield.

A: Hamid Faki

(1) The north has the advantage of high wheat yields which has been shown in the presentation. Wheat expansion is, however, influenced by limitations in land availability and the competition with winter crops. There is a trade-off for wheat expansion related to the areas of food legumes. (2) The reasons for yield discrepancies among farmers will be discussed with the technology transfer review component.

Q: Dr. Mohamed Safaa Eldin Sharshar

What is the main factor that affects grain yield because it is clear that the average fluctuated from year to year?

A: Hamid Faki

Weather, mainly winter temperatures, is the most important single factor affecting year-to-year fluctuations in wheat yield. There are also other management factors related to the level of input availability, such as irrigation water and fertilizers. If the crop is well managed, the effect of weather could be reduced. More on the factors affecting wheat yields will come under technology transfer.

Comment: Dr. Salah Abdelmagid

There is a contradiction between two issues raised by the speaker: (1) The macro-level issues regarding the supply/demand gap that call for more area expansion, and (2) the micro-level issues that call for less area grown to wheat because of its competitiveness.

A: Hamid Faki

Macro- and micro-level issues are interrelated. Most of the analysis is done at the micro-level with adequate scenarios that examine the impact of macro-level factors on farm-level decisions that affect productivity and technology use. Expansion in areas without full exploitation of benefits from the improved technology through adequate policy and institutional prerequisites will result in low yields, low profitability and low incentives. Reconciliation of area expansion levels and technology use will lead to the efficient use of resources.

Comment: Mostafa Bedier

Reliable statistics are very important. However, the figures and statistics presented did not show precision and accuracy in the estimates, and time-series data before 1989 and from 1989 to 1995 are very important to measure the impact of NVRP.

A: Hamid Faki

Data collection methods and analysis procedures are related to the nature of topic and objectives. Yield statistics and time-series data are usually secondary sources of records in irrigation schemes which are acceptably reliable due to the high precision in data recording. Farm data are collected through surveys using the known statistical procedures of sampling (size, design, etc.), and analysis methods according to objectives (descriptive, frequencies, mean comparisons, correlation, regression, etc.) are used, and modelling using techniques such as linear programming is employed. Rigorous statistical analysis is usually made.

Comment: M.B. Solh

It would be interesting to present the production trends (acreage, total production and yield) over the last 20 or 25 years along with the self-sufficiency ratio over the years.

A: Hamid Faki

Most of the wheat statistics on time-series data address long periods. However, the inclusion of more seasons will be considered both for production statistics and self-sufficiency ratios.

Q: Z.T. Dabrowski

Would it be possible to include an economic analysis for the last two seasons for comparing cotton/wheat returns?

A: Hamid Faki

It is important to include later years in the analysis since world-price changes, especially of wheat, will affect its competitiveness. Most of the analysis was done up until 1993/94. The last seasons' data were not available at the time of preparation of the review paper, but will be included later.

Q: Prof. Abdalla A. Abdalla

What are the productivity levels of wheat and faba bean that will make production profitable in view of the high cost of fuel (LS 30,000 per barrel) in the north?

A: Hamid Faki

Costs should not be considered in isolation of returns. Both parameters have escalated due to inflation, but it can be argued that profitability for both crops has been fairly maintained as reflected by the continuation of farmers to grow these crops. Models have been developed that examine technology use in northern Sudan, including different levels of irrigation water, fertilizers and labor for various crops under different price and cost scenarios. This will be presented within the technology transfer session. Nevertheless, high production costs in connection with limited finance have been reported by farmers to be discouraging during a travelling workshop in 1995 in northern Sudan.

Q: Dr. Hassan S. Ibrahim

Wheat production in the Sudan depends mainly on financing. Farmers who are rich or can acquire credit engage in wheat production. Would you please comment on the wheat price rise offered by the government as an incentive to farmers to grow wheat?

A: Hamid Faki

The price level set lately for wheat forms a proper incentive to encourage wheat production. It represents a suitable type of policy intervention if wheat production is to be encouraged. It also goes in line with the high increase in world wheat price which now exceeds US $175 per ton. With the consideration of freight and other costs, border prices are expected to be well above US $200 per ton.

Chapter 2
Breeding and Improvement

Review of Wheat Breeding in the Sudan

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Abstract

The wheat breeding program in the Sudan has been successful in achieving most of its objectives. Thousands of lines have been handled annually to be evaluated for adaptation to the short growing season of the Sudan (about 100 days), as well as for shattering and lodging resistance. During the Nile Valley Regional Program (NVRP, 1988/89-1994/95 seasons), testing and screening was focussed on tolerance to heat and moisture stresses, rust resistance, tolerance to aphids, in addition to high yield and desirable agronomic traits. For heat tolerance, more than 2000 lines were tested and 20% showed tolerance. For tolerance or resistance to moisture stress, more than 1800 lines were tested and 12% were marked as tolerant. Out of more than 300 of the most promising lines tested for resistance to rust, 50% were resistant to stem rust and 40% to leaf rust. More than 1600 of the agronomically desirable lines were evaluated for yield in replicated preliminary and advanced yield trials. Some of those were advanced for test in the on-farm verification yield trials. Two high yielding and stable cultivars were released in 1990 and 1992. Another five cultivars are being reported for release in 1995. A modest 1-6% increase in yield is achieved with high stability. Future strategies for breeding should continue to emphasize the development of genotypes tolerant to high temperature and moisture stress. Monitoring of stem and leaf rust should be continued. Resistance to aphids must be pursued as part of the integrated pest management. Breeding for salt tolerance in the Northern Region and waterlogging in the central plains must receive some concern. More emphasis should be given to the baking quality. However, high yield and adaptation to the short growing season must remain top priority. The purpose of this paper is to review the breeding work carried out on wheat at the different research stations during the period 1985-1995. However, more emphasis will be given to the ARC/ICARDA/The Netherlands Nile Valley Regional Program (1988-1995).

Historical Review

Wheat is a temperate region crop, but has been introduced to northern Sudan from early times. Attempts to extend the crop to the central irrigated plains south of Khartoum were made in 1918 and 1940. Both attempts proved to be a failure due to the very low yields. Such a result should have been anticipated because of the lack of adapted cultivars and appropriate cultural practices.

Interest in wheat research was resumed after World War II due to food shortages. The cultivar grown by the farmers, known as Baladi, was evaluated for both quality and agronomic characteristics. The tests indicated that it had good baking qualities, but the seeds were mixed, late maturing and susceptible to stem rust. Early improvement programs (Massey and Martin 1921) consisted of: (1) mass selection from within Baladi wheat, and (2) germplasm introduction. Reports at that time indicated that the introduced cultivars were inferior to Baladi. By 1943 Snow summarized numerous variety trials and came to the conclusion that the cultivar Hindi 62 (grown in Egypt in 1940) was superior to Baladi, and recommended it for distribution. There was more emphasis on mass selection within local cultivars prior to 1958. After 1958 more weight was given to introductions, especially from international agencies (George 1958–1965). Some of those introductions were included in trials in the 1958/59 season. From 1960 onwards, though introductions were intermittent, testing sites included locations in Gezira, the Blue Nile State, and even under rainfed conditions at Tozi. At Khashm El Girba (New Halfa), the wheat program was not initiated until 1963/64. However, it continued to expand after 1964/65 when a full-time agro-breeder was located at that substation. G.I. George continued to handle the wheat breeding program at Hudeiba Research Station till 1965. His work was mainly based on introductions and testing. It culminated in the release of several cultivars including H57 and H164. Dr. A.I. Imam took over in 1965 and developed a full scale breeding program in subsequent years. His program was active till 1978 and his variety testing covered many locations in the country.

Prior to 1972 two agronomists were stationed at Gezira and Khashm El Girba research stations. Both of them, D.A. Dafalla and M.E. Akasha, were trained at CIMMYT and carried out a limited breeding activity besides their main responsibility as agronomists. In that respect, they were of great help in the process of germplasm screening and testing. The work of Dr. Imam (1974) and the other scientists resulted in the release of several cultivars. The prominent ones that were grown commercially were Mexicani, Giza 155 (from Egypt) and Condor.

In 1972 a full-time breeder, M.A. Khalifa, was assigned to the Gezira Research Station and Abdalla B. Elahmadi to Khashm El Girba in 1974. Full scale breeding programs were established in both stations. The three breeding programs (Shambat, Gezira and Khashm El Girba) flourished between 1974 and 1978 with full cooperation among them. Unfortunately, the program lost both Dr. Imam and Dr. Khalifa in 1978 for secondment abroad. In the same year, Dr. Abdalla B. Elahmadi was transferred to Gezira and Dr. M.S. Mohamed was assigned to Khashm El Girba. Dr. Gaafar Hussein was given partial responsibility to work on wheat breeding at Hudeiba Research Station in 1980. He was followed by Mr. Abdalla I. Sheikh Mohamed in 1984 whose work on wheat was also limited due to his involvement in other crops. Their efforts resulted in the release of the cultivar Wadi El Neil (Giza 160, from Egypt) in 1987.

The period before 1978 was characterized by discontinuity and financial problems. Intensive germplasm introduction, and the limited number of hybridization and germplasm testing resulted in the release of the cultivars Condor, Mukhtar, and Chenab 70 in 1978. However, from 1978 onwards, the breeding programs at Gezira, New Halfa and Hudeiba were active. They slowed down during the early eighties due to financial problems. Wheat research was reactivated to include many disciplines during the pre-Nile Valley Regional Program and the preceding project supported by OPEC funds in 1985. Testing sites covered all wheat-producing areas (Elahmadi 1986, 1987, 1988).

The Nile Valley Regional Program (NVRP, 1988/89–1994/95), a collaborative program involving the ARC and ICARDA with financial support from the Netherlands Government, has been a major milestone in wheat improvement and technology transfer to farmers. CIMMYT continued to collaborate to wheat improvement during that period. The program, coordinated first by Prof. Osman Ageeb and later by Dr. Abdalla B. Elahmadi, strengthened back-up research, transfer of technology, human resources and facilities available to the program. Through program efforts and collaboration with the extension system, irrigation schemes, Gezira Board and Sasakawa-Global 2000 (SG 2000)[3], the cultivars Condor, Debeira and Wadi El Neil were widely demonstrated and disseminated to farmers. Two high-yielding and stable cultivars were released: El Neilain and Sasaraib.

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[3] See note 1, p. 11.

Breeding Program

Since it started in 1956, the breeding work on wheat accumulated a large amount of knowledge with respect to the desirable characters to achieve high and stable yield. This knowledge enabled breeders to focus on the following breeding objectives:

- early maturity
- resistance to shattering and lodging
- heat tolerance
- tolerance to moisture stress
- resistance to rusts
- tolerance to aphids
- high grain yield
- good baking quality.

Early Maturity

The relatively cool season is rather short (100 days) and hence breeding has to be for early-maturing or short season cultivars. The variation in wheat germplasm with respect to this character is very large. Selection for the character is also very easy. Thus, early maturity has never been a limiting factor in acquiring desirable wheat germplasm. In fact, germplasm variation within the limits of 90–120 days' maturity is quite large, giving the breeder a good opportunity for improvement.

Resistance to Shattering

The importance of this character is that the crop is exposed to delay of harvest after maturity. This is caused by shortage in the number of combines. In the Northern Region, harvesting of wheat is partially done manually. It is hand-cut and threshed in bundles by a stationary thresher. The weather during harvest time in March and April is hot, dry and windy, i.e., conducive to shattering. The manual cutting and handling in the Northern Region leads to more losses in cultivars prone to shattering.

For this reason, selection for resistance to shattering is set as an important criterion. However, the character itself is rather simply inherited (Porter 1959) and shattering genotypes are discarded in early generations. Almost all the material that reached the advanced levels was resistant to shattering.

Resistance to Lodging

Lodging used to be a very common characteristic among wheat cultivars before the sixties. It is a known fact that this character is affected by the environment. It is also known to be controlled by many genes. After the introduction of the dwarfing genes in the early sixties, lodging resistance became very common in the active germplasm among wheat breeders around the world. Favorable growth conditions and high fertility are some of the environmental factors that enhance lodging. In the Sudan, the wheat crop is grown under stress conditions of high temperature. Lodging poses a problem only under very specific conditions, especially when old, unimproved cultivars are grown.

Selection against lodging was very successful and almost all the material in the advanced stages is resistant to lodging.

Tolerance to Heat

High temperature is one of the major constraints of wheat production in the Sudan. The winter season is short and warm. The lowest temperatures occur in December and January while the highest ones are predominant at the time of wheat sowing (November) and the time of its maturity. Thus breeding for earliness is a general requirement but tolerance to heat at both early and terminal stages of plant growth will reduce the adverse effect of the high temperatures. Sensitive cultivars exposed to high temperatures show some of the following undesirable characteristics: (1) stunted plant growth, (2) low tillering, (3) hastened developmental phases (heading and maturity) (4) smaller head (low number of grains/head) (5) smaller grain size-shrivelling, and (6) low grain yield.

In the breeding material and introductions at Gezira Research Station, a very large variation in the degree of response to the heat stress with respect to each of the above characters is observed. Correlations among these characters and the variations in temperature with season and their effect on the plant, depending on its phase of growth, make it more difficult to select for heat tolerance. McWilliam (1980) recognized the difficulty of having an adequate definition of heat stress in plants. Fischer (1985) showed that it is difficult to separate the effect of heat stress from that imposed by moisture stress since both are confounded at elevated temperatures.

Many characters have been suggested as selection criteria for heat tolerance or avoidance (Mooney 1980; Ehleringer 1980; Teeri 1980; and others). In the breeding efforts, many criteria are used to screen for heat tolerance at different stations in the Sudan. The degree of the effect of heat on days to heading, maturity and grain yield are some of these criteria.

The genetic base of the germplasm for selection to heat tolerance is broadened through introductions and hybridization. Both CIMMYT and ICARDA have developed and provided nurseries targeted for this purpose in the last ten years. Each year, 200–250 accessions have been received from the two centers. They have been subjected to selection under the Sudan's environment. Hybridization involved parents of proven adaptation and parents known for their tolerance to heat; Baladi and Hindi 62. Advanced lines from such crosses and many others are subjected to selection for heat tolerance.

Recognizing the importance of heat tolerance in cultivars intended for the Sudan, the NVRP assigned a separate and specialized project for the three breeders (Gezira, New Halfa and Hudeiba). To develop a germplasm tolerant to heat stress, the three breeders conducted experiments designed to help in the selection process. Manipulating the sowing date, early November and early December planting, exposes the germplasm to the early season or the late season heat stress. By comparison of the performance of the genotypes grown under stress with that of those grown under normal conditions, tolerant genotypes can be identified.

Breeding for heat tolerance was one of the main breeding objectives for many years, but was given more emphasis after the 1988/89 season, i.e., under NVRP. The work included observation and screening nurseries as well as yield trials. The number of accessions tested and the number selected through the seasons in the three stations, Gezira, New Halfa and Hudeiba, are shown in Table 1. The work in Gezira and New Halfa was directed towards selection for tolerance to early season heat stress while the work at Hudeiba emphasized the terminal heat stress. Selection for tolerance to both stages in the plant development is important, but tolerance in the early stages is more crucial. This is because it allows early planting which makes maximum use of the coolest period in the season and also secures the availability of irrigation water which becomes very scarce in March and April.

Table 1. Number of tested and selected promising wheat lines for heat tolerance at different locations in the Sudan.

Season	Gezira		New Halfa		Hudeiba	
	No. tested	No. selected	No. tested	No. selected	No. tested	No. selected
1988/89	200	31	10	2	9	
1989/90	220	33	16	2	44	10
1990/91	413	87	16	2	45	3
1991/92	230	71	0	0	16	6
1992/93	133	37	160	59	16	3
1993/94	160	54	173	24	16	6
1994/95	320	54	0	0	19	0
Total	1676	313	375	89	165	28

Source: Elahmadi (1989, 1990); A.I.S. Mohamed (1989, 1990); M.S. Mohamed (1989, 1990); Elahmadi *et al.* (1991a, 1992a, 1993a, 1994a).

A total of 2116 genotypes were tested for heat tolerance during the NVRP period (1988/89–1994/95). From these, 420 have shown some tolerance to heat stress. Some of those were advanced to be tested for yield while others were used in the breeding program as parents in the crossing block (Table 1).

In addition to the normal cooperation with the two international centers, CIMMYT and ICARDA, two other activities were initiated within the work for heat stress. One of these is an international heat tolerance trial from CIMMYT with 16 diverse genotypes evaluated in key locations around the world as part of an international effort to identify genotype x temperature interaction and elucidate potential selection traits and environments that can help the breeding programs. This experiment has been ongoing since 1990 and many characteristics, and agronomic and yield components are being studied. The second activity involves two NVRP experiments conducted collaboratively with Egypt and ICARDA as part of regional network activities since 1993. One experiment, the NVRP Regional Heat Tolerance Trial, is conducted using seven commercial cultivars from the two countries, grown in different locations along the Nile Valley, to study the adaptive characters and the changes associated with change of locations in these cultivars. This kind of study helps as a guide for future development of adapted cultivars. This trial has been expanded to include cultivars from Ethiopia, India and Yemen. The second joint experiment is the exchange of germplasm from the advanced material developed in the Sudan and Egypt to be subjected to selection in Gezira (Wad Medani) and in Upper Egypt.

Until 1980, work on breeding for heat tolerance in wheat throughout the world was very meager. However, it became prominent in the last decade. The work in the Sudan, as one of the hottest wheat-growing countries, is an appreciable contribution, especially in the field of germplasm screening and development.

Tolerance to Moisture Stress

Wheat is an irrigated crop in the Sudan, but is frequently exposed to moisture stress. This is the result of the prolonged irrigation intervals caused by the inadequate water delivery system or by high temperatures and low humidity with high evapotranspiration. These periods of stress take place at any stage of plant development leading to yield reductions. Improving the irrigation system and using the appropriate cultural practices might reduce the frequency of occurrence of moisture stress. The development of moisture stress-tolerant cultivars is a protection mechanism against these situations to stabilize yield.

It is generally understood that breeding for moisture stress is more difficult than breeding for favorable conditions. The difficulty is due to the complex genotype x environment interaction and the unpredictability of time and pattern of the stress (Smith 1987). Many strategies of breeding for moisture stress were suggested: early generation testing, testing along a moisture gradient, multilocation testing at different moisture stress levels and many others, but no one of them will fit all the stress situations. Yield has been used very frequently as a criterion of selection for tolerance to moisture stress or drought. However, many other attributes have been suggested as more relevant criteria of selection (Blum 1984). These include morphological traits (awns, leaf waxiness, narrow leaves, root depth, etc.); physiological traits (stomatal regulation, osmotic adjustment, leaf rolling, cell membrane stability, etc); and metabolic traits (Proline accumulation, abscisic acid level, etc.) (Marshall 1987). Breeders generally ignored these attributes as selection criteria because their relation to yield is not well understood. Most breeders use yield and yield stability as criteria for selection (Osmanzai *et al.* 1985; Marshall 1987).

Similar to heat stress, development of germplasm tolerant to moisture stress has been one of the objectives of wheat improvement in the Sudan. Efforts in this respect are being made at Gezira, New Halfa and Hudeiba research stations. The source of germplasm is through introductions of specific and general purpose material and through hybridization. CIMMYT and ICARDA have been sending drought-tolerant nurseries for more than 15 years. The hybridization program involves parents from these nurseries and from selections that showed tolerance to moisture stress from locally bred material.

The technique used by the three breeders is to prolong the intervals between irrigations (normal irrigation is every 12–14 days), irrespective of plant development, to discriminate between genotypes that show tolerance to moisture stress. At Gezira Research Station another technique was used in some seasons. The group of entries under test were prepared in two sets, one was grown under normal conditions and the other subjected to moisture stress after the establishment of the crop by applying irrigation when 75% of the available soil moisture was depleted (using a neutron probe). In both techniques the level of tolerance is measured by the reduction in grain yield caused by the moisture stress. The change in some other agronomic traits and yield components is taken into consideration.

Results indicated that both techniques were successful tools in assisting in the selection for tolerance to moisture stress. However, prolonging the interval of irrigation to three weeks versus the normal two-week interval provides an easier appropriate selection pressure compared to the depletion to 75% level. The irrigation interval technique, apart from the effect of the environment (season) and the germplasm under test, usually reduces yield in the range of 1–50%. The depletion technique (75%) needs a well managed experiment with closer supervision and more testing and adjustments to exert the appropriate selection pressure.

A large number of experiments, screening nurseries and yield trials were conducted under NVRP between 1988 and 1994 at Gezira, New Halfa and Hudeiba research stations. They included 1800 genotypes from which 129 were marked as showing better tolerance to moisture stress (Table 2). The selected lines are subjected to further evaluation to be released as varieties or recycled in the breeding program.

Table 2. Number of tested and selected promising wheat lines for tolerance to moisture stress at different locations in the Sudan.

Season	Gezira		New Halfa		Hudeiba	
	No. tested	No. selected	No. tested	No. selected	No. tested	No. selected
1988/89	150	9	12	2	0	0
1989/90	144	29	12	5	44	14
1990/91	237	25	12	3	0	0
1991/92	267	62	0	0	20	6
1992/93	112	12	221	15	20	4
1993/94	84	12	192	9	20	2
1994/95	240	36	0	0	19	0
Total	1234	149	449	34	123	26

Source: Elahmadi (1989, 1990); A.I.S. Mohamed (1989,1990); M.S. Mohamed (1989, 1990); Elahmadi *et al.* (1990, 1991a, 1991b, 1992a, 1992b, 1993a, 1993b, 1994a, 1994b).

Resistance to Rusts

Fortunately, the only disease of importance is the black stem rust (*Puccinia graminis tritica*) and, recently, the leaf rust (*P. recondita*). Both of them occur annually at New Halfa area on susceptible lines and cultivars. They have never been reported in recent years in the other regions of the country. A review of the disease problems and achievements will be reported in a separate paper in this meeting. However, it should be mentioned that the breeders at New Halfa Research Station are putting much more effort in selecting for rust resistance together with the other desirable characters. The other breeders in the country are relieved, at least temporarily, from this pressure.

The pathologist at New Halfa, Dr. M.S. Ahmed started to cooperate with the breeders at New Halfa and Gezira in 1988/89, i.e., starting with the ARC/ICARDA/The Netherlands NVRP. Their most promising selections are subjected to natural and sometimes artificial infection with stem and leaf rust to test their resistance. The number of genotypes tested in each season and the number of resistant or moderately resistant ones are shown in Table 3.

Table 3. Number of tested and promising wheat lines or commercial cultivars evaluated for resistance to stem and leaf rust in New Halfa.

Season	No. tested	No. resistant to stem rust	No. resistant to leaf rust
1985/86	46	22	NA†
1988/89	40	35	32
1989/90	44	28	22
1990/91	41	22	NA
1991/92	21	19	18
1992/93	59	19	23
1993/94	59	37	41
1994/95	NA	NA	NA
Total	310	182	135
%	.	58	43

† NA = Not available.
Source: Ahmed (1986); Ahmed and Mohamed (1989, 1990, 1991, 1992, 1993, 1994).

Except for the 1992/93 season, the resistant germplasm constituted more than 50% among the most promising genotypes, including those selected under disease-free conditions in Gezira. Thus the situation can be considered satisfactory.

Tolerance to Aphids

This topic is covered in detail under entomology. However, in spite of the fact of having wheat genetic stocks with good tolerance to aphids, there has been no cultivar released with such a desirable trait. Resistance or tolerance to aphids will be a major component of the integrated control measure of this important insect pest of wheat.

Grain Yield

This is a highly multigenic complex character with high genotype x environment interaction. Yield and stability of yield are the top priority objectives in the breeding programs in the Sudan.

Genetic variation in grain yield is obtained through introductions and hybridization. Every year hundreds of lines are introduced from CIMMYT and ICARDA and sometimes from other countries, particularly Egypt. These introductions come in different forms: advanced breeding lines in yield trials or nurseries, and segregating populations for different objectives—specific or general—e.g., heat tolerance as specific-purpose nursery and high yield and wide adaptation for general purpose. The hybridization activity for recombining characters was initiated by Dr. Imam at Hudeiba Research Station in the mid sixties and has been ongoing especially at Gezira and New Halfa research stations in the last twenty years. Thousands of lines have been developed by the hybridization programs at Gezira and New Halfa since the beginning of the NVRP in 1988/89. The pedigree and sometimes the modified bulk breeding methods were used. A total of 150–250 crosses are made annually.

Visual selection is practiced in the lines from the introductions and the hybridization program for many agronomic characters. These are: time to flowering and maturity, plant height, lodging, shattering and other desirable agronomic and yield components. The three breeders at Hudeiba, Gezira and New Halfa follow similar steps in their empirical method of testing for yield. The visually selected lines are subjected to a series of yield trials. The first two, preliminary and advanced, are conducted at the station while the third is a multilocation on-farm trial. The entries included in the on-farm trial are contributed by the three breeders. The number of entries tested at the preliminary level is usually large (40–100) but goes down (20–40) depending on the selection pressure when it reaches the advanced level trial. Any one entry is tested for 2–3 seasons between the preliminary and advanced levels before it is promoted to the multilocation on-farm trial. The number of entries tested for yield in the preliminary and advanced yield trials is shown in Table 4.

Superior genotypes from the preliminary and advanced yield trials are usually included in an on-farm verification yield trial. It is conducted in 9–12 locations covering the wheat producing areas for 2–3 seasons. The data usually includes 16 entries and is analyzed for yield and yield stability and the top genotypes are considered potential candidates for release (Tables 5a, 5b, and 6a to 6e). In 1990, a new cultivar was released to farmers under the name El Neilain. In 1992, Sasaraib, another cultivar, was released to farmers. Reports are prepared for submission to release five new wheat cultivars. These promising lines for release have similar yield levels with high yield stability and their release will widen the genetic base of the commercial cultivars in the Sudan which will reduce genetic vulnerability. In addition to the released cultivars, many lines with desirable attributes are developed and recycled in the breeding program.

Table 4. Number of entries tested in the preliminary (Prel.) and advanced (Adv.) yield trials during the NVRP at the three main breeding locations in the Sudan.

Season	Gezira		New Halfa		Hudeiba	
	Prel.	Adv.	Prel.	Adv.	Prel.	Adv.
1988/89	92	14	46	44	23	9
1989/90	92	14	48	24	23	33
1990/91	138	14	40	22	0	48
1991/92	135	27	48	23	0	19
1992/93	90	39	40	38	0	17
1993/94	90	13	48	46	23	16
1994/95	138	46	0	0	23	19
Total	775	167	270	197	92	161

Source: Elahmadi *et al.* (1991a, 1991b, 1992a, 1992b, 1993a, 1993b, 1994a, 1994b).

Table 5a. Average yield performance of the released cultivar El Neilain in multilocation trials in three crop seasons.

Cultivar	Grain yield (kg/ha)				% superiority
	1987/88	1988/89	1989/90	Mean	
Debeira (check)	2818	3463	3134	3138	1.4
Condor (check)	2711	3465	3251	3142	1.4
El Neilain	2866	3408	3275	3183	

Source: Elahmadi *et al.* (1987, 1988, 1989, 1990).

Table 5b. Average yield performance of the released cultivar Sasaraib in multilocation trials in three crop seasons.

Cultivar	Grain yield (kg/ha)					% superiority
	1987/88	1988/89	1989/90	1990/91	Mean	
Debeira	3463	3755	3134	2277	3157	4.5
Condor	3465	3606	3251	2432	3188	3.5
Sasaraib	3488	3737	3423	2553	3300	

Source: Elahmadi *et al.* (1992b, 1993b, 1994b).

Table 6a. Average yield performance of the promising breeding line L 1543 82/83 F_5 submitted for release in multilocation trials in three crop seasons.

Cultivar/line	Grain yield (kg/ha)				% superiority
	1990/91	1991/92	1992/93	Mean	
Debeira (check)	2277	3598	3043	2973	3.7
Condor (check)	2432	3695	3012	3046	1.2
L1543 82/83 F_5	2254	3824	3175	3084	

Source: Elahmadi *et al.* (1991b, 1992b, 1993b, 1994b).

Table 6b. Average yield performance of the promising breeding line 12300 x 14 PYT V submitted for release in multilocation trials in two crop seasons.

Cultivar/line	Grain yield (kg/ha)		
	1992/93	1993/94	Mean
Debeira (check)	3043	2400	2721
Condor (check)	3012	2324	2663
12300 x 14 PYT V	3035	2561	2798

Source: Elahmadi *et al.* (1993b, 1994b).

Table 6c. Average yield performance of the promising breeding line Condor'S' x Baladi submitted for release in multilocation trials in four crop seasons.

Cultivar/line	Grain yield (kg/ha)					% superiority
	1990/91	1991/92	1992/93	1993/94	Mean	
Debeira (check)	2277	3598	3043	2400	2830	1.3
Condor (check)	2432	3695	3012	2324	2866	
Condor'S' x Baladi	2364	3341	3124	2643	2868	

Source: Elahmadi *et al.* (1991b, 1992b, 1993b, 1994b).

Table 6d. Average yield performance of the promising breeding line Pavon x Condor'S' submitted for release in multilocation trials in three crop seasons.

Cultivar/line	Grain yield (kg/ha)				% superiority
	1991/92	1992/93	1993/94	Mean	
Debeira (check)	3598	3043	2400	3014	6
Condor (check)	3615	3012	2324	3010	6.2
Pavon'S' x Condor'S'	3657	3232	2699	3196	

Source: Elahmadi *et al.* (1991b, 1992b, 1993b, 1994b).

Table 6e. Average yield performance of the promising breeding line Debeira x 21 PHS submitted for release in multilocation trials in four crop seasons.

Cultivar/line	Grain yield (kg/ha)					% superiority
	1990/91	1991/92	1992/93	1993/94	Mean	
Debeira (check)	2277	3598	3043	2400	2830	4.6
Condor (check)	2432	3695	3012	2324	2866	3.3
Debeira x 21 PHS	2721	3466	3191	2464	2961	

Source: Elahmadi *et al.* (1991b, 1992b, 1993b).

Programs for achieving higher yielding cultivars will be emphasized in future breeding efforts. Many reasons, including the narrow genetic base and the inefficiency of the screening procedure, have been suggested. However, a breakthrough from this stagnation in yield research is needed and will be resumed under the harsh short-season environment which prevails in the Sudan.

Quality

Emphasis was directed mainly towards three characters: grain color and size, protein content and baking quality. Grain color and size are visually selected in the early stages of variety development. Protein content and baking quality tests are carried out in the last stages. Except for grain color, other qualities were given a lower priority. Protein content of 11–13 was considered satisfactory.

The baking quality was acceptable if loaf size was similar to that from the released and commercially grown cultivars. This relaxed pressure led to recent complaints from bakeries about the stickiness of dough from wheat flour from the Sudan. Breeding for quality should be given a higher priority.

Seed Increase

It is the responsibility of the breeders to maintain the purity of the commercial cultivars as long as they are grown for production. With the newly released cultivars of wheat, it was found that they reach the farmer in 3–7 years. It was also found that the breeders should shoulder some effort to produce the seed to prefoundation level. This will make it easier and faster for the propagation units to increase the seed for commercial production. In the last two seasons, an attempt was made with the two newly released cultivars, El Neilain and Sasaraib. In only two seasons, seed of El Neilain was increased from about one ton to more than 100 tons. Sasaraib was increased from a few kilograms to more than 500 kg.

Future Strategies of Wheat Breeding

- High yield must remain the top priority objective.
- Advances made in yield increase are very modest and the main constraint is the high temperature and the short season. Emphasis should be given to developing resistant/tolerant genotypes to extend the season and produce high yields under the warmer conditions prevailing in the Sudan.
- Water is limited. Expanding wheat in new areas will be possible if cultivars tolerant to moisture stress or more efficient in water use are available.
- Stem and leaf rust, the two diseases of concern are confined to New Halfa area. Monitoring the disease should be continued and development of resistant genotypes for that area must be a priority.
- Resistance to aphids is one of the cornerstones to an integrated management control. Efforts to develop resistant genotypes must be intensified.
- High quality grain must receive more emphasis to meet the baking requirements of the market.
- Breeding for salt tolerance and resistance to waterlogging was previously neglected. Development of resistant genotypes will cater for marginal saline areas in the Northern Region and the heavy clay soils prone to logging in the central plains.

References

Ahmed, M.S. 1986. Crop Protection, plant pathology. Page 37 *in* Proceedings of the First National Wheat Coordination Meeting, 3–5 August, Wad Medani, Sudan. ICARDA-104 En.

Ahmed, M.S. and Mohamed, M.S. 1989. Investigation into the wheat rust problems in New Halfa. Page 43 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Cereals, Annual Report 1988/89, Sudan. ICARDA/NVRP-DOC-007.

Ahmed, M.S. and Mohamed, M.S. 1990. Pathology screening of the commercial cultivars and promising lines of wheat for resistance to rusts. Page 86 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1989/90, Sudan. ICARDA/NVRP-DOC-012.

Ahmed, M.S. and Mohamed, M.S. 1991. Pathology: Studies on wheat diseases in New Halfa. Page 57 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1990/91, Sudan. ICARDA/NVRP-DOC-017.

Ahmed, M.S. and Mohamed, M.S. 1992. Pathology: Studies on wheat diseases in New Halfa. Page 67 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1991/92, Sudan. ICARDA/NVRP-DOC-025.

Ahmed, M.S. and Mohamed, M.S. 1993. Pathology: Studies on wheat diseases in New Halfa. Page 81 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1992/93, Sudan. ICARDA/NVRP-DOC-031.

Ahmed, M.S. and Mohamed, M.S. 1994. Wheat diseases: Screening of the commercial cultivars and advanced lines of wheat for resistance to rust diseases. Page 230 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat. Breadwheat Annual Report 1991/92, Sudan.

Blum, A. 1984. Breeding crop varieties for stress environments. CRC Critical Reviews in Plants Sciences 2(3): 199–238.

Ehleringer, J. 1980. Leaf morphology and reflectance in relation to water and temperature stress. Pages 295–308 *in* Adaptation of Plants to Water and High Temperature Stress (N.C. Turner and P.J. Kramer, eds.). John Wiley and Sons, Inc.

Elahmadi, A.B.1986. Crop improvement–wheat variety trials, Gezira. Page 33 *in* Proceedings of the First National Wheat Coordination Meeting, 3–5 August 1986, Wad Medani, Sudan. ICARDA-104 En.

Elahmadi, A.B. 1987. Crop improvement–wheat variety trials at Gezira Research Station. Page 19 *in* Proceedings of the Second National Wheat Coordination Meeting, 20–22 July 1987, Wad Medani, Sudan. ICARDA-130 En.

Elahmadi, A.B. 1988. Crop improvement–wheat variety trials at Gezira Research Station. Page 20 *in* Proceedings of the Third National Wheat Coordination Meeting, 4–6 September 1988, Wad Medani, Sudan. ICARDA-147 En.

Elahmadi, A.B. 1989. Crop improvement at Gezira Research Station. Pages 33–34 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Cereals, Annual Report 1988/89, Sudan. ICARDA/NVRP-DOC-007.

Elahmadi, A.B. 1990. Crop improvement–Wheat improvement in the Gezira. Pages 44–48 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1989/90, Sudan. ICARDA/NVRP-DOC-012.

Elahmadi, A.B., Mohamed, S.M., Mohamed, A.I.S. and Ageeb, O.A.A. 1991a. (1) Wheat germplasm development in Sudan. (2) Development of wheat germplasm tolerant to heat and moisture stress. Pages 39–44 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat. Annual Report 1990/91, Sudan. ICARDA/NVRP-DOC-017.

Elahmadi, A.B., Mohamed, S.M., Mohamed, A.I.S., Ageeb, O.A.A., Ishag, H.M. and Mohamed, G.E. 1992a. (1) Wheat germplasm development in Sudan. (2) Development of wheat germplasm tolerant to heat and moisture stress. Page 33 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1991/92, Sudan. ICARDA/NVRP-DOC-025.

Elahmadi, A.B., Mohamed, S.M., Mohamed, A.I.S., Ali, Z.I., Salih, A.A. and Ageeb, O.A.A. and 1994a. (1) Wheat germplasm development in Sudan. (2) Development of wheat germplasm tolerant to heat and moisture stress. Pages 69–84 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat. Breadwheat Annual Report 1993/94, Sudan.

Elahmadi, A.B., Mohamed, S.M., Mohamed, A.I.S., Babiker, E.A., Omer, M.M., Mohamed, B.A. and Mohamed, G.E. 1992b. On-farm verification yield trial. Page 32 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1991/92, Sudan. ICARDA/NVRP-DOC-025.

Elahmadi, A.B., Mohamed, S.M., Mohamed, A.I.S., Ishag, H.M., Ibrahim, O.H., Ageeb, O.A.A. and Ali, Z.I. 1993a. (1) Wheat germplasm development in Sudan. (2) Development of wheat germplasm tolerant to heat and moisture stress. Pages 26–37 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1992/93, Sudan. ICARDA/NVRP-DOC-031.

Elahmadi, A.B., Mohamed, S.M., Mohamed, A.I.S. and Mohamed, G.E. 1987. On-farm verification variety trial. Pages 18–19 in Proceedings of the Second National Wheat Coordination Meeting, 20–22 July 1987, Wad Medani, Sudan. ICARDA-130 En.

Elahmadi, A.B., Mohamed, S.M., Mohamed, A.I.S. and Mohamed, G.E. 1988. On-farm verification variety trial. Pages 15–17 in Proceedings of the Third National Wheat Coordination Meeting, 4–6 September 1988, Wad Medani, Sudan. ICARDA-147 En.

Elahmadi, A.B., Mohamed, S.M., Mohamed, A.I.S. and Mohamed, G.E. 1989. On-farm verification variety trial. Pages 26–28 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Cereals, Annual Report 1988/89, Sudan. ICARDA/NVRP-DOC-007.

Elahmadi, A.B., Mohamed, S.M., Mohamed, A.I.S., Mohamed, G.E., Babiker, E.A., Omer, M.M., Satti, M.A.I. and Mohamed, M.I. 1993b. Wheat on-farm yield verification trial. Pages 24–26 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1992/93, Sudan. ICARDA/NVRP-DOC-031.

Elahmadi, A.B., Mohamed, S.M., Mohamed, A.I.S., Mohamed, B.A., Babiker, E.A., Mohamed, G.E., Omer, M.M., Satti, M.A.I. and Mohamed, M.I. 1994b. Crop improvement: On-farm verification yield trial. Pages 85–89 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat. Breadwheat Annual Report 1993/94, Sudan.

Elahmadi, A.B., Mohamed, S.M., Mohamed, A.I.S., Mohamed, G.E. and Satti, M.A.I. 1990. On-farm verification variety trial of promising wheat lines. Pages 24–26 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1989/90, Sudan. ICARDA/NVRP-DOC-012.

Elahmadi, A.B., Mohamed, S.M., Mohamed, A.I.S., Mohamed, G.E., Satti, M.A.I. and Babiker, E.A. 1991b. On-farm verification yield trial. Pages 36–38 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1990/91, Sudan. ICARDA/NVRP-DOC-017.

Fischer, R.A. 1985. Number of kernels in wheat crops and the influence of solar radiation and temperature. Journal of Agricultural Science, Cambridge 105: 447–461.

George, G.I. 1958–1965. Hudeiba Research Station, Annual Reports, Ed-Damer, Sudan.

Imam, A.G. 1974. Wheat production and research in the Sudan. *In* 11th Research Colloquium, Cereal Crops in the Sudan, March 1974.

Marshall, D.R. 1987. Australian plant breeding strategies for rainfed areas. Pages 89–98 in Drought Tolerance in Winter Cereals (J.P. Srivastava, E. Porceddu, E. Accvedo and S. Varma, eds.). John Wiley and Sons, Inc.

Massey, R.E. and Martin, F.J. 1921. Experiments on wheat growing in the Sudan. Page 24 *in* Chemical Section Publication No.19.

McWilliam, J.R. 1980. Adaptation to high temperature stress. Pages 444–447 *in* Adaptation of Plants to Water and High Temperature Stress (N.C. Turner and P.J. Kramer, eds.). John Wiley and Sons, Inc.

Mohamed, A.I.S. 1989. Crop improvement: Wheat variety trial at Hudeiba Research Station. Page 35 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Cereals, Annual Report 1988/89, Sudan. ICARDA/NVRP-DOC-007.

Mohamed, A.I.S. 1990. Crop improvement in the Northern Region. Page 53 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1989/90, Sudan. ICARDA/NVRP-DOC-012.

Mohamed, S.M. 1989. Crop improvement: Wheat variety trials at New Halfa Research Station. Page 34 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Cereals, Annual Report, 1988/89, Sudan. ICARDA/NVRP-DOC-007.

Mohamed, S.M. 1990. Crop improvement: Wheat improvement in New Halfa. Page 49 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report, 1989/90, Sudan. ICARDA/NVRP-DOC-012.

Mooney, H.A. 1980. Seasonality and gradients in the study of stress adaptation. Pages 279–294 *in* Adaptation of Plants to Water and High Temperature Stress (N.C. Turner and P.J. Kramer, eds.). John Wiley and Sons, Inc.

Osmanzai, M., Rajaram, S.R. and Knapp, E.B. 1985. Breeding for moisture-stressed areas. Pages 151–161 in Drought Tolerance in Winter Cereals (J.P. Srivastava, E. Porceddu, E. Acevedo and S. Varma, eds.). John Wiley and Sons, Inc.

Porter, K.B. 1959. The inheritance of shattering in wheat. Agronomy Journal 51: 1973–1977. Quoted *in* Quisenberry K.S. and L.P. Reitz 1967. Wheat and Wheat Improvement. ASA Inc.

Smith E.L. 1987. A review of plant breeding strategies for rainfed areas. Pages 79–87 *in* Drought Tolerance in Winter Cereals (J.P. Srivastava, E. Porceddu, E. Acevedo and S. Varma, eds.). John Wiley and Sons, Inc.

Snow, 1948. Quoted *in* Khalifa, M.A. 1974. Irrigated wheat in the Northern Province and the Gezira. II. Varietal Improvement. *In* 11th Research Colloquium, Cereal Crops in the Sudan, March 1974.

Teeri, J.A. 1980. Adaptation of kinetic properties of enzymes to temperature variability. Pages 251–260 *in* Adaptation of Plants to Water and High Temperature Stress (N.C. Turner and P.J. Kramer, eds.). John Wiley and Sons, Inc.

Discussion

Q: G.S. Youssef

What is the pedigree of the newly released wheat cultivars?

A: A.B. Elahmadi

The pedigrees of the newly released cultivars El Neilain and Sasaraib are S948-A-SE7 and Veery 5, respectively.

Comment/Q: M.B. Solh

There is a need to specify the breeding methodology (i.e., pedigree vs. bulk or modified bulk, introduction) and the flowchart for evaluation (type of trials). Furthermore, a table of varietal releases, characteristics of the cultivars, date of release, adaptation, and responsible researchers is needed. Also, please specify the resistant genotypes or refer to the source where they may be found.

A: A.B. Elahmadi

For the methodology, we usually use the pedigree method in wheat under normal conditions, however, we go to the modified bulk method if our plots are exposed to stress and segregation is suppressed. Our studies were not directed towards evaluating the efficiency of the methodology. As for the table, it is very difficult in a review to include much detail on varietal improvement, rather, we sum up the most important character, which is yield. Regarding resistant genotypes, these are found with the wheat breeders but are in the form of active germplasm.

Comment: Saeed Farah

Regarding taking yield data for assessing tolerance to heat and moisture stresses, I think that criteria such as root growth, relative turgidity, leaf orientation, etc., would help breeders to better evaluate their material if these could be taken into consideration with close collaboration with agronomists.

A: A.B. Elahmadi

The characters suggested by agronomists are not easy to measure in the field in thousands of lines. Moreover, the relation of these characters to yield is not well understood. Breeders would like to have an easily measurable character without destroying the plant and that would be highly related to yield.

Q: Mohamed Safaa Eldin Sharshar

What is the selection stage for early maturity?

A: A.B. Elahmadi

By early maturity we refer to physiological maturity.

Q: Mohamed Ahmed Khalifa

Could the yield stagnation reached be attributed to a narrow genetic base caused by heavy reliance on Mexican cultivars?

A: A.B. Elahmadi

No, the stagnation is occurring. In CIMMYT, Mexico, where they have access to the World Collection, they are not getting improvements even from new wide crosses. However, we acknowledge that our genetic base is relatively narrow due to selection pressure caused by the many requirements. Broadening the genetic base will definitely help.

Q: Mohamed Ahmed Khalifa

Heat effects and low moisture effects are not easily separated and are usually confounded in the field. How can they be separated visually in the field in the selection process?

A: A.B. Elahmadi

It is not easy to separate the effects of heat and moisture stress visually.

Q: Elfadil Abdel Rahman Babiker

Why are yields near the Rahad River (52% clay) always high compared to those in areas away from the river (76%)? Breeders should look at the root.

A: A.B. Elahmadi

The difference could be due to soil fertility. It is not easy to screen thousands of lines by looking at the roots. It is difficult to measure root depth and volume for a large number of plants. Also, the relationship between the root volume and yield is not well understood.

Q: Abdelmoneim T. Ahmed

I think that wheat production in central Sudan will always be risky without a breakthrough in genetic development. What are the prospects for that?

A: A.B. Elahmadi

We are not expecting to find the answers to all the production problems of wheat in a genetic breakthrough. At this time and even when we have good, improved cultivars, wheat production will continue being risky in central Sudan due to the lack of use of improved cultural practices. It is difficult to foresee a breakthrough, but efforts are being made at all levels (international and national).

Chapter 3
Agronomy

Crop Establishment and Mechanization of Wheat

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Abstract

This review covers research conducted within the Nile Valley Regional Program (NVRP) on crop establishment and mechanization of wheat in the Sudan with emphasis on the 1986–1995 period. It includes studies on tillage, seeding methods, sowing on wet and dry soils, harrow packing, and mechanization of seeding and harvesting. Results from the different studies showed that the best tillage system is disc harrowing or ridging during the rainy season, followed by disc harrowing in November and finally levelling. Sowing on ridges improved irrigation water management and reduced flooding hazards but did not increase yields significantly. Sowing on wet soil and harrow packing increased grain yields. Positive results on crop establishment were observed when using seed drills compared to other seeding machines. Seed drills with tine openers were superior to those with disc furrow openers. Field assessment of combine harvesting losses showed that extremely high harvesting losses (13–31%) were experienced in major wheat production areas. Future research should consider combined tillage and seeding operations, specific soil benchmark tillage recommendations, machine-specific seed rates, harvest loss diagnosis, in addition to combine harvester management studies.

Introduction

Wheat production in the Sudan is fully mechanized. For farmers to obtain high yields and make profits, machinery has to be efficiently used and managed. Wheat cultivation in the Sudan is faced with constraints relating to soil management and the environment. The crop is new to the farmer and the farming system limits holding size, crop sequence, quantity, and distribution of irrigation water. Mechanization faces problems like availability of machinery, unskilled operators, and shortages of fuel and spare parts.

Wheat crop establishment is a result of many factors. These include: seed germination, soil tillage, irrigation water management and the effect of the environment. Ageeb (1994) concluded that poor crop establishment of wheat is a major cause of low yields on the heavy clay soils of the Sudan.

The objective of research in wheat crop establishment and mechanization is twofold: first, to optimize input factors in order to achieve good crop establishment, and second, to select machinery and field operations for efficient and profitable wheat production. The results on which this review was based were derived from experiments carried out in wheat-producing areas in northern, central and eastern Sudan during the Nile Valley Regional Program (NVRP) which involved the collaboration of the Agricultural Research Corporation (ARC) and ICARDA through the financial support of the Netherlands Government.

Climate and Soil

Climate

The climate of the wheat-producing areas is classified as arid and semi-arid. Maximum daily air temperatures range from 32.9°C in January to 41.6°C in May, while minimum daily air temperatures range from 14.3°C in January to 24.5°C in June. The rainy season extends from May to October, with a peak in July. Average annual total rainfall amounts to 306.4 mm. Thirty-year averages of the meteorological data for Wad Medani, representing the major wheat-producing areas of the Gezira, are shown in Table 1.

Wheat is cultivated during the cool season which is short (100–110 days) and experiences short hot spells. Sowing is in November while harvesting is in March and April. Early rain showers in April and May present a hazard to delayed harvesting.

Soil

The soils of the major wheat production areas are cracking heavy clay Vertisols, with 58–66% clay, very low water permeability, pH of 8.5, low on organic matter (0.05%), deficient in nitrogen (300–400 ppm), and low in available phosphorus (2–4 ppm).

Table 1. Meteorological data for Wad Medani (14°23'N, 33°29'E, altitude 405 m), averaged over 30 years, 1961–1990.

Month	Daily air temperature (°C)			Relative humidity (%)	Monthly rainfall (mm)
	Max.	Min.	Mean		
January	32.9	14.3	23.6	32	TR†
February	34.8	15.9	25.3	25	TR
March	38.2	19.1	28.7	20	TR
April	40.0	21.6	31.3	18	1.2
May	41.6	24.5	33.1	27	13.5
June	39.8	24.9	32.3	41	28.2
July	36.3	23.3	29.8	58	88.0
August	34.7	22.5	28.6	67	112.1
September	35.9	22.2	29.1	62	45.9
October	38.0	22.0	30.0	47	16.0
November	36.2	18.4	27.3	35	1.5
December	33.4	15.3	24.3	35	TR
Average annual	36.9	20.3	28.6	39	306.4‡

† TR = Trace.
‡ Total annual rainfall.
Source: Sudan Meteorological Department.

Tillage

The basic purpose of tillage is to provide a favorable soil environment for the germination and growth of the crop. Tillage usually affects four soil physical properties: aeration, moisture-holding capacity, temperature and mechanical impedance. Primary tillage is usually done to break the soil compaction, while secondary tillage is for obtaining a fine final seedbed. Other purposes of tillage include weed control and turning under crop residues for pest control or for easier cultivation.

Vertisols are known to be hard to work when too dry and very muddy for traction when wet. Previously, little research was done in the Sudan with respect to soil tillage. Hence, many questions still needed answers, such as: What is the right time for tillage? What is the best machinery to use? How can the best seedbed be achieved economically? What is the optimum depth of tillage? All these questions were included in the objectives for tillage experiments in the NVRP.

Tillage Tools

The most popular wheat tillage tools in the Sudan are disc harrows and ridgers. Disc harrows are of two main sizes. The small size is of the offset type with disc diameter ranging from 50 to 75 cm and pulled by medium-size tractors (75–80 hp). The large-size disc harrows are offset or tandem types, with discs 75–90 cm in diameter. These are pulled by large-wheeled or crawler tractors (120–180 hp) (Fig. 1).

Ridgers are lister-type surface shapers used as primary and secondary tillage tools for wheat cultivation. Ridgers are made of a toolbar equipped with four bodies and fully mounted on medium-size tractors.

Of lesser popularity as wheat tillage tools are disc plows and wide level discs (WLD). Disc plows are used for weedy and hard soils. These are usually three bottom plows with discs about 70 cm in diameter. The WLD (Fig. 2) is a combined tillage and seeding tool. It is equipped with discs in addition to a seed box. This machine is popular as a tillage tool in New Halfa area. Levelling is usually done using rectangular levelling frames or drag bars pulled by medium-size tractors.

Time of Tillage

With the objective of finding the optimum time for the first harrowing and investigating the effects of this time on wheat establishment and yield, an experiment was conducted at Gezira Research Station for two seasons (Idris 1992; Dawelbeit *et al.* 1993c). Results showed that there were no significant differences in yield (Table 2). However, from a practical point of view and for easier mechanical operation, the first disc harrowing during the rainy season and after the emergence of weeds is the best.

Fig. 1. Large-size disc harrow pulled by crawler tractor.

Fig. 2. Wide level disc, combining tillage and seed drilling.

Table 2. Effect of time of first harrowing on wheat crop establishment and grain yield, 1991/92 and 1993/94.

Season	Tillage time	Number of heads/m^2	Gain yield (kg/ha)
1991/92	Mid-May	385	4100
	Mid-August	403	3700
	Mid-October	392	3900
1993/94	July	633	1506
	August	687	1635
	October	653	1554

Source: Idris (1992); Dawelbeit *et al.* (1993c).

To investigate the effects of time and type of primary tillage (ridging and harrowing) on weed control and wheat yield, an experiment was conducted at Rahad Research Station. Results showed that significant differences (P = 0.05) in grain yield were observed between the treatments (Table 3). The best yields were given by the ridger in September (1085 kg/ha), the disc harrow and ridger in July (1060 and 957 kg/ha, respectively) and the ridger in June (972 kg/ha). However, irrespective of the time of primary tillage operation, there were no differences in weed population between ridging and harrowing (Mohamed *et al.* 1994). As indicated from the above discussion, the best time for the first tillage is during the rainy season when the soil is adequately wet and easy to manipulate. The second tillage could be done before seeding so as to obtain a fine seedbed.

Depth of Tillage

To find the optimum depth of disc harrowing, an experiment was conducted at for two seasons. Five depth treatments were tested (Dawelbeit 1993a; Dawelbeit *et al.* 1994c). Results are shown in Fig. 3. Although there was a trend of increasing yield with the increase in depth of harrowing, statistical analysis did not show significant differences between treatments. Also, no differences were observed in penetration resistance.

Table 3. Effect of time and type of primary tillage on number of tillers, plant height and grain yield of wheat in Rahad Research Station, 1993/94.

Time	Type	No of tillers/m^2	Plant height (cm)	Grain yield† (kg/ha)
May	Ridger	271	56	910 cd
	Harrow	282	52	930 bc
June	Ridger	278	59	972 abc
	Harrow	291	56	806 bd
July.	Ridger	280	57	1060 ab
	Harrow	304	57	957 abc
August	Ridger	302	52	710
	Harrow	287	50	806 de
September	Ridger	329	54	1085 a
	Harrow	330	52	834 cd
SE (±)		21	3	42.5

† Yields having common letters are not significantly different.
Source: Mohamed *et al.* (1994).

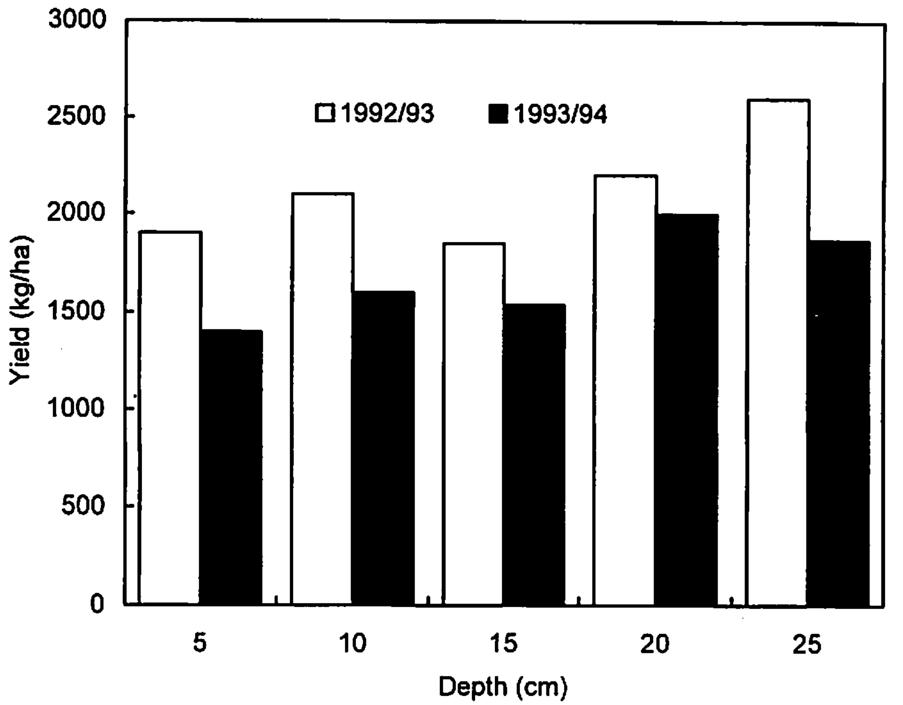

Fig. 3. Effect of depth of harrowing on wheat yield.

Soil Moisture and Tillage

Soil moisture content is one of the most important factors affecting the performance of the tractor operations, the implement, as well as the condition of the final seedbed. An experiment was conducted at Rahad Research Station for three seasons to find the optimum moisture content for effective disc harrowing (Mohamed and Dawelbeit 1992; Mohamed 1993; Mohamed and Babiker 1994). For the 1991/92, 1992/93 and 1993/94 seasons, the tested soil moisture content ranged from 33.2 to 27.4%, 31.2 to 22.7%, and 30.4 to 12.4%, respectively. Aggregate sizes greater than 4 mm in diameter constituted more than 50% of the sample sizes for the three seasons. There was a general increase in the percentage of aggregate sizes that were less than 1 mm as the soil moisture content decreased. Results also showed that soil penetration resistance increased with the decrease of soil moisture content. The percent travel reduction increased with the decrease of soil moisture content, reaching a maximum at 24% on dry basis (db), and then decreased with the decrease of moisture content. However, no significant differences in yield were observed at the different tested moisture contents (Table 4).

Table 4. Effect of soil moisture content on wheat grain yield in three crop seasons in Gezira.

1991/92		1992/93		1993/94	
Soil moisture content (% db)†	Grain yield (kg/ha)	Soil moisture content (% db)	Grain yield (kg/ha)	Soil moisture content (% db)	Grain yield (kg/ha)
33.2	3745	31.2	1078	30.4	1177
31.6	3461	30.2	1066	29.0	1161
30.5	3046	27.7	1136	27.4	1209
29.3	3457	26.5	1154	25.8	1242
28.0	3138	26.1	1076	24.2	1212
27.4	3460	25.7	1213	22.4	1449
		25.0	1353	18.2	1391
		24.2	1339	15.4	1307
		22.7	1226	12.4	1222
SE (±)	273		150.4		163

† db = Dry soil basis.
Source: Mohamed and Dawelbeit (1992); Mohamed (1993); Mohamed and Babiker (1994).

Tillage Systems

A study comparing and evaluating the effect of different tillage systems on wheat was conducted in Gezira for four seasons (Salih and Musa 1987, 1988, 1989; Salih *et al.* 1990). The systems included: chisel plowing, 3-bottom disc plowing, harrowing, rotary cultivator tilling (rotovator), and ridging, in addition to seeding on 40 cm ridges and on flat in the last two seasons. Results indicated that harrowing twice significantly increased grain yield in 1987/88. Ridging slightly increased grain yield over flat in the two tested seasons (Tables 5, 6 and 7).

Table 5. Effect of tillage system on grain yield of wheat in two crop seasons.

Treatment	Grain yield (kg/ha)	
	1986/87	1987/88
3-bottom disc plowing + harrowing + levelling	2490	1630
Harrowing twice + levelling	2180	1800
Ridging + split-ridging + levelling	2380	1302
Ridging + harrowing + levelling		1461
Rotovator	2000	
SE (±)	300	121

Source: Salih and Musa (1987, 1988).

Table 6. Effect of tillage system on grain yield of wheat in Gezira, 1988/89.

	Grain yield (kg/ha)			
	Harrowing + levelling	Chisel + harrow + levelling	Ridging + split-ridging + levelling	Mean (SE = ± 158)
Flat	2970	2920	2890	2927
40 cm ridges	3150	3180	2900	3077
Mean (SE = ± 254)	3060	3050	2895	

Source: Salih and Musa (1989).

Table 7. Effect of tillage system on grain yield of wheat in Gezira, 1989/90.

	Grain yield (kg/ha)			
	Harrowing twice + levelling	Chisel + harrow + levelling	Ridging + split-ridging + levelling	Mean
Flat	1470	1320	1130	1310
40 cm ridges	1590	1360	1170	1370
Mean (SE = ± 50)	1530	1340	1150	

Source: Salih *et al.* (1990).

Four tillage systems were compared in New Halfa. These included: (1) disc plowing, clod crushing and levelling; (2) dry ridging, prewatering, harrowing and levelling; (3) light disc harrowing and levelling; and (4) prewatering, light disc harrowing and levelling. The tillage system had no significant effect on crop establishment and grain yield (ICARDA 1987).

In the White Nile Scheme, ridging and split-ridging resulted in significantly lower yields (2290 kg/ha) when compared to ridging plus harrowing (2550 kg/ha) and disc plowing plus harrowing (2530 kg/ha) at Um Gerr. No difference was observed in the yield of the three tested systems in Abbassya site where the mean grain yield was 2476 kg/ha (Satti 1992).

As a result of a detailed soil survey in the Gezira Scheme, a number of soil mapping units or bench marks were identified. A comparison of different tillage systems was conducted in the 1993/94 season on three different soil bench marks. Tables 8 and 9 show physical and chemical properties as well as chemical parameters of the subsoil and land suitability of these bench marks. Results showed that there were no significant differences in grain yield due to the tillage system on soil mapping units Number 30 and 50. However, in mapping unit Number 31, the ridging plus split-ridging resulted in a significantly lower yield when compared to the other tested systems (Dawelbeit and Abdel Wahab 1994).

Table 8. Physical and chemical properties of selected soil bench-mark sites at 25 cm plow layer.

Bench mark	Bulk density (g/cm^3)	Infiltration (cm/hr)	Hydraulic conductivity (cm/hr)	Wetting front (cm)	Clay content (%)	EC† (mmhos/cm)	ESP‡
30	1.72	1.6	2.7	22.7	58	0.9	11
31	1.72	1.7	3.5	23.2	59	0.5	6
50	1.82	1.0	2.0	18.0	60	0.8	12

† EC = Electric conductivity.
‡ ESP = Exchangeable sodium percent.

Table 9. Chemical parameters of the subsoil (25–100 cm) and land suitability of the selected soil bench-mark sites.

Bench mark	Clay content (%)	Depth of melanic horizon	$CaCO_3$ (%)	EC† (mmhos/cm)	ESP‡	pH paste	Drainage condition	Land suitability§
30	50–59	> 100 cm	4.4	> 4	22	7.8–8.3	moderately well	S2Vaf
31	50–59	> 100 cm	4.4	> 4	> 15	7.8–8.3	moderately well	S2Vf
50	60–70	> 100 cm	5.0	> 4	28	7.8–8.1	imperfect/moderate	S2Vaf

† EC = Electric conductivity.
‡ ESP = Exchangeable sodium percent, according to the American Soil Classification System.
§ S2 = Class 2 suitability with certain limitations; V = Vertisolic limitation; a = Sodicity limitation; f = Fertility limitation.

Tillage Surveys

Various tillage systems are being practiced for wheat production in central and eastern Sudan. In these systems, the unavailability of power and suitable machinery represents the major limiting factors. Tillage surveys were conducted at Gezira, New Halfa and Rahad during the 1991/92 to 1993/94 seasons (Dawelbeit and Salih 1992; Mohamed 1992; Dawelbeit *et al.* 1993a; Abdel Wahab *et al.* 1994b) with the objective of monitoring and evaluating the currently practiced tillage systems and their trends. Results of these surveys showed that two main systems could be identified in the large irrigated schemes. These were: the ridger system (RS) and the disc harrow system (DHS).

In the Gezira Scheme, the RS involved ridging, split-ridging and levelling. It might include an extra ridging operation depending on the soil condition. On the other hand, DHS involved using a disc harrow either pulled by a crawler tractor or a wheeled tractor as the main machine. DHS may be preceded by a ridging operation. During the last three seasons the ridger system gained popularity. Its share increased from 45% of the total cultivated area to 52% in 1993 and to 91% in 1994. It was evident in Gezira that RS could result in higher yields compared to DHS when used wisely by farmers in good, clean soils and followed by good management. This was evident in groups such as Messalamiya, Wadi Shaeer and Wad Habooba. In addition, RS was less expensive (12–40%) than DHS. On the other hand, tillage surveys showed that DHS resulted in increased yields in some areas (Mikashfi, Maatog and the southern groups) over RS.

At New Halfa, RS included two types: ridging plus light disc harrowing using the wide level disc (WLD) and ridging plus split-ridging plus harrowing, also using the WLD. DHS included five different types which were made by combinations of disc harrows having disc diameters of 56, 64 and 71 cm, and the WLD. Results of the survey showed that in 1992/93, 32% of the area was prepared by DHS, while the percentage for 1993/94 was as low as 17%. The shift towards RS was mainly due to the high cost of DHS. No clear trend in grain yield was observed between the two systems.

Land preparation for wheat in Rahad is usually performed by the Agricultural Engineering Department of Rahad Corporation. It was observed that there was a clear shift in using ridgers as primary tillage machinery due to the high operation cost of disc harrows in addition to the availability of ridgers. Ridging in this system, as in other projects, is performed during the rainy season. An extra ridging or harrowing might be added if needed. The final operation is disc harrowing.

Recently, levelling has become more popular. In the early days no levelling operations were performed. Starting from 1991/92, about 45% of Gezira was levelled. In 1992/93, this area increased to 61% and the trend was increasing during later seasons. Farmers became aware of the importance of levelling and its positive effects on irrigation water management and crop establishment.

Crop Establishment

Factors such as the method of sowing, sowing on wet or dry soils, harrow packing and their effects on crop establishment and yield of wheat were studied. Research included on-station back-up experiments as well as on-farm trials.

Method of Sowing

Vertisols are known to impose a physically difficult environment for wheat germination and establishment. Thus, the need for improved methods of crop establishment cannot be overemphasized. To improve crop establishment and increase grain yields, farmers in New Halfa follow practices such as sowing on wet soil, delaying the second irrigation, and sowing on beds 120 cm wide. Sowing on wet soil involves flooding the soil, waiting till it becomes workable (39–23% soil moisture), then using WLD for seeding. Seedling emergence takes place using the residual soil moisture. On the other hand, sowing on dry involves using WLD for seeding on dry soil (less than 20% soil moisture) then applying the first irrigation. Research results (Fig. 4) showed that, out of three seasons, sowing on wet soil increased grain yield significantly (P = 0.05) compared to sowing on dry soil, as reported by Babiker *et al.* (1991) and Ghorashi (1992), except in New Halfa in the 1989/90 season (Ghorashi 1990) (Table 10). Similarly, in Gezira and Rahad, sowing on wet soil significantly increased grain yield (Tables 11 and 12) as reported by Babiker *et al.* (1991).

Farmers in New Halfa believe that delaying the second irrigation by 3–4 weeks increases root depth, tillering capacity and yield. Research results showed that the time of the second irrigation did not significantly affect the tested parameters, including yield.

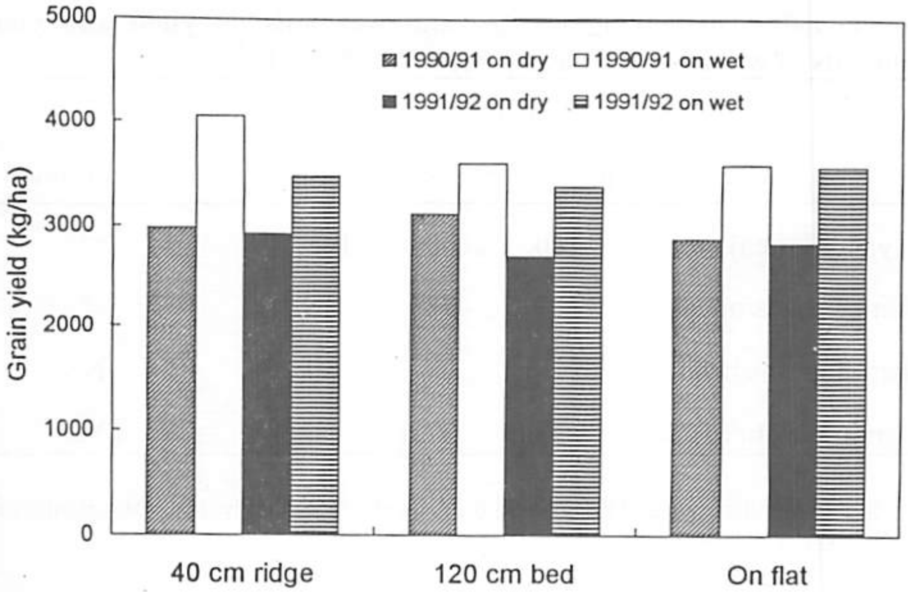

Fig. 4. Effect of sowing on dry and wet soils in New Halfa, 1990/91 and 1991/92.

Table 10. Effect of sowing on dry and wet soils on yield and yield components of wheat in New Halfa, 1989/90.

	Sowing on		Mean	SE (±)
	dry soil	wet soil		
Grain yield (kg/ha)	2860	2537	2699	17
Number of heads/m^2	495	450	473	21
Number of seeds/head	32	29	31	3
Weight of seeds/head (g)	1.33	1.20	1.26	0.14
1000-grain weight (g)	36.1	36.0	36.0	0.5
Plant height (cm)	77	65	71	0.6

Source: Ghorashi (1990).

Table 11. Effect of sowing on dry and wet soils on yield and yield components of wheat in the Gezira Scheme, 1990/91.

	Sowing on			
	dry soil	wet soil	SE (±)	Signif. level
Grain yield (kg/ha)	1700	2600	145	***
Number of heads/m^2	389	478	6	*
Number of grains/head	27	29	0.2	NS
1000-grain weight (g)	37.0	37.6	0.32	NS

*, *** = Significant difference at the 5% and 0.1% levels, respectively; NS = Not significant.
Source: Babiker *et al.* (1991).

Table 12. Effect of sowing on dry and wet soils on yield and yield components of wheat in Rahad, 1990/91.

	Sowing on		
	dry soil	wet soil	SE (±)
Grain yield (kg/ha)	1420	1880	102
Number of heads/m^2	359	381	8
Number of seeds/head	30	30	0.8
Number of weeds/m^2	11.7	5.0	0.86
1000-grain weight (g)	42.0	41.0	0.41
Termite damage (%)	7.9	5.8	

Source: Babiker *et al.* (1991).

The method of sowing (40 and 60 cm ridges, 120 cm beds, on flat) did not affect grain yield significantly. This is in agreement with the results reported by Ghorashi (1990, 1992). Details are shown in Tables 8, 9, 10 and 13.

Table 13. Effect of sowing on ridges and on beds on yield and yield components of wheat in New Halfa, 1993/94.

	Sowing on				Signif. level
	60 cm ridges	120 cm beds	Mean	SE (±)	
Grain yield (kg/ha)	1238	1119	1179	663	NS
Number of heads/m^2	444	493	469	11	*
Number of seeds/head	53	52	53	3	NS
Emergence plants/m^2	444	461	453	15	NS
1000-grain weight (g)	34	33	33.5	0.1	*
Plant height (mm)	690	660	680	20	NS

* = Significant at the 5% level; NS = Not significant
Source: Abdel Gadir (1994).

In Gezira and Managil, sowing on 40 and 60 cm ridges improved water management and reduced flooding hazards (Salih and Musa 1989; Salih *et al.* 1990, 1994), but did not increase yields significantly when compared to sowing on flat. This is shown in Tables 6, 7 and 14.

The same results were obtained at the White Nile Scheme where 40 and 80 cm ridges and chisel plowing were used after seed broadcasting. No significant effect was observed on grain yield but ridges improved water management (Satti 1990).

Table 14. Effect of sowing method on wheat grain yield at Rahad and Managil, 1993/94.

Sowing method	Grain yield (kg/ha)				
	Rahad				Managil
	Block 4	Block 6	Block 9	Mean	
60 cm ridges	1392	1404	1595	1464	1426
On flat	1310	1047	1404	1254	1057
% increase	6	34	14	17	35

Source: Salih *et al.* (1994).

In Rahad, investigations on the effect of the methods of sowing on crop establishment and yield also showed that different ridge sizes (40, 60, 80 and 120 cm) improved water management and avoided crust formation when compared to flat (Tables 15 and 16). However, no significant increase in yield was observed (Babiker and El-Hassan 1990a; Babiker *et al.* 1991; Babiker and Mohamed 1992). In the Blue Nile and Suki schemes, comparison of seeding on flat to 40 cm ridges resulted in no significant differences in grain yield in one season, and in comparatively higher grain yield in the other (Omer 1990; Babiker *et al.* 1991).

Table 15. Effect of sowing method on growth, yield and yield components of wheat, 1991/92.

Sowing method	Plants/m^2	1000-seed weight (g)	Plant height (cm)	No. of seeds/head	Grain yield (kg/ha)
On flat	352	32.5	56	47	2492
40 cm ridges	338	32.1	56	44	2438
60 cm ridges	335	31.9	58	46	2579
80 cm ridges	274	32.7	59	46	2328
SE (±)	8.4	2.0	1.5	2	295

Source: Babiker and Mohamed (1992).

Table 16. Effect of different seeding machines on grain yield of wheat at Rahad, 1989/90.

Machine	Grain yield (kg/ha)			
	Block 1	Block 2	Block 7	Mean
Vicon + 40 cm ridger	1688	1818	1645	1717
Vicon + disc harrow	1688	1802	1558	1682
Wide level disc	1947	2007	1644	1886
SE (±)				39

Source: Babiker and El-Hassan (1990a).

Planting on wet soil is a practical method of controlling weeds and avoiding flooding hazards associated with the first irrigation, especially on inadequately levelled fields. Maximum germination was obtained at a soil moisture of 39% db (dry soil basis), while no germination took place when the soil moisture content was below 22% (Salih 1989). Machine seeding on wet soil at 28% moisture content resulted in 30% increase in yield over neighboring farms sown on dry soil and 120% over the Gezira average yield. Similar results were also reported in an on-farm trial conducted at the Gezira Scheme (Salih 1990). This increase in yield was mainly due to the increased number of heads per unit area.

Harrow Packing

Pressing the soil with a harrow after placing and covering the seeds (harrow packing or HP) was found to improve crop establishment and increase sorghum yields in Gedarif area (Sim Sim Dryland Farming Project 1989). Better seed/soil contact could result from this operation leading to better water absorption by the seeds and hence better seed germination and seedling emergence.

At Gezira Research Station (Dawelbeit and Ishag 1992; Dawelbeit 1993b), HP was evaluated at three levels (0, 1250 and 1550 kg/m^2) with three different seeding machines (seed drill, wide level disc and broadcaster). Results showed that HP did not result in a significant increase in yield compared to the control (Table 17). However, in the first season, seed drilling resulted in a significantly lower yield (P = 0.05) when compared to the other treatments. In the second season, no differences were observed. Harrow packing at three different soil moisture contents (26, 21 and 20% db) also showed that varying the soil moisture content had no effect on grain yield (Dawelbeit 1992a).

On-farm evaluation in the Gezira Scheme showed that HP made the first irrigation easier and faster. In the first season, there was a 7% increase in yield due to HP, while no differences were observed in the second season (Dawelbeit 1992b, 1993b).

Investigations at New Halfa on three levels of HP and wide level disc plowing showed no significant differences in yield (Abdel Gadir 1992). Similarly, at Rahad, HP at three levels and with three seeding machines: seed drills (SD), wide level discs (WLD) and broadcasters (BC) resulted in no significant differences in yield due to treatment (Mohamed and Dawelbeit 1992) (Table 18).

Table 17. Effect of seeding method and harrow packing on wheat crop establishment and yield in Gezira, 1991/92 and 1992/93.

Seeding method	Plant population (plants/m²)		Yield (kg/ha)	
	1991/92	1992/93	1991/92	1992/93
Seed drilling	188	290	2069	2489
Broadcasting, disc harrow covering	218		2618	
Broadcasting, tine covering	208		2515	
Wide level disc		295		2582
Broadcasting		281		2397
Mean	205	289	2400	2489
SE (±)	14.7	67.3	108.9	22.1
Harrow packing (kg/m²)				
Zero	206	285	2411	2461
1250	201	287	2354	2482
1550	208	300	2438	2528
Mean	205	291	2401	2489
SE (±)	14.7	67.3	108.9	22.1

Source: Dawelbeit and Ishag (1992); Dawelbeit (1993b).

Table 18. Effect of harrow packing and three sowing methods on crop establishment and yield of wheat at Rahad Scheme, 1991/92.

	Sowing method			Harrow packing (kg/m²)			SE (±)
	Seed drill	Wide level disc	Broad-casting	0	1250	1550	
Seeds/head	45.2	43.6	42.8	44.4	43.0	44.2	0.9
Heads/m²	568	547	568	568	556	556	10.1
Grain yield (kg/ha)	2590	2570	2464	2505	2462	2652	40.6

Source: Mohamed and Dawelbeit (1992).

Mechanization

Seeding Machines

Broadcasters and seed drills (SD) are the two main seeding machines used in the Sudan. The most popular broadcasting machine is the wide level disc (WLD). WLD is composed of a seed box, a metering device and a disc covering device. The resulting pattern is random scattering of seeds over the surface of the field. Seed drills, in addition to the seed box and the metering device, have separate furrow openers and covering devices (Fig. 5). The resulting pattern is definite rows.

Fig. 5. Seed drill for sowing wheat in rows.

Three seeding machines were evaluated at New Halfa: WLD without hoses, WLD with hoses, and a seed drill (ICARDA 1987). The SD had a positive effect on crop establishment but none of the seeding machines had a significant effect on grain yield.

On-farm studies conducted at Rahad to compare the Vicon spreader + 40 cm ridger; Vicon spreader + disc harrow; and WLD showed that WLD increased yield over the Vicon by 10–12% (Babiker and El-Hassan 1990b).

Babiker *et al.* (1991) tested three seeding machines with two land preparation methods and two irrigation methods (Tables 19 and 20). Results showed that seeding with the tine opener drill at 6 cm depth gave the highest yield which significantly (P = 0.05) outyielded the other two machines. Mohamed and Dawelbeit (1992) studied the performance of three seeding machines. Although the seed drilling with a tine opener gave positive results, no significant differences were observed in grain yield (Table 19).

Table 19. Effect of three seeding machines and two irrigation methods on yield of wheat at Rahad Scheme, 1990/91.

Method of sowing	Grain yield (t/ha)			Plant population (plants/m²)		
	On flat	40 cm ridges	Mean (SE = ± 0.094)	On flat	40 cm ridges	Mean
Drill A tine furrow openers, 6 cm depth of seeding	1.56	1.29	1.42	190	216	203
Drill B disc furrow opener, 4 cm depth of seeding	0.98	1.19	1.08	197	189	193
Broadcasting	1.04	1.14	1.09	229	225	227
Mean	1.19	1.21		205	210	

Source: Babiker *et al.* (1991).

A two-season study at Gezira, Rahad, New Halfa and the Blue Nile evaluated a number of seeding machines (Dawelbeit *et al.* 1993d, 1994b). At Gezira, SD resulted in the highest yields (1890 kg/ha), followed by WLD (1785 kg/ha), and then the press drill (1460 kg/ha) in the first season. However, in the second season, the WLD resulted in significantly (P = 0.05) higher grain yields (1944 kg/ha) when compared to the press drill (1661 kg/ha) and the seed drill (1589 kg/ha).

Comparing four different machines at Rahad during two seasons showed that, for the two seasons; there were no significant differences in yield (Table 21). Fuel consumption and cost were higher for broadcasting by Vicon and covering by ridger than for the other treatments.

Table 20. Effect of three sowing machines and two seedbed preparation methods on wheat crop establishment and yield, 1990/91.

Method of sowing	Grain yield (t/ha)			Plant population (plants/m²)		
	C + H + L†	DH‡	Mean (SE = ± 0.069)	C + H + L	DH	Mean
Drill A tine furrow openers, 6 cm depth of seeding	1.15	1.12	1.14	193	190	191
Drill B disc furrow opener, 4 cm depth of seeding	0.88	0.85	0.86	190	179	184
Broadcasting	0.74	0.90	0.82	196	185	191
Mean	0.92	0.96		185	185	

† C + H + L = Chisel + Harrow + Levelling.
‡ DH = Disc harrow.
Source: Babiker *et al.* (1991).

Table 21. Comparison of four seeding machines at Rahad, 1992/93 and 1993/94.

Seeding machine	Fuel consumption (l/ha)		Cost (LS/ha)		Grain yield (kg/ha)	
	1992/93	1993/94	1992/93	1993/94	1992/93	1993/94
Seed drill	4.28	4.25			1650	1321
WLD† with tubes	3.75	3.80	476	833	1620	1334
WLD without tubes	3.75	3.80	476	833	1718	1220
BC‡ + ridger	5.14	5.14	833	1357	1810	1393
SE (±)					162	191

† WLD = Wide level disc.
‡ BC = Broadcasting.
Source: Dawelbeit *et al.* (1993b, 1994b).

At New Halfa, different seeding machines and their combinations were tested (Table 22). Results showed that, for the first season, the highest grain yield was obtained from 60 cm wide ridging, while the least yields were obtained by WLD without tubes. However, in the second season, no significant differences in grain yield were obtained. The WLD alone had the highest field capacity and the least cost. At the Blue Nile, yield was not significantly different between the three tested machines (WLD with tubes, WLD without tubes, and broadcasting + 60 cm ridging).

Table 22. Comparison of various seeding machines at New Halfa.

Seeding machine	Field capacity (ha/hr)		Cost (LS/ha)		Grain yield (kg/ha)	
	1993	1994	1993	1994	1993	1994
WLD† without tubes + 100 cm beds	1.5		952		2750	
WLD without tubes + 60 cm ridge	1.8		952		3179	
WLD without tubes on flat	3.5	3.5	476	595	2286	1820
WLD with tubes on flat	3.5	3.5	476	595	2571	1728
Seed drill	3.2	3.1	476		2476	1571
Mean					2652	1706

† WLD = Wide level disc.
Source: Dawelbeit *et al.* (1993d, 1994b).

A study of the effect of seeding machines and seed rate on wheat yield was conducted at Gezira and Rahad (Abdel Wahab *et al.* 1994a). Results of the on-farm trial at Gezira (Table 23) showed no significant yield differences between the treatments which included a seed drill and a WLD and two seed rates (95 and 143 kg/ha).

At Rahad, the results showed that lower grain yields were obtained with lower seed rates in both locations (Table 23). The SD was superior to the WLD and was more effective in nullifying the drawbacks of using lower seed rates compared to the WLD. When applying 143 kg/ha, the SD outyielded the WLD by 11.4%; but when the seed rate was lowered to 95 kg/ha, the increase was 22.2% and was significant at $P = 0.05$.

Table 23. Effect of different seeding machines and seed rates on grain yield of wheat at Rahad and Gezira.

Machine/Seed rate (kg/ha)	Grain yield (kg/ha)			
	Rahad			Gezira
	Block 4	Block 6	Mean	Taiba
Wide level disc/95	1071	857	964	1180
Wide level disc/143	1428	1071	1250	1160
Seed drill/95	1428	928	1178	1120
Seed drill/143	1666	1119	1392	1210

Source: Abdel Wahab *et al.* (1994a).

Six seed rates (71, 95, 119, 143, and 167 kg/ha) were evaluated at Rahad. The increase in seed rate did not result in a significant change in grain yield (Abdel Wahab *et al.* 1994a).

Wheat Harvesting

Wheat is harvested in the large irrigation projects using combine harvesters. Total harvesting losses could be divided into pre-harvest, header, and processing losses. Pre-harvest losses are caused by wind, birds, rats, and rain, or by the movement of people in the fields. Header losses include dropped heads, shuttered seeds, and missed heads which happen as the combine header passes over the wheat plants. Header losses are usually due to operational factors, such as combine speed. Processing losses include cylinder loss, separation losses, shoe losses, and cleaning losses. Processing losses are mainly due to machine adjustments.

Results of a two year on-station study at Gezira Research Station showed that the average total losses amounted to 2.6% in the first season and 2.3% in the second season. Processing losses were very low. That was before the rains. After the rain showers, total losses increased drastically (Dawelbeit and Idris 1992; Dawelbeit *et al.* 1993b). Table 24 shows that in the 1992/93 season the last harvesting date which occurred after a rain shower resulted in very high grain losses.

Table 24. Effect of harvesting date on total grain losses in wheat in Gezira.

1991/92		1992/93	
Date	% total loss	Date	% total loss
March 31	0.9	March 20	1.1
April 6	3.1	March 27	2.3
April 13	2.4	April 3	1.2
April 20	2.8	April 10	1.3
April 27	3.7	April 17	2.1
May 4	2.3	April 24	1.7
May 13	2.9	May 1	2.6
		May 8	2.4
		May 15	6.4
		May 29	28.0

Source: Dawelbeit and Idris (1992); Dawelbeit *et al.* (1993b).

Field assessment of combine harvesting losses showed that in New Halfa the mean total losses were about 31 and 24% in 1992/93 and 1993/94, respectively. These high losses were mainly header losses. It seemed that the farmers' bad preparation of their holdings for combine harvesting—by not breaking the *tangats* and *gadwals*—was the main cause of these high losses. No differences were observed in the performance and grain losses of the different combine makes.

Average total harvesting losses at the Rahad Scheme were found to be 18.5%. The field survey also concluded that losses increased with the delay of harvesting, header losses increased with the increase of combine forward speed, and the cultivar Condor resulted in losses double those of the cultivar Debeira.

At the Gezira Scheme, field surveys showed that an increasing trend was observed in percent total grain losses with the delay of harvest. In the 1993/94 season, mean total harvesting losses amounted to about 13% (Dawelbeit *et al.* 1994a).

Future Research Strategy

This review showed that extensive research was done during the NVRP period in establishment and mechanization. The outcome of this work was manifested in the availability of technologies and information and the many questions answered. However, with the current economic situation and the adoption of the free market policies, technologies have to be economically feasible. Hence, many questions about the cost-benefit implications of already proven technically feasible technologies pose themselves.

The future strategy should, therefore, emphasize the efficient use of resources and economically feasible practices as well as operations. Work on tillage for specific soil bench marks to produce specific tillage recommendations is needed. Technologies such as combined tillage operations and machines should be investigated. Since research results have shown that the type of seeding machine is not critical, a simple seeder/ridger or a combined seeder/fertilizer applicator should be developed. Also, specific seed rates should be recommended for each seeding machine.

Very high grain losses of combine harvesting is a serious problem for wheat producers. Research to monitor, diagnose and decrease harvesting losses is a future research priority.

References

Abdel Gadir, S. 1992. Effect of harrow packing on wheat crop establishment and yield at New Halfa. Pages 93–95 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1992, Wad Medani, Sudan.

Abdel Gadir, S. 1994. Wheat performance as affected by ridges and beds in New Halfa. Pages 100–101 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 28 August–1 September 1994, Wad Medani, Sudan.

Abdel Wahab, A.A., Dawelbeit, M.I., Babiker, E.A. and Mohamed, A.O. 1994a. Effect of seeding machine and seed rate on wheat yield. Pages 112–116 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 28 August–1 September 1994, Wad Medani, Sudan.

Abdel Wahab, A., Dawelbeit, M.I., Musa, A.M., Abdelnur, Mohamed, A.O. and Abdel Gadir, S. 1994b. Surveys of wheat tillage systems in Gezira, Rahad and New Halfa. Pages 102–108 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 28 August–1 September 1994, Wad Medani, Sudan.

Ageeb, O.A.A. 1994. Agronomic aspects of wheat production in Sudan. *In* Wheat in Heat-Stressed Environments: Irrigated, Dry Areas and Rice-Wheat Farming Systems (D.A. Saunders and G.P. Hettel, eds.). Mexico, D.F.: CIMMYT.

Babiker, E.A. and El-Hassan, A.A. 1990a. Effect of sowing method on crop establishment and yield of wheat at Rahad. Pages 31–32 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annnual Report 1989/90, Sudan. ICARDA/NCRP-DOC-012.

Babiker, E.A. and El-Hassan, A.A. 1990b. The efficiency of using 40 cm ridger as a seed covering tool compared to disc harrow and wide level disc at Rahad. *In* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, 27–31 August 1990, Wad Medani, Sudan.

Babiker, E.A., Elsir, A.T., Ghorashi, A.M., Kennan, H.O., Mohamed, A.O., Omer, M.M., Satti, M.A.E. and Taha, M.B. 1991. Wheat crop establishment studies. Pages 49–59 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Cereals-Sudan. Breadwheat Report, Anual Coordination Meeting, 16–23 September 1991, Cairo, Egypt.

Babiker, E.A. and Mohamed, A.O. 1992. Effect of sowing method on crop esatblishment and yield of wheat at Rahad.Pages 111–112 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1992, Wad Medani, Sudan.

Dawelbeit, M.I. 1992a. Effect of harrow packing and initial moisture content on wheat yield. Pages 104–105 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1992, Wad Medani, Sudan.

Dawelbeit, M.I. 1992b. Effect of harrow packing on wheat yield in Gezira. Pages 112–116 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1992, Wad Medani, Sudan.

Dawelbeit, M.I. 1993a. Effect of depth of disc harrowing on wheat establishment and yield. Pages 91–92 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 29 August–2 September 1993, Wad Medani, Sudan.

Dawelbeit, M.I. 1993b. Effect of harrow packing on wheat establishment and yield. Pages 104–105 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 29 August–2 September 1993, Wad Medani, Sudan.

Dawelbeit, M.I. and Abdel Wahab, A. 1994. Comparison of tillage systems under known soil bench marks. Pages 91–93 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wl eat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 28 August–1 September 1994, Wad Medani, Sudan.

Dawelbeit, M.I., Abdel Wahab, A., Abdel Gadir, S. and Musa, A.M. 1993a. Survey of wheat tillage systems in Gezira and New Halfa. Pages 107–111 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 29 August–2 September 1993, Wad Medani, Sudan.

Dawelbeit, M.I., Abdel Wahab A. and Abdel Gadir, S. 1993b. Wheat harvesting losses. Pages 112–116 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 29 August–2 September 1993, Wad Medani, Sudan.

Dawelbeit, M.I., Abdel Wahab, A., Abdel Gadir, S. and Mohamed, A.O. 1994a. Evaluation of wheat harvesting losses in Gezira, New Halfa and Rahad. Pages 116–122 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 28 August–1 September 1994, Wad Medani, Sudan.

Dawelbeit, M.I., Abdel Wahab, A., Abdel Gadir, S. and Mohamed, A.O. 1994b. Comparison of wheat seeding machines. Pages 109–112 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 28 August–1 September 1994, Wad Medani, Sudan

Dawelbeit, M.I., Abdel Wahab, A.A. and Idris, E.A. 1993c. Effect of time of first harrowing on wheat establishment and yield. Page 90 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 29 August–2 September 1993, Wad Medani, Sudan.

Dawelbeit, M.I. and Idris, E.A. 1992. Effect of time of harvesting on wheat combining losses. Pages 99–100 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1992, Wad Medani, Sudan.

Dawelbeit, M.I. and Ishag, H.M. 1992. Effect of harrow packing and seeding method on wheat establishment and yield. Pages 107–110 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1992, Wad Medani, Sudan.

Dawelbeit, M.I., Mohamed, A.O., Abdel Gadir, S. and Omer, M.M. 1993d. Comparison of wheat seeding machines. Pages 96–104 in Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, annual National Coordination Meeting, 29 August–2 September, Wad Medani, Sudan.

Dawelbeit, M.I. and Salih, A.A. 1992. Survey of tillage systems in the Gezira Scheme. Pages 101–104 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1992, Wad Medani, Sudan.

Dawelbeit, M.I., Salih, A.A. and Abdel Wahab, A. 1994c. Effect of depth of disc harrowing on wheat establishment and yield. Pages 93–95 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 28 August–1 September 1994, Wad Medani, Sudan.

Ghorashi, A.M. 1990. The response of wheat under two methods of sowing and the timing of the second irrigation in New Halfa. Pages 29–30 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annnual Report 1989/90, Sudan. ICARDA/NCRP-DOC-012.

Ghorashi, A.M. 1992. The response of wheat to two types and three methods of sowing at New Halfa. Pages 118–120 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1992, Wad Medani, Sudan.

Idris, E.A. 1992. Effect of time of first harrowing on wheat establishment and yield. Pages 106–107 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1992, Wad Medani, Sudan.

ICARDA. 1987. ICARDA/OPEC Pilot Project for Verification and Adoption of Improved Wheat Production Technology in Farmers' Fields in the Sudan. Proceedings of the First National Wheat Coordination Meeting, 3–5 August 1986, Wad Medani, Sudan. ICARDA, Aleppo, Syria.

Mohamed, A.O. 1992. Survey of tillage systems for wheat production at Rahad Integrated Scheme. Pages 90–92 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1992, Wad Medani, Sudan.

Mohamed, A.O. 1993. Effect of initial soil moisture content on seedbed preparation and wheat yield. Pages 92–95 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 29 August–2 September 1993, Wad Medani, Sudan.

Mohamed, A.O. and Babiker, E.A. 1994. Effect of initial soil moisture content on land preparation and establishment of wheat. Pages 95–96 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 28 August–1 September 1994, Wad Medani, Sudan.

Mohamed, A.O. and Dawelbeit, M.I. 1992. Effect of initial soil moisture content on seedbed finenesss and establishment of wheat. Pages 88–90 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1992, Wad Medani, Sudan.

Mohamed, A.O., A.A. Hamada, and E.A. Babiker 1994. Comparison of ridging and harrowing at different times on establishment of wheat. Pages 97–99 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 28 August–1 September 1994, Wad Medani, Sudan.

Omer, M.M. 1990. Effect of planting method on wheat establishment and yield in the Blue Nile and Suki. Pages 32–33 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annnual Report 1989/90, Sudan. ICARDA/NCRP-DOC-012.

Salih, A.A. 1989. Effect of planting on wet and dry soil on wheat establishment at Gezira Research Station. Page 36 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annnual Report 1988/89, Sudan. ICARDA/NCRP-DOC-007.

Salih, A.A. 1990. Effect of sowing wheat in wet soil in Gezira. Pages 26–27 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annnual Report 1989/90, Sudan. ICARDA/NCRP-DOC-012.

Salih, A.A., Dawelbeit, M.I., Mohamed, B.A., Fadul, H., Babiker, E.A. and Mohamed, A.O. 1994. Effect of 60 cm ridging on water management and heat establishment in farmers' fields (Managil and Rahad). Pages 148–150 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 28 August–1 September 1994, Wad Medani, Sudan.

Salih, A.A. and Musa, A. 1987. Effect of land preparation system on wheat grain yield. *In* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1987, Wad Medani, Sudan.

Salih, A.A. and Musa, A. 1988. Effect of different tillage systems on wheat establishment and grain yield. *In* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1988, Wad Medani, Sudan.

Salih, A.A. and Musa, A. 1989. Effect of different tillage systems on wheat establishment and grain yield. Pages 35–36 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annnual Report 1988/89, Sudan. ICARDA/NCRP-DOC-007.

Salih, A.A., Musa, A. and Farah, S.M. 1990. Effect of land preparation techniques and irrigation method on wheat grain yield. *In* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 27–31 August 1990, Wad Medani, Sudan.

Satti, M.A.E. 1990. Land preparation study at the White Nile. *In* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 27–31 August 1990, Wad Medani, Sudan.

Satti, M.A.E. 1992. Land preparation study at the White Nile. Pages 158–159 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1992, Wad Medani, Sudan.
Sim Sim Dryland Farming Project 1989. Sim Sim Sudanese Canadian Dryland Farming Project Annual Report. Mechanized farming Corporation, Khartoum, Sudan.

Discussion

Q: Prof. Hussein Adam

(1) Has the increase in yield when harrowing twice plus levelling been evaluated economically to assess its cost effectiveness? Also, has the effect of the unavailability of disc harrows on the sowing date been considered, i.e., has an integrated evaluation of all factors been made? (2) In Table 24, although the general trend is an increase in harvesting losses with a delay in the harvesting date, the high losses on 6 April in 1992 look rather odd. Would you please comment on this?

A: Mamoun I. Dawelbeit

(1) There is enough information in the report which covers all factors. However, the time for the presentation is not enough to detail all these effects. (2) High losses are due to the machines running with high speeds. A detailed analysis of the loss data is needed to explain that increase of losses on 6 April.

Q: M.B. Solh

How would you assess the improvement of crop establishment in wheat in the Gezira over the last five years and what are the reasons for your assessment?

A: Mamoun I. Dawelbeit

The considerable improvement in crop establishment in the Gezira over the last five years was mainly due to the increasing awareness by farmers of the importance of crop establishment to yield because of the great efforts made by the Scheme and the ARC teams through NVRP on-farm activities.

Comment: Hassan M. Fadul

The soils of the Gezira are adequately described by physical and chemical data on top soil and subsoil. Land suitability is also included and the limitations are well expressed in their yields.

A: Mamoun I. Dawelbeit

The text shows more detail on the description of these bench marks.

Q: Ali Omer Mohamed

Is it possible to quantify soil physical factors in favor of crop establishment?

A: Mamoun I. Dawelbeit

Many efforts have been made to quantify such factors as tillage index, surface shape, etc., but all were not satisfactory. We are trying to develop an evaluation model that takes into consideration surface aggregates, surface shape, weed control and yield.

Q: Mohamed Sidahmed

What matters in land preparation? Is it the type of implement or the quality of tillage? In many instances, high yields are obtained from double ridging.

A: Mamoun I. Dawelbeit

The objective is to create a favorable environment, which is very difficult. International efforts did not give an answer. Actually, we don't need to describe the environment. Any machine that will give a good tillage will do. Although there are many parameters with which to evaluate tillage (e.g., soil physical properties, soil erosion, power use, cost and water use), yield is the parameter that gives the overall effect and is generally used to compare the effects of tillage.

Q: Mohamed M. Omer

Is it the silt to clay content ratio or the inclusion of sodium salts in the soil that affect the establishment of wheat in the Gezira, Rahad and other schemes.

A: Mamoun I. Dawelbeit

A detailed analysis of the tested tillage systems, the soils in question and the management and their correlation with yield is needed. If done, clear answers will be obtained.

Comment: M.C. Saxena

The paper is very comprehensive, but there is a need for a clearer description of terms that have been used and the machines and operations. It may be worthwhile to add clear photographs of these machines. The term 'bench mark', 'wet sowing' and 'harrow packing' all need to be described. There is also a need for drawing conclusions for each of the sections based on the experiment, and if there are differences in the recommendations, there is a need to explain why these differences are there. This will enhance the value of the paper, which has very important information.

A: Mamoun I. Dawelbeit

Photographs will be supplied as well as a more detailed description of the terms. Also, conclusions will be provided for each section.

Q: Ahmed Ali Salih

What is meant by wet sowing? Is it growing on residual soil moisture or is it by recharging the profile before sowing on dry? Also, is it possible to correlate clay content and crop yield?

A: Mamoun I. Dawelbeit

A clear description of wet sowing is provided in the text. Time did not allow this during the presentation. A correlation between clay content and yield is possible and can be made.

Q: Osman A.M. Eltom

What was the economic evaluation of using the machines regarding tillage? Has a team-work approach been followed in this review?

A: Mamoun I. Dawelbeit

A lot of data is available in the text but there is not enough time to go into detail. A team-work approach has been followed in our work and bench marks are found in the text.

Effect of Sowing Time on Wheat Production

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Abstract

The length of the growing season for wheat in the Sudan (90–100 days) is critical in determining its yield. Therefore, optimization of sowing time is of paramount importance in determining the final productivity of the crop. During the past decade (1985/86–1994/95), the popular wheat cultivars, Condor, Debeira, and Wadi El Neil, were studied extensively with reference to sowing time in the different production environments of the Sudan. Average yield data of the three cultivars, obtained from studies conducted from 1985/86 to 1994/95, were used to develop simple models of grain yield response to sowing time. A critical yield level (with 5% reduction from the maximum obtainable yield from the best fitted curve) was used in all environments to define the optimum range of sowing dates (ORSD). Results showed that the ORSD was 5 November–1 December at Gezira Research Station (center), 16 November–16 December at New Halfa Research Station (east), and 1 November–9 December at Hudeiba Research Station (north). The ORSD resulting from plotting data from all over the Sudan was 3 November–12 December. In almost all environments, the genotypes showed differential response to sowing time. Condor, being the most sensitive genotype to heat stress, gave lower grain yield than Debeira and Wadi El Neil when sown before the ORSD, while the reverse was true when sown after the ORSD. Delaying the time of sowing of wheat after the ORSD dramatically reduced grain yield at on-station and farmer levels. For Zeidab Scheme and Hudeiba Research Station, grain yield losses associated with delayed sowing (after November) at three management levels (research, research/ extension/farmer, and farmer) were quantified. Results revealed that losses of up to 86% can occur when sowing is delayed to February. It was also found that losses at the research level (environment for the highest yield) were comparatively lower than those at the farmers' level. This indicates that, with good management, the stress (heat stress) associated with delayed sowing date can at least be partially alleviated.

Introduction

The length of the growing season for wheat in the Sudan is critical (90–100 days) in determining its yield (Ageeb 1994). Therefore, optimization of sowing time is of paramount importance in determining the final grain production of the crop. It is not uncommon to find farmers throughout the Sudan delaying sowing of their wheat crops to December and January. The reasons are probably late land preparation, unavailability of irrigation water, or sometimes giving priority to other winter crops, like faba bean, as is the case in the Northern Region. High grain yield losses are associated with these delays in sowing time of this determinate crop with little or no compensatory mechanisms after floral initiation is completed. In addition, it was reported in many studies that wheat cultivars grown showed differential response to sowing time. During the past decade (1985/86–1994/95), a large number of studies have been carried out with the objectives of determining the optimum range of sowing dates (ORSD) and to investigate the differential responses of wheat cultivars to sowing time.

Model Development

The three popular wheat cultivars Condor, Debeira, and Wadi El Neil have been studied extensively in the three major production environments (Gezira, Northern Region, and New Halfa) of wheat in the Sudan. Crops were sown at different sowing times over several seasons in each environment.

The average grain yield over the three cultivars in the reviewed studies was used to develop simple models of grain yield response to sowing time in each production environment. A critical yield level with 5% reduction from the maximum obtainable yield on the best fit curve, was selected and imposed on the response curve to define the ORSD for each production environment. With a quoted example from the Zeidab Scheme (River Nile State), grain yield losses with delayed sowing (sowing after November) were quantified at three management levels (research, extension and farmer).

Results and Discussion

The developed grain yield response to sowing time models are shown in Fig. 1. The ORSD was rather narrow at Gezira Research Station (5 November to 1 December). At New Halfa Research Station, the ORSD was slightly expanded and started later than at Gezira Research Station (16 November to 16 December). At Hudeiba Research Station in the north, the ORSD was relatively more expanded (1 November to 9 December). This indicates that, as we move from north to south, the optimum growing season becomes more critical and optimization of sowing time, in turn, becomes more important in affecting final crop productivity. Plotting the reviewed data of all the environments revealed that the ORSD for wheat in the Sudan was 3 November to 12 December (Fig. 1).

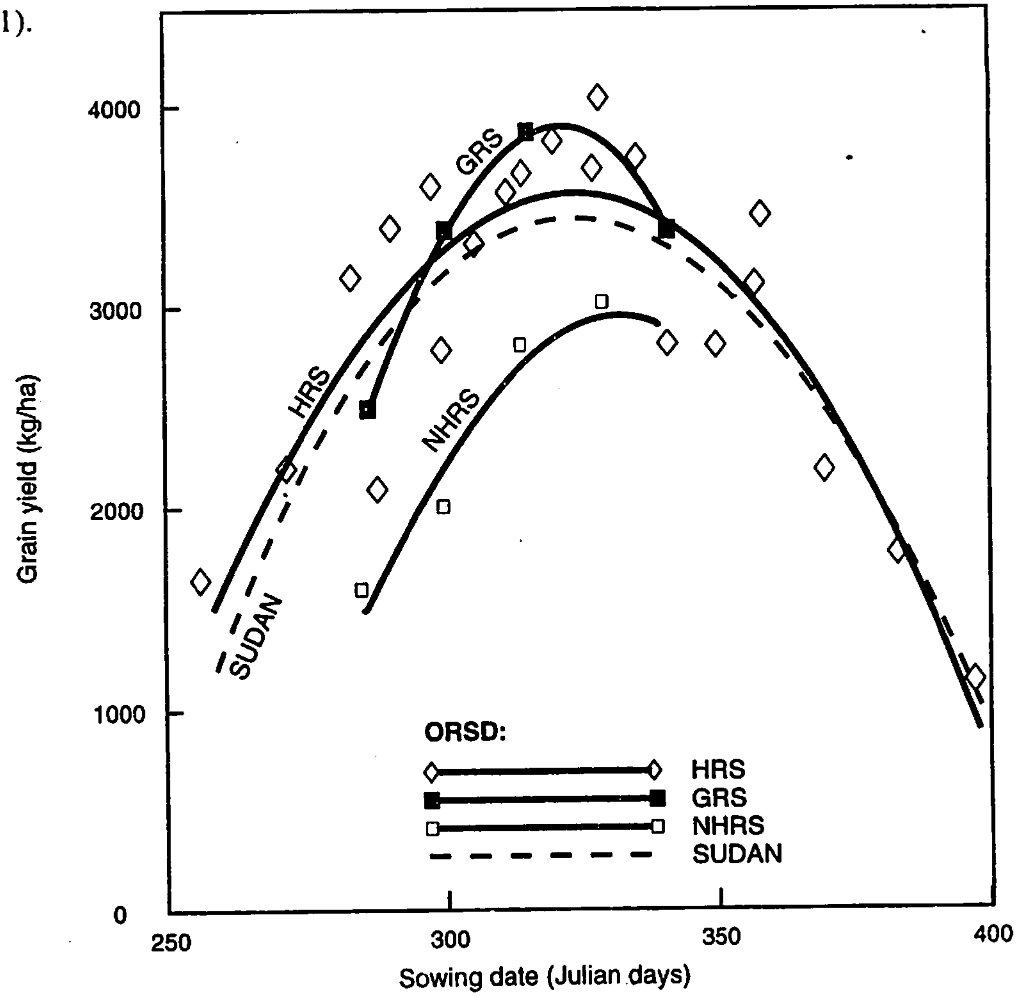

Fig. 1. Response of wheat grain yield to sowing time in the different production environments of the Sudan (Ageeb *et al.* 1988; Gorashi 1989; Ishag and Ageeb 1989; Ishag and Taha 1991; Ibrahim 1993, 1994, 1995).

Hudeiba Research Station (HRS): $Y = -47012.6 + 312.149\ SD - 0.481482\ SD^2$ ($r^2 = 0.83$).
Gezira Research Station (GRS): $Y = -114987 + 739.347\ SD - 1.149420\ SD^2$ ($r^2 = 1.00$).
New Halfa Research Station (NHRS): $Y = -70745.2 + 440.355\ SD - 0.657434\ SD^2$ ($r^2 = 0.95$).
Sudan: $Y = -47262.0 + 310.589\ SD - 0.475486\ SD^2$ ($r^2 = 0.66$).
where: Y = Grain yield in kg/ha; SD = Sowing date in Julian days (with Julian days of second year + 365).

In the various growth environments of wheat in the Sudan, the cultivars showed differential response to sowing time (Tables 1, 2 and 3). Condor, being the most sensitive genotype to heat stress, gave lower grain yield than Debeira and Wadi El Neil when sown before the ORSD. However, the reverse was true when sown after the ORSD. This finding emphasizes the need for scheduling the recommendations on sowing dates on cultivar basis.

Table 1. Effect of sowing time on grain yield of wheat at Hudeiba Research Station.

Sowing date	Grain yield (kg/ha)					
	Means of 1989/90–1990/91			Means of 1992/93–1994/95		
	Condor	Debeira	Wadi El Neil	Condor	Debeira	Wadi El Neil
15 Sept.				1044	1843	2141
29 Sept.				2112	2509	2084
13 Oct.				2985	3158	3303
20 Oct.				3132	3517	3355
27 Oct.				3602	3708	3393
3 Nov.				3254	3419	3410
10 Nov.				3301	3778	3602
17 Nov.				3858	4007	3503
24 Nov.				3812	3571	3704
26 Nov.	4280	3810	3900			
1 Dec.				3890	3526	3802
8 Dec.				3655	3373	3227
15 Dec.				3215	2543	2797
22 Dec.				3639	2765	3008
24 Dec.	3785	3395	3225			
5 Jan.				2591	1930	2119
19 Jan.				2056	1708	1631
2 Feb.				1298	710	1313

Source: Taha (1990); Ishag and Taha (1991); Ibrahim (1993, 1994, 1995).

Table 2. Mean effect of sowing time on grain yield of wheat at New Halfa Research Station, 1987/88–1988/89.

	Sowing time/Grain yield (kg/ha)				
Cultivar	15 Oct.	29 Oct.	12 Nov.	26 Nov.	10 Dec.
Condor	1332	1881	2786	3063	2868
Debeira	1566	1828	2716	2954	2762
Wadi El Neil	1847	2332	2953	3223	3011

Source: Ageeb *et al.* (1988); Gorashi (1989).

Table 3. Effect of sowing time on grain yield of wheat at Gezira Research Station.

	Grain yield (kg/ha)								
Sowing date	1987/88 and 1988/89†			1989/90 and 1991/92†			1992/93		
	C‡	D‡	WN‡	C	D	WN	C	D	WN
15 Oct.	2269	2474	2879						
17 Oct.							1650	1230	1450
29 Oct.	3285	3448	3582						
6 Nov.				1941	2208	2286			
12 Nov.	3863	3791	3974						
14 Nov.							2130	2510	2430
24 Nov.				2509	2545	2612			
26 Nov.	3978	3720	3744						
10 Dec.	3706	3353	3170						
12 Dec.							1430	1110	1150
15 Dec.				1529	1279	1318			

† Values of grain yield are the means of two seasons.
‡ C = Condor; D = Debeira; WN = Wadi El Neil.
Source: Ageeb *et al.* (1988); Ishag and Ageeb (1989); Ishag (1990, 1992); Ishag *et al.* (1993).

The effect of delayed sowing on wheat productivity are shown in Table 4. High grain yield losses were associated with late sowing. Grain yield losses of up to 86% occurred when farmers delayed sowing to February. However, the effects of late sowing on grain yield varied with the crop management level. Grain yield losses with delayed sowing (sowing after November) were comparatively low under good management (research level) than under poor management (farmers' practice). This implies the possibility of alleviating late heat stress effects by improving the crop management level.

Table 4. Effect of delayed sowing time on grain yield of wheat at Hudeiba Research Station and Zeidab Scheme, 1994/95.

Cultivar	Sowing time/Grain yield (kg/ha)			
	November	December	January	February
Hudeiba Research Station				
Condor	3776	3737 (1.0)†	2580 (31.7)	1556 (58.8)
Debeira	4014	3533 (12.0)	1895 (52.8)	1365 (66.0)
Wadi El Neil	3804	3452 (9.3)	1956 (48.6)	1835 (51.8)
Mean	3865	3574 (7.5)	2144 (44.5)	1589 (58.9)
Zeidab Scheme				
Condor	1936	1255 (35.2)	741 (61.7)	
Debeira	1120	794 (29.1)	547 (51.2)	119 (89.4)
Wadi El Neil	786	783 (0.4)	117 (85.1)	
Giza 155	1814	962 (47.0)	673 (62.9)	340 (81.3)
Mean	1655	936 (43.8)	469 (71.8)	230 (86.2)
Overall mean‡	1517	924 (39.1)	425 (72.0)	
Improved production package at Zeidab	2173	1697 (21.9)		

† Numbers in parentheses represent the percentage reduction in grain yield due to delayed sowing with reference to November sowings.
‡ Overall mean grain yield of Condor, Debeira and Wadi El Neil.
Source: Ibrahim (1995).

Conclusions and Recommendations for Future Studies

- The ORSD for wheat in the Sudan is 3 November to 12 December.
- The ORSD in the different production environments varied from 5 November–1 December (center), 16 November–16 December (east), to 1 November–9 December (north).
- The medium maturing genotypes (Debeira and Wadi El Neil) should be planted early in the season, while the early maturing genotype Condor can be planted relatively late.
- When sowing after the ORSD becomes unavoidable, the relevant option for farmers is to grow Condor.
- Future studies should focus on investigating more genotypes under the three thermal environments (before, during and after the ORSD) to provide options for farmers in each thermal environment.
- Future studies should also address crop management as a means for alleviation of heat stress effects.

References

Ageeb, O.A.A. 1994. Environments for yield testing of wheat populations. Page 30 *in* First Six-Month Report for the ODA Holdback Project R5960 (H), Selection Criteria for Adaptation to High Temperature in Wheat. Wheat Program, CIMMYT, Mexico.

Ageeb, O.A.A., Taha, M.B. and Gorashi, A.M. 1988. The response of three wheat cultivars to sowing date at Wad Medani, New Halfa and Hudeiba. Pages 37–41 *in* ARC, ICARDA, OPEC Pilot Project on: Verification and Adoption of Improved Wheat Production Technologies in Farmers' Fields in the Sudan. Third National Wheat Coordination Meeting, 4–6 September 1988, Agricultural Research Corporation, Wad Medani, Sudan.

Gorashi A.M. 1989. Response of wheat cultivars to sowing date at New Halfa Research Station. Page 37 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Cereals. Annual Report 1988/89, Sudan. ICARDA/NVRP-DOC-007.

Ibrahim, O.H. 1993. Effects of sowing time on growth and yield of wheat. Pages 160–161 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 29 August–2 September 1993, Agricultural Research Corporation, Wad Medani, Sudan.

Ibrahim, O.H. 1994. Effects of sowing time on growth and yield of wheat. Pages 172–175 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 28 August–1 September 1994, Agricultural Research Corporation, Wad Medani, Sudan.

Ibrahim, O.H. 1995. Effects of sowing time on growth and yield of wheat. Paper presented at the Annual National Coordination Meeting, 27–31 August 1995, Agricultural Research Corporation, Wad Medani, Sudan.

Ishag, H.M. 1990. Growth, development and yield of wheat cultivars under tropical conditions. Page 117 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Breadwheat Report, Annual Coordination Meeting, 27–31 August 1990, Agricultural Research Corporation, Wad Medani, Sudan.
Ishag, H.M. 1992. The effect of time of sowing on growth and yield of wheat cultivars in irrigated Gezira. Page 123 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1992, Agricultural Research Corporation, Wad Medani, Sudan.
Ishag, H.M. and Ageeb, O.A.A. 1989. Response of wheat cultivars to sowing dates. Page 36 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Cereals. Annual Report 1988/89, Sudan. ICARDA/NVRP-DOC-007.
Ishag, H.M., Ageeb, O.A.A. and Elahmadi, A.B. 1993. Phenology, growth and yield of wheat genotypes in the Gezira environment. Page 134 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Breadwheat Report, Annual National Coordination Meeting, 29 August–2 September 1993, Agricultural Research Corporation, Wad Medani, Sudan.
Ishag, H.M. and Taha, M.B. 1991. Response of wheat cultivars to sowing date. Page 45–48 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat. Annual Report 1990/91, Sudan. ICARDA/NVRP-DOC-017.
Taha, M.B. 1990. Effect of sowing date of five wheat cultivars on growth, development and yield. Page 111 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Breadwheat Report, Annual National Coordination Meeting, 27–31 August 1990, Agricultural Research Corporation, Wad Medani, Sudan.

Discussion

Q: Mohamed El Borai

You said that under good management, the effect of delayed sowing on wheat yield could be reduced. What sort of good management did you mean?

A: O.H. Ibrahim

Management mentioned was at three levels: research, improved package, and farmers' practice. Under the research level, standard cultural practices were followed (best management). In the improved package level, the standard practices were adopted at a relatively lower level, i.e., factors like irrigation and weed control were applied at a suboptimal level. The third management level (farmers' practice) is relatively poor in comparison with the previous levels. Farmers' practice is characterized by poor land preparation and crop establishment, use of mixed cultivars and low fertilizer rates, application of few irrigations and the absence of weed control.

Comment: Dr. Hassan S. Ibrahim

Farmers grow wheat late in the Northern State because of bird damage which is very serious for early-sown wheat crop.

A: O.H. Ibrahim

Birds in the Northern State constitute a chronic problem and the solution developed by farmers over their long experience is to plant their cereal crops (wheat or sorghum) at the same time so that losses are shared between farmers. However, losses due to bird damage are always there whether you advance or delay your sowing dates.

Comment: Prof. Hussein S. Adam

It would be better to talk about saving cubic meters of water than number of irrigations. When you lengthen the irrigation interval, the soil profile takes more water.

A: O.H. Ibrahim

I agree about quantification, but the availability of equipment is the limiting factor. If we get neutron probes and other measuring devices, we will definitely go for measuring quantities of water in cubic meters.

Nutrition of Wheat

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Abstract

This work was conducted in most of the wheat-producing areas of the Sudan. Wheat responded significantly to nitrogen and phosphorus application. A dose of 86 kg N + 43 kg P_2O_5 kg/ha was recommended for wheat on the 'High Terrace' soil of the Nile River and Northern states, Gezira, White Nile, Sennar and Rahad. Recommendations for 'Karu' soil and soil in New Halfa was 86 kg N/ha. On High Terrace soil, nitrogen had to be split-applied at tillering and booting. On 'Gurier' soil, N application was not needed. Foliar fertilizer effects were inconsistent, but Bayfolan, Greenzit, K101 and K186 gave some positive results. The effect of micronutrient application was similar to that of foliar fertilizers. Organic fertilizers (farmyard manure and compost) also had positive effects on wheat grain yield and some soil properties. Future work on fertilizer use should be based on soil and plant-tissue testing and be related to bench-mark soils.

Introduction

Wheat production in the Sudan started thousands of years ago on the fertile soils of the banks of the Nile in the Northern and Nile River states. Since the early 1960s, wheat production has moved southward and the crop is now also cultivated in Khartoum, Gezira, White Nile, Gedarif, Kassala and Darfur states.

With the exception of the Gurier and High Terrace soils of the Nile State, the soils of the other states are silty to heavy clay and most belong to the Vertisol order with montmorillonite being the dominant clay mineral. The clay percentage ranges between 19 and 72 and pH values from 7.4 to 8.4 (Table 1). Cracking is a dominant feature in most of these soils, but with a varying intensity depending on the amount of clay and the environment. The permeability of these soils varies between low and medium. Salinity and sodicity hazards are encountered to some extent, but their occurrence is more common in the soils of the White Nile State.

Table 1. Some chemical and physical properties of the soils of wheat-producing areas in the Sudan.

Property	Northern State		Nile River State			Gezira State	Sennar State	Gedarif State	White Nile State
	Selaim	Burgaig	Hudeiba (Gurier)	Ed-Damer (Karu)	Shendi (High Terrace)				
pH	7.8	8.2	7.4	7.8	8.1	8.1	7.9	8.4	8.2
EC (mmho/cm)	1	1.3	0.5	0.8	5	1.5	0.7	0.9	6
ESP (%)	10	6	4	10	18	12	14	12	30
Clay (%)	19	40	28	41	25	62	64	72	60
Silt (%)	50	26	42	40	27	15	12	13	12
Sand (%)	31	34	30	19	48	23	24	15	28
Total-N (ppm)	770	330	850	360	120	380	440	500	500
Organic-C (%)	0.8	0.4	0.95	0.4	0.12	0.4	0.45	0.5	0.37
$NaHCO_3$-P (ppm)	10	4	15	8	2	4	5	6	5
NH_4 acetate K (ppm)			420	340	170	410	405	430	260
DPTA-Mn (ppm)				14	5				
DPTA-Zn (ppm)				1.4	1.4	0.8			
DPTA-Fe (ppm)				10	26				
DPTA-Cu (ppm)				1.7	0.5				

Soil total-N ranges between 330 and 440 ppm and organic carbon is considerably low (0.37–0.45%). Sodium bicarbonate-extractable phosphorus varies between 2 and 6 ppm. Available micronutrients such as copper, zinc and manganese are low and in most cases deficient in these soils. On the other hand, the Gurier soil of the Nile River State is very fertile and occupies the banks and islands of the Nile River. The total-N of the soil has an average value of 850 ppm whereas sodium bicarbonate-extractable phosphorus is more than 10 ppm. Soil organic carbon is comparatively higher here than in the other soils. This soil is very permeable and has comparatively adequate amounts of available micronutrients. Conversely, the High Terrace soil of the Nile River State is an infertile sandy soil and occasionally suffers from salinity and/or sodicity hazards. It occupies large areas in the Nile River State and future expansion in agricultural production has to utilize this type of soil.

The literature review reported in this paper covers the research on fertilizer management in wheat, conducted under the Nile Valley Project (NVP), and, later, the Nile Valley Regional Program (NVRP), from 1985 to 1994 in the Northern, Nile River, Gezira, Sennar, White Nile, Gedarif and Kassala states.

Nitrogen, Phosphorus and Potassium Application

Most of the soils where this work was carried out are deficient in N and P (except Gurier soil). Ageeb *et al.* (1986) conducted a researcher-managed trial at Wad Medani, Turabi and New Halfa to study the effects of land preparation, irrigation interval, sowing date and P application on wheat grain yield. It was found that the addition of 43 kg P_2O_5/ha caused an increase of 325 kg/ha in grain yield in Gezira, while the increase was even greater (500 kg/ha) when adequate irrigation was applied. Conversely, P application had no significant effect on yield in New Halfa.

Ibrahim (1987a, 1989) at Hudeiba, Mohamed (1989a) at Shendi, and Ibrahim and Mohamed (1988) investigated the response of three wheat cultivars, namely, Condor, Wadi El Neil and Debeira to different rates of N application (0, 43, 86 and 129 kg N/ha) at different sites representing the three major soil types in the Nile River State, i.e., Gurier, Karu and High Terrace soils. Generally, N application increased wheat grain and straw yields considerably on the Karu and High Terrace soils (Table 2), but there was no response to N on the Gurier soil of Shendi because this soil is very fertile and has a total-N of about 950 ppm; actually, high levels of N application depressed wheat grain yield (Table 3). Similarly, N application significantly increased N uptake by wheat on the Karu soil, but not on the High Terrace and Gurier soils (Table 2). The response of wheat to N application was not significant on the High Terrace because of the deficiency in P. It was later found that positive and significant response to N application was associated with P application on the High Terrace soil.

Table 2. Effect of the rate of nitrogen fertilizer application on wheat grain yield and total-N uptake on Karu and High Terrace soils.

Treatment (kg N/ha)	Cultivar†	Karu soil			High Terrace soil		
		Yield (kg/ha)	% increase	Total-N uptake (kg/ha)	Yield (kg/ha)	% increase	Total-N uptake (kg/ha)
0	V1	2363		29.32	1876		24.85
	V2	3323		42.26	1400		17.27
	V3	4350		52.20	1501		20.23
43	V1	4883	107	66.16	1596	-15	24.72
	V2	4193	21	55.81	1319	-6	24.53
	V3	4437	2	57.33	1502	0	27.28
86	V1	5817	146	90.84	2831	51	40.73
	V2	5700	72	76.69	1381	-1	27.96
	V3	5830	34	96.97	1934	29	35.15
29	V1	5017	112	65.91	2003	7	32.35
	V2	6326	90	86.91	1585	13	29.24
	V3	5900	36	81.75	1765	18	30.41
SE (±)							
Nitrogen (N)		233***		6.75*	197^{NS}		2.62*
Variety (V)		200^{NS}		2.24*	67^{NS}		1.52*

† V1 = Condor; V2 = Debeira; V3 = Wadi El Neil.
*, *** = Significant at the 5 and 0.1% levels, respectively; NS = Not significant.
Source: Ibrahim (1989).

Table 3. Effect of cultivar and nitrogen level on wheat grain yield at Shendi Research Farm (Gurier soil) and Messeiktab (High Terrace soil).

	Site/Grain yield (kg/ha)	
	Shendi Research Farm (Gurier soil)	Messeiktab (High Terrace soil)
Nitrogen level (kg/ha)		
0	4757	1300
43	4785	1700
86	4752	1500
129	4638	1800
Mean	4733	1600
SE (±)	192^{NS}	100***
Cultivar		
Wadi El Neil	4458	1500
Condor	5007	1600
Debeira	4733	1700
SE (±)	135^{NS}	90^{NS}

*** = Significant at the 0.1% level; NS = Not significant.
Source: Mohamed (1989a).

Abdalla and Izzat (1987) conducted an on-farm trial at three sites in the Gezira Scheme representing the Central, Southern and Northern groups where different combinations of N and P were tested with three methods of P application. The results showed that the highest grain yield was obtained by the 2N + 1½P (86 kg N + 64.5 kg P_2O_5/ha) treatment and the second highest yield by the 2N + P (86 kg N + 43 kg P_2O_5/ha) treatment with no significant difference between the two treatments. Results also indicated that wheat grain yield was highest in the Northern Group (Turabi) and lowest in the Central Group (Wad Medani). Moreover, band placement of P fertilizer resulted in higher wheat grain yield and P uptake than the other methods of P application. The authors concluded that the mode of response of wheat to P application is site-specific and needs to be closely identified with soil phases for appropriate transfer of technology (Table 4).

Table 4. Response of wheat to N and P application at some locations in Gezira Scheme.

Treatment (kg/ha)	Location/Grain yield (kg/ha)		
	Wad Medani	Wad El Nau	Turabi
86-0 N-P	1518	2948	2941
86-43 N-P	2303	3060	4259
43-43 N-P	1771	2725	4147
129-64.5 N-P	2351	3125	4456
SE (±)	114	156	44

Source: Abdalla and Izzat (1987).

Ibrahim (1987b) subjected 10 lines of wheat, including released varieties and promising genotypes, to three levels of P fertilizer (0, 43 and 86 kg P_2O_5/ha) on two different soil types (Karu and High Terrace). The grain and straw yields were not significantly affected by P application on the Karu soil. However, straw yield and P uptake increased significantly by P application on the High Terrace soil. This study revealed the need of wheat to P application on the High Terrace soil.

Gorashi (1988) conducted a factorial experiment involving N and P on wheat at New Halfa. N and P application did not have a significant effect on wheat grain yield in spite of the fact that the soils of New Halfa are generally poor in N and P. No soil analysis was presented for the site where the study was conducted.

Ageeb and Abdalla (1988) conducted an on-farm trial where selected treatments of N, P and K combinations were applied to wheat (cultivar Condor) at four different sites in the Gezira Scheme. Phosphorus application significantly increased wheat grain yield in all locations except Dirwish where the site is known to have a fertile soil (Table 5). There was no significant response to potassium application indicating that Gezira soil has adequate amounts of available K as previously reported (Finck 1962). Wheat did not respond significantly to levels of N greater than 86 kg N/ha in the absence of P application and the response to P application increased from the Central Group (Dirwish and Wad Sulfab) to northern Gezira (Kab El Gidad). The response of wheat to P in El Gadeed Block in Managil Group was similar to that of northern Gezira. The addition of 43 kg P_2O_5/ha increased wheat grain yield by 52% over the recommended practice (i.e., 86 kg N/ha) at Kab El Gidad and El Gadeed. The authors recommended the addition of 43 kg P_2O_5/ha and 86 kg N/ha to wheat in the Gezira and White Nile schemes.

Table 5. Response of wheat to N, P and K fertilizers in Gezira.

Treatment (kg/ha)	Location/Grain yield (kg/ha)				
	Dirwish	Wad Sulfab	Kab El Gidad	El Gadeed	Mean
129 N	4567	2347	2625	1747	2822
129 N	4741	2287	2968	1468	2866
43-43 N-P	3146	2839	3249	2547	2958
86-43 N-P	4446	3061	3982	2658	3537
86-43-43 N-P-K	4482	3139	3929	2420	3443
129-64.5 N-P	5267	3370	4353	3001	3998
SE (±)	257	86	200	93	

Source: Ageeb and Abdalla (1988).

Satti (1989) conducted a factorial on-farm trial at Reimaitab and Ataya blocks of the southern Gezira Group where four levels of N (0, 43, 86 and 129 kg N/ha) and three rates of P (0, 43 and 86 kg P_2O_5/ha) were applied at sowing. The results showed that the application of 43 kg P_2O_5/ha in addition to the standard N dose (86 kg N/ha) caused an increase in grain yield of 1695 and 1326 kg/ha at Reimaitab and Ataya sites, respectively (Table 6). Increasing the P dose to 86 kg P_2O_5/ha resulted in an increase in grain yield over the control (2N + 0P) of 2083 kg/ha at Reimaitab. N and P uptake by wheat significantly increased by the application of N and P at both sites.

Ibrahim *et al.* (1988), Ibrahim and Adlan (1989) and Ibrahim (1990) conducted a factorial on-farm trial in which the response of wheat (cultivar Wadi El Neil) to different levels and times of N and P application was investigated. The levels of N application were 0, 43, 86 and 129 kg N/ha, whereas the times of application were at sowing, tillering and booting as single or split applications.

Phosphorus was applied at two levels (0 and 43 kg P_2O_5/ha) at sowing. The trial was conducted at Hudeiba on two soils: Karu and High Terrace. Nitrogen application significantly increased wheat grain and straw yields on both soil types. On the other hand, P application increased wheat grain and straw yields significantly on the High Terrace soil only (Table 7). N and P application significantly increased N and P uptake by wheat on the High Terrace soil, whereas N alone increased N uptake in wheat on the Karu soil. The results of wheat yields and N and P uptake indicated that the optimum fertilizer dose for wheat production on the Karu soil was 86 kg N/ha applied at sowing, and on the High Terrace soil also 86 kg N/ha but split equally at tillering and booting. The optimum fertilizer P dose was 43 kg P_2O_5/ha applied at sowing.

Table 6. Response of wheat to various levels of N and P fertilizer treatments at Reimaitab and Ataya sites in southern Gezira.

Treatment (kg/ha)	Reimaitab		Ataya	
	Grain yield (kg/ha)	Relative response† (%)	Grain yield (kg/ha)	Relative response (%)
0-0 N-P	1894	84	2339	73
0-43 N-P	2869	128	2065	66
0-86 N-P	3181	142	2244	72
43-0 N-P	2102	94	2471	80
43-43 N-P	3125	139	3606	116
43-86 N-P	4090	182	3608	116
86-0 N-P	**2244**	**100**	**3106**	**100**
86-43 N-P	3939	176	4432	143
86-86 N-P	4327	193	4204	135
129-0 N-P	2415	108	3238	104
129-43 N-P	3910	174	4678	151
129-86 N-P	4223	188	5094	164

† % response was compared to the present practice (86 kg N + 0 kg P_2O_5 /ha) at the Gezira Scheme.

Source: Satti (1989).

Table 7. Effects of rate and time of N application with P on grain yield of wheat under two soil types at Hudeiba (Ed-Damer).

Treatment† (kg/ha)	Soil type			
	High Terrace		Karu	
	Grain yield (kg/ha)	% increase	Grain yield (kg/ha)	% increase
0-0 N-P	**1364**		**2517**	
0-43 N-P	1521	12	2134	-15
43-0 N-P (S)	2004	47	5856	133
43-0 N-P (ST)	2334	71	4441	76
43-0 N-P (SB)	2048	50	5584	122
43-0 N-P (TB)	1890	39	4255	69
43-43 N-P (S)	2761	102	5819	131
43-43 N-P (ST)	3018	121	5910	135
43-43 N-P (SB)	2844	109	6002	145
43-43 N-P (TB)	3050	124	5576	122
86-0 N-P (S)	2001	47	6350	153
86-0 N-P (ST)	2208	62	5624	123
86-0 N-P (SB)	2417	77	5641	124
86-0 N-P (TB)	2825	107	5789	130
86-0 N-P (S)	3232	137	5410	115
86-43 N-P (ST)	2768	103	5890	134
86-43 N-P (SB)	2813	106	5698	126
86-43 N-P (TB)	3654	139	6294	150
SE (±) N	205		320***	
SE (±) P	97		151	

† S = N applied at sowing; ST = N applied ½ at sowing + ½ at tillering; SB = N applied ½ at sowing + ½ at booting; TB = N applied ½ at tillering + ½ at booting.
*** = Significant at the 0.1% level.
Source: Ibrahim and Adlan (1989).

Mohamed (1989b) conducted an on-farm trial in Shendi area on Gurier and High Terrace soils similar to the one previously reported by Ibrahim *et al.* (1988), Ibrahim and Adlan (1989) and Ibrahim (1990) and obtained similar results.

Omer (1989), in an on-farm factorial trial at Massara Scheme (Blue Nile Agricultural Corporation), tested three levels of N (0, 43 and 86 kg N/ha) and two levels of P (0, 43 kg P_2O_5/ha) with the wheat cultivar Condor. The results indicated that both N and P increased plant height, total biological yield and grain yield significantly. On the other hand, P application significantly increased 1000-seed weight, number of seeds per spike and number of heads/m^2. There was no significant interaction between N and P. The highest yield was realized by treatment 86 kg N + 43 kg P_2O_5/ha.

Babiker and Abdalla (1990) conducted a farmer-managed trial in six locations covering Rahad Scheme. In this trial two levels of N (43 and 86 kg N/ha) and two levels of P (0 and 43 kg P_2O_5/ha) were used in four treatment combinations with a 0N and 0P control. N application at the higher rate increased wheat grain yield significantly, and the addition of 1P (43 kg P_2O_5/ha) resulted in a further increase of 50% over the 2N treatment which was attributed to the higher number of plants/m^2 and greater 1000-seed weight (Table 8). Treatment 1N + 1P resulted in a higher grain yield than 2N suggesting that P was a growth-limiting factor in Rahad Scheme. The authors also conducted two pilot demonstration plots each on an area of 36.8 ha. The percent increase in yield in these plots due to P application ranged between 58 and 113. In addition to this, a large-scale trial was conducted and P addition resulted in grain yield increases ranging between 43 and 84%.

Table 8. Response of wheat grain yield, number of plants/m^2 and 1000-seed weight to N and P application in the North and South groups of Rahad Scheme.

Treatment (kg/ha)	Block 3 (South Group)			Block 7 (North Group)		
	Grain yield (kg/ha)	Plants/ m^2	1000-seed wt. (g)	Grain yield (kg/ha)	Plants/ m^2	1000-seed wt. (g)
0 N	1664	189	32	1518	185	33
43 N	2286	203	34	2054	201	34
86 N	2414	207	34	2518	224	35
43 P	1729	190	32	1589	184	34
43-43 N-P	3001	269	35	3089	273	36
86-43 N-P	3500	295	39	3786	283	36
SE (±)	158	14	8	158	10	5

Source: Babiker and Abdalla (1990).

Ibrahim *et al.* (1991b) carried out a countrywide on-farm trial, covering most of the wheat-producing areas of the Sudan, to test the response of wheat to different rates of N and P combinations as well as the methods of P application. The rates of N were 0, 43, 86 and 129 kg N/ha, and those of P were 0, 43 and 86 kg P_2O_5/ha. Methods of P application used included broadcasting, band placement and mixing the P fertilizer with the seed. The fertilizer treatments significantly increased wheat grain yield in Burgaig (Northern State), Shendi High Terrace soil (Northern State), Blue Nile and Rahad. Wheat grain yields did not increase significantly because of the fertilizer treatments in case of Shendi (Gurier soil), Ed-Damer (High Terrace soil), and the White Nile and New Halfa sites. The lack of response on Gurier soil in Shendi was attributed to its high fertility, while in Ed-Damer and the White Nile it was due to the high salinity/sodicity encountered at both sites. The reason for the lack of response at New Halfa was not clear as the soil there is poor in both N and P. The highest grain yield in this trial was realized at Shendi site with Gurier soil (soil total-N 990 ppm). The lowest yields were achieved by Ed-Damer and the White Nile High Terrace soils. N and P uptake by the crop also followed a pattern similar to that of grain yield at the different sites. There were no significant differences between the different methods of P application, but mixing the P fertilizer with the seed or broadcasting it gave grain yields higher than band placement in most of the locations. It was concluded that the dose of 86 kg N + 43 kg P_2O_5/ha could be recommended for Burgaig, Blue Nile, Rahad, Ed-Damer and the White Nile. In Shendi Gurier soil, although there was no significant response to N and P fertilizers, a maintenance dose of 43 kg N + 21.5 kg P_2O_5/ha could be recommended.

Ibrahim and Satti (1991) at Hudeiba and the White Nile conducted an on-farm factorial trial where different rates of potassium fertilizer (0, 21.5, 43 and 86 kg K_2O/ha) and two times for K application (T_1, where all the fertilizer treatment was given at sowing and T_2, where ½K dose was given at sowing and ½K dose at booting) were tested. The experiment at Hudeiba was carried out on two soil types: Karu and High Terrace. K_2SO_4 was used at Hudeiba and KCl at the White Nile State. All treatments at all sites received a basal dose of 86 kg N/ha and 43 kg P_2O_5/ha. Wadi El Neil wheat cultivar was grown at Hudeiba and Condor at the White Nile. Both the rates and times of K application had no significant effect on wheat grain yield and yield components at all sites. Mohamed-Ali (1990) reported that Giza 155 and Wadi El Neil wheat cultivars significantly responded to N and P and not to K application in Ed-Damer area. Although Finck (1962) and others had reported that the soils of the Sudan have adequate supply of available K, they believed that the high soil salinity/sodicity encountered in the High Terrace and White Nile soils and the use of KCl in the White Nile might have hampered K utilization by wheat and eventually reduced crop yield.

Babiker (1994), in an on-farm trial at Rahad Scheme, tested three levels of N application (65, 112 and 86 kg N/ha) on two different soil types. Although there were differences between the two soil types in terms of total-N, organic carbon and $NaHCO_3$-P, there were no significant differences in wheat grain yields due to the fertilizer treatments. The author attributed this to the unfavorable weather conditions experienced during the 1993/94 season.

Abdalla and Mohamed (1994) tested different rates of fertilizer N and P combinations in an on-farm trial on four different mapping unit soils which represent more than 250,000 ha in the Gezira Scheme. Mapping unit 11 had very fine Vertisol, while 30, 31 and 45 had fine Vertisol. Units 30 and 11 had slight sodicity. The rates of N application ranged between 43 and 170 kg N/ha, whereas those of P ranged between zero and 129 kg P_2O_5/ha. Yield data reported on mapping units 11, 30, 31 and 45 indicated that wheat grain yield significantly increased with increasing levels of both N and P. There was also a significant interaction between N and P and the highest yields were achieved by the highest rates of N and P application. Mapping units 30 and 45 gave the highest and lowest wheat grain yields, respectively (Table 9). Mapping unit 30 also showed the highest yield (5688 kg/ha), realized with a fertilizer input of 129 kg N + 86 kg P_2O_5/ha. The authors concluded that soil unit 30 appeared to be the most suitable for wheat production.

Table 9. Mean wheat seed yield and yield at two contrasting levels of fertilizer application for four contrasting mapping unit sites in Gezira Scheme.

Mapping unit	Mean grain yield (kg/ha)	Yield (kg/ha) at two levels of fertilizer application		Max. level of fertilizer (kg/ha)
		Control†	Maximum	
30	4676	2886	5688	129-86 N-P
11	3623	1802	5249	172-129 N-P
31	3155	1916	4076	172-86 N-P
45	2311	1616	3013	129-129 N-P

† Control = 43 kg N/ha.
Source: Abdalla and Mohamed (1994).

Application of Foliar Fertilizers

All the areas where wheat is produced in the Sudan have pH values higher than 7. The organic matter of most of these soils is very low and the amounts of available micronutrients (Cu, Zn and Mn) are inadequate. Foliar fertilizers containing macro- and micronutrients have been recently introduced into the Sudan by some private companies.

Ibrahim *et al.* (1991a) conducted a large-scale on-farm trial using different foliar fertilizers at Hudeiba, Gezira, Rahad and New Halfa. Some locations had more than one site. The foliar fertilizers were applied at different wheat growth stages. Wheat grain yield increased significantly by the application of the foliar fertilizers at all the sites. The percent increase in grain yield over the control (86 kg N/ha applied at sowing) was in the range of 13–110. The increase in yield was highest in Gezira, lowest in Rahad and New Halfa, and intermediate in Hudeiba. Foliar fertilizers Greenzit NPK, Greenzit NK, Bayfolan and Wuxal Suspension Polymicro, applied at the rate of 3.91–4.76 l/ha, split equally at booting and two weeks later, resulted in the highest yield.

Gorashi (1992) applied Wuxal Suspension Polymicro in New Halfa at the rate of 2.38 l/ha to wheat in plots of size 2.1 ha. The mean grain yield of the foliar-treated plot was 2.86 t/ha, whereas that of the control (86 kg N/ha applied at sowing) was 2.38 t/ha.

Mohamed (1992) investigated the response of wheat in Shendi to several foliar fertilizers on Gurier (Shendi) and High Terrace (Messeiktab) soils. There was no significant effect on wheat grain yield grown on Shendi Research Farm Gurier soil which is well known for its high fertility. On the Messeiktab High Terrace soil, some foliar fertilizer treatments resulted in considerable yield increases. Wuxal, applied as a single dose at the booting stage, resulted in the highest grain yield (1383 kg/ha) compared with the recommended practice 2N + 1P (1000 kg/ha) (Table 10).

Ibrahim (1992) tested the same foliar fertilizers on two soil types (Karu and High Terrace) at Hudeiba. Wheat grain and straw yields increased significantly on the Karu soil and two applications resulted in higher grain yield than the single application (Table 10). The 1000-seed weight was significantly affected by foliar application. The response of wheat to foliar fertilizers on the High Terrace soil was not significant (Table 10).

Table 10. Effect of different foliar fertilizer treatments on grain yield of wheat in different soil types.

Treatment†	Site/Grain yield (kg/ha)			
	Shendi Research Farm§ (Gurier soil)	Messeiktab§ (High Terrace soil)	Hudeiba¶ (Karu soil)	Hudeiba¶ (High Terrace soil)
Control (0-0 N-P kg/ha)	3184	555		
Basal N-P‡	3124	1000	3386	2675
Basal + Bayfolan I	3055	1111	3807	2261
Basal + Bayfolan II	3075	991	4107	2514
Basal + Wuxal I	3085	1383	2984	2590
Basal + Wuxal II	3125	1346	4171	2441
Basal + Greenzit I	3421	1227	4576	2442
Basal + Greenzit II	3190	977	4712	2530
SE (±)	159^{NS}	177*	237**	125^{NS}

† Bayfolan, Wuxal I and Greenzit I were applied as a single dose at 2.38 l/ha at booting, while Bayfolan II, Wuxal II and Greenzit II were applied at 2.38 l/ha at booting + 2.38 l/ha 15 days later.
‡ Basal N-P application was 86 kg N + 0 kg P_2O_5/ha at Shendi and Messeiktab and 86 kg N + 43 kg P_2O_5/ha at Hudeiba.
*, ** = Significant at the 5 and 1% levels, respectively; NS = Not significant.
Source: Mohamed (1992)§; Ibrahim (1992)¶.

Salih (1992) tested several foliar fertilizers at Tayeba Block in the Messalamiya Group of the Gezira Scheme and compared them with the recommended dose of the fertilizer (2N + 1P) on large experimental plots of 2.1 ha each. The foliar fertilizers, which were applied at booting, increased wheat grain yield by 10–22% over the recommended dose. The foliar fertilizer Greenzit NPK realized the highest wheat grain yield (2473 kg/ha), whereas the control (2N + 1P) gave 2237 kg/ha.

Babiker (1992) conducted an on-station experiment and an on-farm trial at Rahad to test the response of wheat to three foliar fertilizers (Wuxal Suspension Polymicro, K101 and K180) at two rates of application (2.38 l/ha as a single dose given at booting, and 4.76 l/ha dose split-applied equally at booting and two weeks later). All the foliar fertilizers caused increases in wheat grain yield in the on-station experiment. Foliar fertilizer K101 gave the highest wheat grain yield in the on-station experiment, whereas foliar K180 gave the highest yield in the on-farm trial.

Ishag (1992) conducted two trials, one at the Gezira Research Farm and the other a large-scale on-farm trial in the Gezira Scheme, to find out the response of wheat cultivar Debeira to the application of two foliar fertilizers (Wuxal Suspension Polymicro and Bayfolan 11-8-8). The foliar fertilizers were applied at different developmental stages. Wheat grain yield increased by 37% when the foliar fertilizers were applied at ear emergence (Table 11). There were no significant differences between the two foliar fertilizers in the on-station trial. Foliar fertilizer application increased wheat grain yield in some on-farm sites (Messalamiya, 36%; El Gamousi, 44%), whereas in other sites there was no response. The overall average response of wheat to foliar fertilizers in the large-scale trial was 13%. The author believed that foliar fertilizers reduced the deleterious effect of high temperatures common in the wheat-growing areas in Gezira.

Table 11. Effect of foliar fertilizer and time of application on grain yield of wheat in Gezira.

Time of application†			Grain yield (kg/ha)			
DR	TSI	EE	Wuxal Suspension Polymicro	Bayfolan	Mean	% increase over control
-	-	-			2332	
+	+	+	2632	2707	2670	14.5
+	-	-	2986	2686	2830	21.6
-	+	-	2970	3049	3010	29.1
-	-	+	3111	3265	3188	36.7
+	+	-	3049	3286	3168	35.8
+	-	+	2932	2995	2964	27.1
-	+	+	3365	2799	3082	32.2

† DR = Double ridge; TSI = Terminal spikelet initiation; EE = Ear emergence; + = Application; - = No application.
Source: Ishag (1992).

Ishag (1993a) further tested the response of wheat to five foliar fertilizers at Gezira Research Station. The foliar fertilizers increased wheat grain yield, but there was no significant difference between the treatments. Foliar Bayfolan 11-8-6 attained the highest grain yield (2.32 t/ha).

Ishag (1993b) also conducted a large-scale on-farm trial in the Gezira Scheme to test the response of wheat to three foliar fertilizers, namely, Bayfolan 11-8-6, Foliar X (powder) and Wuxal Suspension Polymicro. The trial was carried out in an area of 37.8 ha where the wheat cultivar El Neilain was sown. A first dose of the foliar fertilizers was sprayed aerially at stem elongation and a second dose at ear emergence. There were no significant differences between the treatments. The author observed that all foliar fertilizers gave negative effects under poor farm management. Under good management, foliar Bayfolan 11-8-6 and Wuxal Suspension Polymicro affected wheat grain yield positively (Table 12).

Table 12. Effect of foliar fertilizer on grain yield of wheat under two levels of management in Gezira Scheme.

Treatment	Grain yield (t/ha)	
	Good management	Poor management
Control	3.35	2.19
Bayfolan 11-8-6	4.53	1.34
Foliar X	2.64	1.73
Wuxal Polymicro	3.71	1.84

Application of Micronutrients

Soil availability of such micronutrients as Cu, Zn and Mn is likely to be reduced under high pH conditions, common to most wheat-growing areas in the Sudan. Ibrahim (1990), therefore, studied the effect of a foliar application of cocktails of Zn, Fe and Mn on wheat yield. The treatment increased the yield on the Karu soil of northern Sudan by more than 15% over the N-treated control.

Abdalla *et al.* (1993) conducted a large-scale on-farm trial in most of the wheat-producing states of the Sudan to test the effect of the application of single micronutrients and their combinations on the productivity of wheat. The micronutrients were applied either as soil application or foliarly. At Hudeiba, soil application of micronutrients had a positive effect on grain yield of wheat on Karu soil but negative on High Terrace soil. Soil application of 520 g Cu/ha gave the highest increase in yield (31%), and soil application of 600 g Mn/ha gave the second highest increase (28%). Foliar application had a positive effect on High Terrace soil and a negative effect on Karu soil. The highest rate of Cu or Mn application gave the highest increase (39%) in grain yield (Table 13) which was attributed to the increase in 1000-seed weight. Soil application of micronutrients had no significant effect on wheat grain yield at Shendi on both soil types (Gurier and High Terrace), as also at Rahad. At Sennar and Gezira Research Farm the soil application had, in most cases, negative effects on wheat grain yield.

Table 13. Effect of micronutrient application on wheat grain yield in two soil types at Hudeiba.

Treatment	Grain yield (kg/ha)			
	Soil application†		Foliar application‡	
	Karu	High Terrace	Karu	High Terrace
Cu0 Zn0 Mn0	3037	1787	3553	1148
Cu1 Zn0 Mn0	3327	1712	3666	1270
Cu2 Zn0 Mn0	3962	2058	3137	1278
Cu0 Zn1 Mn0	3374	1652	3169	1352
Cu0 Zn2 Mn0	3692	1378	3880	1255
Cu0 Zn0 Mn1	3176	1910	3123	1025
Cu0 Zn0 Mn2	3600	1942	3353	1592
Cu1 Zn1 Mn1	3293	1502	3163	1528
Cu2 Zn2 Mn2	3638	1763	2979	1362
Cu1 Zn0 Mn2	3894	1637	3291	1372
Cu2 Zn0 Mn2	3308	1002	3554	1203
SE (±)	263^{NS}	108**	251^{NS}	131^{NS}

† For soil application: Cu0 = 0; Cu1 = 260; Cu2 = 520; Zn0 = 0; Zn1 = 700; Zn2 = 1400; Mn0 = 0; Mn1 = 600; Mn2 = 1200 g/ha.
‡ For foliar application: Cu0 = 0; Cu1 = 32.5; Cu2 = 65; Zn0 = 0; Zn1 = 42; Zn2 = 84; Mn0 = 0; Mn1 = 48; Mn2 = 96 g/ha.
** = Significant at the 1% level; NS = Not significant.
Source: Abdalla *et al.* (1993).

Abdalla *et al.* (1994) repeated the on-farm trial the following season, but more locations, such as the White Nile and New Halfa, were included. The response of wheat to micronutrient application was not significant and was inconsistent on the Karu soil of Hudeiba, Shendi Research Farm, Sennar, Rahad, White Nile and New Halfa. There was, however, a general trend for a positive response to the application of Zn and Mn at several locations. Clearly, there is a need for more studies with greater information on soil and plant tissue analysis.

Application of Organic Fertilizers

The soils of the Sudan where wheat is produced are poor in organic matter and as such they have inadequate supplies of many essential nutrients. The cropping systems adopted in the irrigated sector do not allow for the build up of high levels of organic matter since all crop residues are either removed or burned. Organic matter is also important in improving the chemical and physical properties of the soils. Because of these reasons, research work on the application of organic fertilizers was started under the NVP in the 1992/93 season. Ali *et al.* (1993) conducted on-station trials at Gezira Research Farm and Hudeiba Research Station and an on-farm trial at New Halfa to study the effect of different routes of application of organic fertilizers on soil properties and wheat yield. The organic fertilizer in Gezira was a compost prepared from cotton residues and farmyard manure, whereas cattle manure was used at New Halfa and Hudeiba. The N percent of the organic fertilizer at New Halfa and Hudeiba was 2.8 and 0.6%, respectively, and organic carbon 22 and 7%, respectively. The N percent of the organic fertilizer for the on-station and the on-farm trials at Gezira was 1 and 0.5%, respectively,. and organic carbon 12 and 5%, respectively. The rate of organic fertilizer application was 0–4 t/ha while that of inorganic N fertilizer was 0–86 kg N/ha. The experiment was a factorial involving both the organic and the inorganic fertilizers. The incorporation of compost at Gezira Research Farm was not appropriate so the effects on soil properties and crop productivity were inconsistent. Generally, grain yield increased with the increase in compost level in all the nitrogen treatments. In the on-farm trial at the Gezira Scheme, the plots that received organic fertilizer gave a higher grain yield (2738 kg/ha) than those receiving no compost (2246 kg/ha). The author attributed the increase in grain yield to the improvement of the soil physical properties rather than to the fertility status. Organic manure alone or in combination with added N had no significant effect on grain yield or any of the other yield components on the Karu soil of Hudeiba Research Station. This is presumably due to the low levels of organic manure applied in this particular experiment. At New Halfa, compost alone had no significant effect on wheat grain yield, but increasing the level of compost with increased N application caused considerable yield increases. The highest yield was attained by the treatment receiving 4 t compost/ha + 64.5 kg N/ha. This was attributed to the efficient utilization of N in the presence of the compost.

Salih *et al.* (1994) tested different sources of organic fertilizer, along with inorganic nitrogen, on wheat at Rahad, New Halfa, Sennar and Hudeiba. At

Rahad a mixture of animal manure and sorghum residue was applied; at New Halfa fresh animal manure was broadcast before the second irrigation; at Sennar sheep manure, which was heaped, kept moist and left to mature was used; and at Hudeiba air-dried farmyard manure was applied before sowing. Different rates of inorganic N in the form of urea ranging between zero and 100 kg N/ha were used, while the levels of the organic manure ranged between zero and 20 t/ha. There were no significant differences between the treatments at New Halfa (Table 14), but the highest yield was obtained with the application of 5 t/ha of manure + 43 or 65 kg N/ha. At Rahad, grain yield increased with higher levels of both manure and inorganic N fertilizer, and the highest yield was achieved by 10 t manure/ha + 60 kg N/ha. At Sennar a linear increase in yield occurred as the level of manure and nitrogen increased. The highest grain yield was realized by 20 t manure/ha + 60 kg N/ha.

Table 14. Wheat grain yield response to inorganic nitrogen and manure application at Rahad, New Halfa and Sennar.

	Grain yield (kg/ha)				
Nitrogen level	Manure (t/ha)				
(kg/ha)	0	5	10	20	Mean
Rahad					
10	1238	1308	1385	1487	1355
20	1359	1462	1436	1590	1468
40	1436	1513	1513	1487	1487
60	1462	1692	1743	1718	1654
SE (±)					62.8
New Halfa					
0	2708	2583	1917		2403
43	2125	1833	2373		2111
65	2250	2542	2375		2399
66	2125	2375	2042		2181
SE (±)					175.9
Sennar					
10	88	1500	1600	1763	1438
20	1738	1500	2000	2100	1850
40	2137	2400	2575	2763	2463
60	2625	2925	3125	3188	2963
SE (±)					53.8

Source: Salih *et al.* (1994).

At Hudeiba the application of both organic manure and N had no significant effect on grain yield and yield components in the Karu soil. However, the effect of manure in the High Terrace soil was highly significant on wheat grain yield; the increase was 18 and 48% for the addition of 7 and 14 t/ha, respectively. No significant response was found for N application. This result indicates that the response to the application of manure on saline soil (High Terrace soil) is probably due to the improvement in soil physical properties rather than chemical properties.

Conclusions

The following conclusions can be drawn from this review:

- For wheat production in the High Terrace soil of Gezira, Rahad, Sennar, White Nile, Northern and Nile River states, the optimum fertilizer dose is 86 kg N + 43 kg P_2O_5/ha. The N fertilizer dose should be split at tillering and booting stages.
- Wheat on Karu soil responds to N fertilization only and the optimum rate is 86 kg N/ha. As there was no significant response to P application on Karu soil, the application of 43 kg P_2O_5/ha is recommended as a maintenance dose for intensively cropped areas.
- Wheat does not respond to N and P fertilization on Gurier soil, however, a maintenance dose of 43 kg N/ha is recommended for wheat on that soil.
- Although research on K fertilization for wheat is not adequate, the results showed that wheat does not respond to K fertilization on most soils in the Sudan.
- Some foliar fertilizers (e.g., Bayfolan, Greenzit, Wuxal Suspension Polymicro, K101 and K186) have shown positive results on wheat grain yield in a crop which is grown with the recommended dose of N and P. Although the response of wheat to these foliar fertilizers at different localities was inconsistent, positive and significant response was usually associated with good crop management.
- The response of wheat to the application of micronutrients was also inconsistent. However, on soils like High Terrace, Karu and Gezira, some positive response to the application of Zn and Mn was obtained.
- On the High Terrace soil of Gezira and Sennar and in New Halfa, the application of organic fertilizers proved advantageous. Some of the soil properties seem to be affected favorably by the addition of these manures.

Proposed Future Research on Wheat Nutrition

The following areas need further investigation:

- Previous experimental work showed that wheat grain yield response to N and P fertilizers is greatly influenced by the degree of irrigation. Therefore, research work on N and P fertilization with differential irrigation regimes should be initiated, taking into consideration the rates and times of fertilizer application.
- Work on the response of wheat to N and P fertilization at New Halfa and the White Nile is not adequate. More experimentation involving several sites, soil testing and plant analyses should be conducted. Research work on High Terrace soil should receive similar attention.
- Work on foliar fertilizers showed positive and promising results. Foliar fertilizers of known composition should be tested in large-scale experiments.
- Soil and foliar application of individual or several micronutrients (i.e., Zn, Mn, Cu) sometimes caused significant wheat grain yield increases, but the work conducted was not enough. Experimental work in this area and on N and P fertilization should take into consideration soil and plant testing in order to arrive at sound recommendations.
- Work carried out on organic fertilizers showed their positive effects on wheat grain yield and soil properties. This work should continue and should also include methods of preparation and application.
- The Soil Survey Administration has recently identified bench-mark soils in the Gezira Scheme. The research proposed above should be conducted extensively on these soils and under farmers' conditions in other locations to enhance the recommendation domain of the results.

References

Abdalla, H.H., Ibrahim, B.A., Gorashi, A.M., Babiker, E.A., Satti, M.A., Mohamed, B.E.A., Ibrahim, H.S., Omer, M.M. and Mohamed, G.E. 1994. Response of wheat to micronutrient fertilization. Pages 68–70 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1993/94, Sudan. ICARDA/NVRP-DOC-037.

Abdalla, H.H., Ibrahim, H.S., Babiker, E.A., Omer, M.M. and Mohamed, G.E. 1993. Response of wheat to Zn, Cu and Mn fertilizers. Pages 206–224 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Bread Wheat Report, Annual National Coordination Meeting, 29 August–2 September 1993, Agricultural Research Corporation, Wad Medani, Sudan.

Abdalla, H.H. and Izzat, A.H. 1987. Response of wheat to N and P fertilization. Paper presented at the Second Wheat Coordination Meeting, 20–22 July 1987, Agricultural Research Corporation, Wad Medani, Sudan.

Abdalla, H.H. and Mohamed, B.A. 1994. The soil potential assessment network (SPAN) for wheat in Gezira Scheme. Pages 195–199 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Bread Wheat Report, Annual National Coordination Meeting, 28 August–1 September 1994, Agricultural Research Corporation, Wad Medani, Sudan.

Ageeb, O.A.A. and Abdalla, H.H. 1988. Researcher-managed trials, the response of wheat to NPK fertilizers in farmers' fields in Gezira. Paper presented at the Third Wheat Coordination Meeting, 4–6 September 1988, Agricultural Research Corporation, Wad Medani, Sudan.

Ageeb, O.A.A., Mohamed, M.S. and Faki, H.H. 1986. Researcher-managed trial, Gezira and New Halfa. Paper presented at the First Wheat Coordination Meeting, 3–5 August 1986, Agricultural Research Corporation, Wad Medani, Sudan.

Ali, N.A., Salih, A.A., Ahmed, S.H., Ibrahim, B.A., Mohamed, B.A., Mansi, M.G. and Abdel Wahab, O.A. 1993. Effect of organic fertilization on wheat production under Sudan conditions. Pages 45–47 *in* Nile Valley Regional Program for Cool-Season Food Legumes and Wheat, Annual Report 1992/93, Sudan. ICARDA/NVRP-DOC-031.

Babiker, E.A. 1992. Response of wheat to foliar fertilizer at Rahad. Pages 115–118 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Bread Wheat Report, Annual National Coordination Meeting, 6–10 September 1992, Agricultural Research Corporation, Wad Medani, Sudan.

Babiker, E.A. 1994. Effect of nitrogenous fertilizers levels in zones of different soil types on Rahad Scheme (on-farm). Pages 177–179 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Bread Wheat Report, Annual National Coordination Meeting, 28 August–1 September 1994, Agricultural Research Corporation, Wad Medani, Sudan.

Babiker, E.A. and Abdalla, H.H. 1990. Response of wheat to N and P fertilizers in farmers' fields at Rahad. Annual National Coordination Meeting, 27–31 August 1990, Agricultural Research Corporation, Wad Medani, Sudan.

Finck, A. 1962. Potassium status of some Sudan soils. Plant and Soil 16(3): 293–311.

Gorashi, M.A. 1988. the response of wheat to different levels of N and P at New Halfa. Paper presented at the Third Wheat Coordination Meeting, 4–6 September 1988, Agricultural Research Corporation, Wad Medani, Sudan.

Gorashi, A.M. 1992. Response of wheat to micronutrient application at New Halfa. Page 151 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Bread Wheat Report, Annual National Coordination Meeting, 6–10 September 1992, Agricultural Research Corporation, Wad Medani, Sudan.

Ibrahim, H.S. 1987a. Varietal response to N fertilizer on the major soil types in the Northern Region. Paper presented at the Second Wheat Coordination Meeting, 20–22 July 1987, Agricultural Research Corporation, Wad Medani, Sudan.

Ibrahim, H.S. 1987b. Screening of promising wheat lines for P response under two soil types in the Northern Region. Paper presented at the Second Wheat Coordination Meeting, 20–22 July 1987, Agricultural Research Corporation, Wad Medani, Sudan.

Ibrahim, H.S. 1989. Varietal response to N fertilizer on the major soil types of the Northern Region of Sudan. Annual National Wheat Coordination Meeting, 4–7 September 1989, Agricultural Research Corporation, Wad Medani, Sudan.

Ibrahim, H.S. 1990. Effects of different levels of fertilizer N and P application on the yield and NP uptake by wheat under the High Terrace soils of the Northern Region of Sudan. Annual National Coordination Meeting, 27–31 1990, Agricultural Research Corporation, Wad Medani, Sudan.

Ibrahim, H.S. 1992. Response of wheat to foliar fertilizers under two soil types. Pages 141–143 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Bread Wheat Report, Annual National Coordination Meeting, 6–10 September 1992, Agricultural Research Corporation, Wad Medani, Sudan.

Ibrahim, H.S. and Adlan, M.A. 1989. Effects of time and date of N application with P on the yield and uptake of N and P by wheat under two soil types in the Northern Region. Annual National Wheat Coordination Meeting, 4–7 September 1989, Agricultural Research Corporation, Wad Medani, Sudan.

Ibrahim, H.S., Babiker, E.A., Gorashi, A.M., Salih, A.A. and Ishag, H.M. 1991a. Response of wheat to foliar micronutrient fertilizer application in the Sudan. Pages 77–81 in Nile Valley Regional Program. Bread Wheat Report–Sudan, Annual Coordination Meeting, 16–23 September 1991, Cairo, Egypt.

Ibrahim, H.S., Babiker, E.A., Mohamed, G.E., Omer, M.M., Gorashi, A.M., Salih, A.A., Satti, E. and Mohamed, M.I. 1991b. Response of wheat to different rates of NP combinations and the method of P application in the Sudan. Pages 60–70 in Nile Valley Regional Program. Bread Wheat Report–Sudan, Annual Coordination Meeting, 16–23 September 1991, Cairo, Egypt.

Ibrahim, H.S. and Mohamed, G.E. 1988. Varietal response to N fertilizer on the major soil types in the Northern Region of Sudan. Paper presented at the Third Wheat Coordination Meeting, 4–6 September 1988, Wad Medani, Sudan.

Ibrahim, H.S., Mohamed, G.E. and Adlan, M.A. 1988. Effects of time and rate of nitrogen application with P on the yield and uptake of N and P by wheat under different soil types in the Northern Region. Paper presented at the Third Coordination Meeting, 4–6 September 1988, Agricultural Research Corporation, Wad Medani, Sudan.

Ibrahim, H.S. and Satti, M.A. 1991. Response of wheat to different levels and times of potassium application in Sudan. Pages 71–76 in Nile Valley Regional Program. Bread Wheat Report–Sudan, Annual Coordination Meeting, 16–23 September 1991, Cairo, Egypt.

Ishag, H.M. 1992. Effect of foliar micronutrient fertilizers on the yield of wheat in irrigated Gezira. Pages 128–132 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Bread Wheat Report, Annual National Coordination Meeting, 6–10 September 1992, Agricultural Research Corporation, Wad Medani, Sudan.

Ishag, H.M. 1993a. Effects of foliar fertilizers on yield of wheat in the Gezira environment. Pages 178–180 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Bread Wheat Report, Annual National Coordination Meeting, 29 August–2 September 1993, Agricultural Research Corporation, Wad Medani, Sudan.

Ishag, H.M. 1993b. Large-scale trial on foliar fertilizers in wheat in farmers' fields. Pages 180–182 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Bread Wheat Report, Annual National Coordination Meeting, 29 August–2 September 1993, Agricultural Research Corporation, Wad Medani, Sudan.

Mohamed, G.E. 1989a. Wheat varietal response to N under two different soil types in Shendi area. Annual National Wheat Coordination Meeting, 4–7 September 1989, Agricultural Research Corporation, Wad Medani, Sudan.

Mohamed, G.E. 1989b. Effect of N level and time of application and P fertilization on wheat grain yield under two different soil types in Shendi area. Annual National Wheat Coordination Meeting, 4–7 September 1989, Agricultural Research Corporation, Wad Medani, Sudan.

Mohamed, G.E. 1992. Response of wheat to foliar micronutrient fertilizer in Shendi area. Pages 154–156 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Bread Wheat Report, Annual National Coordination Meeting, 6–10 September 1992, Agricultural Research Corporation, Wad Medani, Sudan.
Mohamed-Ali, G.H. 1990. Response of two bread wheat cultivars to N, P and K application in Northern Sudan. Rachis 1(9): 27–30.
Omer, M.M. 1989. Response of bread wheat to nitrogen and phosphorus application in the Blue Nile Agricultural Corporation. Annual National Wheat Coordination Meeting, 4–7 September 1989. Agricultural Research Corporation, Wad Medani, Sudan.
Omer, M.M. 1990. Response of bread wheat to nitrogen and phosphorus fertilization. Annual National Wheat Coordination Meeting, 27–31 August 1990, Agricultural Research Corporation, Wad Medani, Sudan.
Omer, M.M. 1992. Effect of foliar fertilizers on grain yield of wheat. Pages 151–152 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat. Bread Wheat Report, Annual National Coordination Meeting, 6–10 September 1992, Agricultural Research Corporation, Wad Medani, Sudan.
Salih, A.A. 1992. Effect of foliar fertilizers on wheat in Gezira. Pages 159–160 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat. Bread Wheat Report, Annual National Coordination Meeting, 6–10 September 1992, Agricultural Research Corporation, Wad Medani, Sudan.
Salih, A.A., Babiker, E.A., Ibrahim, B.A., Ahmed, S.H. and Mohamed, B.A. 1994. Effect of organic fertilizer on wheat production at Rahad, New Halfa, Sennar and Hudeiba. Pages 153–158 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Bread Wheat Report, Annual National Coordination Meeting, 28 August–1 September 1994, Agricultural Research Corporation, Wad Medani, Sudan.
Satti, M.E.A. 1989. Effect of fertilizer application and soil nutrients on nutrient uptake and grain yield of wheat. Annual National Coordination Meeting, Agricultural Research Corporation, Wad Medani, Sudan. Annual National Wheat Coordination Meeting, 4–7 September 1989. Agricultural Research Corporation, Wad Medani, Sudan.

Discussion

Q: Dr. Shama Elamin Dawelbeit

Could you comment on the use of organic fertilizers through composting, mainly for their economic value and effect on soil structure and pesticide use? Research should be directed towards the quality of compost and its benefit to farmers and, later, on biogas production.

A: H.S. Ibrahim

Organic fertilizers can be used as compost and this requires that the method for composting should be efficiently and correctly used. The economics of the organic fertilizers and compost are very important. Good quality compost is required and this is achieved by using good sources of animal and plant residues and good methods for compost preparation.

Q: Osman A.M. Eltom

What about the application of organic fertilizers on a large scale, is it practical?

A: H.S. Ibrahim

In most of the irrigated schemes of the Sudan, especially Gezira, Rahad and New Halfa, there are a lot of animals and several crops are grown. Crop and animal remains can be used as organic fertilizers. Therefore, it is possible and practical to use organic fertilizers in these agricultural schemes and other similar ones. China, being the largest country in the world in terms of population, uses mainly organic fertilizers for its agricultural production.

Comment/Q: Mamoun Dawelbeit

The review did not cover an important area which is how to apply the fertilizers and the effect of time. These questions are frequently asked by farmers and administrators. Also, what will happen if there is a delay in fertilizer delivery?

A: H.S. Ibrahim

It is known to all of us that fertilizers in the Sudan are applied by hand. We want our agricultural engineers to help farmers in using machinery for fertilizer application. Some work has been done with respect to the time of N and P application. Also, if the fertilizer is delayed up to the flowering and seeding stages, I think that it should not be applied.

Comment: Mohamed M. Omer

In New Halfa Scheme, the response to phosphorus application was not significant and was not recommended.

A: H.S. Ibrahim

Yes, there was no wheat response to P application in New Halfa. I draw the attention of the audience to correct that in the text.

Q: Prof. Hassan M. Ishag

What is the possibility for screening genotypes for efficient use of soil nutrients, and are there any plans for the introduction of mobile labs to determine the amount of nutrients needed for a particular soil?

A: H.S. Ibrahim

I think there is a possibility for screening genotypes that are efficient users of soil nutrients. Regarding mobile laboratories that can be used in the field and are able to determine the concentration of some nutrients in the leaf and soil, these are not available in the Sudan. I hope we will be able to acquire such facilities soon.

Comment/Q: Prof. Osman Ageeb

My question is: How would you explain the lack of response to P application in New Halfa? My comment is: I believe that there is a lot of work on source, time and method of fertilizer application that should be covered in the review.

A: H.S. Ibrahim

Although sodium bicarbonate-P is not high in New Halfa, wheat did not respond to P application. I agree with you about the need to include the work on source, time and method of fertilizer application in the review, but unfortunately there is not enough work. There is some work on the time of application and this was reported in the final paper.

Comment: M.C. Saxena

There is a need to direct future research on fertilizer management in the context of the cropping system and nutrient recycling. Wheat's response to direct nutrient application will depend on the history of fertilizer application to previous crops in the rotation. There is also a need for coming up with clear recommendations with respect to up-to-date understanding of the rates and methods of fertilizer application to wheat in major soil types and cropping systems.

A: H.S. Ibrahim

I fully agree with all what you have mentioned. Fertilization of wheat and other crops should be considered with respect to the cropping system and nutrient cycling.

Water Relations and Water Requirements of Wheat

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Abstract

This paper is a review of the work carried out on water relations and water requirements of wheat in the Sudan. The results showed that although a high water status throughout the season was necessary to maintain unimpaired crop growth and high economic yield of wheat, the imposition of some stress by longer irrigation intervals, higher moisture depletion or skipping irrigations during the early vegetative growth stages or during maturation could still attain similar economic yields as well as saving irrigation water and improving water-use efficiency. Cultivars with deeper roots could attain higher grain yields as a result of using more of the available water in the soil profile. The application of presowing irrigation proved very useful, particularly in areas where the soils were heavy, as it facilitated seedbed preparation, reduced weed infestation and increased plant population per unit area. Many farmers over-irrigate their wheat crop. The volume of water needed to achieve optimum grain yields was around 10,000 m^3/ha. Less or more than this amount tended to decrease grain yield. Hence, enhancing the awareness of the farmers of the ill-effects of over-irrigation is necessary for increasing productivity and water-use efficiency. The differential response of the tested wheat cultivars to irrigation regimes should be useful for managers in irrigated schemes to allocate the cultivars more tolerant to moisture stress in locations where irrigation water is limited.

Introduction

Wheat is the second most important cereal after sorghum in the Sudanese diet. The area devoted annually to wheat is about 300,000 ha. The crop is grown entirely under irrigation with water, either from river flows, as in Gezira, New Halfa and the White Nile agricultural schemes, or lifted from the River Nile and wells using diesel pumps, as in the Northern State.

Demand for wheat in the past has not been very high because the diet of the majority of the Sudanese population was based mainly on sorghum. At present, wheat consumption has increased and the government is attempting to attain self-sufficiency in this commodity. In order to fulfill this objective, it is necessary to increase the cultivated area and obtain maximum output from each unit volume of water consumed. Research has, therefore, been conducted to investigate different aspects of irrigation on productivity and water-use efficiency.

The research findings from the work done in the period before the start of the Nile Valley Project (NVP) and during the NVP have been reviewed in the following sections.

The Pre-Nile Valley Project Phase

The start of this phase dates back to the 1960s when water relation studies were based on either omitting irrigations at one of the five major stages of crop growth (Khalifa 1968) or irrigating at fixed intervals throughout the season (El Rayah 1970).

The results obtained by Khalifa (1968) showed that grain yield was not significantly reduced if irrigation was not given at seedling, tillering or milk stages as compared to the fully irrigated treatment, whereas omission at the boot or flowering stages significantly reduced grain yield (Table 1) as a result of the reduction in grain number per head and seed size.

El Rayah (1970) studied the effects of irrigation intervals of 7, 12, 14 and 21 days on the yield of two wheat cultivars: Giza 155 and Mexicani. Grain yield decreased with increasing irrigation interval. However, there were no significant differences in yield with 7- and 12-day interval treatments and between 12- and 14-day interval treatments. For Mexicani, the 7-day interval gave significantly greater yield than the 14-day interval, whereas the 21-day interval gave the lowest yield for.both Mexicani and Giza 155 (Table 2).

The Nile Valley Project Phase

As part of the ARC/ICARDA/OPEC Pilot Project, research on water relations and water requirements of wheat was continued and included studies on irrigation intervals, moisture depletion, skipping irrigations, rooting depth, and on-farm water management.

Table 1. Effect of omission of an irrigation at one of the five growth stages on grain yield and yield attributes of wheat.

Attribute	Irrigation every 14 days	Irrigation at each growth stage	Stage at which irrigation is omitted					SE (±)
			Seedling	Tillering	Boot	Flowering	Milk	
Grain yield (kg/ha)	1005.0	960.0	840.0	828.0	140.0	586.0	948.0	116.4
Grains/head	21.0	23.0	21.0	18.0	11.0	23.0	22.0	0.5
1000-grain wt. (g)	37.2	35.7	35.7	35.7	26.2	26.4	35.7	0.6

Source : Khalifa (1968).

Table 2. Effect of different irrigation intervals on grain yield of two wheat cultivars.

Cultivar	Irrigation interval (days)/Grain yield (kg/ha)				Mean
	7	12	14	21	(SE = ± 77.6)
Giza 155	2643	2900	2619	2243	2601
Mexicani	3835	3500	3207	2712	3314
Mean (SE = ± 108.3)	3289	3200	2913	2478	

Source: El Rayah (1970).

Irrigation Intervals

Farah (1986) studied the response of the cultivar Condor to variations in irrigation intervals at three growth stages. In the first stage—from planting to boot—irrigation was applied in one of three regimes: after 10 days then every 14 days; every 14 days; or every 21 days. In the second stage—from boot to milk—the plots, treated according to one of the above regimes, were irrigated every 10 days or every 14 days. In the third stage—from milk to maturity—the same plots were irrigated every 10 days or every 21 days.

The results (Table 3) showed that the yields were highest when irrigation intervals were shortest in all the three stages of growth. Increasing the interval of irrigation during the second stage had a more adverse effect on yield than in the first and the third stages of growth, indicating that the crop was more sensitive to moisture stress during the second stage of crop growth.

In a second trial (Farah 1987a), the cultivar Condor was subjected to irrigation every 14 or 21 days from sowing to panicle initiation (PI) stage; 10 or 14 days from PI to heading; and 10, 14 or 21 days from heading to maturity. The results (Table 4) showed that the highest grain yield was obtained from irrigating every 14, 10 and 14 days during the first, second and third phases of crop development, respectively. However, increasing the irrigation interval to 21 days in the first phase and irrigating at 10- and 14-day intervals during the second and third phases resulted in a saving of two irrigations without any significant reduction in the yield.

Table 3. Effect of irrigating wheat at different intervals during the three growth stages on grain yield of wheat.

Irrigation interval (days)			Number of irrigations	Grain yield (kg/ha)
Planting to boot	Boot to milk	Milk to maturity		
10-14	10	14	8	1272
10-14	10	21	7	1090
10-14	14	14	7	1089
10-14	14	21	6	1113
14	10	14	7	1257
14	10	21	7	1213
14	14	14	6	1174
14	14	21	6	1055
21	10	14	6	930
21	10	21	5	965
21	14	14	6	797
21	14	21	5	761
SE (±)				118.9

Source: Farah (1986).

The results in Table 4 also show that, in all treatments, grain yield was better when irrigation was applied every 14 days than every 10 days during the final growth stage. This finding should discourage farmers from applying excessive water to their wheat fields during the maturation stages.

In a third trial, Farah (1987b) subjected Condor and Debeira to four irrigation regimes as follows: (1) every 14 days until boot and 10 days thereafter; (2) every 14 days throughout; (3) every 21 days until boot and every 10 days thereafter; or (4) every 21 days until boot and every 14 days thereafter. The highest grain yield was obtained from the first treatment (Table 5). However, the longer irrigation interval of 21 days during the vegetative stage still permitted reasonable grain yields, provided the shorter interval of about 10 days was used during the reproductive stage.

Table 4. Effect of irrigating wheat at different intervals in the three growth stages on yield and water-use efficiency (WUE) of wheat.

Irrigation interval (days)			Grain yield (kg/ha)	No. of irrigations	WUE (kg/m³/ha)
Planting to PI	PI† to heading	Heading to maturity			
14	10	10	1789	9	0.38
14	10	14	1955	8	0.41
14	10	21	1513	6	0.49
14	14	10	1619	8	0.53
14	14	14	1856	7	0.48
14	14	21	1447	6	0.54
21	10	10	1835	7	0.68
21	10	14	1887	6	0.66
21	10	21	1337	5	0.46
21	14	10	1403	5	0.50
21	14	14	1390	5	0.44
21	14	21	1078	5	0.44
SE (±)			74.8		

† PI = Panicle initiation.
Source : Farah (1987a).

Table 5. Effect of variation in the irrigation interval on grain yield and water-use efficiency (WUE) of two wheat cultivars.

Irrigation interval (days)		Grain yield (kg/ha)			WUE (kg/m³/ha)		
Planting to boot	Boot to maturity	Condor	Debeira	Mean	Condor	Debeira	Mean
14	10	2427	2992	2710	0.61	0.74	0.68
14	14	2408	2534	2471	0.62	0.65	0.64
21	10	2293	2489	2391	0.65	0.69	0.67
21	14	1802	2059	1930			
Mean		2232	2518		0.63	0.69	

Source : Farah (1987b).

Irrigation interval studies were also carried out in the Northern State (Ibrahim 1995). In these studies the intervals during the vegetative stage were even longer than those which were imposed in Gezira. Cultivar Wadi El Neil was irrigated at 14-, 21- or 28-day intervals from seedling emergence to PI; 10- or 14-day intervals from PI to 50% flowering; and 10- or 14-day intervals from 50% flowering to maturity.

The results showed that the highest grain yield was obtained when the irrigation interval was 28 days in the first stage and 10 days during the subsequent stages (Table 6). The same treatment also gave the highest WUE value. These findings further confirm the previous results that wheat could tolerate long irrigation intervals of up to 28 days during the early vegetative stages, provided that shorter intervals of about 10 days were used during the reproductive stages.

Table 6. Effect of three irrigation regimes on grain yield of wheat at Hudeiba Research Station.

Irrigation interval (days)			Grain yield (kg/ha)			% increase over control
Seeding to PI	PI† to heading	Heading to maturity	1987/88	1988/89	Mean	
14	10	10	3728	4804	4266	7
14	10	14	3005	4332	3669	-7
14	14	10	3467	4665	4066	2
14	14	14	3684	4299	3992	0
21	10	10	3772	4050	3933	-2
21	10	14	3039	3762	3401	-15
21	14	10	3484	4737	4111	3
21	14	14	3183	3708	3446	-14
28	10	10	4061	4924	4493	13
28	10	14	2683	3924	3304	-17
28	14	10	3617	3042	3330	-17
28	14	14	3006	2698	2852	-29
Mean			3394	4079		
SE (±)			90	410		
Signif. level			***	NS		

† PI = Panicle initiation.
*** = Significant at the 0.1% level; NS = not significant.
Source : Ibrahim (1995).

At Hudeiba Research Station (HRS), cultivars Wadi El Neil, Debeira and El Neilain were subjected in 1993 to the following treatments (Ahmed 1993b): (1) irrigation every 10 days throughout the season (WW); (2) irrigation every 20 days until heading and every 10 days thereafter (DW); (3) irrigation every 10 days until heading and every 20 days thereafter (WD); or (4) irrigation every 20 days throughout the season (DD).

Results showed that irrigating the crops every 20 days prior to heading resulted in very similar grain yield as irrigating every 10 days, while a significant reduction (23%) occurred when the 20-day interval was imposed after the heading stage. The highest grain yield was obtained from cultivar El Neilain followed by Debeira (Table 7). Consumptive water use (CWU) was very similar for the three cultivars. The highest WUE was obtained when irrigation was given every tenth day. The cultivars also differed in WUE values, El Neilain having the highest followed by Debeira. The ability of El Neilain to attain a high value of WUE at all levels of irrigation treatments was probably due to its ability to maintain the highest relative turgidity values at these levels.

Using the same cultivars as above, Farah *et al.* (1993b) compared the following irrigation treatments: (1) every 10 days throughout; (2) every 14 days throughout; and (3) the first post-sowing irrigation after 21 days and subsequent irrigations every 14 days. The highest grain yield was obtained from the 10-day interval regime which was 30 and 54% higher than the yield under the second and the third treatments, respectively. The highest yield was obtained from cultivar Wadi El Neil followed by El Neilain (Table 8).

Irrigation Schedule Based on Moisture Depletion

In the 1993/94 season, irrigation treatments were based upon soil moisture depletion using the neutron scattering technique. Ahmed (1993a) subjected four wheat cultivars (Wadi El Neil, Condor, El Neilain, and Giza 164) at HRS to four irrigation treatments involving moisture depletion to 50% (wet treatment or W) and/or moisture depletion to 75% (dry treatment or D) as follows: (1) irrigation throughout when moisture depletion reached 50% (WW); (2) irrigation when moisture depletion reached 50% in the period from planting to anthesis and at 75% depletion after anthesis (WD); (3) irrigation when moisture depletion reached 75% in the period from planting to anthesis and at 50% depletion after anthesis (DW); and (4) irrigation when moisture depletion reached 75% throughout (DD). Treatment DW caused a nonsignificant decrease

(10%) in seed yield compared to WW, while WD caused a 24% reduction in yield as compared to the WW treatment. The differences in grain yield between the cultivars were highly significant. The highest yield was obtained from El Neilain followed by Condor then Wadi El Neil.

Table 7. Grain yield, consumptive water use (CWU), water-use efficiency (WUE) and relative turgidity of three wheat cultivars as affected by irrigation regime.

	Irrigation regime†				Mean
	WW	DW	DW	DD	
Grain yield (kg/ha)					
El Neilain	3153	2890	2066	2136	2561
Debeira	2688	2416	2045	2074	2306
Wadi El Neil	2186	2111	2753	1867	1979
Mean	2676	2472	1955	2026	
CWU (m^3/ha)	4390	4260	3700	3430	
WUE (kg/m^3/ha)					
El Neilain	0.72	0.68	0.56	0.62	0.64
Debeira	0.61	0.57	0.55	0.6	0.58
Wadi El Neil	0.5	0.5	0.47	0.54	0.5
Mean	0.61	0.58	0.53	0.59	
Relative turgidity (%)					
El Neilain	42			40	41
Debeira	34			32	33
Wadi El Neil	32			31	31
Mean (SE = ± 0.061)	36			34	

† WW = 10-day irrigation intervals throughout the season; DW = 20 days until heading and 10 days thereafter; WD = 10 days until heading and 20 days thereafter; DD = 20 days throughout the season.
Source: Ahmed (1993b).

Table 8. Effect of three irrigation regimes on grain yield and water-use efficiency (WUE) of three wheat genotypes.

Irrigation interval	Grain yield (kg/ha)	WUE† (kg/m³/ha)
10 days		
Debeira	2246	0.42
El Neilain	2511	0.45
Wadi El Neil	2672	0.47
Mean	2477 a†	0.44
14 days		
Debeira	1645	0.31
El Neilain	1247	0.26
Wadi El Neil	2333	0.48
Mean	1742 ab	0.33
21/14 days		
Debeira	797	0.21
El Neilain	1113	0.26
Wadi El Neil	1495	0.35
Mean	1135 b	0.28

† Values within a column followed by the same letter(s) are not significantly different at the 5% level according to DMRT.
Source: Farah *et al.* (1993b).

Testing the above irrigation treatments at Gezira Research Station (GRS) on the same cultivars but replacing Giza 164 by Debeira, Farah *et al.* (1994c) found that the highest grain yield was obtained from treatment WW which outyielded DW, DD and WD by 8, 10 and 14%, respectively, although these differences were not statistically significant. Differences between cultivars were highly significant. El Neilain had the highest grain yield followed by Wadi El Neil then Debeira.

In the 1994/95 season, Farah *et al.* (1995) subjected Debeira and El Neilain to two levels of moisture depletion: irrigation at 50% (not stressed) or irrigation at 75% (stressed) during the four growth phases to formulate four irrigation treatments: no stress (A); stress from mid to late stem elongation (B); stress from anthesis to maturity (C); stress as in B and C (D). No significant differences were noted between cultivars or irrigation treatments.

Effect of Skipping Irrigations

At Gezira Research Station (GRS), Ishag *et al.* (1992) subjected cultivar Debeira to stress by skipping irrigations at different growth stages giving rise to six treatments: T_1 (full irrigation); T_2 (stress at tillering); T_3 (as in T_2 and stress at grain filling); T_4 (stress at tillering, head emergence and first half of grain filling); T_5 (stress at head emergence and dough stage); and T_6 (stress at tillering and dough stage). The results showed that the highest grain yield (2071 kg/ha) was obtained from T_1. T_2 gave 14% less yield than T_1, and T_3 about 2% more than T_2; both differences were not significantly less than T_1. On the other hand, T_5 gave the lowest grain yield (489 kg/ha). This was due to the reduction of grains per spike as a result of infertile grains at both tip and base of the spikes.

At Hudeiba Research Station (HRS), Ahmed (1992) subjected cultivar Wadi El Neil to eight treatments. One treatment was not stressed at any stage, while the others were stressed by skipping one irrigation at various stages. The results showed very little depressive effect on grain yield when irrigation was skipped before heading, while grain yield was considerably reduced when irrigation was skipped during heading and early grain filling stage (Table 9). The reduction occurred because of the reduction in grain size.

Table 9. Effect of water stress on wheat yield and yield components.

Treatment†	Grain yield (kg/ha)	No. of plants /m row	1000-seed weight (g)
T_1	4035 a‡	45	32.2
T_2	2765 b	51	32.2
T_3	2365 b	45	27.2
T_4	2619 b	55	26.0
T_5	604 c	56	14.5
T_6	617 c	61	35.1
T_7	908 c	48	22.8
T_8	982 c	48	23.0
SE (±)	181	5	2.8

† T_1 = Nonstressed control, irrigated at 10-day intervals throughout the season; T_2 to T_8 = Stressed treatments (T_2 = First irrigation skipped, T_3 = First and second irrigations skipped, etc.).
‡ Values within a column followed by the same letter are not significantly different at the 5% level according to DMRT.
Source: Ahmed (1992).

In the following season, studies based upon skipping of irrigations were continued by Ahmed (1993a) at HRS and Farah *et al.* (1993c) at GRS. In these experiments, eight skipping treatments were compared with the nonstressed control which was irrigated at 10-day intervals throughout the season. Cultivar Wadi El Neil was used at HRS while Debeira was used at GRS. The results at both locations indicated that water stress did not significantly reduce grain yield when imposed during the vegetative stage or grain filling stage, whereas considerable reduction in grain yield occurred when the stress coincided with the heading and anthesis stages (Table 10).

Table 10. Effect of water stress on grain yield at different growth stages of two wheat cultivars at two locations.

Treatment†	Grain yield (kg/ha)	
	HRS§	GRS¶
T_1 (control)	3036 ab‡	2807 a
T_2	3295 a	1844 abc
T_3	3093 ab	1266 bc
T_4	3359 a	1512 bc
T_5	2565 c	1744 abc
T_6	2021 d	1623 abc
T_7	2831 bc	1182 c
T_8	2513 a	2062 abc
T_9	2735 bc	2445 ab
SE (±)	140	256

† T_1 = Nonstressed control, irrigated at 10-day intervals throughout the season; T_2 to T_9 = Stressed treatments (T_2 = First irrigation skipped, T_3 = First and second irrigations skipped, etc.).
‡ Values within a column followed by the same letter(s) are not significantly different at the 5% level according to DMRT.
Source: § Ahmed (1993a); ¶ Farah *et al.* (1993c).

In another experiment the following season, cultivar Debeira was subjected to water stress at eight growth stages at GRS (Farah *et al.* 1994b). The results were very similar to those obtained in the previous season (Farah *et al.* 1993c) and indicated that the highest grain yield was obtained from the control which did not experience any stress during the season, while the lowest yields were obtained when the stress coincided with the time of initiation of reproductive tillers and formation of grains. The highest value of WUE (0.27 kg/m³/ha) was attained by the control (T_1) which received nine irrigations, amounting to 8615 m³/ha. Comparatively close WUE values of 0.25 and 0.26 kg/m³/ha were obtained when irrigation was skipped at one of the last two scheduled dates (i.e., during the dough stage), with only eight irrigations amounting to 8100 and 8080 m³/ha.

Rooting Depth

Rooting depth of wheat cultivars was studied in the treatment where the soil moisture in the root zone was permitted to be depleted to 75% of the available water (Salih *et al.* 1993a). Four cultivars, namely, Condor, Debeira, El Neilain and Nesser were used. The results showed that the effective rooting depth of the four cultivars did not exceed 26 cm. Total root length and average rate of extension into the soil was highest for Condor and, to some extent, El Neilain, and lowest in Nesser. The first two cultivars were also able to extract more water from the deeper soil profile and attain greater grain yield than Debeira and Nesser.

In the following season, Salih *et al.* (1994) repeated the above experiment at GRS and compared the effects on rooting depth when soil moisture was depleted to 75% (dry treatment) or to only 50% of the available water in the root zone (wet treatment). The results showed that the rooting depth did not exceed 16 cm under both wet and dry treatments. However, cultivar Nesser gave the highest grain yield under the wet treatment, while El Neilain gave the highest grain yield under the dry treatment. This was in spite of the fact that El Neilain accumulated more straw than the other cultivars under the wet treatment (Table 11). All cultivars used similar amounts of water under the wet treatment, while El Neilain used more water under the dry treatment.

On-Farm Water Management

Presowing irrigation

Presowing irrigation of land in the Gezira Scheme was only practised in cotton fields in the past. Some work was initiated as part of the Nile Valley Project in recent years. Salih (1992) tested the effect of presowing irrigation by selecting 20 farmers, half of whom applied presowing irrigation while the other half did not. The results showed that presowing irrigation resulted in a greater number of plants and heads per unit area and final grain yield by about 14% (Table 12).

Table 11. Effect of soil moisture depletion on four wheat cultivars under wet (W) and dry (D) treatments.

Moisture treatment	Cultivar				Mean
	Condor	Debeira	El Neilain	Nesser	(± 133)
	Grain yield (kg/ha)				
W	1156	856	966	1411	1097
D	866	833	1478	922	1025
Mean (± 268)	1011	844	1222	1167	
	Straw yield (kg/ha) (± 520)				
W	4233	4478	6122	4867	4925
D	3908	4189	3911	4456	4116
	Water use (mm)				
W	681	604	666	633	646
D	635	574	654	591	614
Mean	658	589	660	612	

Source: Salih *et al.* (1994).

Table 12. Effect of presowing irrigation on yield and yield components of wheat in farmers' fields.

Treatment	No. of plants/m²	No. of heads/m²	Grain yield (kg/ha)
With presowing irrigation	328	337	2776
Without presowing irrigation	297	319	2440

Source: Salih (1992).

In the White Nile area, Satti (1992) tested the effects of presowing irrigation in two locations (Abassya and Um Ger) by dividing a piece of land in each location into two halves and applying presowing irrigation to only one half. The results showed that grain yield increased by 26% at Abassya location while no effect was observed at Um Ger location (Table 13). The positive effect of presowing irrigation in the first location was mainly due to the presence of very deep cracks in the soil in this location at the time of land preparation. With presowing irrigation there was improvement of land preparation and the creation of a fine seedbed.

Table 13. Effect of presowing irrigation on wheat grain yield at two locations in the White Nile Scheme.

Treatment	Grain yield (kg/ha)	
	Abassya location	Um Ger location
With presowing irrigation	2900	2020
Without presowing irrigation	2300	2140
% increase	26.1	-5.6

Source: Satti (1992).

In Rahad Scheme, the effect of presowing irrigation was compared between farmers who applied presowing irrigation and those who didn't (Babiker 1992). The results indicated an increase of plant stand and grain yield by about 14 and 9%, respectively, and a decrease in the number of weeds per unit area due to the presowing irrigation (Table 14).

Table 14. Effect of presowing irrigation on wheat yield and yield components at Rahad Scheme.

Treatment	Grain yield (kg/ha)	No. of heads/m^2	No. of weeds/m^2
With presowing irrigation	3606	460	2
Without presowing irrigation	3317	399	3
% increase	8.7	15.3	-33.3

Source: Babiker (1992).

An experiment, conducted in the Blue Nile area (Omer 1992), also showed a significant increase ($P = 0.05$) in grain yield (27.7%) as a result of presowing irrigation. The main factor causing this increase was the greater number of heads per unit area (Table 15).

The effect of presowing irrigation was also tested in the Gezira and White Nile schemes (Salih *et al.* 1993b) with 16 farmers. The results (Table 15) revealed that the farmers who applied presowing irrigation could obtain 60 and 90% increase in grain yield in the Gezira and White Nile schemes, respectively. The positive effects of presowing irrigation were mainly due to the reduction of seed and fertilizer losses down the soil cracks, better levelling of the fields, reduced weed infestation, and greater number of heads per unit area.

Table 15. Effect of presowing irrigation on grain yield and yield components of wheat at three locations.

Treatment	Gezira		White Nile		Blue Nile†	
	Grain yield (kg/ha)	No. of heads/m^2	Grain yield (kg/ha)	No. of heads/m^2	Grain yield (kg/ha)	No. of heads/m^2
With presowing irrigation	2047	328	1886	591	2690	374
Without presowing irrigation	1276	287	994	414	2106	320
% increase	60.4	14.3	89.7	42.8	27.7	16.9

Source: Salih *et al.* (1993b); † Omer (1992).

Effect of over-irrigation

The Gezira canal system is designed to irrigate each 'Number' (a Number consists of 18 farmers' fields, 2.1 ha each, 37.8 ha in total) by a ditch which supplies 5,000 m^3 of water per 12 hours in 7 days every 14 days. However, very few farmers adhere to this rule and the general practice is the application of excessive amounts of water for longer durations than necessary which results in over-irrigation and, very often, reduced yields.

In order to acertain this, surveys (Farah *et al.* 1993a, 1994a) covering 14 and 12 tenancies were conducted in 1992/93 and 1993/94, respectively. Irrigation water was measured with a portable vane flowmeter. The volume of water which was applied ranged from 9,730 to 13,057 m^3/ha (average 10,672 m^3/ha) and grain yield ranged from 2,140 to 4,380 kg/ha (average 2,929 kg/ha) in 1992/93. The amount of water used during 1993/94 ranged from 8,550 to 11,030 m^3/ha (average 9,422 m^3/ha) and grain yield ranged from 690 to 1,370 kg/ha (average 1,062 kg/ha). Thus, the yield in 1993/94 was only 39% of what was obtained in 1992/93, while the total water used remained nearly the same in the two seasons. The data from individual tenancies indicated that yield increased with applied water up to a point beyond which there was a decrease with more addition of water. The highest grain yields were obtained in the range from 9,500 to 10,800 m^3/ha. The amount of water which was applied by the farmers was, on the average, greater than the crop water requirements (CWR) as estimated by the method of Farbrother and Adam (1975) by 46% in 1992/93 and 36% in 1993/94 (Table 16).

Table 16. Applied water as compared to crop water requirement (CWR) in two seasons.

	Irrigation number								Mean
	1	2	3	4	5	6	7	8	
					1992/93				
Applied water (m^3/ha/day)			78	87	118	130	122	116	
CWR			59	62	63	64	46	42	
% CWR			76	71	53	48	38	36	54
Excess water (%)			24	29	47	51	62	64	46
					1993/94				
Applied water (m^3/ha/day)		81	101	147		78			
CWR		49	72	86		52			
% CWR		60	71	58		67			64
Excess water (%)		40	29	42		33			36

Source: Farah *et al.* (1993a, 1994a).

Discussion

For most crops a high water status throughout the growing season is necessary to maintain unimpaired growth. Nevertheless, there are periods of growth in the life cycle of such crops as wheat during which water stress may not result in a considerable reduction in economic yield (Salter and Goode 1967; Slatyer 1969). The various studies conducted in the Sudan before the Nile Valley Project (Khalifa 1968; El Rayah 1970) or within the Project (Ibrahim 1995; Farah 1986) have confirmed this aspect. Elsewhere, Robins and Domingo (1962), for example, indicated that for maximum wheat yields, severe moisture stress should be avoided from boot to maturity. Salim *et al.* (1965) concluded that the most critical stage with respect to water stress was heading. Many of the studies conducted within the Nile Valley Project have indicated that wheat can tolerate irrigation intervals up to 21 or 28 days during the vegetative growth stage and that reasonable grain yields can be obtained if moisture stress is avoided by shorter intervals during the reproductive (heading and anthesis) stages (Ibrahim 1995; Farah 1986, 1987a). Research findings also showed that there was some cultivar x irrigation interaction; yield gaps between cultivars were minimal under favourable moisture regimes but became very wide under stress conditions (Farah *et al.* 1993b). These findings should be very useful for scheme managers to allocate tolerant wheat cultivars in areas where irrigation water is scarce or difficult to manage.

Studies on the effect of skipping irrigations showed that moisture stress would have very little adverse effects on the economic yield of wheat when the second or the final irrigation was not given. Farbrother (1974) indicated that the interval before the second irrigation could well be extended to 20 days without risk of serious grain loss and that a reasonably long interval encourages the rooting system to develop more efficiently to depths greater than 40 cm. The harmful effects of skipping irrigations about 30 days after sowing is because this period coincides with the time of spikelet development. Likewise, the one around 60 days after sowing coincides with anthesis, which is also a very critical stage for moisture stress.

Studies on rooting depth have shown that under the heavy clay soils of Gezira, the maximum depth of rooting of the normally grown wheat cultivars did not exceed 26 cm (Salih *et al.* 1993a, 1994). However, those cultivars which had deeper rooting depths attained the highest grain yield because of their ability to extract more water from the deeper layers of the soil.

Studies on the application of presowing irrigation indicated positive effects on grain yield mainly as a result of improving land preparation, reduction of weed infestation and improvement of plant stand.

Surveys of the effects of over-irrigation in farmers' fields indicated that some farmers were applying amounts of irrigation water which exceeded the CWR by up to 36 or even 46%. Such practice not only results in the wastage of water, but also decreases crop yield.

Conclusions

- Wheat can tolerate irrigation intervals of up to 21 days during the vegetative growth stages and omissions of the second or final (at grain filling stage) irrigations.
- For attaining maximum yield, moisture stress should be avoided at the time of booting and anthesis.
- Application of presowing irrigation should be encouraged, especially in hard cracked soils, to help in the creation of a fine seedbed, reduction of weed infestation, and improvement of plant stand.
- The tested cultivars showed a differential response to irrigation regimes. This should be useful for the agricultural managers in irrigated schemes to allocate the cultivars more tolerant to moisture stress in locations where irrigation water is scarce or more difficult to manage.
- More awareness of the farmers of the ill-effects of over-irrigation on their wheat crops is needed through on-farm demonstration trials and extension services.
- More work is needed on wheat irrigation according to soil moisture depletion levels before a final recommendation is passed to the farmers.

References

Ahmed, S.H. 1992. Effect of water stress on wheat yield components at Hudeiba. Pages 148–150 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Cereals-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1992, Agricultural Research Corporation, Wad Medani, Sudan.

Ahmed, S.H. 1993a. Effect of water stress at different growth stages on wheat yield and yield components. Pages 173–174 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 29 August–2 September 1993, Agricultural Research Corporation, Wad Medani, Sudan.

Ahmed, S.H. 1993b. Effects of water stress on yield and water use efficiency of three wheat genotypes at Hudeiba (Northern State). Pages 175–178 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 29 August–2 September 1993, Agricultural Research Corporation, Wad Medani, Sudan.

Babiker, E.A. 1992. Effect of pre-watering on crop establishment and yield of wheat at Rahad. Pages 112–114 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Cereals-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1992, Agricultural Research Corporation, Wad Medani, Sudan.

El Nadi, A.H. 1969. Efficiency of water use by irrigated wheat in the Sudan. Journal of Agricultural Science, Cambridge 73: 261–266.

El Rayah, A.H. 1970. Agricultural Research Corporation, Gezira Research Station. Annual Report 1969/70, Wad Medani, Sudan.

Farah, S.M. 1986. Irrigation interval effects at three development stages on the yield of wheat. ARC/ICARDA/OPEC Pilot Project for verification and adoption of improved wheat production technology in farmers fields in the Sudan. First Coordination Meeting, 3–5 August 1986, Agricultural Research Corporation, Wad Medani, Sudan.

Farah, S.M. 1987a. Effect of different irrigation intervals at three growth stages of wheat development on growth, grain yield and water use efficiency. ARC/ICARDA/OPEC Coordination Meeting, 20–22 May 1987, Agricultural Research Corporation, Wad Medani, Sudan.

Farah, S.M. 1987b. Effect of four irrigation regimes on the growth of wheat. ARC/ICARDA/OPEC Coordination Meeting, 20–22 May 1987, Agricultural Research Corporation, Wad Medani, Sudan.

Farah, S.M., Elawad, O.M.A., Mansi, M.G., Ahmed, N.E. and Abdel-Wahab, O.A. 1993a. Effect of over-irrigation on wheat yields. Pages 202–205 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 29 August–2 September 1993, Agricultural Research Corporation, Wad Medani, Sudan.

Farah, S.M., Elawad, O.A. and Mohamed, B.E. 1994a. Effect of over-irrigation on wheat yield. Pages 144–147 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 28 August–1 September 1994, Agricultural Research Corporation, Wad Medani, Sudan.

Farah, S.M., Salih, A.A., Ali, Z.I. and Mohamed, B.E. 1995. Effect of four irrigation regimes on two wheat varieties. Pages 140–146 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 27–30 August 1995, Agricultural Research Corporation, Wad Medani, Sudan.

Farah, S.M., Salih, A.A., Ishag, H.M. and Mohamed, B.E. 1994b. Effect of moisture stress at different growth stages on yield and water use efficiency of wheat. Pages 135–139 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 28 August–1 September 1994, Agricultural Research Corporation, Wad Medani, Sudan.

Farah, S.M., Salih, A.A., Mansi, M.G. and Ali, N.A. 1993b. Effect of three irrigation regimes on the grain yield, yield components and water use of wheat. Pages 182–186 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 29 August–2 September 1993, Agricultural Research Corporation, Wad Medani, Sudan.

Farah, S.M., Salih, A.A., Ahmed, S.H., Mansi, M.G. and Ali, N.A. 1993c. Effect of skipping irrigations at different developmental stages of wheat. Pages 59–61 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat. Annual Report 1992/93, Sudan. ICARDA/NVRP-DOC-031.

Farah, S.M., Salih, A.A. and Mohamed, B.E. 1994c. Effect of water stress on water use efficiency of wheat. Pages 140–143 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 28 August–1 September 1994, Agricultural Research Corporation, Wad Medani, Sudan.

Farbrother, H.G. 1974. Irrigation of wheat. 1115 Research Colloquium, Agricultural Research Corporation, Wad Medani, Sudan.

Farbrother, H.G. and Adam, H.S. 1975. Three techniques for applying the first irrigation. Technical Note No.4, Agricultural Research Corporation, Wad Medani, Sudan.

Ibrahim, H.S. 1995. Response of wheat to differential irrigation in the Nile Province. Paper submitted to the Crop Husbandry Committee Meeting, July 1995, Agricultural Research Corporation, Wad Medani, Sudan.

Ishag, H.M., Hussein, A.S. and El Daw, A.K. 1992. Effect of irrigation regimes on growth and yield of wheat. Pages 134–134 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Cereals-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1992, Agricultural Research Corporation, Wad Medani, Sudan.

Khalifa, M.A. 1968, Agricultural Research Corporation, Gezira Research Station, Annual Report 1967/68. Wad Medani, Sudan.

Omer, M.M. 1992. Wheat establishment study. Pages 153–154 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Cereals-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1992, Agricultural Research Corporation, Wad Medani, Sudan.

Robins, J.S. and Domingo, O.E. 1962. Moisture and nitrogen-effects on irrigated spring wheat. Agronomy Journal 54: 135-138.

Salih, A.A. 1992. Effect of pre-watering on wheat in Gezira. Pages 96–97 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Cereals-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1992, Agricultural Research Corporation, Wad Medani, Sudan.

Salih, A.A., Farah, S.M., Mohamed, B.E. and Ali, Z.I. 1994. Moisture depletion and rooting depth of four wheat varieties. Pages 151–153 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 28 August–1 September 1994, Agricultural Research Corporation, Wad Medani, Sudan.

Salih, A.A., Mohamed, B.A. and Farah, S.M. 1993a. Moisture depletion and root depth of four wheat varieties. Pages 186–189 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 29 August–2 September 1993, Agricultural Research Corporation, Wad Medani, Sudan.

Salih, A.A., Satti, S.M., Farah, S.M. and Mohamed, B.E. 1993b. Effect of pre-watering on wheat yield. Pages 196–199 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat-Sudan. Breadwheat Report, Annual National Coordination Meeting, 29 August–2 September 1993, Agricultural Research Corporation, Wad Medani, Sudan.

Salim, M.H., Todd, O.W. and Schlohuber, A.M. 1965. Root development of wheat, oats and barley under conditions of soil moisture stress. Agronomy Journal 57: 603-607.

Salter, P.J. and Goode, J.E. 1967. Crop responses to water at different stages of growth. Commonwealth Agricultural Bureau.

Satti, M.A.E. 1992. Effect of presowing irrigation on wheat yield at the White Nile. Page 157 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Cereals-Sudan. Breadwheat Report, Annual National Coordination Meeting, 6–10 September 1992, Agricultural Research Corporation, Wad Medani, Sudan.

Slatyer, R.O. 1969. Physiological significance of internal water relations to crop yield. The American Society of Agronomy and Crop Science Society of America. Washington, USA.

Discussion

Q: M.B. Solh

I would like to emphasize the importance of water-use efficiency and avoiding excessive irrigation. Is there an incentive for the farmer to use the crop water requirements and avoid excessive irrigation, considering that water is free?

A: Saeed Farah

I believe that farmers are inclined to apply excessive water to their crops because of their uncertainty of getting the next irrigation in good time and quantity. They generally apply a fixed rate for the crop throughout the season without considering the number of irrigations and the volume of water applied per irrigation. To let farmers economize on their water use, charges should be based on the volume of water that each farmer actually applies to his crop.

Comment: Prof. Osman Ageeb

My two comments are that data on crop factors were missing and that the high response mentioned was due to sowing on wet soil and not to presowing irrigation.

A: Saeed Farah

Because crop factors have been intensively used in previous work and because of the huge volume of work needed, we did not consider them much in this work, especially with the newly released cultivar. It is important to consider crop factors, however, in future programs. Regarding the high response, I think that planting on wet soil could be one factor, but the other advantages, such as reduced weed infestation, better land preparation, and loss of seed and fertilizer down the soil cracks, should not be overlooked.

Q: Osman A.M. Eltom

In Table 4 on the effect of different irrigation intervals at three growth stages on yield, Condor under stress outyielded itself under no stress conditions. How would you account for that?

A: Saeed Farah

For some cultivars, the imposition of stress during the early growth stages encourages root growth and helps the crops become more adapted to stress conditions during the successive growth stages. On the other hand, plentiful water during the early growth stages lets the plants keep most of their roots in the surface of the soil and any proceeding stress can adversely affect the yield of these crops.

Q: Mohamed Safaa Eldin Sharshar

Are there lines or cultivars that are resistant to water deficiency?

A: Saeed Farah

Yes, there is a clear interaction between irrigation regime and cultivar in our studies.

Comment: Hassan M. Fadul

It would be better if you related the sites of the experiments to bench-mark sites where the cracking pattern and its depth, salinity and melanic horizon would greatly affect the quantity of water and the irrigation interval.

A: Saeed Farah

I fully agree with your proposal in accordance with what we have noticed from the few measurements and data obtained from the experimental plots in the tested sites.

Comment: Zakia Ibrahim Ali

Regarding the root growth stage, as we know, the soil in central Sudan is very high in clay content, so it is sticky when wet and hard when dry. Therefore, I suggest that such studies be done in tubes rather than under field conditions.

A: Saeed Farah

As conditions vary in studies done in places other than in the field, for example in the laboratory, I would rather suggest doing the study under field conditions but without destructive assessing techniques, as is being done in some studies in Japan using sensors and video cameras.

Growth, Development and Yield of Wheat under Heat Stress Conditions in Central Sudan

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Abstract

Wheat is expanding into lower latitudes of the Nile Valley region, where maximum air temperatures can reach 38–40°C during the short growing season of about 110 days. Grain yield is low in this highly stressed environment. A review of the studies on the growth, development and yield of wheat under heat stress conditions revealed that the phasic development of wheat was affected by genetic and environmental factors. Phyllochron interval was about 140°C d compared with 102°C d reported for temperate regions. Early maturing cultivars had faster leaf appearance than late maturing cultivars. Final leaf number ranged from 8.8 to 12.2 and was highly correlated with thermal time from sowing to double ridge stage. Ear emergence of late maturing cultivars sown early and early maturing cultivars sown late coincided with the coolest period. The most affected yield components were the number of grains per ear and grain weight. Because of its desirable characteristics, El Neilain cultivar was consistently most stable across environments. Adequate fertilization alleviated, to a certain extent, the effect of heat stress. The results will help in the development of crop models for heat stress environments.

Introduction

Wheat is a crop of a temperate origin, but its cultivation has recently expanded into latitudes lower than 15°N as a winter crop. The minimum temperature for wheat growth is about 3 to 4°C; the optimum about 25°C and the maximum about 30 to 32°C. Central Sudan is very hot for wheat production. The region is characterized by high maximum (40°C) and minimum (24°C) temperatures; the mean air temperature for the coolest month, January, is 24°C. Maximum and minimum air temperatures vary greatly from season to season. The region is also characterized by a short growing season of about 110 days (mid-November to early March) with early and terminal heat stress. Short hot spells occur during the grain filling period. Wheat does not tolerate prolonged exposure to temperatures above 35°C (Christiansen 1978). High temperatures will also increase evapotranspiration, crop water use and irrigation demand (Adams *et al.* 1990). Day length average during the growing season is about 11 hr 20 min.

Crop Establishment

High temperature at sowing is considered detrimental as it adversely affects crop establishment and seedling survival. Mean soil temperature of bare soil at 2.5 cm depth is about 38°C in November. Ali *et al.* (1994) found that the optimum temperature for germination of wheat seeds ranged between 22.1 and 29.8°C and that there were differences in response to temperature between genotypes. The optimum temperature for seed germination for cv. Debeira was 26.9°C. The number of plants at harvest ranged between 180 and 340 depending on sowing dates and cultivars (Ishag and Mohamed 1995).

Phasic Development

Phasic developmental stages of wheat are affected by genetic and environmental factors. In wheat, three development phases can be identified, i.e., from sowing to double ridge stage (GS 1), from double ridge to anthesis (GS 2) and from anthesis to maturity (GS 3). The late maturing cultivar Wadi El Neil required a longer duration and more thermal units to reach the double ridge stage (Table 1). Final leaf number was significantly correlated with thermal units from sowing to double ridge stage ($r = 0.74^{**}$) (Ishag and Mohamed 1995). Reduction in the duration of GS 1 and GS 2 is associated with reduced ear number per plant and number of grains per ear (Warrington *et al.* 1977).

The growing season of wheat in temperate environments is about 317 days (Weir *et al.* 1984) and only 85–110 days in central Sudan depending on the seasonal mean air temperature. The late maturing genotypes are sensitive to vernalization (Ibrahim 1994). If the growing season can be extended by sowing vernalized seeds of late maturing cultivars early in October to prevent the initiation of inflorescence in hot periods, the yield will be higher. This idea warrants further investigation. Midmore *et al.* (1982) concluded that vernalization was unlikely to improve adaptation to tropical conditions because the delay in ear emergence would not increase the number of grains per ear.

Table 1. Mean duration (days), temperature (T°C) and thermal units (TU) between wheat phasic developmental stages as affected by cultivars, 1991/92.

Growth stages†	Cultivar					
	Condor	Debeira	El Neilain	Veery	Wadi El Neil	Mean
GS 1 days	27	27	30	32	34	30
T°C	24.5	24.5	24.3	24.3	24.3	24.4
TU	656	656	739	828	790	734
GS 2 days	36	41	33	37	37	37
T°C	22.4	22.2	22.4	21.9	21.6	22.1
TU	790	902	719	800	788	800
GS 3 days	34	38	38	40	35	37
T°C	22.7	23.6	22.9	24.1	23.8	23.4
TU	763	892	868	814	943	856

† GS 1 = Sowing to double ridge stage; GS 2 = Double ridge stage to anthesis; GS 3 = Anthesis to maturity.

Canopy Development

Maximum tillers are produced at about 1000°C d and their formation ceases in the stage between double ridge and terminal spikelet initiation (Ishag *et al.* 1993). Significant differences between cultivars were detected; Wadi El Neil produced more tillers because the late maturing cultivars require longer time to reach double ridge stage, whereas Seri 82 produced the fewest tillers. Ishag and Taha (1974) reported a survival of 20% for T1 (primary tillers) and only 12% for T2 (secondary tillers). Rawson (1986), working under phytotron conditions at 30/25°C, found that wheat plants produced between 6.1 and 11.9 reproductive tillers per plant compared with only 1.5 to 2.0 under normal conditions in the Sudan. Poor tillering might be due to nutritional stress and shading. Peak tiller production was reached before ear emergence (Ishag and Taha 1974; Mahmoud and Osman 1981). Nitrogen fertilization increases tillering. However, phosphorus application alone decreased tiller production (Ishag, ongoing study).

Growth of Leaves

The total number of leaves varied from 8.4 to 12.2. Late maturing cultivars, e.g., El Neilain, Seri 82 and Wadi El Neil, produced more leaves than early cultivars, e.g., Ciano 79 and Condor (Table 2). The rate of leaf appearance is influenced by temperature. The thermal time required for the appearance of successive leaves of wheat—phyllochron interval (PI)—under central Sudan conditions was about 140°C (Ishag 1994) compared with 80 to 102°C under temperate conditions (Bauer *et al.* 1984; Baker *et al.* 1986). Seri 82 and Ciano 79 had lower PI of 114 and 109°C, respectively, compared with 141 and 136°C for the same cultivars grown in central Sudan. High temperatures (35–40°C), which may last for a week, might be the reason.

Table 2. Phyllochron interval and final leaf number on the main stem of nine spring wheat cultivars sown on three dates in Wad Medani, 1993/94.

Cultivar	Phyllochron interval (°C d/leaf)			Leaf number		
	Oct.	Nov.	Dec.	Oct.	Nov.	Dec.
Ciano 79	134	144	129	9.1	9.1	9.1
Condor	125	146	135	9.6	9.1	8.9
Debeira	148	163	141	9.0	8.4	8.8
EL Neilain	146	146	134	10.3	9.7	9.6
Glennson	141	139	129	10.3	10.5	10.1
Nesser	130	141	132	9.6	9.5	8.5
Seri 82	150	139	133	11.6	11.1	10.4
Trigo 3	143	155	143	8.8	9.0	8.3
Wadi El Neil	136	133	118	12.2	11.3	11.3
Mean	139	145	133	10.1	9.7	9.4
SE (±)	4.6	3.1	3.8	0.5	0.3	0.4

After about 2.9 leaves, tillers started to appear (Ishag 1994) and this agrees with the findings of Baker *et al.* (1986). Maximum leaf area index of wheat in the tropical conditions of central Sudan is small, about 3 (Khalifa *et al.* 1977). Leaf area of all cultivars sown early exceeded those sown late. December sowing produced smaller leaf area. Cultivar Wadi El Neil had twice the leaf area of cultivar Ciano 79 (Ishag 1994). November sowing and application of nitrogen significantly increased leaf area index and leaf area duration (Khalifa *et al.* 1977).

Crop Nutrition

Soils of the central clay plain are known to be deficient in nutrients. Application of phosphorus significantly increased yield (Ageeb 1986). The wheat crop absorbs a large amount of potassium and, therefore, removal of potassium from soils in Gezira has become high as the rotations have become more intensified. A high uptake of potassium of about 110 kg/ha was reported by Ishag and Dawelbeit (1993). Rawson (1988) reported that the low yield in tropical environments is not only related to high temperatures but also to inadequate irrigation and fertilization regimes which play a vital role in the alleviation of heat stress.

Application of phosphorus to wheat in calcareous soils might lead to zinc deficiency, particularly where the soils have a marginal content as in the central clay plain of the Sudan (Agbim 1981). Ishag (1992b) indicated that the application of foliar fertilizers containing micronutrients increased grain yield in the cool season of 1991 by increasing number of ear-bearing tillers, number of grains per ear and grain weight.

Grain Filling

Duration of grain filling was shorter in tropical environments. The lag period of El Neilain cultivar was shorter. Its grain filling period was longer (34 days) compared with 19, 22 and 28 for Condor, Debeira and Veery, respectively (Ishag 1992a). Table 3 shows the mean duration of grain filling phase, rate of grain filling and kernel weight of wheat grown at various mean air temperatures. Higher temperatures during the grain filling phase resulted in lower rates of grain filling and 31% reduction in kernel weight. Ishag and Mohamed (1995) reported that in the prevailing temperature range in this phase, there was a decrease of 3 mg in kernel weight with an increase of 1°C in the mean temperature. Midmore *et al.* (1982) postulated that slower development under hot environmental conditions should lead to greater yield potential than faster development.

Table 3. Duration, rate of grain filling (RGF) and kernel weight (K wt.) of wheat grown at various temperatures.

Mean temp. (°C)	Duration (days)	RGF (mg/k/day)	K wt. (mg)
22.0	39.4	0.96	38.0
22.7	39.8	0.88	35.0
25.3	31.4	0.84	26.3

Yield

Ishag and Ageeb (1991) suggested planting relatively late maturing cultivars early in the season and early maturing cultivars late, so that ear emergence coincides with the coolest period. Sowing in mid-November always resulted in higher yields. However, in some seasons, earlier or later sowings gave better yields depending on the prevailing temperature. Cultivars El Neilain and Nesser both gave best yields and always ranked high.

Yield Components

Table 4 shows the effect of terminal heat stress on some yield components. The number of spikelets per ear ranged from 18 to 23 and the cultivar Condor had fewer spikelets per ear than the other cultivars. High temperatures reduced the number of spikelets per ear only by about 6%. The yield components most affected were ear grain weight and weight of grain. El Neilain and Veery cultivars had more grains per ear and partitioned more of their dry weight to grains.

Stability

Ishag and Mohamed (1995) used different stability indices and found that El Neilain cultivar was consistently more stable across environments. El Neilain had the largest number of grains per ear, heaviest grains and large awns. These traits are desirable characters for adaptation of wheat to hot environments (Wardlaw *et al.* 1989). The optimum temperature for photosynthesis is much higher for awns than for leaves (Blum 1986). Cultivar Nesser also ranked high.

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Table 4. The effect of sowing dates on some yield components of wheat cultivars and their reduction due to high temperature at Gezira Research Station, 1991/92.

Cultivar	Parameter	Nov. 9	Nov. 23	Dec. 14	% reduction
Condor	Spikelet number	21	18	20	5
	Ear grain weight (mg)	1146	923	800	30
	Grain number/ear	35.2	32.9	25.6	27
	Grain weight (mg)	36.1	31.7	24.8	31
	Average no. of grains/sp.	1.68	1.83	1.28	24
Debeira	Spikelet number	22	21	20	9
	Ear grain weight (mg)	1302	1277	694	47
	Grain number/ear	33.8	29.9	25.3	25
	Grain weight (mg)	36.4	34.7	23.9	34
	Average no. of grains/sp.	1.54	1.42	1.26	18
El Neilain	Spikelet number	21	20	20	5
	Ear grain weight (mg)	1635	1185	1011	38
	Grain number/ear	45.6	34.8	24.2	47
	Grain weight (mg)	40.2	39.5	29.2	27
	Average no. of grains/sp.	2.17	1.74	1.21	96
Veery	Spikelet number	20	23	20	0
	Ear grain weight (mg)	1445	1236	920	36
	Grain number/ear	39.5	36	31.6	20
	Grain weight (mg)	37.7	35.4	25.5	33
	Average no. of grains/sp.	1.98	1.56	1.57	21
Wadi El Neil	Spikelet number	21	22	19	10
	Ear grain weight (mg)	1481	1036	794	46
	Grain number/ear	39	29.4	28.2	28
	Grain weight (mg)	39.4	33.8	28.6	27
	Average no. of grains/sp.	1.86	1.34	1.48	38

References

Adams, R.M., Rosenzweig, C., Peart, R.M., Ritchie, J.T., McCarl, B.A., Glyer, J.D., Bruce Curry, R., Jones, J.W., Boote, K.J. and Hastwell Allen, L. 1990. Global climate change and US agriculture. Nature 345: 219–224.

Agbim, N.N. 1981. Interaction of phosphorus, magnesium and zinc affecting the iron content of maize. Journal of Agricultural Science, Cambridge 97: 79–82.

Ageeb, O.A.A. 1986. Researcher-managed full factorial trial. Land preparation, irrigation, sowing date and phosphorus. Paper presented at the First National Wheat Coordination Meeting, 3–5 August 1986, Wad Medani, Sudan.

Ali, Z.I., Mahalakshmi, V., Singh, M., Ortiz Ferrara, G. and Peacock, J.M. 1994. Effect of temperature on germination in wheat (*Triticum aestivum*): determination of cardinal temperature. Annals of Applied Biology 125: 367–375.

Baker, J.T., Pinter, P.J., Reginato, R. and Kanemasu, E.T. 1986. Effects of temperature on leaf emergence in spring and winter wheat cultivars. Agronomy Journal 78: 605–613.

Bauer, A., Frank, A.B. and Black, A.L. 1984. Estimation of spring wheat leaf growth rates at anthesis from air temperature. Agronomy Journal 76: 829–835.

Blum, A. 1986. The effect of heat stress on leaf and ear photosynthesis. Journal of Experimental Botany 37: 111–118.

Christiansen, M.N. 1978. The physiology of plant tolerance to temperature extremes. Pages 173–191 *in* Crop tolerance to suboptimal land conditions (G.A. June, ed.). American Society of Agronomy, Crop Science Society of America and Soil Science Society of America, Madison, Wisconsin.

Ibrahim, A.M.H. 1994. Association of morphophysiological traits with grain yield under heat-stressed conditions in bread wheat (*Triticum aestivum*). M.Sc. Thesis, the American University of Beirut, Lebanon.

Ishag, H.M., 1992a. The effects of time of sowing on growth and yield of wheat cultivars in irrigated Gezira. Pages 121–127 *in* Proceedings of the Annual National Wheat Coordination Meeting, 6–10 September 1992, Wad Medani, Sudan.

Ishag, H.M. 1992b. Effect of foliar micro-nutrient fertilizers on the yield of wheat in irrigated Gezira. Pages 128–132 *in* Proceedings of the Annual National Wheat Coordination Meeting, 6–10 September 1992, Wad Medani, Sudan.

Ishag, H.M. 1994. Physiological basis of variation in yield of wheat (*T. aestivum* L. em Thell) in heat stressed environment of the Nile Valley. Paper presented at the Regional Coordination Meeting, 1–4 October 1994, Cairo, Egypt.

Ishag, H.M. and Ageeb, O.A.A. 1991. The physiology of grain yield in wheat in an irrigated tropical environment. Experimental Agriculture 27: 71–77.

Ishag, H.M., Ageeb, O.A.A. and Elahmadi, A.B. 1993. Phenology, growth and yield of wheat genotypes in the Gezira environment. Pages 130–139 *in* Proceedings of the Annual National Wheat Coordination Meeting, 29 August–2 September 1993, Wad Medani, Sudan.

Ishag, H.M. and Dawelbeit, S.E. 1993. Alleviation of heat stress in wheat. Pages 148–153 *in* Proceedings of the Annual National Wheat Coordination Meeting, 29 August–2 September 1993, Wad Medani, Sudan.

Ishag, H.M. and Mohamed, B.A. 1995. Phasic development of spring wheat and stability of yield and its components in hot environments. Paper submitted to Field Crops Research.

Ishag, H.M. and Taha, M.B. 1974. Production and survival of tillers of wheat and their contribution to yield. Journal of Agricultural Science, Cambridge 83: 117–140.

Khalifa, M. A., Akasha, M.H. and Said, M.B. 1977. Growth and N-uptake as affected by sowing date and nitrogen in irrigated semi-arid conditions. Journal of Agricultural Science, Cambridge 89: 35–42.
Mahmoud, Z.M. and Osman, A. M. 1981. Tillering of wheat as influenced by nitrogen and seed rate in the Sudan. Journal of Agricultural Science, Cambridge 97: 619– 627.
Midmore, D.J., Cartwright, P.M. and Fischer, R.A. 1982. Wheat in tropical environment. I. Phasic development and spike size. Field Crops Research 5: 185–200.
Rawson, H.M. 1986. High temperature tolerant wheat: a description, variation and a search of some limitations to productivity. Field Crops Research 14: 197–212.
Rawson, H.M. 1988. Effects of high temperatures on the development and yield of wheat and practices to reduce deleterious effects. Pages 44–62 *in* Proceedings of the International Symposium on Wheat Production Constraints in Tropical Environments (A.R. Klatt, ed.). Mexico, D.F.: UNDP/CIMMYT.
Wardlaw, I.F., Dawson, I.A. and Munibi, P. 1989. The tolerance of wheat to high temperature during reproductive growth. II. Grain development. Australian Journal of Agricultural Research 40: 15–24.
Warrington, J.J., Dunstone, R.L. and Green, L.M. 1977. Temperature effects at three development stages on the yield of the wheat ear. Australian Journal of Agricultural Research 28: 11–27.
Weir, R.H., Bragg, P.L., Porter, J.R. and Rayner, J.H. 1984. A winter wheat crop model without weather or nutrition limitations. Journal of Agricultural Science, Cambridge 102: 371–382.

Discussion

Q: Mostafa Bedier

Why did the study assume that the effect of heat on crop yield followed a linear relationship while the scatter of the raw data indicated that it was curvilinear.

A: H.M. Ishag

In fact, the results did not represent only the effect of biomass on grain yield. The data presented were from one season. Wheat yield in Shandaweel area was exceptionally low because aphids were not controlled. Now we have accumulated more data and it might be true that the relationship between biomass and grain yield is curvilinear as there is an indication that in Upper Egypt the curve will flatten, i.e., form a plateau.

Comment/Q: Prof. Hussein S. Adam

First, I think that the title should have been "Agroclimatology, crop physiology and agronomy," as so many papers stressed climatic effects. And second, was the soil temperature of 38°C at 2.5 cm measured in the meteorological station or under the crop? Temperature under the irrigated crop is generally lower.

A: H.M. Ishag

I agree that soil temperature is defined as that measured under the crop and, therefore, it would be better to measure it where it should be. However, we need equipment to measure the microclimate within the crop and if the ARC can acquire such equipment, this would help us go for microclimate monitoring. We are cooperating with the University of Gezira and have started some microclimate monitoring. However, this was discontinued because the U of G staff were too busy. Extensive data on soil temperature on an hourly basis at different depths were obtained, but unfortunately not analyzed yet.

Chapter 4
Crop Protection

Insect Pest Problems of Wheat

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Abstract

Aphids are the only economic pest on wheat that causes an average grain loss as high as 25–30%. Termites are the second important pest but their effect is localized to new areas of wheat production. Chemical control of aphids received most attention and the screening studies culminated in defining some effective chemicals, the ones in current use being Ekatin, Pirimor, Metaystox, Reldan, Dursban and Gaucho. Granular soil-applied insecticides, namely, Confidor, Furadan and Brifur, gave outstanding results and these, with Gaucho used as seed-dressing, are anticipated to be very effective in solving the aphid problem in wheat. Biocontrol was investigated and coccinellids, syrphids and chrysopids were found to be of some effect. Different levels of coccinellids were monitored in the field and positive results were recorded. With the possible new rearing facilities of these predators, it is expected that releases in farmers' fields will be made to establish the predators at required levels. To define resistant/tolerant lines against aphids, few thousands of breeding lines were screened and a few lines from crosses between Amigo, Largo and Bushland and some Egyptian cultivars were found to be highly resistant. Nine of these will be evaluated for agronomic characters and may be potentially released for commercial use. The ones giving mediocre traits will be backcrossed with the commercial cultivars. Termite control was investigated in Rahad area, integrating the interval of irrigation, seed-dressing with insecticide/fungicide and applying fertilizers. Results showed that irrigating at a 7–10 day interval, seed-dressing with Fernasan D at 3 g/kg seed, and applying 1.5–2.0 units of nitrogen/ha gave the best results of reducing termite damage and increasing grain yield.

Introduction

Wheat grown in the Sudan is attacked annually by a number of insect pests. The severity of the attacks is governed mainly by the prevailing climatic conditions, most importantly temperature. The most harmful pest is the aphid, *Schizaphis graminum* Rond, which together with the less important aphid, *Rhopalosiphum maidis* Fitch, causes about 25–30% grain losses. This necessitates annual control of this pest with insecticides applied by aircraft. Normally, 1–2 sprays effectively control the pest at a cost of about 5% of the overall cost of production. All efforts are now directed towards reducing reliance on chemical control and exploring other complementary measures to improve the standard of the on-going control means or at least to maintain it. Areas relevant in this respect are biological control, host-resistance, and the economic use of insecticides.

Termites are of some importance in areas brought recently under wheat production, like the Rahad Scheme. Termites are localized in effect and their attacks are encouraged by long drought conditions. Their control has received some research attention based on integrated control approaches. This paper reviews the progress of investigations in the different areas of the insect pests of wheat in the Sudan, summarizes major achievements and suggests future lines of studies.

Chemical Control

Chemical control normally gives quick and positive results. Accordingly, it received most attention as cultivation of wheat was expanding in central Sudan. Insecticides of organophosphorus, chlorinated hydrocarbons and carbamate groups, both individually or as mixtures, were tested against aphids for 2–3 years in Gezira Research Farm (GRF) and on farmers' fields before their release for commercial use. A number of insecticides have been released and are in use. Chemicals in later tests included pyrethroids as a new group of insecticides together with the single insecticides of already released mixtures. These investigations culminated in the release of a number of chemicals which have been in use for the last few years. Some of these insecticides and their dosage rates are:

- Thiometon (Ekatin) 25% E.C. at 0.60 l/ha.
- Demeton-methyl (MetasystoxR) 50% E.C. at 0.30 l/ha.
- Pirimicarb (Pirimor) 10% DP at 0.24 kg/ha.
- Chlorpyrophos-methyl (Reldan) 50% E.C. at 0.30 l/ha.
- Chlropyrophos (Dursban) 50% E.C. at 0.30 l/ha.

With the need for using soft and selective insecticides to preserve the natural enemies being strongly felt, different preparations of *neem* extracts have been screened. Realizing the deleterious effect of foliar-applied insecticides on natural enemies of insect pests, chemicals formulated as seed-dressing and soil-applied granules were given more attention in the last few years.

Although favorable, results of the *neem* extracts were inferior compared with the standard insecticide treatment (Table 1). It is expected that higher doses of different extracts may give better results. However, *neem* extracts were less deleterious to the natural enemies and that is a very desirable attribute. Seed-dressing and granular soil-applied insecticides are safer to the users and environment, more specific to the target pest and less costly. Recently, the insecticide Imadacloprid, with a different mode of action, was used as a seed-dressing powder (Gaucho) or as a granulated soil-applied formulation (Confidor). It has been intensively evaluated in comparison to Furadan and Brifur. Preliminary studies on Imadacloprid revealed that the insecticide was of superb performance against aphids, providing complete control for a period well over 90 days in addition to improving plant stand which resulted in a significant increase in grain yield. Initially, the chemical was tested for seed dressing at 2.0, 1.5 and 1.0 g/kg seed for a number of years and was first released for commercial use at a rate of 1.0 g/kg seed (Table 2). Lower rates of 0.5 and 0.25 g/kg were then tested to evaluate their effect on the pest and on plant growth and grain yield. Its performance has been monitored in the farmers' fields in the 1994/95 season and recommendation is to be presented to the Pests and Diseases Committee for possible release at low rates (Table 3).

Granular formulations have been subjected to similar studies and their performance has also been monitored in larger areas before release. Confidor (Imadacloprid in granular form) gave outstanding performance in very small dosages compared with Carbofuran (Table 4).

The release of these chemicals and their use commercially is anticipated to mark a breakthrough in the protection of wheat against aphids. These formulations are compatible with integrated pest management programs and will help implement the future policy in which farmers take the responsibility of crop protection.

Biological Control

In nature, aphids are prone to attack by many natural enemies and are easy to suppress due to their non-flying habit, their sluggish movement and their sedentary way of feeding. In the Sudan, predators are the effective group while parasites are virtually absent. The predators prevalent in the Sudan are the coccinellids, chrysopids, syrphids, and Cydonia, the relative abundance of which varies from one year to another.

Table 1. Effect of insecticides on number of aphids/100 plants (data transformed to square root of x + 1) and grain yield of wheat, 1991/92.

Treatment	Number of aphids/100 plants†					Yield† (t/ha)
	28 Jan. 92	31 Jan. 92	11 Feb. 92	22 Feb. 92	Mean	
Hexane extract of *neem*	28.2	17.2 ab	15.8 bc	16.9 cd	19.5	1.809 a
Pure oil extract of *neem*	27.7	5.0 a	17.1 bcd	9.2 ab	14.8	1.709 ab
Methanol extract of *neem*	31.3	15.4 ab	17.8 cd	8.0 ab	18.1	1.733 a
Decis	32.6	34.4 b	30.8 d	12.0 ab	27.5	1.773 a
Decis/Dimethoate	24.6	3.2 a	6.7 ab	5.0 ab	9.9	1.768 a
Sumithion 1.0 l/ha	25.5	3.2 a	3.2 a	3.2 ab	8.8	1.821 a
Sumithion 0.5 l/ha	33.8	3.2 a	3.2 a	9.2 ab	12.4	1.745 a
Danitol-S 0.5 l/ha	23.5	3.2 a	9.4 ab	12.1 ab	12.1	1.666 ab
Danitol-S 0.4 l/ha	31.8	5.6 a	8.3 ab	9.0 ab	13.7	1.697 ab
Brifur	29.2	13.2 a	5.1 a	4.3 ab	13.0	1.714 ab
Pirimor DG 0.2 kg/ha	39.6	22.7 ab	10.7 ab	4.8 ab	19.5	1.852 a
Pirimor DP 0.2 kg/ha	27.8	3.2 a	11.2 ab	9.3 ab	12.9	1.797 a
Ethion 40 E.C.	45.8	25.6 b	17.9 cd	11.0 ab	25.1	1.630 a
Furadan 5 G	35.4	27.2 b	9.6 ab	6.7 ab	19.7	1.804 a
Marshal 25	42.4	11.7 a	18.2 cd	13.5 bcd	21.5	1.566 abc
Carbicorn	27.5	3.2 a	13.0 ab	12.4 ab	14.0	1.737 a
Curacron 0.3 l/ha	26.5	10.7 a	9.0 ab	10.0 ab	14.1	1.573 abc
Curacron 0.6 l/ha	20.2	5.8 a	21.4 cd	7.1 ab	13.6	1.333 c
Ekatin 0.6 l/ha	28.1	3.2 a	7.6 ab	6.0 ab	11.2	1.092 c
Control	34.7	26.7 b	19.2 cd	23.2 d	26.0	1.452 bc
SE (±)	6.11	6.23	3.61	3.18		0.119

† Means within a column followed by the same letter(s) are not significantly different at the 5% level.

Table 2. Percentage infested plants (data transformed to square root of x + 0.5) at different dates, and grain yield of wheat in large-scale monitoring of insecticides, 1992/93.

Treatment	% infested plants†						Yield† (t/ha)
	24 Jan.	1 Feb.	8 Feb.	15 Feb.	6 Mar.	Mean	
Danitol-S 1.0 l/ha	6.2	15.9 b	23.9 bc	54.5 b	0.5	14.9	1.587 b
Danitol-S 0.5 l/ha	4.1	20.6 b	31.7 bc	57.4 b	1.6	16.8	1.540 b
Danitol-S 0.4 l/ha	5.4	14.6 b	34.5 bc	58.4 b	1.2	17.0	1.890 b
Sumithion 1.0 l/ha	5.1	16.3 b	17.8 b	61.4 b	0.5	14.7	1.937 ab
Sumithion 0.5 l/ha	5.9	16.4 b	25.5 bc	39.3 ab	1.8	13.7	1.654 b
Pirimor DG 0.2 kg/ha	7.8	16.2 b	29.8 bc	66.4 b	1.8	18.0	1.640 b
Pirimor DP 0.2 kg/ha	5.5	20.9 b	46.5 c	51.1 b	0.5	18.3	1.913 ab
Ekatin 0.6 l/ha	4.4	11.0 b	17.9 b	41.7 ab	2.2	11.4	2.125 ab
Gaucho 1.0 g/kg	0	0 a	0 a	0 a	0	0	2.009 ab
Gaucho 1.5 g/kg							2.292 ab
Gaucho 2.0 g/kg							2.594 a

† Means within a column followed by the same letter(s) are not significantly different at the 5% level.

Table 3. Percentage infested plants (data transformed to angles) and grain yield of wheat as a result of monitoring of insecticides in famers' fields against aphids, 1994/95.

Treatment	% infested plants†						Yield† (t/ha)
	6 Feb.	11 Feb.	18 Feb.	25 Feb.	5 Mar.	12 Mar.	
Gaucho 0.25 g/kg	9.2 a	6.8 a	14.4 b	21.1 b	12.3 a	10.0 a	1.68 ab
Gaucho 0.50 g/kg	8.2 a	9.3 a	12.5 ab	9.6 a	10.7 a	7.3 a	2.02 a
Gaucho 1.00 g/kg	7.4 a	6.2 a	12.1 ab	9.3 a	7.9 a	6.3 a	1.80 ab
Reldan40 0.4 l/ha	30.9 b	5.7 a	6.2 a	7.3 a	10.4 a	7.0 a	1.55 ab
Reldan50 0.3 l/ha	34.2 b	5.9 a	8.0 ab	7.3 a	11.1 a	7.2 a	1.30 b
Ekatin 0.6 l/ha	30.7 b	7.5 a	5.7 a	7.0 a	7.1 a	6.9 a	1.49 b
SE (±)	2.3	1.13	2.27	1.65	2.64	1.36	0.18

† Means within a column followed by the same letter(s) are not significantly different at the 5% level.

Table 4. Effect of seed-dressing and granular insecticides on aphid infestation and grain yield of wheat, 1994/95.

Treatment	% infested plants†				Yield† (t/ha)
	30 Jan.	12 Feb.	22 Feb.	27 Feb.	
Gaucho 1.0 g/kg	5.7 a	5.7 a	5.7 a	5.7 a	2.236 a
Confidor 11.9 kg/ha	16.7 b	16.0 d	5.7 a	5.7 a	1.919 b
Confidor 6.0 kg/ha	21.4 b	7.3 ab	8.3 ab	5.7 a	1.363 d
Furadan 35.7 kg/ha	21.1 b	9.1 b	15.2 c	8.6 ab	1.645 c
Furadan 19.0 kg/ha	20.6 b	5.7 a	18.7 c	6.4 a	1.563 c
Brifur 35.7 kg/ha	19.3 b	7.5 ab	13.9 bc	7.7 ab	1.963 b
Brifur 19.0 kg/ha	24.2 b	11.4 c	14.1 bc	10.1 b	1.638 c
Ekatin 0.6 l/ha	19.0 b	7.0 ab	13.4 bc	21.2 c	1.351 d
SE (±)	2.36	0.73	2.07	1.2	0.027

† Data transformed to angles; means within a column followed by the same letter(s) are not significantly different at the 5% level.

Studies were undertaken to identify the different species of the predators, quantify their impact on the pest and assess their natural build-up throughout the season compared with that of the aphid. Also, laboratory work was carried out to determine the feeding capacities of the main enemies, and *Coccinella* was identified as suitable for use in biological control.

Studies revealed that by the time the pest infestation reached the economic threshold level in mid-January, the predator was only encountered in very small numbers to exert any check on the pest progress (Table 5). This necessitated an early augmentation of predator population by releasing *Coccinella* in the field. To execute this, field experiments were conducted where the adult predators in variable levels were placed in the plots. Four levels (50, 100, 150, and 200 adults/plot of about 10 x 15 m) were monitored in comparison with a standard sprayed and an unsprayed control. The generated results were promising but experiments were stopped due to the unavailability of the predator in the required numbers. The new facilities of the IPM project will support further work on effective biological control.

Table 5. Population dynamics of the wheat aphid and its natural enemies, 1993/94.

Date of count	% infested plants	Aphids/ plant	Number of predators/m²†			
			Chrysopa	*Coccinella*	Syrphids	*Cydonia*
11 Jan. 94	29.3	3.7	4.8	1.1	0	0.3
18 Jan. 94	42.6	3.8	6.1	1.1	0.3	1.1
28 Jan. 94	38.9	4.3	6.1	1.4	0.6	1.3
9 Feb. 94	30.2	2.3	5.2	1.6	0.1	0.3
18 Feb. 94	22.7	2.3	3.1	3.9	0.01	0.5
Mean	32.7	3.3	5.2	1.8	0.2	0.8

† All developmental stages.

Host Resistance

Host resistance is an effective source of protection of crops from pests with a number of benefits. In cooperation with breeders from ICARDA, CIMMYT, Egypt and the Sudan, a few thousands of breeding lines were tested in the different parts of the Sudan to identify lines resistant/tolerant to aphid attack. Early results were not encouraging as lines found resistant one year would fail to maintain this characteristic the following year, and also lines showing resistance in one area would be susceptible in another the same year.

However, some lines derived from crossing *Aegilops* sp. with Bush/Amigo, consistently showed a good level of resistance. Further back-crossing will be carried out to transfer the resistance character into the commercial cultivars. Another aspect of host resistance is the evasion by the crop of the peak infestation through early maturation of the plant. This was used as a criterion to identify some resistant lines. Some lines combined both resistance and early maturity and future work will be directed towards this combined effective approach. A few lines were selected as they combine both resistance and earliness. All crosses containing Bush, Largo and Amigo showed some level of resistance as indicated by the selected entries (Appendix 1).

The results of screening the breeding lines against aphids revealed that there was inconsistency in the results, perhaps due to the occurrence of different biotypes in different localities or perhaps within the same locality in different seasons. To verify this, green-bug differentials were obtained from Stillwater Research Station, Oklahoma, USA and tested in the Gezira environment. Results confirmed the presence of A and H biotypes in Gezira, but further work stopped because of insufficient seeds of these differentials. It is important to resume this activity in order to identify the distribution of aphid biotypes within the Sudan.

The Economic Threshold Level for Spraying

Chemical application is practiced only when the pest infestation reaches a level which can cause economic yield reduction—known as the economic threshold level (ETL). This is currently 35% infested plants and has been long established based on studies undertaken in Gezira. Since there are possible differences in the distribution of aphids within the crop in the different areas of wheat production, studies were carried out in New Halfa, Rahad and Gezira to reappraise and confirm the validity of this ETL. All results confirmed that 35% is the appropriate ETL for spraying wheat in the Sudan (Table 6).

Table 6. Determination of the economic threshold level of aphid control in wheat considering percentage infestation, dates, number of insecticide sprays and grain yield, 1991/92.

% infested plants	Number of sprays	Date of spray	Yield (t/ha)
15	4	8, 19 and 26 Jan., 8 Feb.	2.404
25	3	8 and 19 Jan., 8 Feb.	2.475
35	2	8 and 19 Jan.	2.642
45	2	8 and 26 Jan.	2.190
55	2	8 and 26 Jan.	2.190
Control	0		1.952
SE (±)			0.090

Some workers expressed the need to integrate the intensity of pest population with the percentage infestation rather than relying solely on the percentage infestation as the population intensity could be affected by temperature and other climatic conditions. The new parameter, known as the degree of infestation was, therefore, developed and an experiment was designed to monitor the effect of spraying insecticides at a number of degrees of infestation levels (50, 100, 150, and 200) in contrast to spraying at the current ETL. The results showed some differences in aphid numbers and wheat yield, but further work is still needed to finalize the results.

The Termite Problem in the Sudan

Termites can sometimes cause serious damage in Rahad Scheme particularly in the seasons with accentuated drought. Investigations were undertaken to assess the damage and develop control. Cultural practices, including the frequency of irrigation, seed-dressing with the standard insecticide mixture, Fernasan D, and nitrogen application, were evaluated for a number of years at Rahad Research Farm. The recommendations were verified in farmers' fields last season and the results confirmed that irrigation at short intervals of 7–10 days, dressing the seeds with Fernasan D at 3 g/kg, and fertilizer applied at 1.5–2.0 units of N/ha (64.5–86 kg N/ha) considerably reduced termite infestation and boosted grain yield (Table 7).

Table 7. Farm testing of effect of cultural practices on incidence of termites.

Treatment†	% mean infestation/m^2‡
Seed dressing + 1P + 0N	4.1
No seed dressing + 1P +1N	3.8
Seed dressing + 1P + 1.5 N	3.4
Seed dressing + 1P + 1N	1.7
Seed dressing + 1P + 1.5 N	1.5
Seed dressing + 1P + 2N	1.2

† 1N = 43 kg N/ha; 1P = 43 kg P_2O_5/ha.
‡ Mean of four counts; data transformed to arc sine.

Appendix 1

Resistant Breeding Lines

1993/94 Selections

1. W/89D09/110
2. G.160/Largo/74/2/22/3/398/2
3. G.162 x Bush/3/73/2/18/1/18/1/370/1
4. G.160 x Largo/74/1/19/2/379/1
5. G.160 x Largo/72/4/26/5/421/1
6. G.160 x Largo/72/4/26/5/445/1

1994/95 Selections

1. G.162 x Bush/1/3/17/3/369/3/648/1
2. G.162 x Bush/1/3/17/3/369/3/648/2
3. G.162.x Bush/1 3/17/3/369/3/649/6
4. G.162 x Bush/1/3/17/3/369/3/649/7
5. G.162 x Bush/1/3/73/4/18/1/370/2/651/2
6. G.160 x Largo/19/1/376/3/667/4
7. G160 x Largo/20/6/387/3/695/2
8. G.160 x Largo/20/6/387/4/696/2
9. G.164 x Bush 1/77/4/32/2/452/4/848/1
10. G.164 x Bush 1/77/4/32/2/452/4/848/2
11. G.164 x Bush 1/3/32/3/454/3/853/1
12. G.164 x Bush 1/3/32/3/454/3/853/2
13. G.164 x Bush 1/3/32/3/454/3/853/3
14. G.164 x Bush 1/3/32/3/454/4/854/1
15. G.164 x Bush 1/3/33/1/456/1/858/1
16. G.164 x Bush 1/3/33/1/456/5/860/1
17. G.164 x Bush 1/3/33/2/459/3/868/1
18. G.164 x Bush 1/3/33/2/459/3/868/2
19. G.164 x Bush 1/3/33/2/459/3/868/4
20. G.164 x Bush 1/3/33/2/489/3/950/1
21. G.164 x Bush 1/3/40/7/491/3/955/3
22. G.164 x Bush 1/3/40/7/491/6/956/1

Rahad Selections

1. G.162 x Bush 1/3/18/3/375/6
2. G.160 x Largo/74/2/25/3/417/4
3. G.160 x Largo/30/1/441/4
4. G.162 x Amigo/44/1/5/2/4
5. G.162 x Amigo/44/2/5/4/6
6. G.164 x Largo/55/1/562/6
7. G.165 x Ger.2/29/2/3/1/306/6
8. G.165 x Ger.2/29/2/3/1/309/4
9. G.160 x Largo/74/2/23/6/405/3
10. S.69 x Kud/41/5/496/6
11. G.163 x Bush 1/1/48/1/535/5.

Discussion

Comment: Prof. Asim

The 100% effect of Gaucho on aphids is not very good from an IPM point of view. This 100% mortality could create a biotic vacuum due to the eradication of the natural enemies which could cause a serious resurgence of the target pest. This effect could only be evident in very large-scale tests.

A: N. Sharaf Eldin

The control was not practically 100% because only an extremely small portion of the plants were taken and there were some aphids to feed the natural enemies. Moreover, the natural enemies could find other aphid species on other crops and, therefore, there is no possibility of aphid extinction (eradication).

Q: Mostafa Bedier

How has the cost of protection against aphids on wheat been estimated by 5% from the overall cost of production.

A: N. Sharaf Eldin

All input items are supplied by the Gezira Scheme administration. As such, their costs are recorded and debited to farmers' accounts. The cost of protection constituted the price of chemical and application. Therefore, the cost of protection divided by the cost of production and multiplied by 100% gives the percentage of protection cost.

Comment: Prof. Elamin M. Elamin

My first comment is that more elaboration is needed on the degree of infestation as a yardstick for aphid control in wheat. My second comment is that more team-work in breeding for aphid resistance should be adopted by the ARC scientists.

A: N. Sharaf Eldin

Infestation is categorized into three groups depending on the number of aphids. The infestation intensity is calculated from the number of categories divided by the number of plants and then this is multiplied by the percent infestation.

Comment: Dr. Musa Adullah

The problem of aphids on wheat could be tackled by ecological manipulation rather than by chemicals. Natural enemies moving from cotton to wheat could check aphids. Work should be on monitoring the population intensity per plant.

A: N. Sharaf Eldin

Selective chemicals are to be used judiciously, and when a reasonable predator population is secured, ecological approaches would be addressed.

Q: M.B. Solh

The data collected on faba bean yield and leaf miner infestation in 1993 and 1994 were low and insignificant compared to the yield of 1992. What is the interpretation if leaf miner infestation were similar, or even less?

A: N. Sharaf Eldin

The large reduction was due to the attack of thrips and *Spodoptera* and not to leaf miner. In general, yield fluctuations are basically due to temperature which directly affects pod setting.

Comment: Dr. M. Salih Mohamed

The termite problem in wheat is more serious than anticipated, not only in Rahad but also in Gezira, New Halfa and other wheat areas. Control by irrigation water does not eradicate the pest, therefore, eradication control is needed.

A: N. Sharaf Eldin

The use of newly released seed dressings and granular formulations accompanied by the integration of other control measures will reduce the termite problem.

Wheat Diseases

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Abstract

Field resistance of the advanced national wheat genotypes to stem rust (SR) and leaf rust (LR) was evaluated. Forty-four percent of the genotypes showed adequate combined resistance, while 57% and 60% of the genotypes were resistant to SR and LR, respectively. Cultivars Condor and Debeira were adequately resistant to both rusts. Some exotic sources of resistance were determined. The relative prevalence of rust physiological races was determined in the 1991/92–1993/94 seasons. Three SR races and seven LR races were identified. Effectiveness of SR and LR resistance genes in adult and seedling plant resistance was determined. The presence and density of the urediniospores of SR and LR in the air in New Halfa was determined in the period from October to July. Wheat grain yield loss due to rust infection was 17.5 to 72%, while the 1000-kernel weight loss was 12 to 49.6%, depending on the severity of infection. In Gezira, wheat seed treatment with systemic fungicides significantly improved crop stand, grain yield and yield attributes. Damping-off disease levels of 0 to 30% and 0.1 to 3% were found in Gezira and Rahad, respectively. Pathogens involved were *Rhizoctonia solani*, *Fusarium solani*, and *Pythium debaryanum*. *Fusarium* spp. and *Helminthosporium* sp. were initially identified as causal agents of the "white head phenomenon." The presence of Barley Yellow Dwarf Virus (BYDV) on wheat and other graminaceous hosts in Gezira was established. The present work is a summary of research conducted under the auspices of the Nile Valley Regional Program (NVRP) from 1986/87 to 1994/95.

Introduction

Disease surveys revealed that the only important diseases on the wheat crop in the Sudan are rust diseases. Two types of rust infect wheat annually in New Halfa area. These are black stem rust (SR), caused by the fungus *Puccinia graminis* f. sp. *tritici*, and leaf rust (LR), caused by *Puccinia recondita* f. sp. *tritici*. These diseases are confined to the New Halfa area, and are rarely seen in other wheat-growing areas. Severe infection with both diseases, especially with SR, can develop on susceptible wheat cultivars. Weather conditions, particularly temperature and humidity, during the wheat season, are more conducive to SR than to LR disease development. Optimum temperatures for the different phases of SR are higher than those for LR by about 5.5°C (Roelfs *et al.* 1992). Stem rust has been observed to be usually more severe and more destructive than leaf rust. Progress of SR infection continues all the season, but that of LR is sometimes interrupted.

Control of rust diseases in the Sudan has been, and will continue to be in the foreseeable future, dependent on genetic resistance. Resistance of cultivated varieties is at present adequate. The work described in this paper is a summary of research conducted under the auspices of the Nile Valley Regional Program (NVRP) from 1986/87 to 1994/95.

General Methods

Rust infection levels on adult plants were scored by determining infection type (response) and severity of infection on a 0–100% scale (modified Cobb scale). The coefficient of infection (CI) was calculated by multiplying disease severity (%) by the corresponding response value (Table 1). Entries with CIs equal to 0–5 possessed good resistance, 6–10 fair, 11–20 marginal, and more than 20 poor. Good and fair resistances are adequate; marginal and poor inadequate (Saari and Wilcoxson 1974; Prescott and Saari 1975).

Table 1. Infection types and corresponding response values.

Infection type	Response value
No infection	–
Resistant (R)	0.2
Moderately resistant (MR)	0.4
Intermediate (mixed reaction) (X)	0.6
Moderately susceptible (MS)	0.8
Susceptible (S)	1.0

Source: Prescott and Saari (1975).

Seedling resistance evaluation, physiological race identification and frequency determination, and the evaluation of the effectiveness of resistance genes at the seedling plant stage were carried out by Y.H. El Daoudi and coworkers at the Agricultural Research Centre (ARC), Giza, Egypt. The work was done in a glass house under temperatures between 18 and 24°C. Disease samples were sent from New Halfa.

Varietal Resistance and Sources of Resistance

Results

National varieties and advanced lines of wheat have been screened annually for resistance to rust diseases since 1986/87. Similarly, exotic materials have been screened for resistance. Screening and resistance evaluation have been done on adult plants under field conditions.

In the 1986/87 season, 19% of the national cultivars and advanced lines showed adequate resistance to stem rust. Resistance of the cultivars Debeira and Condor was adequate, that of Giza 155, Mexicani and Giza 160 inadequate.

In 1987/88, rust infection level was low. Ninety-four percent and 83% of the entries had adequate resistance to stem rust (SR) and leaf rust (LR), respectively, while 69% had combined resistance to both rusts. These included cultivars Debeira, Condor, Giza 155 and Mexicani.

In 1988/89, the disease level was also low; 87.5% and 80% of the national entries showed adequate resistance to SR and LR, respectively. In addition, 52.5% of the entries had combined resistance. These included Debeira and Condor. Giza 155 and Mexicani showed adequate resistance to SR and inadequate resistance to LR. Giza 160 was inadequately resistant to both rusts.

In 1989/90, 64% and 50% of the entries possessed adequate resistance to SR and LR, respectively. On the other hand, 41% of the entries had combined resistance. Debeira, Condor and Giza 155 showed adequate resistance to SR, and inadequate resistance to LR. Resistance of Giza 160 to both rusts was inadequate.

In 1990/91, the infection level of leaf rust was too low for valid resistance assessment. On the other hand, 54 % of the entries showed adequate resistance to SR. Debeira, Condor, Giza 155 and Condor'S' showed adequate resistance to this rust. Resistance of Giza 160 and El Neilain was inadequate.

Valid resistance evaluation in 1991/92 was not possible as the disease level was too low. The 1992/93 season, on the other hand, was a good one for screening for resistance. The levels of both SR and LR were high. Of the total national entries, 32% and 39% were adequately resistant to SR and LR, respectively, while 23.7% had combined resistance, including cultivars Condor, Condor'S' and Sasaraib. Debeira and Giza 155 were resistant to SR and susceptible to LR. El Neilain and Giza 160 were susceptible to both rusts. In the Nile Valley Rust Trap Nursery (NVRTN), Condor and Condor'S' showed adequate combined resistance. Six Ethiopian cultivars: Enkoy, K6290-Bulk, Dashen, ET-13, K6295-4A, and C.T.71/CII (DW) possessed adequate combined resistance. Lines Thatcher^6 x RL5406, St. 1.25 TC Lr-26, and Prelude x Reliance, also had adequate combined resistance. Within the Durable Leaf Rust Resistance Screening Nursery (1st DLRRSN, 1992/93-CIMMYT), adequate combined resistance was expressed by lines Noroeste 66, Exchange/6TC-RL6011, and TC6/St.1.25-RL6078.

In 1993/94, 64% and 71% of the national entries showed adequate resistance to SR and LR, respectively, while 55% of the entries had adequate combined resistance, including cultivars Debeira, Condor and Condor'S'. Giza 155 had adequate resistance to SR and inadequate resistance to LR. Resistance of El Neilain and Sasaraib was inadequate to both rusts. In the NVRTN, five Ethiopian cultivars: Enkoy, K6890-Bulk, ET13, K6295-4A, and C.T.71/CII (DW) showed adequate combined resistance. Six of the Thatcher^6 lines also showed adequate combined resistance.

In 1994/95, 40% and 34% of the national entries were adequately resistant to SR and LR, respectively, while 23% of the entries showed combined resistance, including Debeira and Condor. Giza 155 was resistant to SR and susceptible to LR. In the NVRTN, 43% and 40% of the entries were resistant to SR and LR, respectively, while 15% possessed combined resistance. These included Giza 162 (Egypt), Enkoy, K6290-Bulk, Dashen, ET13, K6295-4A, Bohai and D204-118 (Ethiopia) and Marib-1 (Yemen). Giza 160 and El Neilain were susceptible to both rusts.

In the 1991/92 season, the reaction of Sudanese cultivars to dominant LR races in Egypt and in the Sudan was determined by El Daoudi and coworkers at the ARC in Egypt. Results of the study on the seedling plant stage are shown in Table 2.

Table 2. Reaction at the seedling plant stage of five wheat cultivars from the Sudan to dominant leaf rust races in Egypt and the Sudan, 1991/92.

Cultivar	Dominant races							
	Egypt						Sudan	
	R12	R77	R84	R144	R158	R192	R57	R167
Condor	MS	MS	MS	MS	S	MR	S	MS
Condor'S'	MS	MS	MS	MS	S	MR	S	S
Debeira	VR	MR	R	VR	R	R	R	VR
El Neilain	MS	S	S	MS	S	S	MS	MR
Baladi	MS	S	S	S	S	S	S	S

VR = Very resistant; MR = Moderately resistant; MS = Moderately susceptible; S = Susceptible.

In the same study, seedling reaction of Giza 155 and Giza 160 to SR and LR races was determined. The disease score on these cultivars at the adult stage was also determined at various locations in Egypt. At the seedling plant stage, Giza 155 was susceptible to LR races 12, 21, 77, 151, 158, 211, 218, 222 and 206 and moderately susceptible to R 57. Adult stage reaction was up to 40S. This cultivar was also susceptible to SR race 11B, moderately susceptible to race 15, moderately resistant to race 11, resistant to race 17, and immune to races 24 and 34. Adult plant reaction of Giza 155 to SR was up to 50 MR-MS. Genes conditioning resistance to SR in this cultivar were identified as Sr-6 and Sr-11, in addition to other genes.

Seedling reaction of Giza 160 to different races of the LR pathogen was susceptible to races 13, 21, 57, 77, 158, 211, 218, 222, and moderately resistant to races 151 and 206. Adult plant reaction to LR was up to 80S. At the seedling plant stage, the reaction of Giza 160 to SR races was susceptible to races 11B, 15, 17, 24, and 34 and moderately susceptible to race 11. Adult plant reaction to SR was up to 70S.

Discussion and Conclusions

The fluctuation in the proportions of resistant genotypes, and the oscillation of the individual cultivars and lines between resistance and susceptibility from season to season can be mainly attributed to the dynamic nature of the natural rust inoculum. The identities and frequencies of the rust physiological races as well as the inoculum densities and environmental conditions change from season to season. Most of the resistance thought to be race nonspecific is combined in cultivars with specific resistance that is sensitive to inoculum density and effective at only certain growth stages and temperatures (Roelfs *et al.* 1992).

None of the cultivated varieties is immune. Based on the above results, it may be concluded that cultivars Condor, Debeira and Condor'S' are resistant to stem and leaf rusts under natural field conditions. Giza 155 is resistant to stem rust and susceptible to leaf rust. El Neilain, Giza 160 and Sasaraib are susceptible to both rusts. The Ethiopian cultivars Enkoy, K6290-Bulk and ET13 were found to possess good combined resistance for three consecutive seasons (1992/93-1994/95). Such cultivars are recommended as sources of resistance.

Physiological Races of Rust Pathogens

Results

Puccinia graminis* f. sp. *tritici

Earlier investigations and studies of rust races in the Middle East and Nile Valley regions was carried out, mainly at the ARC in Egypt, by Abdel Hak and Kamel (1972). The earliest record of the physiological races of the stem rust pathogen (*Puccinia graminis*) in the Sudan was in the 1963/64 season. In that season, nine races were identified. These were, in order of prevalence: R17, R24, R14, R117, R9, R21, R19, R53, R75 (Abdel Hak *et al.* 1982). In 1970, races 21 and 222 were identified at the Estaco Nationale de Melhoramento de Plantas (ENMP) in Portugal by Santiago (1970). Races 21, 34, 186 and 194 were identified from the Sudanese samples by M. Julia Concalves in 1973, also at ENMP in Portugal. In the 1973–1980 seasons, the prevalent stem rust races in the Sudan were R17, R19, R117 and R222, in addition to two newly identified races, 11 and 189 (Abdel Hak *et al.* 1982). R15 was identified by M.E.K. Ali in 1977.

Therefore, prior to the start of the Nile Valley Regional Program, 13 races of the stem rust pathogen had been identified in the Sudan. Within the NVRP, rust samples were sent to Dr. Y.H. El Daoudi, at the ARC in Egypt for race identification and determination of their relative prevalence. In the 1991/92–1993/94 seasons, the prevalent stem rust pathogen races in New Halfa were identified and their relative frequencies determined. Frequency is the percentage of isolates representing the given race relative to the total number of isolates tested. Identified races were:

1991/92

Race:	R 9	R 15	R 117
Frequency (%):	50	33	17

1992/93

Race:	R 15	R 123
Frequency (%):	66.7	33.3

1993/94

Race:	R11	R17	R14	R19	R122	R39	R15	R24	R34	R123
Frequency (%):	10	5	3	2	2	2	1	1	1	1

In the 1991/92 season, R 15 was identified in the Sudan and Egypt only. It was not identified in Ethiopia nor in Syria. Races 39 and 122 were newly identified in the Sudan in 1993/94 season. In 1994/95, the prevalent stem rust races were R11, R15, R17, R24, and R123.

Puccinia recondita **f. sp.** ***tritici***

All the known races of the leaf rust pathogen in the Sudan were identified within the NVRP at the ARC in Egypt. In 1991/92–1993/94, the following nine physiological races of *P. recondita* were identified on disease samples sent from New Halfa:

1991/92

Race:	R 57	R 167
Frequency (%):	67	33

1992/93

Race:	R 144
Frequency (%):	100

1993/94

Race:	R 12	R 57	R 144	R 151	R 206	R 221
Frequency (%):	64	16	8	4	4	4

In 1992/93, race 144, the only race identified in the Sudan, was most prevalent in Egypt, and was identified in Ethiopia and Syria.

Conclusions

Results of race identification and frequency determination show that, for both rust pathogens, the identities, numbers and frequencies of physiological races vary from season to season. This variation has a direct bearing on varietal resistance and the effectiveness of the resistance genes.

Genes Conditioning Resistance to the Rust Pathogens

Results

Stem rust (SR)

Effectiveness of SR resistance genes (Sr-genes) was determined on adult plants under field conditions. Lines with one (monogenic resistance) or more Sr-genes were grown, and their resistance level was determined. Sr-genes conferring adequate resistance (CI = 0–10) to their respective lines were considered effective. Effectiveness of Sr-genes to Sudanese isolates or SR-races was determined at the ARC in Egypt on seedling stage resistance. This was done on monogenic resistance lines in the glass house by El Daoudi and coworkers.

In 1986/87, effective Sr-genes at the adult plant stage were 27 and Tt-2. Ineffective genes were 7b, 8, 9e, 9d, 10, 12, 13, 14, 16, 22, 26, 30, 36(Tt-1), 5, 9a, 15, 25, and 29.

In 1987/88, effective genes were 9e, 22, 25, 36(Tt-1), and Gt+. Ineffective genes were 5, 7b, 8, 9a, 9d, 10, 12, 13, 14, 15, 26, 39, 30 and Tt-3.

In 1988/89, infection level was low. Effective Sr genes were 5, 7b, 9e, 10, 12, 15, 22, 25, 26, 29, 30, 36(Tt-1), Tt-2, Tt-3 and Gt+. Only genes 8, 9a, 13 and 14 were ineffective.

In 1989/90, infection level was also low. Out of 11 genes tested, 10 were effective. These genes were 9e, 9d, 10, 15, 22, 25, 26, Tt-1, Tt-2, and Gt+. Only Sr-8 was ineffective.

In 1990/91, 14 monogenic lines were tested. Genes 9e, 26, 30, 36(Tt-1), Tt-2, and Gt+ were effective. Genes 8, 9d, 10, 11, 15, 22, 25 and 27 were ineffective.

In the 1991/92 season, infection level in New Halfa was too low to justify valid conclusions on adult plant resistance. In that season, SR isolates from the Sudan were tested for virulence on monogenic resistance lines at the ARC in Egypt. The effectiveness (per cent resistant reactions) of the Sr-genes on seedling resistance was thus determined. Results were:

Sr-gene:	9d	26	5	29	36(Tt-1)	8	Tt-2	76	27	9e	9a
Effectiveness (%):	100	100	83	83	83	67	67	50	50	33	17

Sr-gene:	15	30	9b	10	11	12	13	14	16	22	24
Effectiveness (%):	17	17	0	0	0	0	0	0	0	0	0

In 1992/93, SR infection level was high. Effective Sr-genes on adult plants were Sr-5, Sr-Gt+, Sr-24 and Sr-31. Genes 6, 9e, 11, 21, 25, combination Sr-2/Sr-26, and Sr-27 were ineffective. In the NVRTN, Sr-genes conferring highest adult plant resistance were Sr-6, 9e, 24, 26, and Gt+. Effectiveness of Sr-genes was also determined on Sudanese isolates on monogenic lines at the seedling stage. Results were:

Sr-gene:	29	30	36(Tt-1)	5	7b	8a	9a	9b
Effectiveness(%):	17.7	17.7	11.8	5.88	5.88	5.88	5.88	5.88

Sr-gene:	9d	11	25	26
Effectiveness(%):	5.88	5.88	5.88	5.88

Sr-30 was effective at the seedling stage in the three Nile Valley countries and in Syria. Sr-29 was effective on isolates from Ethiopia and from the Sudan. At the seedling stage, Srs 5, 29, 30, 36(Tt-1) followed by Sr-26 and Sr-Gt+ provided the highest levels of resistance regionally.

In 1993/94, stem rust severity was high. On adult plants in New Halfa only, Sr-31 was effective. Ineffective Srs were 5, 6, 9e, 11, 21, 24, 25, 27, combination Sr-2/Sr-26, and Gt+. In the Nile Valley Region, the most effective genes on the adult plants were Sr-31, Sr-36(Tt-1), Sr-Gt+ and Sr-9e.

Effectiveness of Sr-genes against Sudanese isolates at the seedling stage, was determined. The relative effectiveness of Sr-genes were:

Sr-gene:	8a	Gt+	7b	9e	5	29	9b	21	24	30
Effectiveness (%):	46.4	39.3	35.7	35.7	32.1	25.0	14.3	14.3	14.3	14.3

Sr-gene:	36(Tt-)	25	26	10	9a	9d	9g
Effectiveness (%):	14.3	10.7	10.7	7.1	3.6	3.6	3.6

Relative effectiveness of Sr-genes at the seedling stage in the region was:

Sr-gene:	Gt+	7b	8a	5	29	21	9e	30	10	24	11
Effectiveness (%):	54.8	49.6	39.3	17.8	17.8	14.8	13.3	11.9	11.1	10.4	8.1

Sr-gene:	36(Tt-1)	6	26	27	25	9a	9b	17	8b	9g	9d
Effectiveness (%):	6.7	5.9	5.9	5.4	5.2	4.4	4.4	3.7	3.5	2.2	1.5

In 1994/95, effective Sr-genes on adult plants in the Sudan (NVRTN) were Sr-5, Sr-Gt+, and Sr-31. Ineffective genes were 6, 9e, 11, 21, combination 2/26, 25, and 27. On other isogenic lines tested Srs 5 and 31 were also effective.

Leaf rust (LR)

Effectiveness of LR resistance genes (Lr-genes) was determined under field conditions on adult plants. Wheat lines with single resistance genes (monogenic resistance) were grown in the field. The genes conferring adequate resistance (CI = 0–10) to their respective lines were considered effective. Effectiveness of Lr-genes at the seedling stage was determined by El Daoudi and coworkers at the ARC in Egypt; leaf rust isolates or races were tested for virulence on leaf rust monogenic resistance lines. Effectiveness of a resistance gene was taken as the percentage of the resistant reactions of the isolates or races tested.

In 1988/89, effective Lr-genes identified on adult plants in New Halfa were Lr-1, 12, 19, 31, 22, and 25. Ineffective genes were 2a, 2b, 2c, 3, 3ka, 9, 10, 13, 14a, 14b, 16, 17, 18, 20 and 23.

In 1992/93, effective Lr-genes on adult plants were 12, 21, 26, and gene combination Lr-1/Lr-13/Lr-17 (Noereste). Ineffective genes were 1, 2a, 2b, 9, 17, 18, 23, 24, 34, 16, and combinations Lr-13/Lr-26 and Lr-1/Lr-13. In the same season, leaf rust physiological races, identified on Sudanese samples, were tested for virulence on 17 leaf rust monogenic resistance lines at the ARC in Egypt.

Relative effectiveness of the tested Lr-genes was thus determined on the seedling stage. Results were:

Lr-gene:	11	3ka	18	9	1	30	2c	10	17	23	24	22b
Effectiveness (%):	14.8	11.1	11.1	7.4	7.4	7.4	3.7	3.7	3.7	3.7	3.7	3.7

Gene Lr-11, also exhibited high effectiveness at the seedling stage in Egypt (18.4%), Ethiopia (18.2%), and Syria (16.2%). Effective genes at the seedling stage in the Nile Valley Region, in order of effectiveness, were Lr-11, Lr-9, Lr-23 and Lr-24. At the adult stage, the most effective genes in the region were Lr-21 and Lr-24.

In 1993/94, effective Lr-genes on adult plants in New Halfa were Lr-2a, 9, 11, 17, 18, 21, 23, 24 and 26. Effective Lr-genes on adult plants in the region were Lr-2a, 9, 18, 21 and 26. It is noteworthy that all genes found effective in the region were also effective in the Sudan in the same season.

In this season effectiveness of Lr-genes was also determined at the seedling stage. Sudanese leaf rust isolates were tested on leaf rust monogenic lines at the ARC in Egypt. Results were:

Lr-gene:	2a	1	16	26	21	24	11	3ka	2c	17	9	18	3a	10
Effectiveness (%):	80	72	60	60	44	44	40	28	20	20	9	8	4	4

Identified physiological races of the leaf rust pathogen (seasons 1992/93–1993/94) in the region were tested for virulence on leaf rust monogenic lines. The effectiveness of the tested genes was:

Lr-gene:	1	2a	24	26	21	9	3ka	11	18	12	17
Effectiveness (%):	69.6	68.9	45.9	42.6	29.7	22.3	20.2	20.2	14.9	12.8	8.1

Lr-gene:	16	10	23	30	22b
Effectiveness (%):	5.4	5.4	5.4	4.1	2.0

In that season, gene Lr-2a was the most effective in the Sudan, both on adult plants and seedlings, and was also most effective in the region both at the adult and seedling plant stages. Genes 2a, 1, 26, 21, 24, 11 and 3ka were most effective in the Sudan and in the region at the seedling stage.

In 1994/95, effective Lr-genes on adult plants in New Halfa were 9, 17, 19, 24, and 26. Ineffective genes were 1, 2a, 3a, 3ka, 11, 17, 18, 21, 22b, 23, 24, 26, and 30.

Genes Lr-17, Lr-24 and Lr-26 were also effective at the adult stage in 1993/94. Genes Lr-24 and Lr-26 were also highly effective on Sudanese leaf rust isolates at the seedling stage in the 1993/94 season.

Discussion and Conclusions

Effectiveness of single resistance genes, or combinations of few genes of stem rust or leaf rust, varies from season to season. A single gene provides resistance to one (or a few) physiological races of the pathogen and is not effective against other races. The natural rust inoculum is composed of races, which vary in identity, frequency and numbers from season to season. Moreover, the specific resistance provided by single or a few genes is sensitive to environmental conditions, particularly temperature. Under warm, humid conditions some of the specific resistances, e.g., Sr-6, Sr-10 and Sr-17, are ineffective due to high temperatures (Roelfs *et al.* 1992). Genes effective at the seedling stage are not necessarily effective at the adult stage of the host on the same pathogen races.

Monogenic resistance, as such, is not, therefore, reliable or useful in cultivated varieties. Breeders should aim at a broader resistance, based on gene combinations; or at generalized tested resistances. Moreover, under Sudanese conditions, it is necessary to have varieties with resistance to both stem and leaf rust. The varieties and lines possessing good combined resistance could be good sources of field resistance, e.g., the Ethiopian cultivars Enkoy, K6290-Bulk and ET-13 (mentioned earlier).

Air Sampling for Rust Urediniospores

Materials and Methods

In the 1992/93, 1993/94 and 1994/95 seasons, air sampling for stem and leaf rust urediniospores was done at New Halfa using a volumetric 7-day Burkard Spore Sampler. The air suction pump of the sampler was adjusted at a suction rate of 10 litres of air per minute (0.6 m^3/hr).

After each 7-day period, the tape was removed and divided into 48 mm sections representing the trapping lengths for 24 hour periods (2 mm/hr). The tape sections were mounted on microscope slides in lactophenol, and covered with glass cover slips. Each slide was then scanned under the microscope; stem and leaf rust urediniospores were identified and counted. Spore counting was done in 1 microscope field width (10 x 40) along the length of the tape (48 mm).

The number of spores of each rust per cubic metre of air was calculated according to the formula:

$$\textit{Number of spores/m}^3 \textit{ of air} = \frac{\textit{Spore count} \times 14 \times 100}{0.47 \times 0.6 \times 24 \times 70}$$

where: Spore count = counted number of spores in one microscope field width (48 mm) along the length of the tape section,
14 = width of the trapping surface in mm,
0.47 = diameter of one microscope field in mm,
0.6 = volume of air sucked into the sampler per hr in m^3,
24 = number of hours per day,
70 = estimated efficiency of the sampler in percent,
100 = factor to correct sampler efficiency to 100%.

Results and Discussion

Biweekly averages of urediniospore numbers are shown in Table 3 for the three seasons, 1992/93, 1993/94 and 1994/95. Results show the continuous presence of rust urediniospores in the air in New Halfa during the sampling periods. Stem rust spores have been detected without fail. Leaf rust spore presence was not as consistent; it was not detected in May, June and July of 1994, and was absent in the second half of April and the first half of October 1993, and in January and the first half of February 1995. Stem rust spore concentration was, generally, higher than leaf rust spore concentration in the three seasons.

From May to November each year, there is no wheat crop in the Sudan. Alternative grass hosts of SR or LR were not reported or found. Likewise, the alternative hosts have not been seen or reported. It is noteworthy to mention that not a single aeciospore of either rust was seen on any of the slides. The presence of urediniospores out of the wheat season is a very strong indication that the source of these spores is distant and not local. The peaks of spore concentrations observed during the wheat season, especially in February, March, and April are thought to be due to local sources.

Table 3. Air sampling for rust spores in New Halfa: Average biweekly number of urediniospores/m^3 of air, 1992/93, 1993/94 and 1994/95 seasons.

Type of rust	October		November		December		January		February		March		April		May		June		July	
	1st†	2nd†	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
	1992						**1993**													
Stem			0.4	1.6				4.1	4.1	3.3	2.0		1.2	2.0						
Leaf			10.2	9.0				7.8	4.1	3.7	2.0		0.8	0						
	1993						**1994**													
Stem	0.9	2.6	1.3	1.3	0.5	5.0					112.0		89.0	3.2	3.5	4.0	3.0	2.6	1.7	
Leaf	0	0.4	0.4	0.7	0.4	0.7					16.3		0.9	0.2	0	0	0	0	0	
	1994						**1995**													
Stem	4.9	2.0	3.9	3.2	2.2	3.7	1.8	5.7	5.0	6.6	4.1	9.4	10.0	18.3	12.9	11.0				
Leaf	0.9	1.0	2.5	0.9	0.9	3.0	0	0	0	0.4	1.3	0.8	0.6	2.4	0.9	3.0				

† 1st = First half of the month; 2nd = Second half.

Workers on the spread of rust fungi generally agree that urediniospores can spread disease over great distances (Ingold 1971). Long distance transport occurs annually (800 km) across the North American Great Plains (Roelfs 1985), and nearly annually from Australia to New Zealand (2000 km) (Lug 1985), and at least three times in the past 75 years from East Africa to Australia (Watson and de Sousa 1983).

Since disease incidence on the wheat crop occurs towards the end of December at the earliest, spores found in the air before that time must be the source of the primary infection.

Crop Loss Assessment

Assessment of wheat crop loss due to infection by stem and leaf rusts was done during the 1988/89–1994/95 seasons. Assessment was made mainly on the cultivated varieties and cultivar Baladi, in the field. Eight cultivars were tested for sensitivity to rust diseases in the different seasons.

The design of the field experiment was a split-block, with three or four replicates. Two treatments were applied to the entries: (1) inoculation by rust spores, and (2) spraying with fungicides.

Sowing was done in continuous rows, 20 cm apart. Plot sizes ranged, in the different seasons, from 7 x 6 m to 7 x 3.2 m. Urea fertilizer was applied at sowing at a rate of 98 kg N/ha. Spraying the controlled plots of the trials was done 2-3 times during the season. Inoculation was done 2-3 times by dusting a mixture of rust urediniospores and talcum powder on the plots to be infected. Spraying was done by either Bayleton (25% WP) at a rate of 1200 g/ha or by Tilt EC 250 at a rate of 500 cc/ha.

Stem and leaf rust infection levels in each plot were assessed at heading. Weight of grain yield per plot and 1000-kernel weight were taken after harvest.

Results and Discussion

Four season (1989/90, 1992/93, 1993/94 and 1994/95) average grain yield loss (%) and kernel weight reduction are shown in Table 4. Resistant cultivars showed less reduction both in grain yield and kernel weight. Yield loss of the susceptible Baladi was 100% in some plots. Even the most resistant cultivars, Condor and Debeira, showed appreciable yield and kernel weight reduction under artificial inoculation. Results show that these cultivars can be affected under high inoculation density when conditions are favourable for rust disease development.

Table 4. Average percent reduction in grain yield and 1000-kernel weight in different cultivars due to stem and leaf rust infection over four seasons.

Cultivar							
Condor	Debeira	Condor'S'	Giza 155	El Neilain	Giza 160	Sasaraib	Baladi
Reduction in grain yield							
19.5	17.5	19.0	26.3	34.2	33.1	20.0	72.0
Reduction in 1000-kernel weight							
26.5	16.5	12.0	14.5	30.2	31.7	23.5	49.6

Soilborne Pathogens

Effect of Seed-Dressing Systemic Fungicides on Yield and Yield Components

A field experiment was conducted by Drs. Nafisa E. Ahmed and Badr El Din Abdel Rahman in 1992/93 in the Gezira Research Farm, and in 1993/94 it was repeated (with some modification) on a farmer's field and on a large scale in Gezira.

The design of the experiment was a randomized complete block (RCB) with three replications (four replications in 1993/94). Seeds of wheat cultivar Debeira were treated and sown at a seed rate of 143 kg/ha. Nitrogen and phosphorous (P_2O_5) were applied at 86 and 43 kg/ha, respectively.

In 1992/93, the treatments were:

- Triadimenol (Baytan 15%) at two rates (3 and 2.25 g a.i./kg seed).
- Tebuconazole (Raxil 2%) at two rates (4 and 3 g a.i./100 kg seed).
- Carboxin (Vitavax 200) at three rates (5, 6 and 7 g/100 kg seed)
- Baytan 15% + Gaucho (30 g a.i. + 105 g a.i./100 kg seed).
- Baytan 15% + Gaucho (30 g a.i.+ 70 g a.i./100 kg seed).
- Raxil 2% + Gaucho (3 g + 105 g a.i./100 kg seed).
- Raxil 2% + Gaucho (3 g + 70 g a.i./100 kg seed).
- Fernasan D (300 g/100 kg seed) (standard check).
- Untreated control.

In 1993/94 treatments were:

- Vitavax at three rates (5, 6 and 7 ml/kg seed).
- Vincit at three rates (2, 3 and 4 ml/kg seed).
- Fernasan + Lindane (standard check).
- Fernasan D WP at two rates (2 and 3 g/kg seed).
- Fernasan D WP + Lindane WP (3 g + 3 g/kg seed).
- Raxil (1.5 g/kg seed).
- Gaucho (1.5 g/kg seed).
- Untreated control.

Results and discussion

Seed treatment with Baytan, Raxil and Vitavax, at all rates tested, significantly improved crop stand and plant fresh weight at all locations. All the fungicides, at all rates, increased the number of spikes/m^2, the number of seeds/spike, and the seed size (100-kernel weight), and resulted in significantly ($P \geq 0.001$) higher grain yield. The grain yield increase was up to 70% over the standard check (Fernasan D). Effects of Baytan and Raxil were enhanced by mixing with Gaucho. Raxil + Gaucho treatment resulted in the highest yield in all locations.

The increase in grain yield associated with the treatments was attributed to the improvement in crop establishment, plant stand, number of spikes/m^2, number of grains/spike and grain size. The indication was that the observed improvement in the yield components and the resultant higher yield, came as a result of effective control of the damping-off, and other soilborne pathogens, by the fungicides tested.

Soilborne Pathogen Surveys

Damping-off Disease

This survey was conducted in 1993/94, in farmers' fields in Gezira and Rahad schemes. Random samples were taken from the two schemes. Observations were collected on disease percentage within the sampled areas and on the frequency of diseased samples (% diseased samples).

Damping-off disease was found to be predominant in low-lying areas, and in badly prepared, and badly managed fields, especially waterlogged fields. Well managed fields were free of the disease. The percentage of infected areas ranged from zero to 30%. Field frequency of the disease occurrence was very high (up to 100%) in Massalamia and Centre groups of Gezira. In Rahad Scheme, both the mean percent infection (0.1–3%) and the field frequency (0–25%) of the disease occurrence were low. Pathogens causing the disease were found to be mainly *Rhizoctonia solani* and *Fusarium solani*. *Pythium debaryanum* was predominant in waterlogged areas.

Damping-off diseases could lead to serious losses. Use of seed-dressing fungicides is recommended. Good land preparation, good husbandry and avoidance of waterlogging reduce the chances of infection.

The White Head Phenomenon

In 1993/94 the wheat crops in Gezira and Rahad were observed to be infected with the white head syndrome, head epinasty, and lodging. This phenomenon was widespread in the two schemes.

Samples were randomly taken and a survey of this disease was made in the Gezira and Rahad schemes. A questionnaire was also distributed to determine the factors conducive to the disease. Isolation and laboratory examination were done to identify the pathogens involved.

The incidence over the two schemes ranged between 0.001 and 30%. Messalamia Group in Gezira showed maximum infection level. Neither farmers' practices nor rotation were found to have an impact on the disease.

It was established that in Gezira and Rahad, the disease was caused by a number of *Fusarium* spp., including *F. culmorum* and a *Helminthosporium* sp., probably Drechslera. All cultures were sent to the Commonwealth Mycological Institute (CMI) for confirmation and identification of the species.

Incidence of Barley Yellow Dwarf Virus (BYDV)

This work was carried out in 1993/94. Field surveys on barley, wheat and sorghum plants were done in the testing site of the ARC at Turabi in northern Gezira. Leaf samples with symptoms of BYDV (yellowing, stunting, reddening) were collected. Other samples were collected from seemingly healthy wheat plants, growing in the vicinity of barley plots with severe BYDV-like symptoms. A total of 131 samples were collected and brought to the laboratory of the University of Gezira.

Juice was extracted from each of these samples and used to perform the DAS-ELISA test using rabbit anti-BYDV-PAV serum. Sample reactions were compared with those of positive and negative controls (BYDV diseased and healthy) freeze-dried plant materials.

About 30% of the samples tested gave positive reactions in the ELISA test. The highest proportions of positive tests were obtained in barley lines ACSAD 1394 (20–30%), ACSAD 1420 (25–35%), sorghum with leaf reddening symptoms (3–5%), and durum wheat (3–5%). On wheat cultivar Debeira, positive tests were less than 1%. Disease incidence levels estimated on the basis of visual symptoms ranged between 1–5% in wheat and 5–35% in barley.

These results confirm the association of BYDV with the yellowing, reddening and stunting symptoms observed in barley and other graminaceous plants in northern Gezira. This is the first confirmed report of this virus in the Sudan.

Future Research Prospects

Rust Diseases

Rust disease control in the Sudan is carried out by growing resistant cultivars (genetic resistance). Genetic resistance may collapse sooner or later due to the dynamic nature of the rust inoculum. Virulences (races) change from season to season. Research should therefore continue on the following aspects·

- Evaluation of the resistances of cultivars and promising lines.
- Physiological race identification and evaluation of virulences on cultivars and promising lines.
- Determination of sources of resistance and resistance genes.
- Breeding for combined resistance (i.e., resistance for both stem and leaf rusts), and generalized broad-based (polygenic) resistance, rather than specific (monogenic) resistance.
- Conducting epidemiological studies on sources of primary infection, accessory hosts and alternate hosts, and environmental factors conducive to disease development.

Soilborne Diseases

These diseases are likely to gain importance. At present, they are important in some areas. Research should continue on:

- Prevalence, severity and economic importance.
- Conditions conducive to disease development.
- Identification of pathogens involved.
- Control methods.

Barley Yellow Dwarf Virus

BYDV is an important disease. Its presence in the Sudan has now been confirmed. Research should continue on:

- Determining the disease situation in the different wheat growing areas.
- Elucidating the nature of the virus, its survival and carry over.
- Determining the factors affecting the spread of the virus.
- Determining the resistance of wheat cultivars.

References

Abdel Hak, T.M. and Kamel, A H. 1972. Present status of wheat stem rust in the Near East region. Paper presented at the Regional Wheat Workshop, 14–17 February 1972, Beirut, Lebanon.

Abdel Hak, T.M., El Sherif, N., Shafik, I., Bassioni, A.A., Keddis, S. and El Daoudi, Y. 1982. Studies on wheat stem rust virulences and resistance genes in Egypt and neighbouring countries. Egypt Journal of Phytopathology 14(1-2): 1–10.

Ali, M.E.K. 1977. Studies on stem rust of wheat in the Sudan with special reference to Khashm El-Girba district. M.Sc. Thesis, University of Khartoum.
Ingold, C.T. 1971. Fungal Spores: Their Liberation and Dispersal. Oxford University Press.
Luig, N.H. 1985. Epidemiology in Australia and New Zealand. Pages 301–328 *in* Cereal Rusts Vol. II; Diseases, Distribution, Epidemiology, and Control (A.P. Roelfs and W.R. Bushnel, eds.). Academic Press, Orlando.
Prescott, T.M. and Saari, E.E. 1975. Major disease problems of durum wheat and their distribution within the region. Pages 104–114 *in* Third Regional Wheat Workshop, 28 April-2 May 1975, Tunis, Tunisia.
Roelfs, A.P. 1985. Epidemiology in North America. Pages 403–434 *in* Cereal Rusts Vol. II; Diseases, Distribution, Epidemiology and Control (A.P. Roelfs and W.R. Bushnel, eds.). Academic Press, Orlando.
Roelfs, A.P., Singh, R.P. and Saari, E.E. 1992. Rust diseases of wheat: Concepts and methods of disease management. Mexico, D.F., CIMMYT.
Saari, E.E. and Wilcoxson, R.D. 1974. Plant disease situation of high-yielding durum wheats in Asia and Africa. Ann. Rev. Phytopath. 12: 49–68.
Watson, I.A., and de Sousa, C.N.A. 1983. Long distance transport of spores of *Puccinia graminis tritici* in the Southern Hemisphere. Proceedings of the Linnean Society, N.S.W. 106: 311–321.

Discussion

Q: M.C. Saxena

You do not specify in the 'Crop Loss Assessment' section of your paper the rusts for which the yield loss assessment was done. Was it for LR or SR or both? And what is your definition of effectiveness (%) of the different rust genes which you have used in the 'Genes Conditioning Resistance to the Rust Pathogens' section?

A: Mohamed S. Ahmed

The reported crop loss was due to both LR and SR infections. Under field conditions, both rusts attack the wheat cultivars simultaneously. The levels of infection by each rust were assessed separately, but the effect on yield was confounded. The effectiveness (%) of a resistance gene is the number of resistant reactions of the monogenic resistance line (containing that gene) when inoculated by a number of rust races or isolates, expressed as a percentage of the total number of races or isolates.

Comment: Mohamed M. Omer

BYDV cannot reach serious disease levels in the Sudan as climatic conditions are not favorable for the disease development.

A: Gasim Dafalla

As a result of our survey conducted in 1995 in the Gezira, Rahad and Managil schemes, plants showing yellowing symptoms constituted from less than 1% up to 80% of the samples. Also, the serological test used to confirm the presence of the virus as a causal agent gave a positive reaction in more than 48% of the tested plants showing yellowing symptoms. Thus, we think that the climatic conditions are favorable for the disease and for the presence of the virus vectors.

Comment: M.B. Solh

Based on the comment on the insignificance of BYDV in the Sudan, I would like to emphasize that BYDV is a very serious disease that can cause complete destruction of the crop (wheat and barley) if conditions are favorable, as was the case in eastern Algeria in the 1988/89 season. We should learn from the example of the FBYNV epidemic of 1991/92 in Egypt when 140,000 acres were wiped out in one season without any previous warning. BYDV should definitely be monitored in the Sudan. Breeders should start looking for resistant lines to be ready when the disease becomes serious rather than be taken by surprise.

Comment: Mohamed M. Omer

Your survey provided no data to show the effect of wheat virus diseases on plant height, head size and grain yield.

A: Gasim Dafalla

The objective of the survey was to determine the presence and relative prevalence of the wheat virus disease, BYDV. Its effect on yield will be the objective of our next season's plan of work.

Weed Control in Wheat

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Abstract

Weed surveys in wheat fields in Gezira and in northern Sudan were undertaken to determine the most common and prevalent weeds associated with wheat production. There are some variations in composition and distribution of weed flora in the Sudan. The most common and prevalent weeds include *Brachiaria eruciformis*, *Sorghum sudanensis*, *Sinapis arvensis*, *Malva* sp., *Rhyncosia memnonia* and *Chenopodium* sp. The studies on weed competition showed that unrestricted weed growth and delayed weeding reduced wheat yield by 20% and the critical period of crop/weed competition was between two and six weeks from sowing. The effect of varying population densities of *Sinapis arvensis* and wild sorghum on wheat growth and yield significantly reduced wheat grain yield; the reduction increasing with increasing densities. For profitable wheat production, timely removal of wild sorghum is necessary. However, similarity in the appearance of wheat and wild sorghum in the early stages of growth precludes early hand-pulling. Delayed hand-pulling is difficult and provides less incentive to farmers as serious losses would have already been inflicted during the early stage of crop growth. Presowing irrigation was found to be effective in controlling grasses, but was less effective against other weeds. Moreover, presowing irrigation is expensive and may not be feasible. However, coupled with broadcasting and ridging and early hand-weeding, presowing irrigation proved to be very effective as an integrated weed management practice in northern Sudan. A post-emergence application of the herbicides Puma or Topik gave complete and lasting control of wild sorghum and increased grain yield of wheat by up to 61%.

Introduction

Work at Gezira Research Station and elsewhere showed that weeds had no adverse effects on wheat growth and yield (Babiker 1978). The implementation of the policy of diversification and intensification in irrigated agriculture has been accompanied by serious weed problems and changes in weed flora.

Experience with other crops has shown that the crop/weed interrelationship is influenced by crop variety and weed species (De-Datta 1977; Rao *et al.* 1977). The introduction of new wheat cultivars and changes in husbandry practices may have induced changes in the crop/weed interrelationships and accordingly necessitate the re-evaluation of the effect of weeds on wheat grain yield. Weed surveys and studies on competition and management of weeds in wheat were conducted in different regions in the Sudan from 1988 to 1995. The results of these investigations are summarized in this paper.

Weed Survey

Weed surveys in wheat in Gezira and in northern Sudan were conducted to determine the most common and prevalent weeds associated with wheat production (Babiker *et al.* 1989; Mohamed and Mohamed 1992a, 1992b). The surveys were based on the stratified random sampling procedure. A total of 10–24 weed samples (0.25–1.0 m) were taken randomly. The total number of various weed species was determined in each sample. Field frequency, mean field density, field uniformity and relative abundance for each weed species were calculated.

The survey was carried out in three 'Groups' (the main divisions) in the Gezira: Center, Messalamiya and Wad Haboba. The weed flora varied from one Group to another. The important weed species were *Brachiaria eruciformis*, *Ocimum basilicum*, *Rhyncosia memnonia*, *Dinebra retroflexa*, wild sorghum (*Sorghum sudanensis*) and *Cynodon dactylon*. *B. eruciformis* was the most abundant species. The other weeds were predominant in certain areas, but had localized distribution. Wild sorghum infestation was higher in the Center Group and the level increased where wheat was preceded by wheat.

In northern Sudan the survey was carried out in Hassa, Aliab, Zeidab and Burgaig Schemes. The most common and prevalent weeds associated with wheat production were *Beta vulgaris* and *Portulaca oleracea* in Aliab; *Sorghum* sp., *Sinapis arvensis* and *Brachiaria eruciformis* in Zeidab; *B. eruciformis*, *B. vulgaris*, *Melilotus* sp. and *Sorghum* sp. in Hassa; and *S. arvensis*, *Chenopodium* sp., *Melilotus* sp. and *Malva* sp. in Burgaig. The survey indicated that there were some variations in composition and distribution of weed flora. Some weeds (*Malva* sp., *Chenopodium* sp. and *Sinapis arvensis*) started dominating in the new areas. The use of unclean wheat seeds was one of the main reasons for the introduction of weeds in new areas.

Weed Competition Studies

Weed/wheat competition studies and chemical weed control were first initiated in the Sudan by the late Dr. A. Saeed in the early seventies in the Eastern Region (Saeed 1973). Few herbicides were tested but the work did not reach recommendation levels. Work done by Osman (1987), on the other hand, showed that taller cultivars of wheat compete with weeds better than shorter ones. Presowing irrigation yielded better than no presowing irrigation treatments (Bushara and Osman 1987).

Studies on weed competition were undertaken to determine the magnitude of yield losses due to weeds and to determine the critical period of weed/wheat competition (Mohamed and Mohamed 1992b, 1993b). Weeds were not removed for a period of two, four, six, eight and ten weeks after sowing. Other plots were maintained weed-free for the same periods. Weed-free and weedy checks were also included. The results in northern Sudan showed that unrestricted weed growth and delayed weeding reduced wheat grain yield across the region by about 20%. The critical period of weed/crop competition was between two and six weeks after sowing.

In other experiments the effect of individual weed species on the growth and yield of wheat was studied. The effect of varying population densities of *Sinapis arvensis* and wild sorghum on the growth and yield of wheat was studied at Hudeiba and Gezira agricultural research stations, respectively (Babiker and Mohamed 1990, 1991, 1992; Mohamed 1994b). The results showed that the presence of six or more plants/m^2 of *S. arvensis* reduced wheat grain yield significantly and that the reduction increased with increasing densities (Table 1). Wild sorghum at a population density of 2.5 to 10 plants/m row reduced wheat yield by 18 to 35% (Table 2).

Weed Management

The biology and control of wild sorghum were studied at Gezira Agricultural Research Station (Babiker and Mohamed 1989, 1990, 1991, 1992). The results showed that freshly harvested seeds were dormant and this dormancy was physically controlled by glumes. Glume removal resulted in more than 80% germination. Presowing irrigation once or twice and early hand-weeding were ineffective in controlling wild sorghum (Tables 3 and 4). Delayed weeding gave better control but provided less incentive to farmers as serious losses would have already been inflicted during the early stages of crop growth.

Table 1. Effect of different population densities of *Sinapis arvensis* on wheat grain yield at Hudeiba Research Station, 1993/1994.

Weed population		Grain yield (kg/ha)	% decrease in yield due to wild sorghum
% w/w†	Plants/m^2		
0	0	1799	
0.5	6	592	67
1.0	12	273	85
2.0	22	145	92
4.0	43	159	91
6.0	60	35	98
SE (±)		95	

† % w/w = Percent weight of weed seeds in wheat seed used for sowing.

Table 2. Effect of wild sorghum population densities on wheat yield, 1989/90.

Treatment	Grain yield (t/ha)
10 wild sorghum plants/m row length	2.1
5 wild sorghum plants/m row length	2.4
2.5 wild sorghum plants/m row length	2.6
1.7 wild sorghum plants/m row length	3.0
1.3 wild sorghum plants/m row length	3.0
1 wild sorghum plant/m row length	3.2
Hand-weeded control	3.2
Unweeded control	2.7
SE (±)	0.3

Table 3. Effect of presowing irrigation on wild sorghum infestation and wheat yield at Gezira Research Station, 1989/90.

Presowing irrigation	Wild sorghum population (1000/ha)		Grain yield (t/ha)
	Just before sowing	70 days after sowing	
None	0	38	1.60
One	55	47	1.80
Two	60	54	1.50
SE (±)			0.23

Table 4. Effect of weeding time on wild sorghum control and yield of wheat at Gezira Research Station, 1989/90.

Treatment	% control	Grain yield (t/ha)
Uninfested control		3.4
Infested control	0	2.3
Single weeding 3 WAS†	0	2.6
Single weeding 6 WAS	70	2.8
Single weeding 9 WAS	86	2.7
Two weedings 3 and 6 WAS	58	3.1
Two weedings 3 and 9 WAS	91	2.6
Two weedings 6 and 9 WAS	90	2.4

† WAS = Weeks after sowing.

The efficacy and selectivity of the herbicides Puma (phenoxy-p-ethyl) and Topik (clodinafop-propargyl), as post-emergence treatments, were evaluated for weed control (including wild sorghum) in wheat at Gezira and New Halfa (Babiker and Mohamed 1991, 1992; Osman 1992, 1993; Babiker *et al.* 1993; Babiker and El Mana 1994). The herbicides gave complete and lasting control of wild sorghum and increased wheat grain yield by up to 61% (Tables 5, 6 and 7). However, they displayed poor activity against broad-leaf weeds. In an on-farm trial, Puma was aerially sprayed at 0.071 kg a.i./ha, 28–42 days after planting on 145 ha in Gezira. The results indicated the feasibility of aerial application and possible control of wild sorghum on a large scale.

Table 5. Performance of post-emergence application of Puma† in controlling wild sorghum and affecting yield of wheat at Gezira Research Station, 1990/91 and 1991/92.

Treatment‡	% control		Grain yield (t/ha)	
	1990/91	1991/92	1990/91	1991/92
Weeded control	100	100	3.50	2.55
Unweeded control (WSI)	0	0	1.37	2.14
Puma 2 WAS at 0.036 kg a.i./ha	80	100	2.90	2.62
Puma 2 WAS at 0.072 kg a.i./ha	92	100	3.18	2.95
Puma 2 WAS at 0.108 kg a.i./ha	100	100	3.20	3.17
Puma 3 WAS at 0.036 kg a.i./ha	100	100	2.73	3.40
Puma 3 WAS at 0.072 kg a.i./ha	100	100	2.67	3.57
Puma 3 WAS at 0.108 kg a.i./ha	100	100	3.11	3.81
Puma 4 WAS at 0.036 kg a.i./ha	92	100	2.09	3.02
Puma 4 WAS at 0.072 kg a.i./ha	96	100	1.99	3.25
Puma 4 WAS at 0.108 kg a.i./ha	94	100	1.39	3.38
SE (±)			0.20	0.48

† Puma = Phenoxy-p-ethyl.
‡ WSI = Wild sorghum infested; WAS = Weeks after sowing.

Table 6. Performance of post-emergence application of Topik† in controlling wild sorghum and affecting yield of wheat at Gezira Research Station, 1991/92.

Treatment‡	% control	Grain yield (t/ha)
Wild sorghum-free control	100	3.88
Wild sorghum infested control	0	2.38
Topik 2 WAS at 0.04 kg a.i./ha	100	3.07
Topik 2 WAS at 0.08 kg a.i./ha	100	3.26
Topik 2 WAS at 0.12 kg a.i./ha	100	3.40
Topik 3 WAS at 0.04 kg a.i./ha	100	3.31
Topik 3 WAS at 0.08 kg a.i./ha	100	3.47
Topik 3 WAS at 0.12 kg a.i./ha	100	3.70
SE (±)		0.09

† Topik = Clodinafop-propargyl.
‡ WAS = Weeks after sowing.

Table 7. Performance of post-emergence application of Puma and Topik† at Gezira Research Station in controlling wild sorghum and affecting wheat yield, 1992/1993.

Treatment‡	% control	Grain yield (t/ha)
Wild sorghum-free control	100	3.62
Wild sorghum infested control	0	2.67
Topik 3 WAS at 0.08 kg a.i./ha	100	3.38
Topik 3 WAS at 0.12 kg a.i./ha	100	3.50
Topik 4 WAS at 0.08 kg a.i./ha	100	3.05
Topik 4 WAS at 0.12 kg a.i./ha	100	3.25
Puma 3 WAS at 0.072 kg a.i./ha	92	3.18
Puma 3 WAS at 0.108 kg a.i./ha	100	3.25
Puma 4 WAS at 0.072 kg a.i./ha	92	3.23
Puma 4 WAS at 0.108 kg a.i./ha	100	3.23

† Puma = Phenoxy-p-ethyl; Topik = Clodinafop-propargyl.
‡ WAS = Weeks after sowing.

Presowing irrigation, in addition to two methods of sowing and early hand-weeding were evaluated as an integrated weed management practice in wheat at Hassa and Zeidab in northern Sudan (Mohamed and Ibrahim 1993, 1994). Presowing irrigation resulted in an average of 21% increase in yield over the irrigated control. Broadcasting the seed and ridging, as a method of sowing, was superior to sowing on flat. Early hand-weeding significantly increased grain yield of wheat. However, the increase in yield at Hassa was not significant (Table 8).

Weeding regime experiments were conducted at Zeidab and Rahad with the objective of determining and recommending an economic weeding treatment (Hamada 1994; Mohamed 1994a). One or two hand-weedings at different times were compared with weed-free and weedy checks. The results showed that weeding twice (at four and eight weeks after sowing) was best (Table 9).

Pre-emergence herbicides, as a prophylactic measure, were tested at New Halfa (Osman 1992, 1993). All herbicides tested gave satisfactory to excellent control of grasses, but only Starane and Logran displayed good activity against broad-leaf weeds (Table 10). In general, Starane, Logran and Goal showed promising results but need to be further evaluated for confirmation of their efficacy.

Table 8. Effect of integrated weed management in wheat on grain yield in northern Sudan, 1992/93 and 1993/94.

Treatment	Grain yield (t/ha)			% increase in yield
	Hassa 1992/93	Zeidab 1993/94	Means	
Presowing irrigation				
No	3.50	1.40	2.5	
Yes	4.10	1.90	3.0	21
SE (±)	0.13	0.16		
Method of sowing				
Sowing on flat	3.50	1.50	2.5	
Broadcasting and ridging	4.00	1.80	2.9	18
SE (±)	0.13	0.12		
Weed control				
Unweeded	3.70	1.50	2.6	
Weeded control	3.90	1.80	2.9	10
SE (±)	0.13	0.10		

Table 9. Effect of different weeding regime treatments on seed yield of wheat at Zeidab, 1993/94.

Treatment	Grain yield (kg/ha)	% increase over weedy check
One weeding at 4 WAS†	1648	33
One weeding at 6 WAS	1741	33
One weeding at 8 WAS	1694	37
Two weeding at 4 and 6 WAS	1685	36
Two weeding at 4 and 8 WAS	1815	46
Weed-free check	1658	33
Weedy check	1241	
SE (±)	321	

† WAS = Weeks after sowing.

Table 10. Effect of different pre-emergence herbicides on weed control and wheat yield at New Halfa, 1991/92 and 1992/93.

Herbicide rate (kg a.i./ha)	% weed control				Grain yield (t/ha)	
	1991/92		1992/93		1991/92	1992/93
	Grasses	Broad-leaf weeds	Grasses	Broad-leaf weeds		
Starane at 0.595	93	65	62	60	3.9	3.6
Starane at 0.833	89	75	75	65	2.7	3.4
Logran at 0.0178	89	74	65	82	3.4	3.6
Logran at 0.0238	89	93	71	80	3.3	3.9
Granstar at 0.0178	87	41	70	63	3.0	3.3
Granstar at 0.0238	79	38	72	70	2.6	3.4
Harmony at 0.0178	59	41	42	50	2.9	3.3
Harmony at 0.0238	85	41	30	42	3.1	3.1
Goal at 0.297	100	42	91	47	3.9	3.7
Goal at 0.357	100	63	95	65	2.8	3.4
Stomp at 1.428	96	51	92	51	3.0	3.1
Weeded control	100	100	100	100	3.5	3.9
Unweeded control	0	0	0	0	2.2	3.2
SE (±)					0.4	0.3

Conclusions

Weed surveys indicated that there are some variations in composition and distribution of weed flora in the Sudan. Some weeds (*Malva* sp., *Chenopodium* sp., *Sinapis arvensis* and wild sorghum) started to spread and dominate new areas. Wheat, a crop which is not normally weeded in the Sudan, provides an environment which is conducive to spreading and multiplication of these weeds. The use of weed-free wheat seeds should be emphasized. Monitoring weeds helps to determine the appropriate control measure and may allow prediction of future changes in the weed flora under given cultural practices.

For profitable wheat production, timely removal of wild sorghum (three to six weeks after sowing) is necessary. However, dormancy of seed and/or crop mimicry—the weed looks similar to wheat—precludes efficient removal during early stages of growth. Dormancy in wild sorghum is broken when glumes are removed. In nature, this could occur through operation of agricultural implements or by the activity of insects and soil microorganisms.

Presowing irrigation was ineffective in controlling wild sorghum at Gezira, but still gave higher yields. The practice was more effective in Hassa and Zeidab where it improved the seedbed and reduced weed population, particularly that of grasses, although it was less effective against broad-leaf weeds. Coupled with broadcasting of seed and ridging and early hand-weeding, presowing irrigation appeared to be very effective as an integrated weed management practice at Hassa and Zeidab schemes. Time and frequency of presowing irrigation are very important and should be further studied since most broad-leaf weeds need low temperatures to germinate.

The herbicides Puma and Topik proved to be very effective against wild sorghum in wheat. Since the wild sorghum infestation is generally localized and the two herbicides are applied post-emergence, they can be applied when the problem is noticed. However, these herbicides do not control broad-leaf weeds and there may be a need for other post-emergence herbicides to be mixed with them to provide wide-spectrum weed control. A proper control strategy is to use clean wheat seed and adopt an integrated weed management policy that includes cultural and chemical methods.

References

Babiker, A.G.T. 1978. Agricultural Research Corporation, Gezira Research Station, Annual Report 1977/78, Wad Medani, Sudan.

Babiker, A.G.T. and El Mana, M.E. 1994. Weeds and weed control in wheat. Pages 247–250 *in* Annual National Coordination Meeting on Wheat Report, 28 August–1 September 1994, Agricultural Research Corporation, Wad Medani, Sudan.

Babiker, A.G.T. and Mohamed, A.H. 1989. Chemical control of wild sorghum in wheat at Gezira Research Station. Pages 45–46 *in* Nile Valley Regional Program on Cool-Season Legumes and Cereals, Annual Report 1988/89, Sudan. ICARDA/NVRP-DOC-007.

Babiker, A.G.T. and Mohamed, A.H. 1990. Wild sorghum in wheat, biology, importance and control. Pages 285–296 *in* Annual National Coordination Meeting on Wheat Report, 27–31 August 1990, Agricultural Research Corporation,Wad Medani, Sudan.

Babiker, A.G.T. and Mohamed, A.H. 1991. Wild Sorghum (*Sorghum sudanensis*), importance and Control in Wheat. Pages 59–63 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1990/91, Sudan. ICARDA/NVRP-DOC-017.

Babiker, A.G.T. and Mohamed, A.H. 1992. Wild Sorghum (*Sorghum sudanensis*), importance and Control in Wheat. Pages 73–76 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1991/92, Sudan. ICARDA/NVRP-DOC-025.

Babiker A.G.T., Mohamed, A.H. and El Mana, M.E. 1993. Herbicidal efficacy of Topik and Puma on wild sorghum and its selectivity to wheat. Pages 78–79 *in* Nile Valley Regional Program on Cool- Season Food Legumes and Wheat, Annual Report 1992/93, Sudan. ICARDA/NVRP-DOC-031.

Babiker, A.G.T., Mohamed, A.H., Mansi, M.G., Adam, A., Beshir, Y.A., Ahmed, A.J. and El Mardi, A. 1989. Weed survey in wheat in the Gezira Scheme. Page 45 *in* Nile Valley Regional Program on Cool-Season Legumes and Cereals, Annual Report 1988/89, Sudan. ICARDA/NVRP-DOC-007.

Bushara, A. and Osman, A.G. 1987. Agricultural Research Corporation, New Halfa Research Station, Annual Report 1986/87, Wad Medani, Sudan.

De-Datta, S. K. 1977. Weed control in rice in Southeast Asia. Methods and trends. Philippine Weed Science Bulletin 4: 39–65.

Hamada, A. A. 1994. Weed management in wheat at Rahad. Pages 250–253 *in* Annual National Coordination Meeting on Wheat Report, 28 August–1 September 1994, Agricultural Research Corporation, Wad Medani, Sudan.

Mohamed, E. S. 1994a. Weeding regime in wheat in Northern Sudan. Pages 254–255 *in* Annual National Coordination Meeting on Wheat Report, 28 August–1 September 1994, Agricultural Research Corporation, Wad Medani, Sudan.

Mohamed, E. S. 1994b. Weed competition in wheat in Northern Sudan. Pages 255–256 *in* Annual National Coordination Meeting on Wheat Report, 28 August–1 September 1994, Agricultural Research Corporation, Wad Medani, Sudan.

Mohamed, E.S. and Ibrahim, O.H. 1993. Integrated weed management in wheat. Pages 80–81 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1992/93, Sudan. ICARDA / NVRP-DOC-031.

Mohamed, E.S. and Ibrahim, O.H. 1994. Integrated weed management in wheat. Pages 257–259 *in* Annual National Coordination Meeting on Wheat Report, 28 August–1 September 1994, Agricultural Research Corporation, Wad Medani, Sudan.

Mohamed, E.S. and Mohamed, M.I. 1992a. Weed survey in wheat in the Northern State. Pages 24–25 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1991/92, Sudan. ICARDA/NVRP-DOC-025.

Mohamed, E.S. and Mohamed, M.I. 1992b. Weed competition in wheat in the Northern State. Pages 69- 70 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1991/92, Sudan. ICARDA/NVRP-DOC-025.

Mohamed, E.S. and Mohamed, M.I. 1993a. Weed survey in wheat in the Nile River and Northern States. Pages 23–24 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1992/93, Sudan. ICARDA/NVRP-DOC-031.

Mohamed, E.S. and Mohamed, M.I. 1993b. Weed competition in wheat in the Nile River and Northern State. Pages 74–75 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1992/93, Sudan. ICARDA/NVRP-DOC-031.

Osman, A.G. 1987. Agricultural Research Corporation, New Halfa Research Station, Annual Report 1986/87, Wad Medani, Sudan.

Osman, A. G. 1992. Chemical weed control in wheat in New Halfa. Pages 70–73 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1991/92, Sudan. ICARDA/NVRP-DOC-025.

Osman, A. G. 1993. Chemical weed control in wheat in New Halfa. Pages 75–77 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1992/93, Sudan. ICARDA/NVRP-DOC-031.

Rao, M.V., Dubey, A.N. and Manna, G.R. 1977. Probability of existence of pre-emergence herbicides-moisture-variety interaction adverse to direct seeded rice on uplands. Indian Journal of Weed Science 8: 22–31.

Saeed, A. 1973. Agricultural Research Corporation, New Halfa Research Station, Annual Report 1972/73, New Halfa, Sudan.

Discussion

Q: Tag Elsir Elamin

What is the possibility of using chemicals (post-emergence herbicides) to control noxious weeds such as *Brachiaria* and *Cynodon dactylon*?

A: El Sadig Mohamed

It is possible to control most of those weeds with the same herbicides, but *Cynodon dactylon* cannot be controlled. However, the competition ability of this weed is less when winters are good.

Q: G. Youssef

What do you think has brought about wild oats in wheat in Egypt and wild sorghum in wheat in the Sudan all of a sudden? My second question is, when the herbicide loses effectiveness, could that be due to the plant forming a resistance mechanism, and would it be chemical, taxonomical or genetic?

A: El Sadig Mohamed

The weeds were introduced through contaminated seeds. The use of clean, weed-free seeds should be emphasized. As for your second question, resistance was not developed through the continuous application of the herbicides.

Comment: Mohamed A. Gabbar

I disagree with the use of herbicides for controlling wild sorghum. The use of high quality seed is the proper solution.

A: El Sadig Mohamed

I agree with you, but the similarity between wild sorghum and wheat seeds precludes having clean, weed-free seeds through conventional cleaning devices.

Q: M.S. Mohamed

What are the weeds that are controlled by pre-emergence herbicides? Also, please specify the weeds favored by the wheat growth environment.

A: El Sadig Mohamed

Weeds controlled by pre-emergence herbicides include wild sorghum, *B. eruciformis* and *Dinebra retroflexa*. Weeds favored by wheat include *Malva* sp., *Sinapis arvensis*, *Chenopedia album* and *Beta vulgaris*.

Comment: Participant

I think that it would have been appropriate to include the pre-Nile Valley Project in the wheat review in order to include the work done in the Eastern Region, especially the work of the late Dr. A. Saeed.

A: El Sadig Mohamed

This should have been included but, unfortunately, I have not done that because of the specified peroid limitation of the review (1984/85–1994/95).

Q: Mohamed M. Omer

You mentioned that farmers who applied nine irrigations, which were five irrigations more than what the other farmers applied, still found them cheaper and more economical. Please comment on that.

A: El Sadig Mohamed

The amount of irrigation in the case of long intervals is 3–4 times that applied in the case of frequent irrigation.

Q: Mostafa Bedier

Any recommendation on using herbicides or not should be based on economic feasibility and the benefit to farmers. Pollution of the environment is another issue of major concern. Therefore, all these factors should be considered when economic evaluation is carried out.

A: El Sadig Mohamed

Economic evaluation is always considered. No recommendation is issued without first conducting an economic evaluation. Regarding environmental pollution, herbicides are less harmful than insecticide.

Q: M.A. Rizk

Did you study the residual effect of the used herbicides on subsequent crops?

A: El Sadig Mohamed

The effect of the herbicides on subsequent crops was also studied (bio-assay of residual effect). Most herbicides tested had no effect.

Comment: Omer H. Ibrahim

Some integrated work on timing of prewatering, sowing date and control of weeds outside the conventional domain is needed.

A: El Sadig Mohamed

I gratefully acknowledge this initiative and am willing to do some joint work.

Chapter 5
Technology Transfer

Wheat Technology Transfer

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Abstract

The major wheat-productivity constraints which technology development and transfer address can be grouped into weather, cultivars and sowing dates; crop establishment practices; nutrition and irrigation; harvesting practices; and biological factors. The total yield effect of these factors, adjusted for factor interactions, ranged from 2.12 to 2.84 t/ha in 1985/86, with high potential profitability. Technological production packages, suited to different localities, have been verified with farmer-managed and demonstration trials, after previous testing through on-farm researcher-managed and on-station trials. With time, the technologies have been modified in response to feedback from trials and economic changes. Wheat yields with the technology reached 4.26 t/ha in traditional wheat-producing areas and 3 t/ha in new areas of wheat production. Average yield increases in different areas ranged from about 0.57 to 0.93 t/ha in the period 1985/86–1994/95, with an overall average yield advantage of 0.83 t/ha, representing 52% increase. Improvements in net returns due to the technology varied from LS 2,460 to LS 21,402 per ha, which were 314 to 5,564% of extra technology costs. Still, wheat yield has been influenced by the levels of nitrogen, irrigation regime, sowing date, land preparation, harvesting time, type of cultivar and sowing method. Farmers' reactions to the improved technology was generally positive and their actual adoption was substantial, though variable among seasons and areas. Improved cultivars, tillage operations and mechanical planting were generally highly adopted. The irrigation regime was often suboptimal, and adoption of the fertilizer recommendations was variable and moderate. Limited availability of inputs and their high costs were major reasons behind the partial adoption failure. Farmers' awareness of specific recommendations was unexpectedly low, implying the need for intensifying extension services. Yield variability prevailed, where yield gaps of 1.02 to 1.7 t/ha were reported among locations and 0.58 t/ha among farmer groups. Gaps of up to 1.09 t/ha were recorded between demonstration plots and low-yielding locations. Location differences and various management practices were found responsible for yield gaps, which entails uncertain wheat profitability in poor locations. The impact of technology transfer has been reflected in the increased production, brought by a modest rising yield trend and increasing wheat areas.

Production reached a level adequate to meet domestic needs in the 1991/92 season. Besides, the intervention of many institutions has been enhanced, government support has been encouraged, and high interaction among researchers, extension staff, farmers and decision makers has been initiated.

Productivity-Limiting Factors and Research Response

Many factors are known to affect wheat productivity in its main growing areas. Generally classified (Hassan and Faki 1993), these factors may be grouped into weather, cultivars and sowing dates; crop establishment practices; nutrition and irrigation; harvesting practices; and biological factors.

Weather, especially winter temperatures, is probably the most important single yield-influencing factor that has critical implications on the choice of cultivars and sowing dates. Significant negative correlation between wheat yields and mean temperatures in December, January and February was computed for the Gezira (Faki and Ismail 1994a). In response, research recommendations have shifted from long- to short-maturing cultivars such as Condor, Debeira and Wadi El Neil that have also better response to fertilizers and irrigation water. Similarly, agronomic research (Ageeb *et al.* 1988b, 1989) has induced a delayed shift in the sowing date from mid-October to November. However, sowing later than November may actually take place as a result of problems in the calendar of summer cropping that jeopardize water availability for wheat sowing, in addition to land preparation bottlenecks.

Crop establishment is associated with the quality of tillage operations, seed rate and the sowing method. According to research recommendations, mechanical sowing and disc harrowing are being increasingly applied. Currently, research tends to identify location-specific and cost-effective methods associated with minimum tillage. In places where farmers are in a position to apply presowing irrigation or wet planting, crop stands are much better in some seasons (Faki 1992). The seed rate interacts with land preparation practices, shortcomings of which have induced recommending a relatively high seed rate of 143 kg/ha.

The traditional fertilizer levels, which comprised nitrogen alone at 86 kg N/ha, have been modified to include a phosphorus supplement at 43 kg P_2O_5/ha, based on results of on-farm researcher-managed trials which ensured profitability of this dose (Ageeb *et al.* 1987b, 1988a). However, a blanket dose of fertilizer applied over vast areas of irrigation schemes would not be expected to comply with an economically optimum use of such a scarce input. Differential fertilizer doses are currently being tested in on-farm trials in different locations according to defined bench-mark soils.

Irrigation water and irrigation practices are factors that have always limited wheat productivity. Prevailing methods run short of attaining the recommended eight attended waterings in 56 small basins of the standard 2 ha wheat holdings. Water difficulties dictate less watering, while fields with large-sized basins is a common phenomenon. Water is left to flow unattended in the field, many times by night. Farmers who applied an average of 7.8 irrigations in the 1985/86 season were reported to obtain 23% more yields than the schemes' average (with 5.7 irrigations) and 43% more yields than with four irrigations (Faki and Abdel Fattah 1986). On-station and on-farm researcher-managed trials produced profitable yield increases of 0.76 and 0.75 t/ha, respectively, with the application of nine versus five waterings under the Gezira conditions (Ageeb *et al.* 1987b). The recommendation is that the 14-day watering regime needs to be shortened at the reproductive stages, especially under warm weather conditions.

Sizeable losses are encountered due to harvest delays induced by the limited availability of combine harvesters for which competition exists between rainfed sorghum and wheat harvesting. Inappropriate harvesting practices are themselves important factors that result in harvest losses which were reported to range from 13 to 21% in Gezira, Rahad and New Halfa in 1993/94 (Dawelbeit 1994).

Aphid insects and many types of weeds, especially wild sorghum, are the major biological constraints to wheat production in central and northern Sudan. Although aphids are usually easily controlled by one or two insecticidal sprays, wild sorghum and noxious weeds such as *Cynodon dactylon* 'nagil', that are found in most irrigation schemes, are difficult to control. Keen farmers collect rhizomes of *Cynodon dactylon* 'nagil' after ploughing and burn them (Faki and Abdel Fattah 1986). Wild sorghum (*Sorghum sudanenses*) poses an important problem, especially in warm seasons. Besides hand-weeding, chemical control is currently being recommended against this weed.

The effects of individual production factors on wheat yield were quantified from field survey data collected in eight locations of four traditional wheat areas in the 1985/86 season (Faki and Abdel Fattah 1986). The sowing date and land preparation, particularly levelling, were common influencing factors almost in all areas. Irrigation contributed significantly in most areas. Crop establishment status was evaluated for the Gezira through visual field rating of crop stands, patchiness and weeds. The effects of the seed rate and fertilizers were monitored in areas where variable quantities of these inputs were applied, such as in north Sudan and New Halfa. The estimated effect of these factors was large. Yield increases with high levels of their application ranged from 0.41 to 1.85 t/ha, associated with extra net benefits that ranged between LS 53 and LS 1,854 per ha at the price and cost levels of 1986. Taking factor interactions into consideration, the sum of the individual factor effects, as adjusted to match the differences between average and highest yields in each region, was significant (Table 1).

Table 1. Adjusted total factor effects on wheat yields in traditional wheat-producing areas in the Sudan, 1985/86.

Area	Adjusted improvement (t/ha)
Gezira/Managil	2.25
New Halfa	2.60
North	2.84
Nile	2.12

Source: Faki and Abdel Fattah (1986).

Subject to those situations, many farm-level improvements were possible. Yields and incomes could be raised within the prevailing conditions at that time through better quality operations which were actually followed by some farmers. Yet, further improvements were reported as feasible through the development and transfer of improved technology. Fig. 1 shows improvement potentials as reflected by gaps among average farmers' yields, highest yields attained by some farmers, and research yields attained from on-farm trials.

Informal field surveys were employed in 1990/91 to monitor wheat production conditions in schemes to which wheat had been recently introduced, namely, Rahad, Blue Nile and White Nile schemes. The surveys exposed many important constraints to wheat production (Faki *et. al.* 1991a). The warm weather in those areas entails the use of adaptable wheat cultivars and better tuning of sowing dates for efficient utilization of the short cool winter period. Improvement in the quality of land preparation practices and sowing methods was regarded as important to ensure better crop establishment. An adequate supply of seeds free from weed seeds is essential, while an assured supply of different cultivars is needed to allow farmers to shift to the suitable one in response to pressures in sowing time as affected by water availability in the Blue and White Nile schemes. Inconsistent irrigation regimes and fertilizer doses were noticed that necessitate an initial recommendation of their minimum levels of six irrigations and 86 kg N/ha and further research to delineate optimum levels tailored to each locality. Weeds posed considerable problems. Of special significance was wild sorghum which was observed to infest wide areas and for which appropriate weed management strategies should be designed. Policy and institutional aspects acquire high relevance in those areas where wheat is a new crop with which farmers have limited acquaintance and where weather conditions are less favorable. Measures need to be taken at regional and national levels that provide incentives to farmers, such as sound input and crop prices, adequate supply of credit and intensification of extension services.

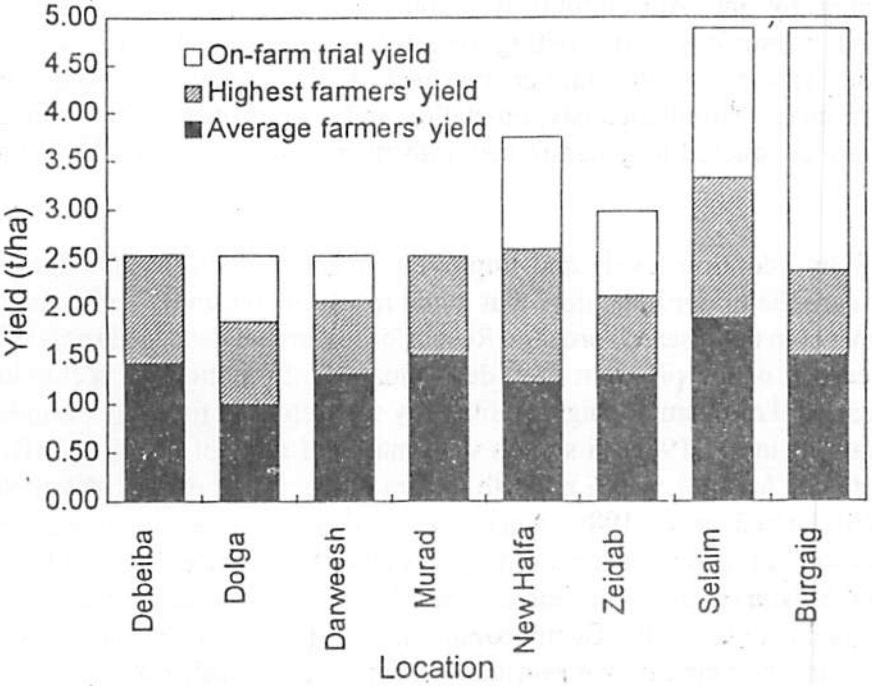

Fig. 1. Wheat yield gaps in the main wheat-producing areas in the Sudan, 1985/86.

On-Farm Research Activities

Wheat has enjoyed high research attention for many decades. On-station research is pursued within all irrigation schemes to address different natural factors. Both yields and quality aspects were considered in past research. Many recommendations found acceptance and use among producers, such as improved cultivars, rotational aspects and various cultural practices. The research approach adopted by the Nile Valley Project (NVP) on Faba Beans, coordinated by ICARDA since the late 1970s, has encouraged on-farm research with farmers' participation and involvement of extension, schemes' administration and field staff. This has strengthened the researcher-farmer linkage and induced plenty of feedback on problems faced by producers. Wheat research benefitted from this approach since 1985/86 under an ICARDA/OPEC project for wheat improvement. The NVP was replaced by the Nile Valley Regional Program (NVRP) on Cool-Season Food Legumes and Wheat within which wheat constitutes a major research component. Under both the ICARDA/OPEC project and the NVRP, technological packages have been formulated by the Agricultural Research Corporation (ARC), based on identified constraints and existing research findings, and verified in all irrigation schemes with farmer-managed trials and pilot production/ demonstrations. Simultaneously, on-station and on-farm researcher-managed trials were conducted to generate new information and consolidate available findings.

Technology adoption levels and improvement in productivity and farmers' incomes are the major indicators that guide research continuity and needs for amendments in the research process. Results of researcher-managed trials in the early seasons of the program provided valuable information for technology modification. For example, high profitability was reported for higher numbers of irrigations in the 1985/86 season with marginal rates of return (MRR) of 557% at Wad Medani, 940% in north Gezira (Turabi) and over 100% at New Halfa (Mohamed *et al.* 1986; Ageeb *et al.* 1987b). In north Sudan, more irrigations could increase net benefits by LS 203 per ha (at Zeidab) and LS 155 per ha (at Selaim) in the same season. The effect of phosphorus application was positive and high under the Gezira conditions, with MRR of 98% and 166% at two locations. Pest control was profitable in north Sudan, with extra net benefits of LS 117 per ha at Zeidab and LS 101 per ha at Selaim where, at the latter site, nitrogen improved net returns by LS 445 per ha. As also reported from field surveys, early sowing had negative effects in Gezira and north Sudan. The effect of tillage (disc ploughing) was variable, being negative in Gezira and positive in New Halfa with MRR of 312%.

Many other factors and sites have been investigated to contribute to improvements in the technology development. An overview of the components of technological packages verified with on-farm trials and their development since the mid-eighties are shown in Table 2.

Table 2. Overview of wheat technology development with on-farm verification in the Sudan, 1985/86–1994/95.

Location	Basic package components	Developments
Gezira/Managil	• Tillage: disc harrowing, levelling • Sowing date: 15 Oct. to 15 Nov. • Irrigation regime: 14-day interval	• Introduction of phosphate fertilizers • New cultivars: Debeira • Sowing date: through Nov. • Seed rate: from 114 to 143 kg/ha • Tillage: cost-effective methods (harrowing or ridging, split ridging and levelling) • Sowing method: wide level disc, planter • Sites: to low producing areas • Differential fertilizer levels (soil type) • Presowing irrigation, water ties
New Halfa	• Varieties: Condor, Debeira • Tillage: discing, harrowing, levelling • Sowing date: 15 Oct. to 15 Dec. • Irrigation regime: 14-day interval	• Good levelling (with steel frame) • Sowing method: ridger *mastabas* • N fertilizer (86 kg N/ha) • Timely harvesting
North Sudan	• Sowing date: early Nov. • Variety: Giza 160 • Nitrogen: 86 kg N/ha • Irrigation: 14-day interval • Aphid control	• Far north: weed control, presowing irrigation, farm diagnosis • Movement to southern areas: - Small private schemes - High Terrace soils, manure • Split N doses, P application

Table 2. (Cont'd).

	Movement to new areas of wheat production in 1990/91
Rahad	• Tillage: early ridging (Sept.), disc harrowing, levelling (frame) • Sowing date: Nov. • Sowing method: wide level disc vs. seed drill • N and P fertilizers • Fertilizer application: seed drill vs. Vicon spreader
White Nile	• Good levelling • Sowing method: 60 cm ridges • Variety: Condor (possibility of late sowing) • Seed rate: 143 kg/ha • Sowing date: Nov. • N and P fertilizers (86 kg N + 43 kg P_2O_5/ha) • Irrigation regime (14-day interval), water ties
Blue Nile	• Tillage: subject to machine availability; Sept. ridging, ridging/harrowing, levelling • Variety: Condor (possibility of late sowing) • Seed rate: 143 kg/ha • Sowing date: Nov. • Sowing method: 60 cm ridges; hand broadcast • N and P fertilizers (86 kg N + 43 kg P_2O_5/ha) • Irrigation regime: 14-day interval

Source: Ageeb *et al.* (1987a, 1988a, 1989, 1990); Taha *et al.* (1986); Mohamed *et al.* (1987); Taha and Mohamed (1987); Babiker *et al.* (1990, 1992); Omer (1990); Salama *et al.* (1990, 1992); Sarrag and Taha (1990); Taha (1990); Faki *et al.* (1991a, 1993, 1994); Mohamed and Ahmed (1991, 1992); Sarrag *et al.* (1991, 1992); Omer and Faki (1992); Satti and Faki (1992); Ahmed *et al.* (1995).

Trial conduct has been dynamic to adjust to changing situations. The main developmental features are modifications in technology components; technology developments for new areas of wheat production; change in trial locations; expansion in the scale of trials and change in emphasis, subject to the evaluation of results; emerging biological factors; farmers' feedback; and policy measures. Greater emphasis has been given in later seasons to poor wheat-producing sites, such as Managil and some parts of southern Gezira, after considerable trials' success at relatively more favorable sites in early seasons. Modifications in technology components were made to match such a shift and to benefit from the results of back-up research. Response to economic changes was reflected by widening the technology options to exploit the feasibility of use of low-cost inputs and allow more technology tuning to location-specific characteristics, such as soil status and climate.

Trial conduct, in terms of site selection and trial execution, is a joint responsibility of researchers, extension workers and administrative staff of production schemes. The package factors are applied by farmers themselves with direct advice, supervision and monitoring by researchers and extension staff. The trials have continued to provide a good environment for extension work, among which the organization of field days has been important. They have also encouraged policy support to wheat production through illustration of the technology's effectiveness to decision makers.

Enormous contributions to demonstration trials were made by interventions of the Sasakawa-Global 2000 Agricultural Project (SG 2000)[4] and the extension departments of irrigation schemes, especially the Gezira. The SG 2000's activities started in 1986/87 and continued to 1989, covering many schemes and crops. The 1990/91 season witnessed high intervention of the Gezira Extension Department through elaborate technology demonstration in one large area. This was followed by a wider spread in other locations in the following seasons, though with the involvement of fewer farmers. In total, both spatial spread and involvement of more farmers have characterized such interventions, as summarized in Table 3 and detailed in Appendix 1.

Table 3. Summary of areas and farmer participation in demonstration trials administered by the ARC, SG 2000 and extension departments of irrigation schemes in the Sudan, 1988/89–1993/94.

Season	No. of farmers	Wheat area (ha)
1988/89	3087	6470
1989/90	916	1863
1990/91	12750	26517
1991/92	1345	2784
1992/93	454	647
1993/94	844	1721

Source: Nile Valley Regional Program, Annual Reports (1989 to 1994); SG 2000 Annual Reports (1989, 1990); records of the Sudan Gezira Extension Department.

[4] See note 1, p. 11.

These undertakings were accompanied by endeavors to promote technology use over the whole Gezira, as well as in other schemes, depending on government support in the form of input availability and price policy incentives. Together with wheat area expansion, appreciable success has been achieved in increasing wheat production. Variability, however, has been exorbitant due to inconsistent availability of the technology's prerequisites to match the ambitious scale of operation, and inadequate institutional and policy tools to secure the desired farmers' response.

Results of Technology Transfer Activities

Effect on Wheat Yields

Average wheat yield levels of participant farmers in farmer-managed and demonstration trials, as compared with those of similar numbers of neighboring nonparticipant farmers, in the period 1985/86–1994/95 are detailed in Appendix 2 for different localities. Significantly higher yields were realized by participant farmers, reflecting the enormous effect of the improved technologies. Trial average yields in individual seasons ranged from 1.28 to 4.26 t/ha in the four old wheat-producing areas (Gezira and New Halfa schemes, and North and Nile River states) and between 0.9 and about 3 t/ha in new areas (Rahad, White Nile and Blue Nile). High average yield improvements were realized over the specified period in different areas, as depicted in Fig. 2, which ranged from about 0.57 to 0.82 t/ha. Highest average extra yields were gained in Gezira/Managil. Paramount yields that exceeded 6.5 t/ha were obtained by some farmers in many seasons. The percentage yield increase varied from 26% in the North to 79% in the Blue Nile. The overall yield improvement averaged 0.83 t/ha, representing 52%.

Based on the magnitude of control over trial conduct, types of technology components under test and input availability, the levels of yield improvements were different. The best improvements were realized with the ARC-supervised farms, while the two other institutions drew the attention of large numbers of farmers to the benefits of improved technology and also achieved good results. Table 4 summarizes yields and scale of demonstration trials executed by different agencies in the Gezira Scheme in the period 1986/87–1990/91.

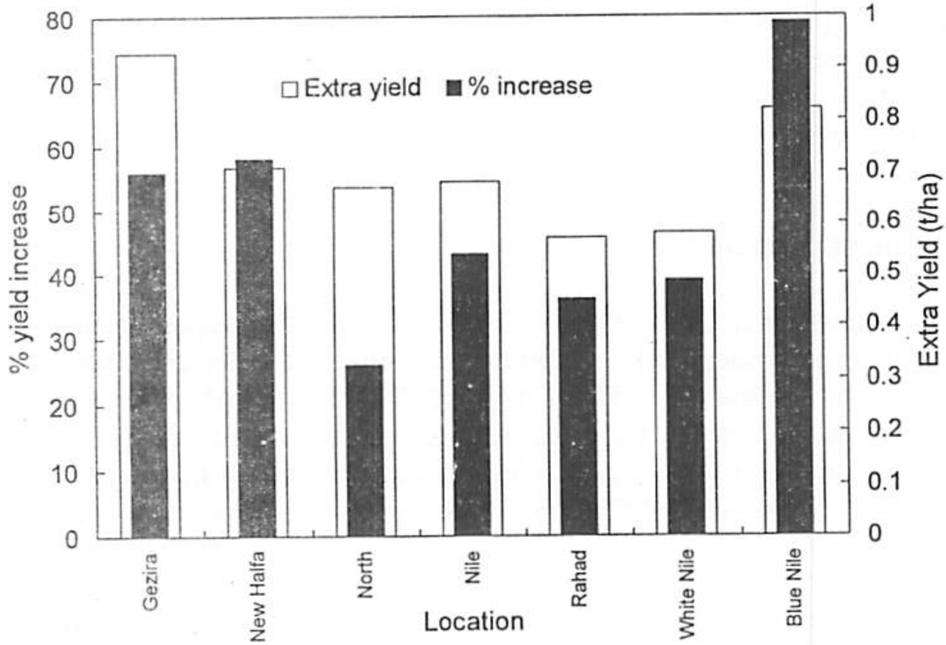

Fig. 2. Extra wheat yields with demonstration trials in irrigated areas (averages of 1985/86–1994/95).

Table 4. Average wheat yields under various levels of verification by three different agencies in the Gezira in the period 1986/87–1990/91.

Agency	Average yield (t/ha)	Total area of demos (ha)
ARC†	3.7	160
SG 2000‡	2.8	3702
Gezira Pilot Farm§	2.3	26272
Average, all Gezira Scheme	1.4	

† Full package of all technology components.
‡ Varying number of harrowings and irrigations and comparison of mechanical planting and fertilizer application to hand broadcast.
§ Without phosphorus and with less than seven irrigations.
Source: Nile Valley Regional Program, Annual Reports (1987 to 1991); SG 2000 Annual Reports (1989, 1990); records of the Sudan Gezira Extension Department.

Despite the apparent yield differences with different implementation levels, high yield improvements with the technology are apparent from the comparison of the three average trial yields with the Scheme's average of 1.4 t/ha. Yield advantages amounted to 2.3, 1.4 and 0.9 t/ha under the three modes, respectively.

Financial Benefits

Improvement in net returns due to the use of technology represents the major incentives to farmers and an important economic indicator of the technology advantage. The marginal rate of return (MRR), calculated as the percentage value of extra net benefits to extra costs that vary due to technology use, forms another profitability indicator which shows returns to investment in the technology. Another useful indicator is the ratio of participants' net benefits to those of their neighbors. Levels of these indicators, as computed with partial budget analysis for many individual areas and seasons, were encouragingly high. In later seasons (since 1990/91), when the technology use had diffused to more farmers, extra net returns, using whole farm budget analysis, and extra net benefits to individual yield-influencing factors were derived for many areas to evaluate the technology's economic feasibility. Table 5 shows average values of extra net returns, MRR and the ratio of net benefits of participant to those of nonparticipant farmers.

Table 5. Average financial profitability of wheat technology in different wheat-producing areas in the Sudan (average of variable seasons in the period 1985/86–1993/1994†).

Area	Extra net benefits (LS/ha)	MRR (%)	Ratio of net benefits
Gezira	4705	1204	181
New Halfa	9092	1383	178
North	21402	5564	142
Nile	2460	314	202
White Nile	13504	4144	229
Blue Nile	8643	1355	265

† Years: Gezira and Nile: 1986, 1987, 1989, 1994; New Halfa: 1986, 1987, 1989, 1992, 1994; North: 1986, 1987, 1994; White Nile: 1992, 1993, 1994; Blue Nile: 1992 (one season).
Source: Same as of Table 2.

These figures are indicative of the technology's profitability with respect to the three indicators. Moreover, improvements in extra net benefits were high over time. They increased from LS 227, LS 104, LS 53 and LS 49 to LS 14,759, LS 34,605, LS 64,047 and LS 70,000 per ha in Gezira, New Halfa, North and Nile, respectively, over their specified periods. The increase was partly due to inflation, but in considerable part due to rising profitability in response to technology improvements. In real terms, as measured by the exchange rate, changes in extra net benefits were positive and high, varying from 43 to 960% in these areas. The high MRR also implies high stability in the technology's profitability. Sensitivity analyses in individual seasons showed high tolerable reductions in wheat prices or high increases in package variable costs before the technology starts to become unprofitable. Such break-even values revolved mostly around 80% reduction in wheat prices in different areas or many-fold increase in package costs that ranged from 114% to as high as 11-fold. The break-even values were, however, low in a few seasons and areas, being influenced by low yield levels in response to unfavorable location effects. Moreover, extra net benefits to significant yield-influencing factors were found to range between LS 6,368 per ha in Rahad to LS 11,982 per ha in Gezira in the 1990/91 season. Whole-farm budget analysis in 1992/93 depicted improvements in farmers' net returns that varied form LS 7,291 per ha in Rahad to LS 10,756 per ha in Gezira/Managil due to the use of the technological packages. Averaged over six producing areas, improvements amounted to LS 42,486 per ha in the 1994/95 season (Ahmed *et al.* 1995).

The development of wheat improvement in on-farm trials is displayed by a comparison of average trial yields in the four traditional wheat areas over two periods: 1985/86–1987/88 and 1988/89–1994/95 which coincide with two phases of the Nile Valley Regional Program (Fig. 3). Modifications and improvements in trial components and conduct have been associated with positive improvements in trial yields that ranged from 20 to 190 kg/ha in Gezira, New Halfa and the Nile State in the two periods, respectively.

Effect of Individual Yield-Limiting Factors

The increasing efforts by scheme administrations to implement the recommended technological improvements have induced wider technology use, though with high variability. While the technology use in on-farm trials was high, some of the neighboring farmers were found to apply part of the technology. Such variability provided the possibility to trace the effects of individual package components, as well those of some other management factors, on wheat yields as from the 1990/91 season. Important factors in most schemes were the levels of nitrogen, irrigation regime, sowing date, land preparation and harvesting time. Their effects were variable among seasons and sites.

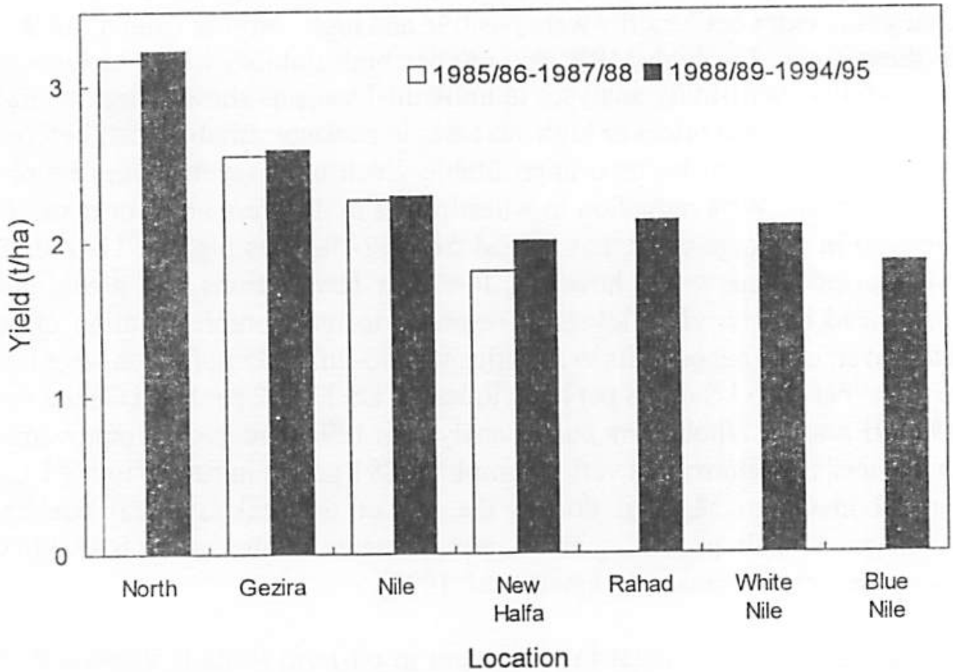

Fig. 3. Wheat yields of demonstration plots in two periods, 1985/86–1987/88 and 1988/89–1994/95.

Regression coefficients for nitrogen amounted to 10, 11 and 3 kg wheat per kg of urea at Gezira, Rahad and New Halfa, respectively, while negative coefficients were computed for the White Nile in 1990/91 (Faki *et al.* 1991a). Urea application date (with second irrigation) induced a yield increment of 616 kg/ha in Rahad in 1991/92. Similar responses to N fertilizer doses were reported for the 1992/93 season when regression coefficients ranged from 8.5 to 12.6 kg wheat per kg of urea at Managil, southern Gezira and Rahad (Faki *et al.* 1993). A quadratic response was estimated for northern Sudan in that season which depicted a functional yield increment (in kg) of 135 N - 8.8 N^2, where N denoted kg of nitrogen per ha. In 1994/95, the response ranged from 5 to 9 kg wheat/kg urea (Ahmed *et al.* 1995).

The effect of irrigation on grain yield increase in 1990/91 ranged from 174 to 229 kg/ha per irrigation at Gezira, New Halfa and the White Nile. In 1991/92, it was 156 kg/ha for New Halfa and 234 kg/ha at the Blue Nile (Salama *et al.* 1992; Omer and Faki 1992). The figures for 1992/93 ranged from 124 to 190 kg/ha per extra irrigation in central Sudan and from 311 to 811 kg/ha in north Sudan, while those for 1994/95 ranged from 117 to 622 kg/ha for north Sudan (Ahmed *et al.* 1995).

The sowing date was, in most seasons and areas, negatively correlated with wheat yield. Marginal productivities were -180 and -434 kg/ha per week of delay at Rahad and the White Nile, respectively, in the 1990/91 season. Sowing during the second half of December in 1991/92 was associated with yield advantages of 1.48 and 0.80 t/ha at the White Nile and Blue Nile schemes, respectively, as compared with those of the second half of November (Satti and Faki 1992; Omer and Faki 1992). In the following season, sacrifices ranging from 0.21 to 0.39 t/ha were recorded for delayed sowing in Managil, Gezira, Rahad and the White Nile. The effect was variable in 1994/95, being positive in Gezira and Managil, negative in the White Nile and Zeidab, and insignificant in other areas (Ahmed *et al.* 1995).

The type of cultivar was significant in many cases. Condor revealed yield advantages of 0.41 t/ha at Gezira and 0.22 t/ha at New Halfa in 1990/91. In the following season (1991/92), yield advantages of the same cultivar were 0.41 t/ha at New Halfa and 0.75 t/ha at the White Nile (Salama *et al.* 1992; Satti and Faki 1992). In northern Sudan, the cultivar Wadi El Neil gave 1.66 and 0.563 t/ha higher yield than traditional ones in 1992/93 and 1994/95, respectively.

Mechanical sowing with planters was superior to other methods at Rahad by 0.59 t/ha in 1991/92 and scored 0.41 t/ha additional yields over hand sowing (Babiker *et al.* 1992). Sowing with the wide level disc was advantageous in all areas in the 1992/93 season, with yield increments ranging between 0.17 to 0.85 t/ha. In 1994/95, its superiority was reported in Rahad, with 607 kg/ha higher yield (Ahmed *et al.* 1995). Harvesting date was important in Gezira and Rahad in 1990/91 with yield losses of 0.21 and 0.73 t/ha, respectively, with late harvesting.

Other factors contributing to yield variability were weeds and the location of tenancy with respect to the irrigation water source. Some factor interactions were also reported, especially at Rahad for cultivar/harvesting date, sowing method/urea application date, sowing method/presowing irrigation and presowing irrigation/cultivar.

Total yield improvements due to improved levels of the above-mentioned factors were paramount. Calculations for the 1990/91 season depicted total extra yields ranging between 1.17 and 2.26 t/ha and net returns between LS 6,368 and LS 11,982 per ha. When these net returns were related to corresponding variable costs, MRRs of 771%, 987%, 523% and 1646% were computed for Gezira, New Halfa and the White Nile, respectively. Yield increments of the upper 20% over the lower 20% in yield frequency distributions were 1.55, 1.29, 1.61 and 1.69 t/ha in Gezira, Rahad, New Halfa and the White Nile, respectively.

Estimation of technology parameters that depict important interactions among various yield-influencing factors in Gezira using transcendental production function (Hassan and Faki 1993) showed physical and economic feasibility of all improved technology components. This was reflected by their positive marginal products which were associated with higher values than the corresponding marginal costs at the 1990 price levels (Table 6).

Table 6. Marginal productivity of inputs under new and traditional wheat technology in Gezira, 1989/90.

Technology Component	Marginal product (kg/unit/ha)	Marginal value product (LS/unit/ha)	Input price (marginal cost) in 1990 (LS/unit)
Nitrogen (kg/ha)	20	61	2.5
Phosphorus (kg/ha)	163	189	4.1
Number of irrigations	161	183	37
Harrowing†	40	121	85
Levelling†	171	513	41
Mechanical sowing†	114	342	57
Mechanical fertilizer application†	192	576	36
Date of fertilizer application (weeks after sowing)	-40	-121	
Sowing date (weeks from mid-November)	-10	-31	

† Dummy variables with values of '1' for being done and '0' otherwise.
Source: Hassan and Faki (1993).

Technology Adoption

Indicators for technology adoption were examined in many seasons by tracing the reactions of farmers participating in on-farm trials to the verified technology. Generally, farmers' reactions were positive in most cases but differed with the circumstances in different seasons. In poor seasons, such as 1990/91, farmers hardly recognized any yield improvement (Faki *et al.* 1991a). Major limiting factors in such seasons were mostly irrigation problems, seed quantity and quality, presowing irrigation and fertilizer supply. Generally, low input supply hindered the package application at a wider scale. Minimum levels of irrigation (6), nitrogenous fertilizers (86 kg N/ha) and seed rate (143 kg/ha) seemed vital to supply for all farmers for reasonable and sustainable average wheat productivity. With such levels, the factors in question could be excluded from the package so that fewer components could be verified. In good seasons, on the other hand, such as in 1991/92, highly positive responses to the package were reported. Problems were usually limited and mention was made of regular water application, clean seed, fertilizer supply and better land preparation, with different ranking in different producing areas.

Actual levels of technology adoption were monitored for many seasons during the period 1989/90–1991/92 in the Gezira Scheme (Table 7). The studies covered past participants and their neighbors with sampling taken at different locations in the Scheme.

Generally, encouraging adoption levels were reported, especially among former participants in on-farm trials, but with considerable variability among seasons. Even the former SG 2000 farmers applied suboptimal rates of fertilizers and irrigation. Adoption by all farmers was low as apparent from the figures of 1989/90. However, almost all farmers used the recommended cultivars while a large part complied with the recommendations of land levelling, mechanical planting and sowing during November. The irrigation regime was suboptimal and adoption of fertilizer recommendations was variable and often moderate. Farmers' accessibility to inputs, especially irrigation water, fertilizers and machinery, was the main reason for the partial adoption failure. Input costs, such as those of fertilizers, were reported in some seasons to hinder full adoption.

Table 7. Adoption levels of wheat technology over three seasons in the Gezira Scheme (% of farmers adopting).

Package factor	All Gezira, average, 1989/90‡	SG 2000 farmers, 1989‡	Former SG 2000 farmers‡	1990/91§	1991/92§
Cultivar	89	89	100	97	100
Mechanical					
Disc harrowing	40	90	62		66
Levelling	31	100	100	100	90
Planting	44	79	54	100	100
Nov. sowing	97	96	100	100	87
Fertilizer					
Optimum N dose	22	98	92	93	100
Optimum P dose	18	92	72	97	100.
Irrigation†	5	6.2	6.4	6.4	7.1
Yield (t/ha)	1.4	2.8	2.3		2.8
No. of farmers	80018	111	111	30	68

† Number of applied waterings.
Source: ‡ Hassan and Faki (1993); § Faki (1991a, 1992).

High farmers' enthusiasm and awareness of general technology benefits were reported. Farmers, however, rated package components differently, as influenced by their specific conditions. Former trial participants gave priority for land preparation, followed by fertilizer levels in two seasons (1990/91 and 1991/92), and seed drilling and irrigation. The sequence for neighbors was seed drilling, irrigation, land preparation and fertilizers. Similar levels of use of inputs and cultural practices were reported by the two farmer groups, showing the diffusion that had been enhanced by the Gezira Scheme's continuous intervention in production. Preference for wheat, which highly affects technology adoption as forced by the competition for scarce inputs, varied among seasons according to economic considerations. While priority to cotton was reported in 1990/91, wheat enjoyed top position in the following season. Disc harrowing found low adoption in earlier seasons due to the lack of equipment.

Farmers' demand was mostly for better and timely land preparation, presowing irrigation and adequate supply of finance. Some farmers believed in increased fertilizer rates which could be explained within the considerable soil variability. Farmers were often reluctant to sow early. Significantly higher yields were obtained by participants in past trials and those acquainted with the recommendations of nonparticipants. Critical factors for better wheat yields in the opinion of farmers were land levelling, better use of seed drills, fertilizer availability and regular irrigation. Wet sowing was noticed to be associated with high yields, a factor that might be considered in technology development and institutional set-up. More farmers' acquaintance with the recommendations seemed to be an important factor that necessitates more intensive extension. It was also deduced that the quality of cultural practices, especially land preparation, plays an important role in productivity improvement.

A wider adoption study was conducted in the 1992/93 season that covered most wheat-producing areas (Faki *et al.* forthcoming). A total of 336 farmers were sampled in five areas with sample sizes of 90 in Gezira, 43 in New Halfa, 63 in Shendi, 80 in Rahad and 60 in the White Nile. Sampling was based on stratification according to geographical location and type of farming system, and randomization within strata. Average adoption levels of the most important technology components in different areas are shown in Fig. 4. Mechanical sowing and improved cultivars were highly adopted in most areas. Adoption of the irrigation regime and sowing date was moderate to poor. Recommended tillage operations generally received low adoption. It was interesting to note that farmers' awareness of specific recommendations was unexpectedly low. The highest average awareness was for improved cultivars (41%), especially in New Halfa. The recommended sowing date was recognized by 27%, while tillage, sowing method and the irrigation regime were, on the average, known by only 17% of the farmers in all areas. Considerable discrepancies existed between farmers' preferred and actual management practices related to the recommended technology. The main reasons for these discrepancies were deficiencies in input markets, high input prices and inadequate accessibility to finance with reasonable terms. Poor knowledge was reported for the recommended N and P fertilizer doses. Despite that, farmers' preferred technology levels and their actual management practices conformed more with the recommended levels than with actual knowledge of the recommendations. This signals the high need for intensifying extension services and improving the efficiency of extension messages. The portion of farmers receiving extension visits varied from 26 to 41%, while extension media represented important sources of information, especially in the North and New Halfa.

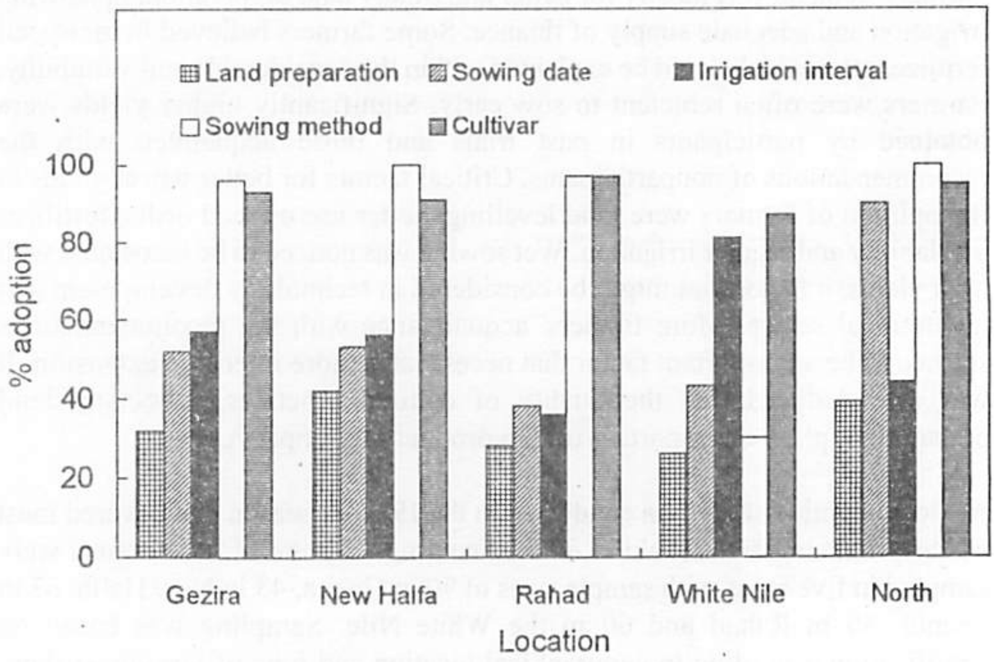

Fig. 4. Wheat adoption levels in the main producing areas in the Sudan, 1992/93.

A study conducted in Shendi area in the 1994/95 season (Ahmed and Mohamed 1995) revealed high adoption of recommended land levelling (84%), urea application (76%) and timely sowing (73%). The adoption of the improved cultivar Wadi El Neil was considerable (50%), while that of weed control, irrigation and pest control were moderate to low. These represent encouraging results, given the recent experience of farmers with wheat in that area.

Yield Gaps

Despite continual research and government support to enhance wheat productivity, considerable time and space yield variability still prevails in all irrigation schemes. Yield gaps were monitored in Gezira through selective sampling for high-, medium- and low-yielding administrative regions (blocks) and farms (Faki and Ismail 1993; 1994b). High-yielding blocks had yield advantages of 1.02 and 1.7 t/ha, respectively, over medium- and low-yielding ones in the 1992/93 season. Gaps between high- and low-yielding farms averaged 0.58 t/ha over all blocks. Significant wheat yield gaps of 1.09 and 0.59 t/ha were computed in the 1993/94 season between demonstration plots and low- and medium-yielding blocks, respectively, corresponding to 52 and 28%. Yield gaps between high-yielding and each of the medium- and low-yielding farms of 0.72 and 0.85 t/ha, respectively, were significant as well. The yield gap between demonstration plots and high-yielding plots was, however, not significant (15%). Variability in both seasons increased from high- to low-yielding blocks and from high- to low-yielding farmers' plots.

Location differences and various management practices were found responsible for yield gaps. Soil, land levelling, type of preceding crop and weeds are problems associated with location. Management factors comprised levels of seed cleaning, tillage intensity and quality, sowing date, weed management, fertilizer dose, irrigation regime, and harvesting date. The levels of these practices decrease from high- to low-yielding blocks and from high- to low-yielding farms. The effects of individual factors for all sampled farmers in 1992/93, as examined by a regression model, revealed the importance of location, tillage practices, the levels of urea and irrigation water management (Table 8).

Table 8. Regression results of wheat yield with important management factors in Gezira, 1992/93.

Variable	Regression coefficient (t/ha)	P-value
Constant	0.89	
Block (high)	1.61	0
Block (medium)	1.27	0
Tillage operations (no.)	0.25	0.09
Land preparation level (good)	0.23	0.08
High-yielding farms	0.22	0.06
Extra urea (sacks)	0.09	0.08
Irrigation interval (days)	0.08	0
R^2	0.77	
F-value	38.9	0

Source: Faki and Ismail (1993).

The total yield gap between high- and low-yielding farms due to these factors was 2.46 t/ha, computed according to upper and lower confidence limits of the factors' levels. The comparison of yields of on-farm trials with yields associated with location and management practices is shown in Fig. 5 which reveals yield gaps that could be narrowed through various strategies.

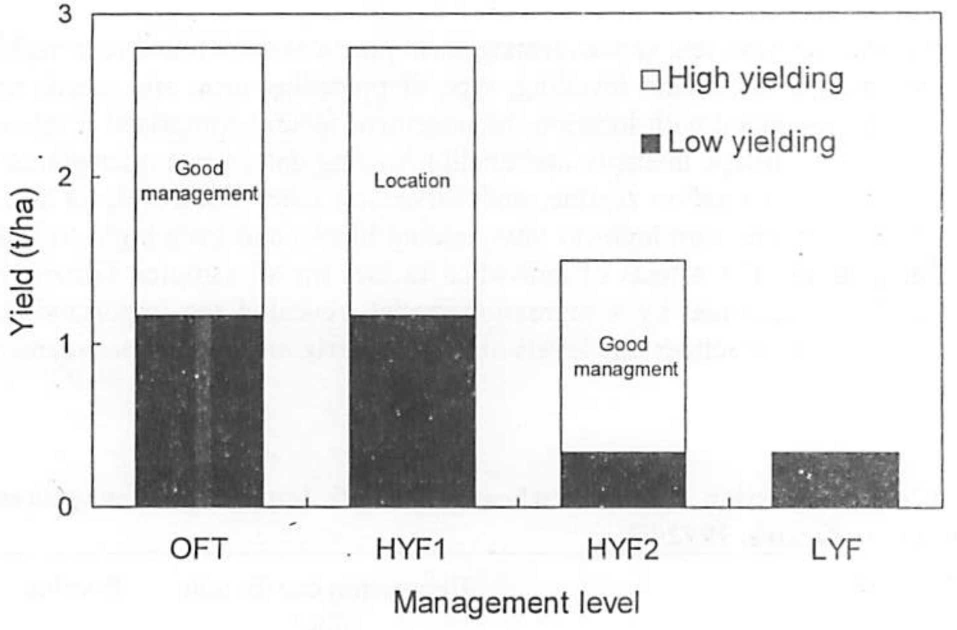

Fig. 5. Wheat yield gaps at different management levels in the Gezira Scheme, 1992/93 (OFT = On-farm trials; HYF1 = High-yielding farms in good locations; HYF2 = High-yielding farms in other locations; LYF = Low-yielding farms).

Factors with significant contributions to yield gaps at different locations in Gezira were quantified for the 1993/94 season (Table 9).

A cereal as a preceding crop, was the most important factor, with the highest effect in low-yielding blocks. Other important factors were the Sudan-grass weed intensity and the irrigation regime. More factors contribute to yield gaps in demonstration trials. These include the number of tillage operations, date of first irrigation and the amount of urea application.

Table 9. Yield gaps due to individual yield-influencing factors at different locations in Gezira, 1993/94.

Factor	Yield gaps (t/ha)			
	High-yielding (Wad Elbur)	Medium-yielding (Tebub)	Low-yielding (Beda)	On-farm trials
Preceding crop (cereal)	0.43	0.49	0.73	
Weeds (Sudan-grass)	0.22		0.35	0.32
Irrigation interval	0.12	0.20		0.24
Tillage operations (no.)				0.22
Date of first irrigation				0.25
Urea dose				0.11

Source: Faki and Ismail (1994b).

An analysis in Rahad Scheme in 1994/95 (Ismail and Ahmed 1995) revealed the contribution of many factors to yield gaps, among which the level of farmers' preference for wheat, location effects, irrigation and seed quantity were the most important with respective shares of 30, 21, 19 and 14%.

It is important to consider location-specific factors where wheat would not be profitable in low-yielding locations in irrigation schemes. Across Gezira and Managil, for example, only 45% of the area in 1992/93 produced an average yield higher than 1.4 t/ha, which approximately approached the break-even yield. Locations with lower yields were more manifested in Managil and the southern parts of Rahad. In locations with improvement potential and interested farmers, attention should be given to the supply of adequate inputs and provision of intensive extension services. Priority should be given to factors contributing most to yield gaps. There is a good potential to bridge part of the yield gap in a trend approaching the yield of on-farm trials.

Technology Impact

Although a real impact study has not yet been carried out, there are many indicators that reflect the positive impact of technology transfer which is also difficult to isolate from the effect of other factors. Government support has enhanced the technology impact in many seasons, although policy measures and the magnitude of institutional support were limiting in others. Positive effects of the technology transfer process are mentioned below.

Improvement in wheat yields represents the most important factor. Despite the yield fluctuations over years due to the interaction of many factors, a moderately-rising yield trend of wheat can be depicted in most producing areas. This is shown in Fig. 6 for Gezira and northern Sudan which are two important wheat-producing areas that received research input since 1985/86. The trend is more clear for Gezira, while the North enjoys higher productivity. Comparison of wheat yields before and after the technology transfer program with on-farm trials showed a yield increase in Gezira from an average of 0.975 t/ha in the period 1978–1986 to 1.448 t/ha in the period 1987–1994 (by 49%) and in the North from 1.708 to 2.178 t/ha (by 28%) in the same period. The overall trend in the country was also rising, but the rise in some areas, such as New Halfa, was quite limited.

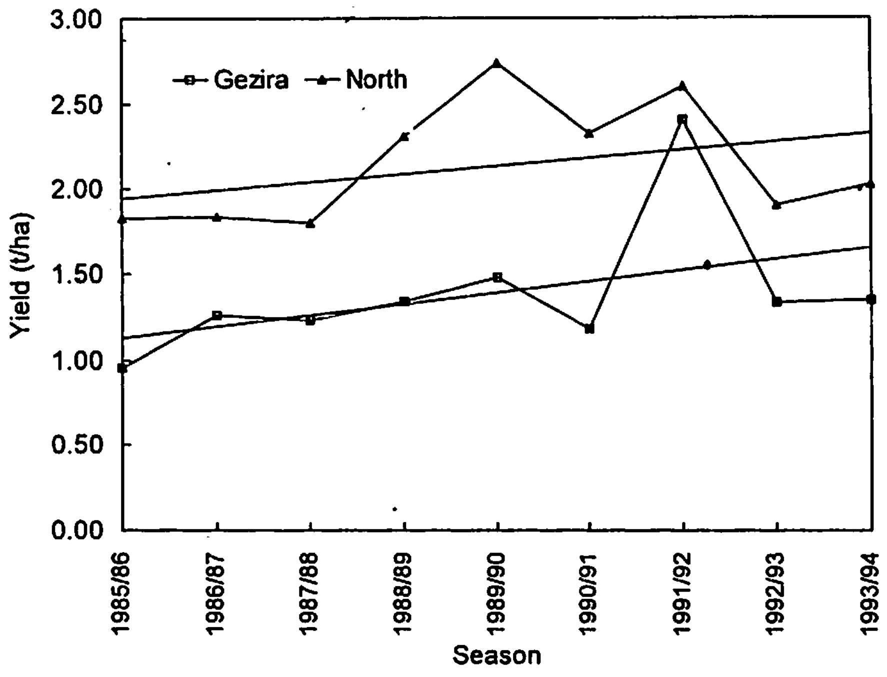

Fig. 6. Wheat yields and their trends in two producing areas (Gezira and north Sudan), 1985/86–1993/94.

Technology contribution to the overall wheat production situation in the country has reflected on the development of areas, production and average yields. The technology development has encouraged large area expansion, both within existing producing areas as well as wheat introduction in new areas (Rahad, White Nile and Blue Nile). The wheat areas reached current levels of around 336,000 ha, compared with 151,000 ha in 1985/86; an increase of 2.2 times. Total production rose from about 200,000 t in 1985/86 to over 600,000 t, representing the average of the past three seasons. The increase of production by 3.1-fold is overproportional to that of the area, reflecting a reasonable yield improvement level. The production of 836,000 tons in the 1991/92 season, that was adequate to meet domestic needs, was a big achievement. Despite the relatively high annual fluctuations, the trend is towards more productivity and production. Trends in areas, production, average yields and self-sufficiency are reported in "The Sudan's Wheat Situation and Economic Aspects" paper in this volume.

Efforts in most schemes are being continually strengthened to avail inputs and encourage technology adoption. The government support for such efforts has been enormous.

The process of technology generation and transfer has encouraged the intervention of agencies such as SG 2000 to demonstrate, at a much wider scale, the effect of technology improvements that were developed by the ARC. The areas covered by such demonstrations exceeded 1,000 ha in the Gezira in some seasons.

The Gezira Scheme has administered 'Pilot Farms' which have contributed to the wide demonstration of improved technology. Large areas and farmers accommodated such activities over time. A whole Group (Messalamiya) was selected for Pilot Farm demonstrations in 1988/89 with a wheat area of 25,000 ha grown by 12,000 farmers. Currently, the Pilot Farm demonstrations cover selected farmers and areas in all administrative groups of the Scheme in which the package components are applied and their effects monitored.

The technology transfer process has initiated high interaction among researchers, extension staff, farmers and decision makers. Most of the daily activities of trial conduct are done by extension staff. Important feedback flows through the interaction of these groups.

References

Ageeb, O., Faki, H., Abdel Fattah, A. 1987a. Farmer-managed trials, Gezira Scheme. Pages 19–21 *in* Proceedings of the 1st National Wheat Coordination Meeting, 3–5 August 1986, Wad Medani, Sudan. ICARDA-104 En.

Ageeb, O., Faki, H., Abdel Fattah, A., Musa, A. and Khalid, I. 1988a. Wheat pilot production and demonstration plots, Gezira. Pages 11–13 *in* Proceedings of the 2nd National Wheat Coordination Meeting, 20–22 July 1987, Wad Medani, Sudan. ICARDA-130 En.

Ageeb, O., Faki, H., El Makki, I., Musa, A. and El Noor, A. 1989. Wheat pilot production and demonstration plots in Gezira. Pages 1–15 *in* Proceedings of the 4th National Wheat Coordination Meeting, 4–7 September 1989, Wad Medani, Sudan. ARC/ICARDA Nile Valley Project.

Ageeb, O., Ghorashi, A. and Taha, M. 1988b. Response of three wheat cultivars to sowing date in Gezira, New Halfa and Hudeiba. Pages 22–23 *in* Proceedings of the 3rd National Wheat Coordination Meeting, 4–6 September 1988, Wad Medani, Sudan. ICARDA, Aleppo, Syria.

Ageeb, O., Mohamed, M.S. and Faki, H. 1987b. Researcher-managed trials, Gezira and New Halfa Schemes. Pages 26–29 *in* Verification and Adoption of Wheat Production Technology in the Sudan. Proceedings of the First Wheat Coordination Meeting, 3–5 August 1986. Wad Medani. ICARDA-104 En.

Ageeb, O. and Staff of Sudan Gezira Board. 1990. Pilot production and demonstration plots in Gezira. Pages 5–10 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1989/90, Sudan. ICARDA/NVRP-DOC-012.

Ahmed, A.T., Ibrahim, H.S., Salih, A.A., Babiker, E.A., Omer, M.M., Satti, M.A., Mohamed, G.E., Ibrahim, O.H., Mohamed, M.I., Salih, M.A., Dawelbeit, M.I., Kannan, H.O., Hamada, A.A., Mohamed, A.O., Mohamed, E.S., Ahmed, E.H., Mohamed, Samira A., Ahmed, M.S., Musa, A., Luka, A. and Soheib, A. 1995. Wheat pilot production/demonstration plots, irrigation schemes. Pages 1–18 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Bread Wheat Report 1994/95, Annual Coordination Meeting, 27–30 August 1995, Agricultural Research Corporation, Wad Medani, Sudan.

Ahmed, A.T. and Mohamed, G.E. 1995. Adoption of wheat production and practices in south Shendi area. Pages 30–34 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Bread Wheat Report 19945/95, Annual Coordination Meeting, 27–30 August 1995, Agricultural Research Corporation, Wad Medani, Sudan.

Babiker, E.A., Faki, H., Kannan, H.O., Mohamed, A.O., Abdalla, E., El Hassan, I.M. and Ugool, M.E. 1992. Wheat pilot production and demonstration plots in Rahad. Pages 1–3 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1991/92, Sudan. ICARDA/NVRP-DOC-025.

Babiker, E.A., Kannan, H.O., Abdalla, E., El-Hassan, A. and Ugool, M. 1990. Wheat pilot production and demonstration plots in Rahad Scheme. Pages 13–14 in Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1989/90, Sudan. ICARDA/NVRP-DOC-012.

Dawelbeit, M. 1994. Effect of time of harvesting, type of combine and cross ridges on wheat combine losses. In: Annual Report 1993/94, Sudan. Pages 57–61 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, ICARDA/NVRP-DOC-037.

Faki, H. 1991. Survey on the adoption of the wheat package in Gezira. Pages 44–48 *in* Nile Valley Regional Program, Annual Coordination Meeting, 16–23 September 1991, Cairo, Egypt. Abridged Report, Agricultural Research Corporation, Wad Medani, Sudan.

Faki, H. 1992. Adoption levels of wheat technology in the Gezira Scheme. Pages 15–18 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1991/92, Sudan. ICARDA/NVRP-DOC-025.

Faki, H. and Abdel Fattah, A. 1986. Wheat socio-economic surveys. Presented at the First Wheat Coordination Meeting, 3–5 August 1986, Wad Medani, Sudan.

Faki, H., Aw-Hassan, A. and Ahmed, A.T. (forthcoming). Wheat technology adoption in the Sudan: results of surveys in wheat producing areas in 1992/93. Draft envisaged for publication by ICARDA.

Faki, H. and Ismail, M.A. 1993. Wheat yield gaps: results of analysis in Gezira. Pages 40–50 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Bread Wheat Report, Annual Coordination Meeting, 29 August–2 September 1993, Agricultural Research Corporation, Wad Medani, Sudan.

Faki, H. and Ismail, M.A. 1994a. Some economic indicators for wheat production prospects in the Sudan. Pages 96–104 *in* Wheat in Heat Stressed Environments: Irrigated, Dry Areas and Rice-Wheat Farming Systems (D.A. Saunders and G.P. Hettel, eds.), 1994. Mexico, D.F., CIMMYT.

Faki, H. and Ismail, M.A. 1994b. Wheat yield gaps in the Gezira Scheme. Pages 41–54 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Bread Wheat Report, Annual Coordination Meeting, 28 August–1 September 1994, Agricultural Research Corporation, Wad Medani, Sudan.

Faki, H., Salih, A.A., Omer, M.M., Babiker, E.A., Kannan, H.O., Mohamed, A.O., Satti, M.A.I., Salama, M.A., Ghorashi, A.M., Gasm El-Seid, A.M., El-Sarrag, G., Ahmed, A.T., Mohamed, M.I., Ibrahim, H.S., Ibrahim, O.H., Mohamed, E.S. and Mohamed, S.A.1993. Wheat pilot production and demonstration plots in irrigation schemes. Pages 1–40 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Bread Wheat Report, Annual Coordination Meeting, 29 August–2 September 1993, Agricultural Research Corporation, Wad Medani, Sudan.

Faki, H., Salih, A.A., Fadul, H., Babiker, E.A., Kannan, H.O., Mohamed, A.O., Satti, M.A.I., Salama, M.A., Amin, M.S., Ghorashi, A.M., Gasm El-Seid, A.M., Abdel Gadir, S.E. Hassan, A.H., Sid Ahmed, M., El-Sarrag, G., Ahmed, A.T., Mohamed, M.I., Ibrahim, H.S., Ibrahim, O.H., Mohamed, E.S., Mohamed, S.A., Luka, A.M. and Soheib, A.Y. 1994. Wheat pilot production and demonstration plots in irrigation schemes. Pages 1–21 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Bread Wheat Report, Annual Coordination Meeting, 28 August–1 September 1994, Agricultural Research Corporation, Wad Medani, Sudan.

Faki, H., Babiker, E.A., Omer, M.M. and Satti, M.E. 1991. Diagnostic survey of wheat production in Rahad, Blue Nile and White Nile Schemes. Pages 15–20 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1990/91, Sudan. ICARDA/NVRP-DOC-017.

Faki, H., Ageeb, O.A.A., Satti, M.A.E., Omer, M.M., Babiker, E.A., Kannan, H.O., Mohamed, A.O., Ugool, M.O., El Hassan, I.M., Abdalla, E., Salama, M.A., Ghorashi, A.M., Ibrahim, F.M., Amin, M.S. and Gasmelseed, A.M. 1991. Wheat pilot production/demonstration plots in Sudan, 1990/91. Pages 1–15 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Bread Wheat Report, Annual Coordination Meeting, 16–23 September 1991, Agricultural Research Corporation, Wad Medani, Sudan.

Hassan, F.M., and Faki, H. 1993. Economic Policy and Technology Determinants of the Comparative Advantage of Wheat Production in Sudan. CIMMYT Economic Paper No. 6. Bangkok, Thailand, CIMMYT.

Ibrahim, M.A.A. and Gasm El-Seid, A.M. 1991. Wheat pilot production and demonstration plots in Sudan. Pages 1–15 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat -Sudan. Bread Wheat Report, Annual Coordination Meeting, 16–23 September 1991, Agricultural Research Corporation, Wad Medani, Sudan.

Ismail, M.A. and Ahmed, A.T. 1995. Wheat yield gap analysis in Rahad Scheme. Pages 19–29 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Bread Wheat Report 1994/95, Annual Coordination Meeting, 27–30 August 1995, Agricultural Research Corporation, Wad Medani, Sudan.

Mohamed, M.I. and Ahmed, A.T. 1991. Wheat pilot production and demonstration plots in Dongola area. Pages 26–32 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat -Sudan. Bread Wheat Report 1990/91, Annual Coordination Meeting, 16–23 September 1991, Agricultural Research Corporation, Wad Medani, Sudan.

Mohamed, M.I. and Ahmed, A.T. 1992. Wheat pilot production and demonstration plots in the Dongola area. Pages 10–12 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1991/92, Sudan. ICARDA/NVRP-DOC-025.

Mohamed, M.S., Ghorashi, A.M., Omer, A.B., Faki, H., Arman, G. and Abdel Fattah, A. 1987. Wheat pilot production and demonstration plots, New Halfa Scheme. Pages 13–15 *in* Proceedings of the 2nd National Wheat Coordination Meeting, 20–22 July 1987, Wad Medani, Sudan. ICARDA-130 En.

Mohamed, M.S., Faki, H. and Abdel Fattah, A. 1986. Farmer-managed trials, New Halfa Scheme. Page 21–22 *in* Verification and Adoption of Wheat Production Technology in the Sudan. Proceedings of the First Wheat Coordination Meeting, 3–5 August 1986, Wad Medani, Sudan. ICARDA-104 En.

Omer, M.M. 1990. Farmer-managed trials in the Blue Nile and Suki Corporations. Pages 14–17 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1989/90, Sudan. ICARDA/NVRP-DOC-012.

Omer, M.M. and Faki, H. 1992. Wheat pilot production and demonstration plots in the Blue Nile. Pages 9–10 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1991/92, Sudan. ICARDA/NVRP-DOC-025.

Salama, M.A., Ghorashi, A.M., Ibrahim, S.M., Ibrahim, F.M., and Amin, M.S. 1990. Pilot production and demonstration plots in New Halfa. Pages 10–13 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1989/90, Sudan. ICARDA/NVRP-DOC-012.

Salama, M.A., Faki, H., Amin, M.S., Arman, G., Ghorashi, A.M., and Gasm El-Seid, A. 1992. Wheat pilot production and demonstration plots in New Halfa. Pages 4–6 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1991/92, Sudan. ICARDA/NVRP-DOC-025.

Sarrag, G. and Taha, M.B. 1990. Wheat pilot production/demonstration in Kali and Kaboushia Agricultural Schemes. Pages 20–22 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1989/90, Sudan. ICARDA/NVRP-DOC-012.

Sarrag, G., Ahmed, A.T., Luka, A.M. and Abdel Aziz, A.M. 1992. Wheat pilot production and demonstration plots in the Shendi area. Pages 13–14 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1991/92, Sudan. ICARDA/NVRP-DOC-025.

Sarrag, G., El Tigani, H., Luka, A.M. and Taha 1991, A.M. Wheat pilot production and demonstration plots in Shendi area. Pages 16–25 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat–Sudan. Bread Wheat Report, Annual Coordination Meeting, 16–23 September 1991, Agricultural Research Corporation, Wad Medani, Sudan.

Satti, M.A.E. and Faki, H. 1992. Wheat pilot production and demonstration plots in the White Nile. Page *7–8* in Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1991/92, Sudan. ICARDA/NVRP-DOC-025.

Taha, M.B. 1990. Pilot production plots in Dongola and Rubatab. Pages 18–20 *in* Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1989/90, Sudan. ICARDA/NVRP-DOC-012.

Taha, M.B. and Mohamed,G.E. 1987. Wheat pilot production and demonstration plots, northern Region. Pages 15–16 *in* Proceedings of the 2nd National Wheat Coordination Meeting, 20–22 July, Wad Medani, Sudan. ICARDA-130 En.

Taha, M.B., Ibrahim, H.S. and Faki, H. 1986. Farmer-managed trials, northern Sudan. Pages 22–25 *in* Proceedings of the 1st. National Wheat Coordination Meeting, 3–5 August, Wad Medani, Sudan. ICARDA-104 En.

Appendix 1. Development in areas and farmer participation in demonstration trials administered by the ARC, SG 2000 and extension departments of irrigation schemes in the Sudan, 1988/89–1994/95.

Season/Item†	Gezira	New Halfa	North	Blue Nile	Rahad	White Nile
1988/89						
Farmers (no.)	3034	30	17	6‡		
Area (ha)	6373	63	22	12		
1989/90						
Farmers (no.)	817	30	16	35	18	
Area (ha)	1716	63	4	38	42	
1990/91						
Farmers (no.)	12008	644	34	23	27	14
Area (ha)	25025	1346	12	48	62	24
1991/92						
Farmers (no.)	1192	40	19	20	60	14
Area (ha)	2504	84	15	21	132	28
1992/93						
Farmers (no.)	238	36	42		126	12
Area (ha)	395	76	26		189	37
1993/84						
Farmers (no.)	480	60	NA§	40	192	36
Area (ha)	1008	126	NA	42	444	75
1994/85						
Farmers (no.)	188		45	11	46	9
Area (ha)	500		17	23	119	23

† Demonstrations include Gezira extension plots administered by the Gezira extension staff in what is known as 'pilot farms' which extended from 1986/87 to 1991/92, and SG 2000 activities which extended from 1986/87 to 1988/89 and covered demonstrations with 984 farmers in a total area of 2067 ha over the three seasons.

‡ Wheat research in the Blue Nile was introduced for the first time with wheat introduction there in the form of 'reference plots' to verify wheat production technology developed for the Gezira in such a new area.

§ NA = Not available

Source: As in Table 2.

Appendix 2. Wheat yield levels of participant and nonparticipant farmers in farmer-managed and demonstration trials in different areas of the Sudan, 1985/86–1994/95.

	Yield (t/ha)									
Locality/Farmer status	1985/86	1986/87	1987/88	1988/89	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95
Gezira/Managil										
Participants	1.70	3.25	2.70	4.27		2.70		2.16	1.96	1.88
Nonparticipants	1.25	2.39	1.50	2.58		1.50		1.44	1.35	1.19
Yield improvement	0.45	0.86	1.20	1.69		1.20		0.72	0.61	0.69
New Halfa										
Participants	1.42	1.97	2.04	2.20	2.68	1.47	2.75	1.63	1.28	
Nonparticipants	1.34	1.09	1.24	1.27	1.49	1.02	2.01	0.94	0.66	
Yield improvement	0.08	0.88	0.80	0.93	1.19	0.45	0.74	0.69	0.62	
North (Dongola area)										
Participants	2.79	3.56			3.29	2.26	3.40	3.89	3.76	2.82
Nonparticipants	2.67	3.16			2.73	2.17	2.54	2.14	2.78	2.20
Yield improvement	0.12	0.40			0.46	0.09	0.86	1.75	0.98	0.62

Appendix 2. (Cont'd)

Locality/Farmer status	Yield (t/ha)									
	1985/86	1986/87	1987/88	1988/89	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95
North (Nile)										
Participants	1.55	2.99		2.28	2.27	1.62	3.29	2.45	1.54	2.62
Nonparticipants	1.28	2.42		1.48	1.69	1.19	2.53	1.36	0.98	1.54
Yield improvement	0.27	0.57		0.80	0.58	0.43	0.76	1.09	0.56	1.08
Rahad										
Participants					2.72	1.38	2.97	1.67	1.59	2.47
Nonparticipants					1.65	1.22	2.30	1.12	1.33	1.76
Yield improvement					1.07	0.16	0.67	0.55	0.26	0.71
White Nile										
Participants						0.90	2.47	2.99	2.14	1.93
Nonparticipants						0.57	1.86	2.00	1.77	1.32
Yield improvement						0.33	0.61	0.99	0.37	0.61
Blue Nile										
Participants						1.15	2.68			1.75
Nonparticipants						0.64	1.32			1.17
Yield improvement						0.51	1.36			0.58

Discussion

Comment: M.B. Solh

In considering the impact of technology transfer on national production, the limitations at the national level should be mentioned with respect to input availability and the capacity of available machinery to handle or plant vast areas on time. It has been apparent over the last four to five years that, in spite of the good intentions and hard work of the Gezira Scheme staff, it is impossible to plant all the wheat fields in one month. Last year almost 40% of the fields were late-sown and delayed planting in the Sudan, where the growing season is only 100 days, is the most detrimental factor to yield. Policy issues also contribute to farmers' reluctance to plant early. In 1992/93 farmers in New Halfa were still debating whether to plant wheat in January or not, because of high input prices and unknown wheat prices. Thus, the papers on technology transfer should point out to such constraints in order to realize the actual impact of the improved technology.

A: Hamid Faki

This point is valid. Problems and incentives of policy and institutional interventions should be exposed.

Q: Hassan S. Ibrahim

How would you compare the rate of technology adoption in case of the Gezira Scheme, where the technology components, like fertilizer and seed, are provided by the Scheme, and the northern states where farmers buy their own?

A: Hamid Faki

We were aware of the situation of guided production in Gezira when adoption studies were conducted. But since there is technology transfer to farmers, adoption should be documented that explores adoption levels and identifies causes of adoption failure or justifications for adoption success, whether these relate to scheme-level or farmer-level interventions. However, farmers play an important role in many areas, such as irrigation water management, level of tillage, fertilizer doses, sowing date and others.

Q: Mohamed Safaa Eldin Sharshar

Some farmers apply N and P fertilizers after irrigation and at different times when the plant does not benefit from them. What is the farmers' practice with respect to N and P application?

A: Hamid Faki

In all irrigation schemes in central Sudan, urea is applied at sowing and seeds are often sown mechanically together with fertilizers. Phosphate is applied before ploughing. Past experimental results did not expose advantages of split application. However, farmers in northern Sudan apply N fertilizer with the second irrigation.

Comment: M.C. Saxena

First, it would be worthwhile to update those papers covering the data that have become available during the 1994/95 season, and second, the problems of adoption and impact for schemes like 'Gezira' will have to be very different from those for farmers in the North. It would be important to bring about the differences in the production situation of these two groups in the introductory parts of the paper and adoption has to be brought in light of these considerations.

A: Hamid Faki

Both comments will be taken into consideration.

Q: M.B. Solh

I would like to commend Dr. Hamid on his thorough and comprehensive presentation. However, the financial benefits expressed in Sudanese pounds over years may be irrelevant, considering the change in purchasing power of the Sudanese pound.

A: Hamid Faki

This is correct. The main reason for including monetary net benefits is that they represent the main indicator for the technology's profitability. Of course the MRRs are also included. In the introductory paper of the wheat situation, benefits were computed at constant prices. Calculating this way or including exchange rates will be considered.

Q: Mohamed A. Gabbar

Why is the use of high quality seed not considered as one of the technology components which have an impact on production?

A: Hamid Faki

Seed quality, as far as purity from weed seeds,.was considered. Keen farmers were reported in yield-gap studies to clean their wheat seeds. Other seed qualities are of technical nature that is difficult to assess on-farm. They may be evaluated by technical people before the seed is distributed to farmers.

Q: Hassan S. Ibrahim

Please comment on the following: (1) Fertilizers and irrigation are to some extent not adequate, (2) the North does not have enough of cultivar Wadi El Neil, (3) most of the paper is for the Gezira, and (4) extension agencies in the different states are in very bad shape in terms of facilities and staff.

A: Hamid Faki

(1) The constraints on fertilizers and irrigation water result in limited adoption of the technology. (2) Cultivar Wadi El Neil has a high yield advantage. Seed multiplication is an important activity for productivity improvement in the North. (3) Expansion of on-farm work in Gezira was highly induced by interventions of SG 2000 and the Scheme's Extension Department through its Pilot Farm activity. Other research activities were encouraged by data availability, but the Gezira has high similarities to other schemes with respect to production relations and input use. Results of many studies in Gezira, especially with respect to policy analysis, apply to other schemes. (4) Extension is a major factor in the technology adoption. Inadequacy of extension work applies to the North as well as to other schemes, though to a lesser extent.

Q: Abdalla Babiker

New Halfa showed consistently lower wheat yields compared to other areas in the Sudan. Could you identify some constraints and factors that could have led to this in order to include them in the final report?

A: Hamid Faki

Factors affecting wheat productivity in all schemes, including New Halfa, were quantified in many seasons through regression analysis and mean comparisons. They include irrigation problems, sowing date and harvest delay.

Capacity Building and Institutional Development

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Institutional development was a major component of NVRP in order to enhance the capabilities of the Agricultural Research Corporation (ARC) in effective technology development and transfer. Institutional development and technical capacity building included human resource development, establishing research and transfer of technology approaches, strengthening regional cooperation, providing research facilities and encouraging the production of publications.

Human Resource Development

Human resource development was an important component of NVRP for enhancing the technical capacity of the Sudanese national program in agricultural research and transfer of technology. This included nondegree and degree training, participation in national and regional coordination meetings, workshops and conferences, and professional visits to provide experience in specialized disciplines. As a result, technical capacity building of the ARC was enhanced in various disciplines: agronomy, stress physiology, entomology, pathology, weed control, microbiology, biotechnology, seed multiplication, extension and transfer of technology, computer applications and others. The human resource development activities were implemented at ICARDA and other international centers, or locally in countries with good expertise and in universities.

The number of participants in various training activities and professional visits during the NVRP is presented in Table 1. The number of researchers and technicians who benefitted from NVRP human resource development activities were: 86 in nondegree training (both short and long-term), 3 in degree training and 310 in coordination meetings, workshops and conference participation. According to the records of the ARC, the number of research staff who benefitted from NVRP capacity building activities in the wheat and food legumes programs during the NVRP exceeded those who benefitted from such activities in the last seven years.

Table 12. Number of national scientists and technicians involved in staff education, training and professional visits in wheat through the support of the NVRP in the Sudan between the 1988/89 and 1994/95 seasons.

	1988 /89	1989 /90	1990 /91	1991 /92	1992 /93	1993 /94	1994 /95	Total
Nondegree training								
Long term	1	4	1	-	1	1	-	8
Short courses†	4	2	-	2	5	18	1	32
Individual training	6	5	3	1	1	7	-	23
Professional visits	3	4	2	-	3	4	7	23
Subtotal	**14**	**15**	**6**	**3**	**10**	**30**	**8**	**86**
Degree training								
(ongoing)				1¶	2¶			3
Workshops/meetings/conferences								
Travelling Workshops‡	3	3	6	6	4	21	15	58
Conferences	-	4	1	-	-	5	2	13
Regional CM§	1	1	8	12	9	8	7	45
National CM	21	32	28	24	23	31	35	194
Subtotal	**25**	**40**	**43**	**42**	**36**	**65**	**59**	**310**

† Including in-country and regional training courses.
‡ Excluding annual travelling workshops in Sudan in which all NVRP program scientists were involved.
§ CM = Coordination Meeting.
¶ Beginning of M.Sc. program.

In degree training, the three M.Sc. graduates—now members of the research teams of the wheat and food legumes programs at the ARC—were involved in activities in the fields of agronomy, stress physiology, wheat and food legume breeding, soils (soil-water-plant relationships) and virology.

In addition to research staff capacity building, in-country training was held regularly for extension agents within the different irrigation schemes or in research stations. This was mainly for introducing extensionists to improved technologies. On-the-job extension training was also done by involving extensionists in selecting the farmers and implementing on-farm verification trials and demonstrations in cooperation with researchers. Farmers' days were organized in production areas where demonstrations were visited by farmers in the neighborhood. This was done through extensionists and researchers to illustrate the advantages of technology adoption and discuss problems raised by farmers in the production of wheat food legumes.

Research Approach

A multidisciplinary research approach was followed in almost all research activities under NVRP. The Annual National Coordination Meetings, which were attended by all research staff involved in wheat and food legume improvement in the Sudan, in addition to irrigation scheme managers and extensionists, contributed greatly to such close cooperation. Progressive farmers were also invited to these meetings which involved the presentation of the previous season's results in various research areas and on-farm activities followed by the development of workplans for the next season in multidisciplinary group discussions. Then, for each research activity, the principal scientist in charge was identified as well as the collaborating scientists in other disciplines. The outcome of this important meeting included two publications: the Annual Report to document research findings of the previous season and a Workplan and Budget for various activities to be implemented the following season.

The cooperation of researchers in various disciplines proved to be essential in the development of improved production packages which included improved cultivars and a set of appropriate cultural practices. Researchers contributing to such production packages, which are transferrable to farmers, involved agronomists, socioeconomists, breeders, entomologists, pathologists, weed control specialists, mechanical engineers, soil fertility specialists and a microbiologist. The extent of involvement of these various researchers depended on the components of the production package and the production constraints facing the farmers.

The verified technology in farmers' fields also involved researchers, extensionists and farmers in an on-farm participatory approach. This is further discussed in the following section on technology transfer.

National Travelling Workshops held annually during the peak of the growing season involved researchers and extensionists from various disciplines. These workshops covered back-up research and on-farm activities. The participants exchanged views with each other on the ongoing research activities and interacted with extensionists and farmers in the on-farm activities, particularly in technology verification trials and demonstrations.

Technology Transfer Approach

Technology development and transfer in NVRP started with the farmer and ended with the farmer (Fig. 1). Diagnostic surveys at the farmers' level were the initial activity to assess production constraints and set research priorities based on farmers' problems. Then the developed technology to solve those problems was verified under farmers' conditions to assess the farmers' perception of the new technology. Availability of resources to the farmers was taken into consideration in addition to the farming systems and the socioeconomic situation.

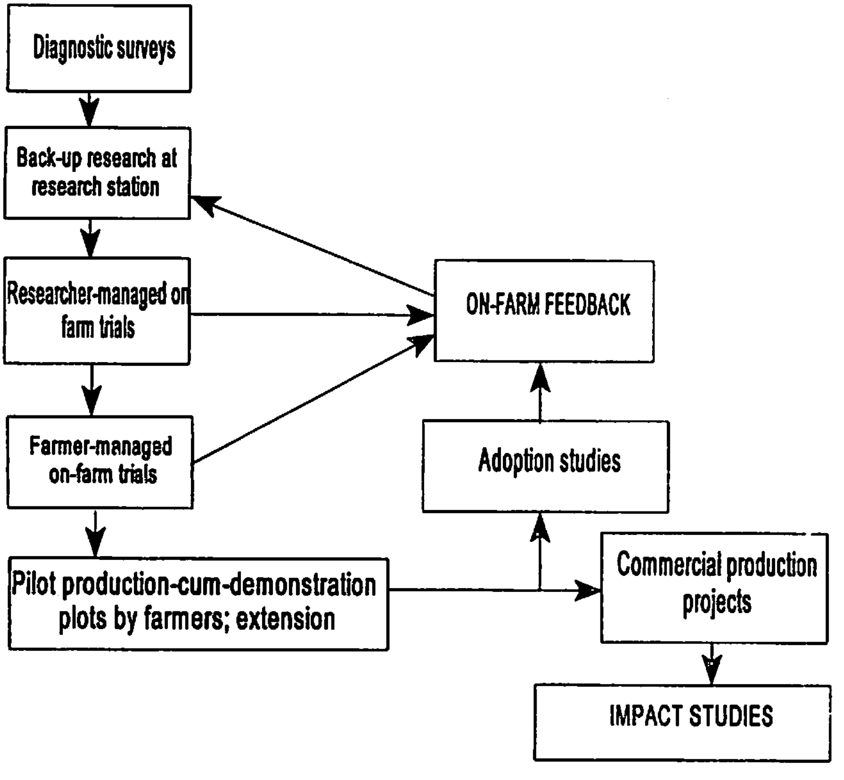

Fig. 1. NVRP strategy for the development and transfer of improved technology.

Thus, the NVRP was characterized by a close relationship between researchers, extensionists and farmers. This relationship was apparent through the various stages of technology development. In addition to the diagnostic surveys, such relationship continued in the researcher-managed trials on farmers' fields, then in farmer-managed demonstrations and later in adoption and impact studies (Fig. 1). In all these activities, extensionists had an important role in the cooperation process between researchers and farmers in addition to acting as a catalyst in that process. In the past, researchers were almost fully restricted to research stations. The approach implemented within the NVRP was initiated in 1979 through the Nile Valley Project (NVP) for Faba Bean Improvement involving the ARC, ICARDA and International Fund for Agricultural Development (IFAD) and was extended and strengthened in 1988/89 by the NVRP to cover, in addition to faba bean, chickpea, lentil and wheat. Thus, the linkages among researchers, extensionists and farmers became part of the NVRP strategy to transfer technology to farmers through the activities presented in Fig. 1.

In addition to verification trials, large demonstrations and field days were conducted in major wheat production areas in the country. The ARC published several extension leaflets through the support of the NVRP for both extensionists and farmers. The NVRP improved production packages were also extended to farmers by other agriculture development organizations. For example, the collaboration with Sasakawa-Global 2000 (which terminated its activities in Sudan in 1992) was very active between 1988/89 and 1991/92 in extending the NVRP-improved wheat production packages to more farmers.

The effects of the on-farm activities and the researcher-extensionist-farmer relationship were apparent in increasing the awareness of extensionists and farmers about the economic advantages of improved technology. It provided the researchers with feedback on the economics and the practicality of the improved technology under farmers' conditions. The shortcomings or limitations of the technology under those conditions were reconsidered by researchers to modify their technology. Such feedback contributed to technology adjustments and fine-tuning to enhance adoption and impact at the farmer's level.

Regional Cooperation

In addition to the major national activities within the NVRP, regional cooperation contributed greatly to capacity building and to accomplishing the objectives of NVRP. Collaborative research between the Sudan, Egypt, Ethiopia and ICARDA involved technology transfer, germplasm exchange and training in a partner relationship. Thus, NVRP has been considered a model for tripartite cooperation involving national agricultural research systems (NARSs), international agricultural research centers (IARCs, mainly ICARDA) and donors (the Netherlands Government, the European Union and SAREC-Sweden). Complementary research efforts among the partners was initiated by the NVRP through regional networks on problems of common interest for the improvement of wheat and cool-season food legumes. To complement back-up research at the regional level, the Sudan, for example, took the lead in heat stress in wheat and socioeconomic studies, while Egypt took the lead in research on leaf and stem rusts of wheat, screening for aphid resistance and water-use efficiency. Ethiopia took the lead in wilt/root-rot diseases of food legumes. Because of the requirements for more basic research, particularly on integrated management, these networks were developed into a new project of formal networks currently supported by the Government of the Kingdom of the Netherlands. NVRP continued to support regional cooperation in the improvement of food legumes, wheat and resource management. The Regional Coordination Meetings and Regional Travelling Workshops, held annually in each country on a rotational basis, provided a good opportunity to strengthen regional cooperation and learn from the experiences of the partners in back-up research and technology transfer to farmers.

Specialized workshops and regional training courses were organized using local expertise to enhance capacity building and technology transfer among the partners. Beyond any doubt, regional cooperation contributed greatly to capacity building and research output through the effective utilization of scarce human and physical resources available to the national programs.

Development of Research Facilities

Through the Netherlands Government support, NVRP was very effective in upgrading the research facilities to enhance institutional development and capacity building. Most of these facilities included capital items purchased from abroad. This, to a great extent, modernized the research institutions and the delivery systems in research and transfer of technology. The capital items included vehicles, field and laboratory equipment and office equipment.

Looking Ahead

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The total area allotted annually to wheat in the Sudan is approximately 400–450 thousand hectares. With an average yield of 2 t/ha, the country would be almost self-sufficient in wheat. Self-sufficiency was realized only in the good crop season of 1991/92, while in most other seasons, average yields were always around 1.4 t/ha. However, yields of 5 t/ha or more are obtained by many farmers. For a crop that covers such valuable irrigated land and that comes top in importation as a food commodity, the government is highly concerned about achieving self-sufficiency in wheat.

The last decade (1985/86–1994/95) represented the most active period in wheat research in the Sudan. The large amount of information documented in this review covered all research disciplines related to the production of the crop. Solutions to many constraints were accomplished and advances made in the way of resolving many others. In spite of the successes achieved, there are shortcomings that need more research attention.

The breeding program has succeeded in releasing many adapted cultivars in addition to developing hundreds of lines with desirable traits in this crop which has been newly introduced to most of the wheat-growing regions of the Sudan. The breeding program should make use of these improved lines, especially those adapted to heat and moisture stress. However, the improvement in yield exhibited in the newly released cultivars is rather low. This may need reconsideration of the strategy and approaches for breeding or of the germplasm. Quality has always been one of the objectives in crop improvement, but more emphasis is needed in future work.

To insure the dissemination of the newly released cultivars, breeders must continue their efforts beyond the production of breeder seed. They have to supervise the production of pre-foundation seed with the seed propagation agencies. Nevertheless, except for their effective seed multiplication, adapted improved wheat cultivars are not a problem in the Sudan, at least at this stage. The current constraint to increasing wheat productivity in the Sudan is the inappropriate crop management practices which a large number of farmers follow.

With respect to land preparation and crop establishment, research conducted on research stations and farmers' fields in central Sudan addressed many factors affecting these two important areas. These factors include timing, depth of soil disturbance, moisture content of the soil, type of implement, and operations needed. Appropriate management technology needs to be transferred to farmers on a much larger scale. The possible interaction of these factors with the different soil types necessitates conducting more on-farm experimentation to establish the exact needs of each soil type.

More on-farm research on wheat is needed to refine the recommendations made with respect to fertilization of the crop for the different soil bench marks. This is necessary to avoid any waste in one of the expensive inputs and to apply the right dose of this important yield-determining factor.

Irrigation water is becoming more scarce and expensive, and more work is needed in crop/water management at the farm level in order to rationalize water use and increase its efficiency.

Growing the crop in the problematic soils of the high terraces of the northern parts of the country is the prospective area of expansion to meet the ever-increasing demand for wheat. The development of cultivars tolerant to the saline and sodic soils in those areas and of better crop management practices must be considered.

Research on the protection of the crop against aphids and termites as well as weeds followed an integrated approach instead of using chemicals only. Efforts in that respect gave promising results and should be further pursued. Monitoring of resistance to stem and leaf rusts is of primary importance in material to be grown in New Halfa because of the prevalence of the two diseases there.

Studies in the on-farm pilot production plots, conducted in the different wheat-producing areas, have revealed the good returns of using the improved technology. Constraints hindering the adoption of the improved technology have been identified. Those constraints should be brought to the attention of the concerned bodies whether they are policy-makers, technical staff or farmers. Economic evaluation of the use of the improved technologies should continue and the impact of adoption should be monitored taking into consideration the new economic reforms and the free agricultural policy in the Sudan.

Publications

Annual Workplan and Budget

ICARDA/ARC. 1993. Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Workplan and Budget 1992/93, Sudan. ICARDA/NVRP-DOC-020.

ICARDA/ARC. 1994. Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Workplan and Budget 1993/94, Sudan. ICARDA/NVRP-DOC-026.

ICARDA/ARC. 1995. Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Workplan and Budget 1994/95, Sudan. ICARDA/NVRP-DOC-034.

Annual Reports

ICARDA. 1989. Nile Valley Regional Program on Cool-Season Food Legumes and Cereals, Annual Report 1988/89, Sudan. ICARDA/NVRP-DOC-007.

ICARDA. 1990. Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1989/90, Sudan. ICARDA/NVRP-DOC-012.

ICARDA/ARC. 1991. Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1990/91, Sudan. ICARDA/NVRP-DOC-017.

ICARDA/ARC. 1992. Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1991/92, Sudan. ICARDA/NVRP-DOC-025.

ICARDA/ARC. 1993. Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1992/93, Sudan. ICARDA/NVRP-DOC-031.

ICARDA/ARC. 1994. Nile Valley Regional Program on Cool-Season Food Legumes and Wheat, Annual Report 1993/94, Sudan. ICARDA/NVRP-DOC-037.

ARC/ICARDA. 1995. Nile Valley Regional Program on Cool-Season Food Legumes and Wheat. Breadwheat Report 1994/95, Annual National Coordination Meeting, 27–30 August 1995, Agricultural Research Corporation, Wad Medani, Sudan.

Papers in Proceedings

Proceedings of the 1st National Wheat Coordination Meeting, 3–5 August 1986, Wad Medani, Sudan. ICARDA-104 En.

Proceedings of the 2nd National Wheat Coordination Meeting, 20–22 July 1987, Wad Medani, Sudan. ICARDA-130 En.

Proceedings of the 3rd National Wheat Coordination Meeting, 4–6 September 1988, Wad Medani, Sudan. ICARDA, Aleppo, Syria.

Proceedings of the 13th International Conference, International Soil Tillage Research Organization, 24–29 July 1994, Aalborg, Denmark.
Dawelbeit, M.I. 1994. Effect of soil compaction and method of seeding on wheat establishment and yield in Vertisols. Pages 887–892 *in* Soil Tillage for Crop Production and Protection of Environment.

Journal Articles

Faki, H., Gumaa, Y.T. and Ismail, M.A. 1995. Potential of the Sudan's irrigated sector in cereal grains production: analysis of various policy options. Agricultural Systems 48: 457–483.

Ishag, H.M. and Ageeb, O.A.A. 1991. The physiology of grain yield in wheat in an irrigated tropical environment. Experimental Agriculture 27: 71–77.

Ishag, H.M. and Mohamed, B.A. 1996. Phasic development and stability of irrigated wheat genotypes in hot environments. Field Crops Research (in press).

Poster Presentations

International Conference on Wheat in Hot, Dry, Irrigated Environments. 1–4 February 1993. Wad Medani, Sudan.

Babiker, E.A. and Abdalla, H.H. Response of wheat to nitrogen and phosphorus fertilizers in farmers' fields in Rahad Scheme.

Babiker, E.A. and Elhassan, A.A. On-farm trials to investigate seeding methods for wheat.

Babiker, E.A. and Mohamed, A.O. Transfer of wheat management technology using demonstration plots in the Rahad Scheme.

Dawelbeit, M.I. On-farm evaluation of harrow packing on wheat yield in the Gezira Scheme.

Dawelbeit, M.I. and Salih, A.A. Wheat tillage systems in Gezira Scheme.

Kannan, H.O. Demonstration of the economic threshold levels of wheat aphids.
Kannan, H.O. Bionomics and seasonal abundance of wheat aphids in the Rahad Scheme.
Mohamed, A.O. Performance of three sowing methods under two tillage systems for wheat production.

Book Chapters

Wheat in Heat-Stressed Environments: Irrigated, Dry Areas and Rice-Wheat Farming Systems (D.A. Saunders and G.P. Hettel, eds.), 1994. Mexico, D.F., CIMMYT.
Ageeb, O.A.A. Agronomic aspects of wheat production in Sudan.
Elahmadi, A.B. Development of wheat germplasm tolerant to heat stress in Sudan.
Faki, H. and Ismail, M.A. Some indicators for wheat production prospects in Sudan.
Hassan, R., Faki, H. and Byerlec, D. Improved wheat production practices and the question of economic efficiency in the Gezira Irrigation Scheme.
Ishag, H.M. Genotype differences in heat stress in wheat in the irrigated Gezira Scheme.
Miller, R.H. Integrated pest management of cereal aphids in the Nile Valley: Problems and potential.
Salih, A.E.M., Abdalla, O.A., Sidahmed, M., Faki, H. and Ismail, M.A. Wheat production in the Gezira.
Sharaf Eldin, N. and Kannan, H.O. Pest problems of wheat in Sudan.

Extension Leaflets

Agricultural Research Corporation (ARC).
Ageeb, O.A.A. 1991. Wheat production in central and eastern Sudan.
Dawelbeit, M.I. Increasing the efficiency of the wheat combine.
Dawelbeit, M.I. How to minimize wheat losses from harvest.
Advantage and disadvantage of prewatering for wheat in farmer fields.
Irrigation management in relation to proper crop maturity in wheat.
Recommendations on crop establishment of wheat and effect of temperature on wheat yield.
Pests of wheat and their control.
Recommendations on land preparation on wheat production and its impact on farmers' fields.
Guidelines for wheat production in central Sudan (Gezira Research Station).
Cultural practices of wheat recommended for Gezira Scheme.

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