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Production and Improvement of Cool-Season Food Legumes in the Sudan

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Production and Improvement of Cool-Season Food Legumes in the Sudan

Proceedin~s of the National Research Review Workshop, 27–30 August 1995, Agricultural Research Corporation, Wad Medani, Sudan

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Foreword

Faba bean, lentil and chickpea are among the most important food legume crops in the Sudan, providing a major part of the daily diet for the population. Because of their high protein content, they also provide a major portion of the protein requirement to alleviate malnutrition problems in the country. Food legume crops also play an important role in sustaining the productivity of the farming systems in the Sudan because of their beneficial effect on the soil through the fixation of atmospheric nitrogen.

Yield levels of food legumes have been considerably low. Because of low production and increasing domestic demand, imports and prices of food legumes have increased to the point of becoming unaffordable to the large low-income sector of the population. Thus, striving to achieve self-sufficiency in food legumes has been vital to meet local demand and reduce imports.

In its efforts to overcome the constraints hindering agricultural development, particularly in the production of food legumes and wheat, the Sudan, through its Agricultural Research Corporation (ARC), has joined forces with the International Center for Agricultural Research in the Dry Areas (ICARDA) in a collaborative program involving two other Nile Valley countries: Egypt and Ethiopia. The Nile Valley Regional Program (NVRP) for Cool-Season Food Legumes started in the Sudan in 1988/89 and extended to 1994/95 through the support of the Directorate for International Cooperation (DGIS), Ministry of Foreign Affairs, the Netherlands. Nearly a decade before, in 1979, the first ICARDA regional outreach project—the Nile Valley Project (NVP)—had started, initially to improve faba bean in Egypt and the Sudan, and later, in Ethiopia as well. The project was financed by the International Fund for Agricultural Development (IFAD) and extended through two phases from 1979 to 1985. In the third phase, Italy joined with IFAD to support NVP activities from 1985/86 to 1987/88. The approach followed in the NVP and, later, in the NVRP is considered as an effective methodology in technology transfer and capacity building.

The Food Legumes Program has the overall objective of developing improved technologies and transferring them to the farmers to enhance productivity and yield stability of food legumes, with due consideration to the sustainability of the farming systems under which these crops are produced. As a partner, ICARDA collaborates with the Sudan in the development of research workplans, technical backstopping, the provision of germplasm and training opportunities, and contributes to research coordination at national and regional levels. In addition to ICARDA, ICRISAT provides chickpea germplasm, particularly genetic stock resistant to wilt/root-rot diseases.

Technology development and transfer, undertaken by multidisciplinary and multi-institutional teams of scientists, extension agents and farmers, resulted in high adoption levels by farmers of improved high-yielding cultivars and recommended cultural practices.

The emphasis of the program was on increasing yields at economically feasible levels—one of NVRP's major objectives. Increasing productivity results in better net returns to the farmers and contributes to alleviating poverty in rural areas.

This book documents the achievements in food legumes in the Sudan within the NVRP in back-up research, technology transfer, human resource development and capacity building. It illustrates the impact of investment in agricultural research. The valuable financial support of IFAD and Italy and that of DGIS of the Netherlands to NVRP is greatly appreciated by the Sudan and ICARDA.

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Preface

The principal cool-season food legumes in the Sudan are faba bean, lentil, chickpea, haricot bean and, to a lesser extent, field pea and lupin. The first three crops have a significant role in the diets of the Sudanese people and contribute substantially to the economy of the country. These crops are gaining further in importance as a source of protein for the majority of the population which cannot afford animal products because of escalating prices.

Research on faba bean, lentil and chickpea started long ago at Hudeiba Research Station of the Agricultural Research Corporation (ARC) at Ed-Damer in northern Sudan. Work on faba bean—the most important food legume in the Sudan—has had a particular boost since 1979 when the Nile Valley Project (NVP) on Faba Beans was started by the ARC in collaboration with the International Center for Agricultural Research in the Dry Areas (ICARDA) through financial support from the International Fund for Agricultural Development (IFAD). Because of the rapid impact achieved by the project on faba bean improvement and production in the target areas (because of the farmer participatory on-farm research), the research was expanded to include other cool-season food legumes as well as wheat in 1988/89 when the Nile Valley Regional Program (NVRP) on Cool-Season Food Legumes and Wheat was launched by the ARC and ICARDA with financial support from the Directorate General for International Cooperation (DGIS) of the Netherlands Government.

The overall objective of this Program was to develop and transfer improved production technologies to the farmers to improve the productivity and economic returns from the major cool-season food legumes and wheat, thereby ensuring improved economic well-being of the people and sustainability of the agricultural production system in the country.

The Program has made remarkable progress in back-up research and transfer of technology during the seven-year period of its operation. Although the results of the work done have been published regularly in the Program annual reports, a collective review and documentation of results will serve as reference and base for further research. Accordingly, a National Research Review Workshop was organized at the ARC headquarters in Wad Medani, Sudan, from 27 to 30 August 1995, as part of the closing activity of the NVRP. This volume presents the Proceedings of that Review Workshop.

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

The Editors

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Introduction

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Faba bean, lentil and chickpea are grown mainly in the northern part of the Sudan where environmental conditions suit their production better than in other parts of the country. Their growing season is restricted to a short period of time by the high temperatures prevailing at the beginning and end of winter. Faba bean is produced exclusively under irrigation, while lentil is raised mainly under irrigation, but also after flood recession in some areas. A large area of chickpea is grown on residual moisture after flood recession. These cool-season food legumes provide a major source of low-cost protein for masses in the Sudan, especially for low-income groups. Faba bean, lentil and chickpea are equally important as income earners for their producers and contribute to soil fertility through biological nitrogen fixation.

Faba bean is the most important food legume in the Sudan. It constitutes the main dish on the breakfast and dinner tables for a large sector of the population. It has the biggest area share, averaging about 20,000 ha to a maximum of over 35,000 ha. Average faba bean yields are about 1.8 t/ha, but annual fluctuations are considerable depending on climatic conditions, mainly temperature. In some years the production of faba bean falls below demand and, thus, a sizeable amount needs to be imported to bridge the gap.

Lentil used to be grown in small areas in the far north. As a result of policies established by the government, lentil production expanded in the last decade resulting in a remarkable increase in its area, which reached 10,000 ha in the 1992/93 season. Lentil yields range between 0.4 and 1.4 t/ha.

Chickpea is an important cash crop in the Sudan which faces strong competition with the other winter grain legumes—faba bean and lentil—as well as with other cash crops like spices. Average area grown to chickpea in recent years reached 5,000 ha. Its yields range between 0.83 and 2.8 t/ha, depending on weather conditions. Optimization of crop yields is a necessity to maintain its rank in the existing cropping system.

Constraints that contribute to low productivity of faba bean, lentil and chickpea include poor cultural practices used by farmers; lack of high-yielding cultivars; stress inflicted by the harsh environmental conditions, particularly high temperatures; diseases; insect pests; weeds; and intrinsic factors pertaining to the sensitivity of these species to sudden changes in climatic conditions. Irrigation water is the most important single constraint to agricultural production in northern Sudan. As a result of the high cost of pumping water from the Nile, irrigation water is a costly resource that justifies strict allocation among the different crops grown.

Wilt and root-rots are the most important diseases of cool-season food legumes in the Sudan, especially in areas where the farmers do not adhere to crop rotations. High temperature has been considered the most important predisposing factor for the development of wilt/root-rots in faba bean. A number of virus diseases affect faba bean in the Sudan. These diseases, particularly the mosaic group, appear late in the season, coinciding with the onset of the cooler weather and the build-up of insect vector populations. Mixed infections occur naturally, leading to substantial yield losses.

Insect pests (e.g., aphid, leaf miner, cutworm, pod borer, etc.) represent one of the major biotic constraints that limit the production of cool-season food legumes in the Sudan. The rate of infestation of the wide range of herbivores which attack every part of the plants, and the magnitude of damage to the crops, which can be tremendous, vary depending on area, season and cultural practice. Control strategies, which should be simple and affordable, should place minimum reliance on chemical insecticides which, in any case, are becoming very expensive besides being hazardous to the environment and to nontarget organisms.

The production of food legumes in northern Sudan is greatly constrained by weeds which cause up to 80% reduction in seed yield. Weeds create serious competition for water, nutrients and light because of the low competitive ability of legume crops during the early stages of their growth.

Overcoming the above constraints is only possible through the adoption of optimum crop management practices and the use of improved, high-yielding, adapted cultivars. The narrow genetic base of faba bean in the Sudan limits the genetic variability of the species required for effective selection for the desirable characters. Thus, the methodology used in faba bean improvement includes an extensive introduction and hybridization program to create wide genetic variability. The limited lentil and chickpea growing areas in the Sudan do not justify extensive breeding programs, thus, the improvement programs rely heavily on introduction of germplasm from ICARDA and other parts of the world.

The Nile Valley Regional Program (NVRP) for Cool-Season Food Legumes and has the overall objective of developing improved technologies and transferring them to the farmers to enhance productivity and yield stability of these food legume crops, with due consideration to the sustainability of the farming systems under which these crops are produced. This Program, which extended between 1988/89 to 1994/95, is a collaborative effort between the Agricultural Research Corporation (ARC) in the Sudan and the International Center for Agricultural Research in the Dry Areas (ICARDA). The Program is financially supported by the Directorate General for International Cooperation (DGIS), Ministry of Foreign Affairs, the Netherlands.

After research workplans are jointly planned by the ARC and ICARDA, the ARC implements the NVRP methodology in three phases. Under back-up research, the first phase, 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 phase, on-farm researcher-managed trials, experiment station research findings are evaluated for verification under actual farm conditions. The organization and management of these trials remain with the national scientists, while the supervision is shared between the scientists and the 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 the farmers in large pilot production fields which the farmers lay out with advice from researchers and extensionists. Throughout the Program, ICARDA provides technical backstopping, germplasm and opportunities for human resource development, and contributes to program management and research coordination. ICRISAT also provides chickpea germplasm, with particular emphasis on resistance to wilt/root-rot diseases.

In the following chapters, a review of the research conducted in the Sudan on the production, improvement, agronomy and protection of faba bean, lentil and chickpea and the transfer of the recommended improved technologies to farmers within the NVRP during the last decade is presented. Achievements and some future directions and strategies for further work are also highlighted.

Chapter 1
Cool-Season Food Legume Production in the Sudan

Food Legume Production Situation

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Abstract

Cool-season food legumes are important crop commodities produced and consumed in the Sudan. They are a major source of low cost protein for the middle and low income strata of the population. They are equally important as income earners for their producers. Important crops of this category are faba bean, lentil and chickpea. Production is concentrated in the Northern State, taking advantage of the relatively cool winter. Area and production of the three crops are variable, reflecting the weather conditions and, to some extent, market and policy-related factors. Faba bean has the biggest area share, averaging about 20,000 ha to a maximum of over 35,000 ha. Average faba bean yields are about 1.8 t/ha, but annual fluctuation is considerable depending on climatic conditions, more particularly temperature. Its consumption has spread over time in all parts of the country. Production is domestically consumed and imports have been required in seasons of short supply. Chickpea average area before 1992/93 was 800 to 2,000 ha. Its yields vary from 0.83 to 2.8 t/ha, depending on weather conditions. Production is also locally consumed. Lentil used to be grown in small areas in the far north. Due to high prices and government support, its production expanded in the last decade reaching 10,000 ha in recent seasons. Lentil yields range between 0.4 to 1.4 t/ha. Production has been short of supply and imports are always needed. Production is under farming systems of small private pump schemes and some big public schemes. The crop sharing system in private schemes is based on resource participation which creates conflicting perception among resource owners towards technology use. In public schemes, the system is based on fixed water charges. Generally, there has been very limited government intervention in the production or pricing of these crop. Producers have acquired considerable freedom in production and marketing. The national strategy for food legumes is aiming to boost production through area expansion and productivity increase, conservation of soil fertility and foreign exchange generation through import substitution and export promotion. Recently the government has been engaged in the provision of subsidized major inputs, particularly fuel and finance. Lentil has received the highest attention.

Consumption Demand

Traditionally, faba bean consumption has been confined to urban areas. It has, however, spread over the last two decades to all parts of the country. Consumption has also been rising due to urbanization, population growth, changing consumption habits and the rising prices of meat. Faba bean is consumed by all income groups, with the consumption in the middle class being the highest. The per capita consumption averages 2.25 kg per month in urban areas (Yousif 1988). The two main demand indicators—its responsiveness to the crop price and consumers' income—are both favorable for faba bean producers. Faba bean has a relatively low price elasticity of demand, estimated at 0.2 (El Mubarak *et al.* 1984). This implies that producers can sustain higher crop prices without a considerable expected decrease in demand. Faba bean income elasticity, on the other hand, ranges between 0.85 and 1.48 in different areas (Yousif 1988). The measure is showing high responsiveness of demand to income, implying that production expansion would still be demanded.

For chickpea, there are no available estimates on consumption and demand. The evidence, however, is that production is consumed domestically and small imports in some years are reported. Chickpea consumption is particularly high during the Holy month of Ramadan (the Moslem fasting month) as an old tradition which is still observed.

For lentil, production and import records indicate that its demand has been rising. Based on these records, the Sudan's annual consumption of lentil has been estimated a few years ago at about 15,000 tons per annum. However, more than 16,000 tons have been imported in 1994.

Production

Food legume production is concentrated in the Northern State, north of latitude 16°, taking advantage of the relatively cool winters in this area. Production takes place under farming systems of small private pump schemes and some big public schemes. The private pump schemes are characterized by a crop-sharing system based on resource participation. The main parties involved are the pump owner, known also as the scheme owner, and the farmer or tenant. The pump owner is responsible for the provision of water while the farmer provides his labor for field operation. Other purchased inputs and services are shared. This traditional arrangement has created a conflicting perception towards technology use by the desire of each party to adopt the technology components provided by the other party. The situation is specifically true for irrigation water, the major component of all technological packages.

Production in public schemes[1], on the other hand, is based on payment of fixed water charges. Production decisions are almost fully under the farmers' control. However, the government can indirectly affect production through credit and price policies. For example, in recent years the government has been encouraging lentil production by the provision of credit, inputs and technical support. As a result, the lentil area is substantially expanding at the expense of other crops.

The three crops are grown at the same time as other annual crops and some perennials, most of which are high value crops. Given the limited cultivable area of the region, this implies high competition for food legumes. The crop mix and areas are determined by several factors of which market-induced ones are the main.

Faba bean is considered among the most important annually produced crops with respect to its share in area and farm income. Area, production and average yield of faba bean are shown in Fig. 1. Faba bean average area is around 20,000 ha and reaches 35,000 ha in some seasons. Compared to an area of 6,700 ha in the early sixties, considerable production expansion has taken place. Its average yields are around 1.8 t/ha, but annual fluctuation is considerable due to weather conditions and biological factors. However, during the last two and a half decades, average yield has indicated an increasing trend (Fig. 2). From 1960 to 1980, there has been an increase in area, but after 1981/82, there has not been a consistent trend. Imports were 14,877 tons in 1991. All domestic production is locally consumed.

Chickpea is grown in an area of about 800 to 2,000 ha (based on data collected up to 1991/92). It is either irrigated or grown under residual moisture following the flood. Yields vary from 0.83 to 1.8 t/ha, depending on winter temperatures and management levels. From 1980/81 to 1991/92, area, production and yield of chickpea have all shown an increasing trend (Fig. 3).

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[1] Public schemes are under the process of privatization.

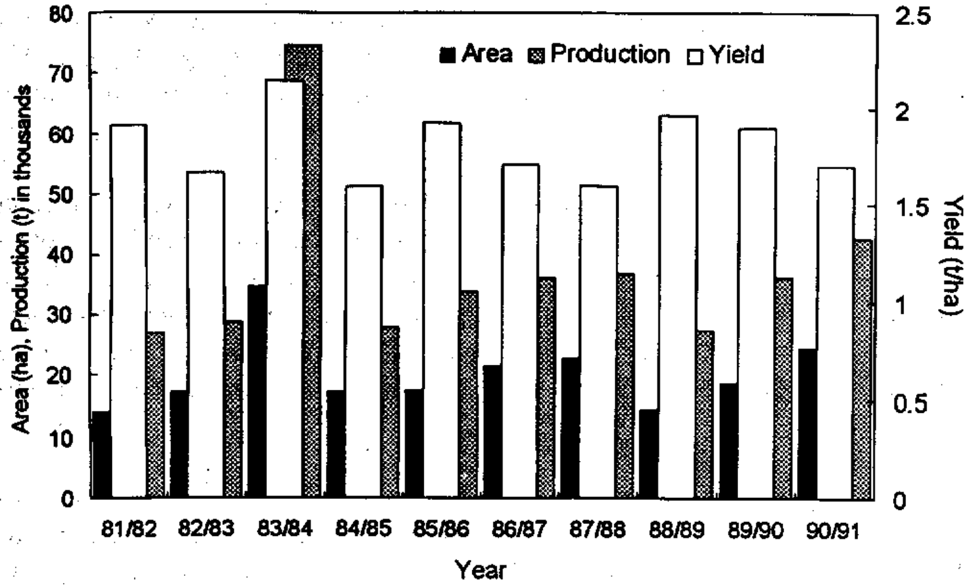

Fig. 1. Area, production and average yield of faba bean, 1981/82–1990/91.

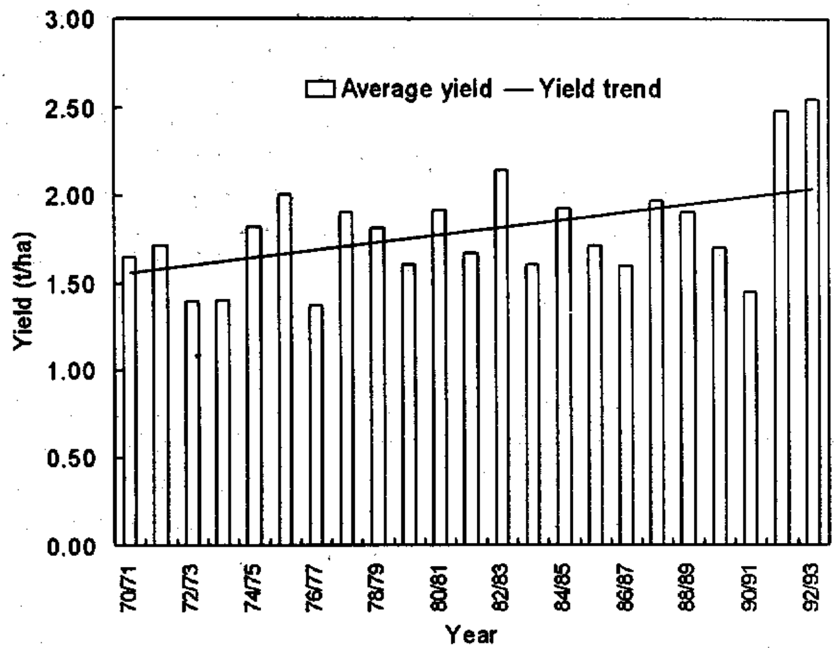

Fig. 2. Faba bean yield and yield trend, 1970/71–1992/93.

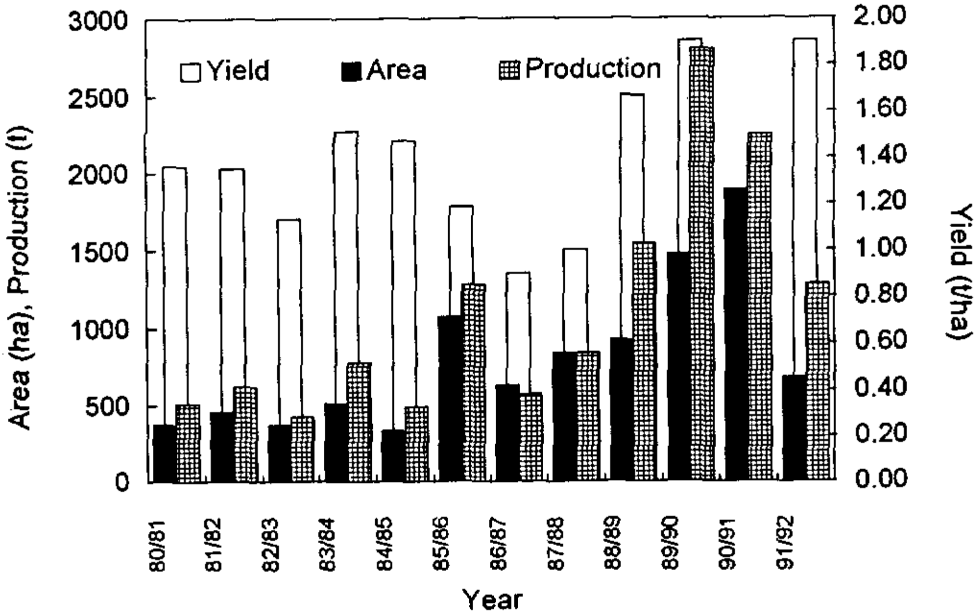

Fig. 3. Area, production and average yield of chickpea, 1981/82–1991/92.

Lentil used to be grown in small areas in the past (up to the 1960s) under river floods in the far north. Since 1984, its production has expanded due to high prices, research input and government support with the objective of reaching self-sufficiency. Within the past five seasons, its area and production have expanded tremendously to reach 10,000 ha and 14,000 tons, respectively, in 1992/93. Lentil yields range between 0.47 to 1.4 t/ha and have shown an increasing trend (Fig. 4). As a result, lentil imports were substantially decreasing (Fig. 5). In the last two seasons, however, the imports again have increased because of the decrease in production after having reached self sufficiency in 1992.

The considerable yield variability in food legumes is related to weather conditions, biological factors and levels of management practices. Given the highly competitive nature of the production systems, production of these crops would not be attractive with the current yield levels. Sustainable increases in yields would be crucial for legumes to keep their well recognized position in the farming systems of the area. Realization of high yields, however, is dependent on farmers' adherence to improved production technology. On-farm research has proved over the years and across locations that improved management practices are superior to traditional practices and, therefore, they assure higher profits for farmers. This has been shown by high yield advantages and higher rates of return on investment.

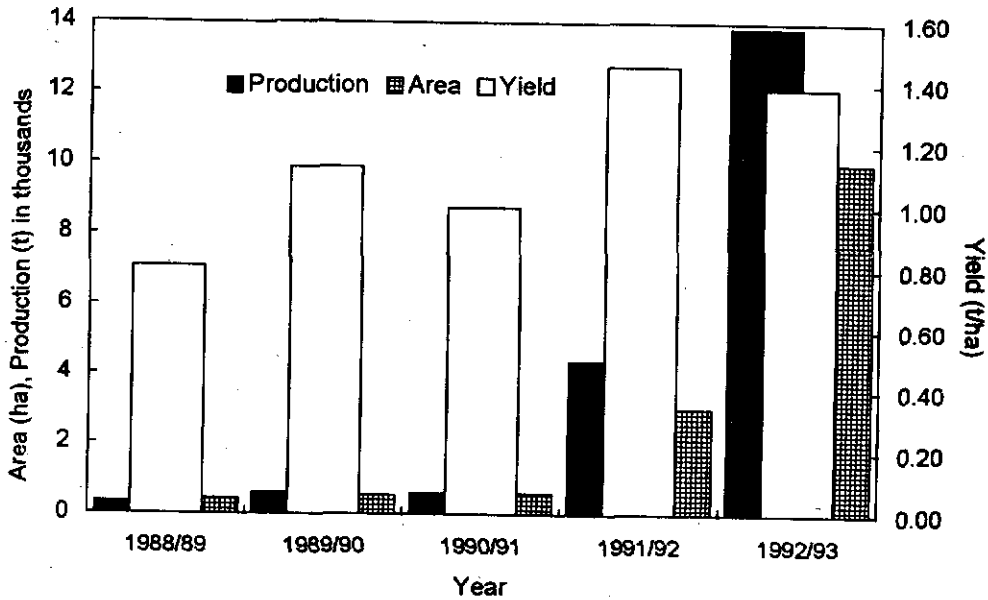

Fig. 4. Area, production and average yield of lentil, 1988/89–1992/93.

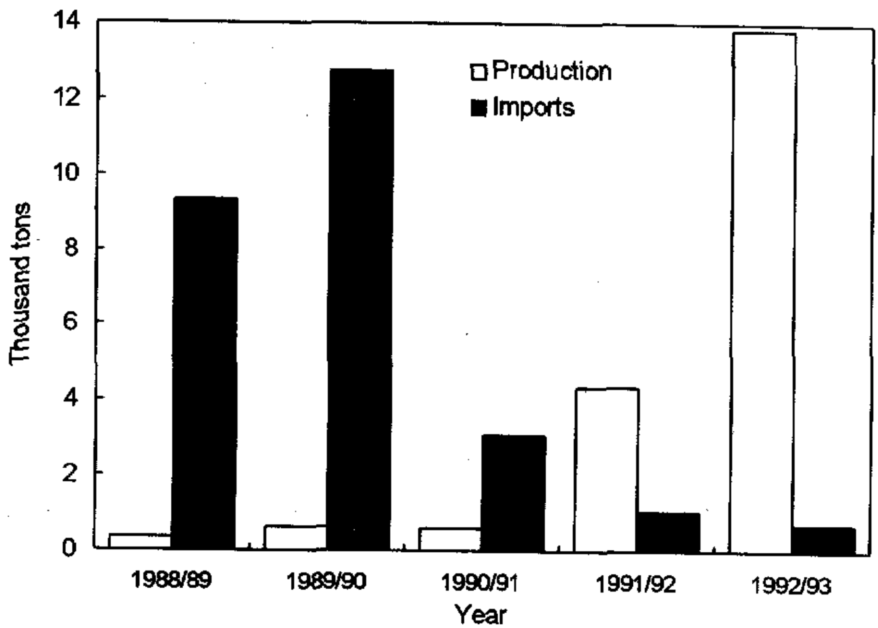

Fig. 5. Production and imports of lentil, 1988/89–1992/93.

Production Constraints

The major constraints to production of food legumes are those related to natural resource endowments, biological factors and institutional limitations. The limited cultivable land of the area and competition from other high-value crops limit area expansion. Legumes are grown among a variety of other crops such as tree crops, vegetables and spices which are all high-value crops.

The yields of legume crops are known to be sensitive to weather conditions, particularly temperature, and are reduced by high temperatures, insect pests and diseases. The adverse effects of natural factors are further magnified by the use of traditional low yielding cultivars and the poor management practices.

Inadequate credit availability and marketing arrangements are also important constraints to production expansion of these crops. The use of low levels of inputs and practices is related to farmers' limited access to credit. Marketing and its implication on benefit distribution is also an important issue in production and technology use. The remoteness of the production region and its lack of infrastructure prevent adequate interaction with the rest of the country. This has forced small farmers to sell their products in local markets at lower prices. There is a widely held belief that crop dealers have market power to affect prices. This is based on the large difference between producer and consumer prices. The implication is that benefits that accrue to marketing agents are more than those to farmers.

The level of financial benefits to producers has been considerably influenced by the recent open market policies. Producers have long been enjoying subsidized inputs, particularly diesel fuel. Due to the policy change, the cost of irrigation has undergone a three-fold increase between 1991 and 1993. Crop prices, however, have increased less proportionately. This has been aggravated by the lack of adequate finance. The implication is that farmers use suboptimal levels of inputs.

The challenge for researchers is to develop a cost-effective production technology that is also tolerant to natural and biological stresses. This could be done by the development of cultivars that are resistant to insect pests and diseases, strategies of integrated pest management and location-specific practices with respect to input levels and practices.

Government Policy for Food Legumes

Generally, there has been limited government intervention in the production or pricing of these crops, except the lentil promotion campaign mentioned earlier. The national strategy for food legumes, however has the following objectives:

- Increase production by eight-fold by the early 2000s.
- Boost production, particularly of lentil, through area expansion and productivity increase.
- Conserve soil fertility.
- Generate foreign exchange through import substitution and export promotion.

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Discussion

Q: Prof. Abdalla A. Abdalla

What are the productivity levels of 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

Fuel, which affects the cost of water provision, is one major component in production costs that affect profitability in northern Sudan. Analysis within the project does not cover whole crop budgets, but faba bean can be argued to have maintained its profitability since farmers in the north who have freedom in cropping have continued to produce the crop with varying levels depending on its profitability in individual seasons.

Chapter 2
Breeding and Improvement

Faba Bean Improvement

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Abstract

The overall objective of the faba bean breeding program in the Sudan has been to develop genotypes having high and stable seed yields and good quality seed, both in the traditional and new areas of production. The specific objectives were to breed for resistance or tolerance to stress conditions especially diseases, insect pests and suboptimal irrigation. Attempts to change the breeding system of the species to autogamy were sought. To fulfill such objectives, genetic variability raised by the conventional methods of germplasm introduction, selection and hybridization, besides mutation breeding, was utilized. Six new cultivars (SM-L, Hudeiba 93, Basabeer, Shambat 75, Shambat 104 and Shambat 616) were released in the past eight years as high yielders, more stable and of better seed quality. Resistant or tolerant genotypes for powdery mildew (PM1, PM2 and F402/4) and wilt root-rot (Shambat 104 and Shambat 616) diseases were identified. Lines tolerant to aphids and leaf miner were also spotted as well as genotypes that could tolerate suboptimal irrigation. Studies on the breeding system showed that the natural outcrossing rate ranged between 12 and 41%. Most of the local germplasm was found to possess high levels of autofertility.

Introduction

Faba bean is the most important food legume in the Sudan. It constitutes the main dish on the breakfast and dinner tables for a large sector of the population, especially low income groups in the urban areas. In addition, it contributes to soil fertility through biological N_2-fixation. The crop is also an important source of income for farmers in northern Sudan. In some years the production falls below the demand and, thus, like in 1994, a sizeable amount needs to be imported to bridge the gap. The area under faba bean cultivation has increased from about 7,450 ha in 1965 to about 30,000 ha in the 1994/95 season. The main production zone of the crop is the Northern State where more than 70% of crop is produced, and the Nile State which produces about 20% of the crop. Small amounts are produced in Khartoum State, central Sudan and Jebel Marra area in western Sudan. The crop is traditionally grown on small holdings by lift irrigation. The productivity of the crop is generally low compared to, for example, the productivity of faba bean in Egypt where the crop is also grown under irrigation. Constraints contributing to this low productivity may be summarized in the following:

- Poor cultural practices practiced by farmers.
- Lack of high yielding cultivars. Most of the released high yielding genotypes have not found their way to farmers because of seed multiplication problems.
- Stress conditions inflicted by harsh climatic conditions, particularly the short growing season, high temperatures, diseases, pests and weeds.
- Some institutional problems related to inferior extension services, lack of certified seed and problems pertaining to the availability of important inputs like irrigation water and pesticides.
- Intrinsic factors pertaining to the species itself, especially the problem of flower and pod shedding which may amount to 90%, and which is aggravated by harsh environmental conditions, particularly hot winds and high temperatures.

Research on faba bean improvement has started at Hudeiba Research Station in the Nile State in the early 1960s and in the Faculty of Agriculture at Shambat in the mid 1960s. In 1980, research was also initiated at Shambat Research Station in Khartoum State. Between 1979 and 1987, the Nile Valley Project (NVP) on faba bean improvement was launched through a joint effort between the Agricultural Research Corporation (ARC), the International Center for Agricultural Research in the Dry Areas (ICARDA) and the International Fund for Agricultural Development (IFAD). In 1988, the Nile Valley Regional Program (NVRP) was initiated to cater for and strengthen back-up research and transfer of technology on other winter legumes, besides faba bean, and wheat. NVRP involved the ARC, ICARDA and the Netherlands Government as the donor. As a result of NVRP efforts, substantial information on the crop improvement has been generated. Improved packages of production, through which the productivity could be highly boosted, were demonstrated on lots of farmers' fields. Remarkable results were obtained. Through the NVP/IFAD and later NVRP/Netherlands endeavors, faba bean production has been advanced to new areas in central Sudan where land and water are more abundant.

This review discusses and summarizes the breeding work on the improvement of faba bean to date with emphasis on achievements under NVRP. Some future directions and strategy for improving this crop are mentioned.

Objectives

The objectives of the faba bean improvement program in the Sudan may be summarized as follows:

- Breeding for high seed yield and yield stability in the traditional and new areas of production.
- Breeding for better seed quality.
- Breeding for resistance or tolerance to biotic stresses, namely, diseases, insect pests and less watering.
- Breeding for early maturity and tolerance to abiotic stresses, namely, limited moisture (less watering) and high temperatures.
- Studying the crop breeding system in an attempt to change the system to full autogamy.

Methodology

In order to achieve the above objectives, the program aimed at increasing the genetic variability of the species to enable effective selection for the desirable characters. The genetic base of this crop is considered to be narrow in this country. To broaden this base, the conventional methods of plant breeding have been used, namely:

- Introduction of exotic germplasm. More than 2,000 accessions have been imported since the mid 1960s from different places including Egypt, Ethiopia, ICARDA, Europe and the former USSR.
- Selection from local landraces. Hundreds of single plant and mass selections were made from different production areas in the country.
- Hybridization among the local and introduced material for attributes of interest by using single, triple, back and multiple crossing. Mutation breeding through x-irradiation has also been used. Few Sudanese cultivars were irradiated in Sweden in the early 1970s, and as a result, many mutants differing in seed characteristics, resistance to diseases and other traits were obtained.

The elite selections raised through these methods were usually maintained, multiplied and purified under insect-proof cages for a number of generations before evaluation. The evaluation of the material was carried out using the conventional procedure of testing in preliminary, advanced, national and/or verification yield trials. The preliminary testing was carried out in the research station where the material was raised; the advanced and national testing was usually done in a number of research stations or research sites, while the verification test was conducted on farmers' fields before varietal releases.

Achievements

High Seed Yield, Yield Stability and Better Seed Quality

It is known that seed yield has low heritability because of the strong influence of environmental effects (Lawes *et al.* 1983), and thus efforts were made to develop selection indices based on other characters correlated with yield and having high heritability.

The main criteria used for selection were a high number of pods per plant, as this was found to be highly correlated with seed yield (Kambal 1969; Yassin 1973), and large or medium seed size. This last character is one of the most stable in faba bean (Dantuma and Thompson 1983) and thus increases in faba bean yields are more likely to occur with larger seed size (Lawes *et al.* 1983). Larger seed size is also a quality character that is preferred by consumers in the Sudan (Ali 1983).

At Hudeiba Research Station, the first released cultivar, BF 2/2, was a single plant selection from the local 'Baladi' genotype (Mutwakil, 1968, personal communication). The cultivar Hudeiba 72 was a selection from an Egyptian variety 'Rebaya' and was released in 1972 for its higher yield and stability than other genotypes (Yassin 1973). These two cultivars, however, are no longer available to farmers.

In the early 1980s, new programs were launched at Hudeiba and Shambat research stations to breed for better performing genotypes. Since then, six new cultivars have been released in the traditional and new areas for their high yield, good stability and seed quality. In 1987, the genotype SM-L, bred at Hudeiba Research Station, was released under the name 'Selaim Improved' for the now

Northern State. The good performance of this cultivar, indicated by Salih and Ali (1989), may be seen in Tables 1 and 2. In 1993, two other genotypes: Bulk 1/3 and BB 7, also bred at Hudeiba, were released under the names 'Hudeiba 93' and 'Basabeer', respectively (S. Salih *et al.* 1993). Tables 3, 4, 5 and 7 show the performance of these cultivars. The genotype 00616 was also released in 1993 for the new areas under the name of 'Shambat 616' (F. Salih *et al.* 1993a). Tables 6 and 7 indicate the superiority of this line. However, two other cultivars, 'Shambat 75' and 'Shambat 104', had already been released. The first was released for Rahad area (Salih and Mohamed 1992) and the other for Gezira (F. Salih 1992). Shambat 75 is more stable in yield and of better seed quality than the check cultivar (Table 8), while Shambat 104 is more yielding than the check cultivar (Table 9). A summary of the characters of the above-mentioned six cultivars is presented in Table 10.

Table 1. Seed yield of eight faba bean lines grown in Selaim area during the 1981/82–1984/85 seasons.

Line	Season/Seed yield (kg/ha)					Relative mean yield (%)
	1981/82	1982/83	1983/84	1984/85	Mean	
SM-L	3173	3655	2824	2369	3005	128
NEB 424 S	3399	4063	2874	1680	3004	128
NEB 152 S	3211	4101	2844	1271	2857	121
Hudeiba 72	3013	3166	2383	1661	2556	109
BM 9/3	2928	2972	2572	1401	2468	105
188 x GI	2496	3475	2158	1457	2397	102
ZB-M	2628	3062	2208	1290	2297	98
Local	3006	3153	2238	1023	2356	100
Mean	2982	3456	2513	1519		
SE (±)	217	313	278	321		

Table 2. Some seed quality attributes for eight faba bean lines grown in Selaim area.

Line	Character			
	100-seed wt.† (g)	% non-soaking‡ seeds	Protein content§ (%)	Cooking time (min)
SM-L	54.9	4.5	31.1	170
NEB 424 S	41.3	7.4	29.7	165
NEB 152 S	43.6	9.8	30.1	185
Hudeiba 72	42.5	13.1	29.6	185
BM 9/3	37.5	10.5	30.2	185
188 x GI	40.3	10.5	30.2	165
ZB-M	38.7	10.9	29.6	165
Local	55.4	3.6	30.8	235

†, ‡, § Average of four, three and one season data, respectively.

Table 3. Average seed yield of some faba bean selections for three seasons in different locations.

Genotype	Season/Seed yield (kg/ha)			
	1990/91†	1991/92†	1992/93‡	Mean
Bulk 1/3 (Hudeiba 93)	2053	3771	4110	3311
Cross 42	1597	3598	4207	3134
SM-L 85/1/1	1641	3587	3963	3064
H.72/7/1	1617	3431	4138	3062
H.72/4	1307	3390	4244	2980
ZBF 9/4	1138	3674	4105	2972
Cross 40	1256	3784	3818	2953
TW 2/1	1577	3528	3716	2940
ZBF 3/3	1317	3179	4207	2901
Hudeiba 72 (check)	1514	3292	3804	2870
ZBF 1/1	1362	3354	3818	2845
F 402/4	1244	3262	3960	2822
BF 2/12/2	1244	3405	3752	2800
Cross 4B/1	909	3114	3788	2504
Mean	1413	3455	3974	

†, ‡ Means of two and three locations, respectively.
Source: S. Salih *et al.* (1993).

Table 4. Seed yield of some promising faba bean lines at various locations, 1991.

Genotype	Location/Seed yield (kg/ha)				Mean
	Hudeiba	Shendi	Shambat	Wad Medani	
BB 7 (Basabeer)	1050	2587	1497	3069	2051
Bulk 1/1	678	2264	1754	3222	1980
Hudeiba 72 (check)	681	2080	1739	3111	1903
ZB 1/1	660	2061	1590	3181	1873
0094	624	1995	1860	3014	1873
557/80	617	1626	2130	3042	1854
00564	679	1668	2106	2944	1849
Kadabas 1/1	698	1537	1888	3181	1824
00594	478	1555	1929	3319	1820
00605	599	1170	1803	3097	1667
ZB2	953	1958	1153	2292	1589
Mean	701	1864	1768	3043	1844
SE (±)	176**	221*	99**	237*	95

*, ** Significantly different at the 5% and 1% levels, respectively.
Source: S. Salih *et al.* (1993).

Table 5. Seed yield of faba bean lines in the national verification trial at various locations, 1992/93 season.

Genotype	Location/Seed yield (kg/ha)							Mean
	Hudeiba	Wad Medani	Faki Hashim	Shambat	Gezira	Rahad	Jebel Marra	
BB 7 (Basabeer)	4.30 (1)†	4.97 (3)	5.35 (8)	3.90 (2)	4.54 (1)	2.29 (1)	3.72 (2)	4.15
Bulk 1/3 (H.93)	3.54 (8)	5.24 (1)	5.70 (5)	4.23 (1)	3.69 (3)	2.06 (7)	3.77 (1)	4.03
00616	3.86 (4)	4.86 (4)	5.77 (3)	3.76 (3)	4.35 (2)	2.22 (4)	3.05 (5)	3.98
00594	3.94 (3)	4.99 (2)	6.54 (1)	3.58 (7)	3.58 (7)	2.19 (6)	3.24 (3)	3.93
00634	3.62 (6)	4.22 (7)	5.76 (4)	3.39 (5)	3.95 (4)	2.24 (2)	2.91 (6)	3.73
557/80	4.05 (2)	3.69 (8)	5.54 (7)	3.40 (4)	4.17 (3)	2.22 (3)	3.06 (4)	3.73
BF 2/2/8/1	3.63 (5)	4.43 (6)	6.06 (2)	3.35 (6)	3.43 (8)	1.94 (8)	2.91 (7)	3.68
H.72 (check)	3.55 (7)	4.78 (5)	5.68 (6)	2.68 (3)	3.85 (5)	2.20 (5)	2.90 (8)	3.66
Mean	3.81	4.65	5.80	3.47	3.94	2.17	3.19	3.86
SE (±)	0.35	0.28	0.28	0.20	0.37	0.09	0.27	
SD	0.62	0.49	0.48	0.35	0.65	0.16	0.46	
CV (%)	16.3	10.5	8.3	10.1	16.5	7.4	14.4	

† Numbers in parentheses indicate rank.
Source: F. Salih *et al.* (1993b).

Table 6. Comparative performance of faba bean line 00616 (Shambat 616) and the mean of Hudeiba 72 and BF 2/2 (checks) in seed yield in different seasons.

Season	Genotype/Seed yield (kg/ha)		% increase
	00616	Checks	
1982/83	2966	2358	26
1983/84	1750	1302	34
1984/85	1380	1588	-15
1985/86	3679	3026	22
1986/87	2078	1725	21
1987/88	3084	2256	37
1988/89	2734	2391	15
1989/90	2785	2868	-3
1989/90	2461	1925	28
1989/90	2250	1795	25
1990/91	1033	658	57
1990/91	1436	1252	15
1991/92	3593	3212	12
1992/93	4020	3600	12
Mean	2518	2140	18

Source: S. Salih *et al.* (1993).

Table 7. Some seed quality attributes for the eight faba bean genotypes tested in the verification yield trial (VYT), 1992/93.

Genotype	Quality trait		
	% hard seeds	% total defective seeds	Protein (%)
BB 7	6.9	9.7	34.7
Bulk 1/3	7.6	9.5	35.5
00616	8.9	11.4	29.2
00594	9.4	13.4	35.0
00634	7.9	11.5	33.9
557/80	8.9	11.8	35.1
BF 2/2/8/1	5.2	7.8	35.0
Hudeiba 72	8.2	14.7	34.6
Mean	7.9	11.2	34.1
SE (±)	0.35	0.63	

Table 8. Some yield components and seed quality attributes of 12 faba bean genotypes grown in Rahad area, 1987/88 season.

Breeding line	No. of pods/plant	1000-seed wt. (g)	Total defective seeds (%)	Hard seed (%)	Hydration coefficient (%)	Cookability (%)	Tannic acid (%)	Crude protein (%)
71	19.1	443	11.3	10.9	174	37.2	0.05	27.4
70	15.5	413	11.9	11.3	174	35.2	0.06	27.8
75	18.4	417	5.9	4.7	193	30.5	0.06	28.0
656	18.6	413	10.4	9.6	173	31.8	0.04	27.1
72	15.5	423	12.6	11.0	179	31.8	0.07	28.1
BF 2/2	18.4	390	13.4	12.7	175	27.8	0.07	29.0
7	18.1	407	10.2	9.6	174	35.2	0.05	27.9
633	20.2	424	11.9	10.9	172	36.0	0.04	27.8
35	15.6	420	16.7	16.1	167	42.5	0.06	26.2
634	18.2	415	12.8	12.4	168	41.0	0.06	29.4
532	19.2	395	6.2	6.0	180	35.5	0.04	29.0
80	17.2	433	13.1	12.0	178	28.2	0.07	30.0
Mean	17.8	416	11.4	10.6	176	34.4	0.06	28.1
SE (±)			1.0	0.9	31	2.3	0	0.5

Table 9. Comparative performance of line 00104 (Shambat 104) and the mean of Hudeiba 72 and BF 2/2 (checks) in seed yield in different experiments and seasons.

Season†	Genotype/Seed yield (kg/ha)		Increase (%)
	00104	Checks	
1981/82	1831	1070	71
1982/83	3183	2456	30
1983/84‡	2679	2214	21
1983/84‡	1761	1550	14
1984/85	1308	1389	-6
1986/87	2079	1709	22
1987/88	2073	1942	6
1988/89	3245	3054	7
1989/90	3183	2825	13
Mean	2371	2023	20

† Results from 1985/86 not available.
‡ Two separate trials were executed in 1983/84, one at Shambat, the other at Wad Medani. In both trials the genotypes were different except for a few common genotypes.

Breeding for Tolerance to Stress Conditions

Diseases and insect pests are among the major constraints of faba bean production in the Sudan. Although these hazards are amenable to control through cultural or chemical methods, the best and cheapest method of control remains to be through breeding resistant/tolerant genotypes. Breeding of tolerant genotypes that give reasonable yields under suboptimal irrigation is another goal of faba bean breeding for stress conditions.

Breeding for resistance to diseases

Powdery mildew. In the Sudan, powdery mildew is caused by the fungi *Leveillula taurica, Erysiphe pologoni* and *Odium* sp. (Hussein and Freigoun 1979). The disease used to be very serious on faba bean in the Sudan in the 1950s and 1960s. Tarr (1955) reported losses of up to 50% in yield due to defoliation and desiccation of the plant. The incidence of the disease, which is usually pronounced in late-sown crop, is now generally decreasing.

Table 10. Faba bean released cultivars in the last eight years.

Cultivar	Year of release	Attributes	Area of release	Breeder
Selaim Improved (SM-L)	1987	High seed yield (> 20% over check). Better seed quality. Tolerant to aphids. High degree of autofertility.	Northern State	Salih H. Salih
Shambat 75	1990	High and stable yield (8% over check). Good seed quality.	Rahad area	Farouk A. Salih
Shambat 104	1990	High and stable yield (20% over check). Early maturing. Tolerant to seedling diseases.	Central Sudan	Farouk A. Salih
Hudeiba 93	1993	High and stable yield (12% over check). Better seed quality. Tolerant to moisture stress. High degree of autofertility.	River Nile State and new areas	Salih H. Salih
Basabeer	1993	High and stable yield (20% over check). Good seed quality. Tolerant to moisture stress. High degree of autofertility.	River Nile State and new areas	Salih H. Salih
Shambat 616	1993	High and stable yield (18% over check). Acceptable seed quality. Tolerant to seedling diseases.	Central Sudan	Farouk A. Salih

Around 1965, Mutwakil (personal communication) identified a powdery mildew-resistant, but unadapted, Russian genotype that was crossed with local material. Unfortunately, no conclusive results were obtained since evaluation for resistance to the disease was usually carried out under natural conditions of infection which vary from one season to another. Resistance to this disease was also sought through mutation breeding where some promising selections were raised from local genotypes treated by x-irradiation in Sweden (T. Yassin and F. Salih, personal communication). However, S. Salih (1992, 1993) was able to select at least three genotypes, namely, PM1, PM2 and F402/4 that were resistant to the disease. The first two selections were from the local collection, while F402/4 was a single plant selection from the Egyptian cultivar Giza 402.

Seedling diseases. Wilt and root-rot diseases, which are attributed to *Fusarium oxysporum* and *F. solani* f. sp. *fabae*, respectively, are the most important fungal seedling diseases of faba bean in the Sudan. The disease complex is aggravated by high temperatures and thus poses a problem in the new areas of production in central Sudan. Hundreds of local and introduced accessions were screened for resistance to this complex in sick plots. No good source of resistance has yet been discovered but many tolerant lines were identified; of these are the cultivars released for the new areas: Shambat 104 (F. Salih 1992) and Shambat 616 (F. Salih *et al.* 1993a).

Virus diseases. About 10 viruses have been reported to attack faba bean in the Sudan. Among these, Bean Yellow Mosaic Virus (BYMV), Bean Leaf Roll Virus (BLRV) and Broad Bean Mottle Virus (BBMV) are the most important (see the review on virus disease on faba bean in these proceedings). A number of genotypes were screened for resistance to these viruses. Noticeable degrees of variability were found among these genotypes in their reaction to the diseases, but as yet no resistant line could be identified.

Breeding for resistance to insect pests

Aphids and the leaf miner, found in the new areas, are the most important faba bean pests. At Hudeiba and Shambat research stations, many local and introduced accessions were screened for resistance to aphids. However, many lines, including the released cultivar Hudeiba 72, were identified as tolerant to the insect (see the entomology report in these proceedings). One introduced line from Egypt, called 'Pakistani', was found to be immune to aphids but, unfortunately, gives very small seed yield and poor seed quality. The line could be hybridized with the released cultivars to transfer this character.

On the other hand, hundreds of breeding lines and cultivars were evaluated for resistance to leaf miner at Gezira Research Station in central Sudan. About 40 lines were identified to have some degree of tolerance to this pest (Sharaf Eldin and El Amin 1994).

Tolerance to limited moisture conditions

The studies carried out to investigate the adoption of the improved cultural practices of faba bean in northern Sudan, consistently indicated that the recommended irrigation regime, in particular, was the least adopted by farmers for various reasons (Ahmed 1991, 1992, 1993). Therefore, if some genotypes that gave reasonable seed yields under suboptimal irrigation could be identified, that would be a significant achievement. For this reason, a number of promising genotypes were evaluated for three seasons under different watering regimes at Hudeiba. Some lines, including the released cultivars Hudeiba 93 and Basabeer, were identified as tolerant to less water application (S. Salih *et al.* 1993; also see the report on food legumes water relations in these proceedings).

Studies on the Breeding System

One of the characteristics of faba bean is its large and unpredictable variation in yield in different locations and seasons. One of various reasons for this instability in yield is thought to be the partial dependence of the crop on insects for pollination since it is partially an outcrossing species.

In recent years, several breeding programs have concentrated on developing *autofertile lines that do not depend in their fertilization* on flower tripping by insects. This is expected to improve the yield stability of the crop (Lawes *et al.* 1983) and would allow populations and segregants to be screened and multiplied under open pollination (Hawtin 1982).

Two aspects of the faba bean breeding system have been investigated in the Sudan: the estimation of the degree of natural outcrossing and the evaluation of some genotypes for their degree of autofertility. These studies will formulate a basis for the attempts to change the breeding system of this species to autogamy.

Estimation of natural outcrossing
The first study in this respect seems to be that of Kambal (1969) at the Faculty of Agriculture at Shambat in Khartoum State. He found the outcrossing to range between 35.8 and 42.1%. Salih (1987) found the range to be between 12 and 18% at Hudeiba in the Nile State. Recently at Shambat, Salih *et al.* (1994) found the outcrossing to range between 14.2 and 17.4%.

Assessment of the degree of autofertility
This study was carried out mainly on local lines and cultivars. The study of Salih (1987) at Hudeiba Research Station revealed that most of the lines tested showed a high degree of autofertility. That study confirmed the work of Saxena *et al.* (1981) and Hawtin (1982) who found the cultivar Hudeiba 72 to be highly autofertile, and in fact, that might explain the result obtained by Yassin (1973) in which he showed this cultivar to have good yield stability. The recent evaluations carried out at Shambat and Hudeiba also showed many lines to possess high degrees of autofertility. The work carried out by Kambal (1969) to study the manual tripping on pod set of six genotypes showed that the line IW did not respond to manual tripping and showed the highest capacity to set pods without flower manipulation.

Future Directions

The work on faba bean improvement in the Sudan revealed that the bulk of the introduced germplasm was not adapted and thus could not be used directly. All of the released cultivars in the last decade were from local selections. This fact necessitates launching proper and intensive campaigns for collection of local germplasm, especially from Merawi and Wadi Halfa areas in the Northern State and Jebel Marra in western Sudan. Nevertheless, germplasm introductions fom abroad should continue as a source for desirable traits.

The prime breeding objective will remain to breed for high and stable yields, especially for new areas of production where land and water are abundant and thus suggested for future horizontal expansion of the crop area. In this context, genotypes that are early maturing, tolerant to heat, salt toxicity and wilt/root-rot complex and of better seed quality will be important. Screening for resistance to wilt/root-rot complex necessitates the establishment of proper sick plots in Shambat and Wad Medani research stations.

Other important areas are breeding for resistance to viruses where promising material is still lacking, continuing screening for tolerance to aphids and leaf miner insects, and breeding for better nitrogen fixation in the new areas in collaboration with rhizobiologists.

Screening for specific traits contributing to high seed yield and stability, e.g., high autofertility, independent vascular system (IVS), closed flower and high number of seeds per pod should continue.

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Discussion

Comment: M.B. Solh

Considering the efforts of NVP in expanding faba bean to nontraditional areas south of Khartoum, placing future emphasis on breeding for these areas may be a waste of time, since faba bean expansion in Gezira is not expected to develop and we already have two released cultivars. My second point is that, based on the literature and on experience, tolerance of faba bean and chickpea to salinity is not expected to yield tangible results or economic yields. Thus, one would save such efforts for other breeding objectives. Thirdly, please specify resistant genotypes or give the reference where they may be found.

A: Salih H. Salih

First, the production of faba bean in the new areas south of Khartoum is a debatable issue. If it is decided to extend faba bean production in that area, whether by policy makers or by farmers, then we are suggesting some areas that could be researched so that the crop gives high productivity. Second, salinity does not pose a problem for faba bean in the traditional areas of production, but it might be a problem in the new areas if it is decided to extend the production of this crop there. Third, the names of tolerant genotypes to disease and aphids are mentioned in the text. Those tolerant to leaf miner will be given. More details will be given in the entomology and pathology reviews.

Comment: M.B. Solh

There is a need to specify the breeding methodology (i.e., pedigree vs. bulk or modified bulk, introduction) and provide the flowchart for evaluation (type of trials). There is also a need to include a table of the cultivars, characteristics, adaptation, year of release, and responsible researchers.

A: Salih H. Salih

Some of the methods are mentioned in the text, more information will be given. The table requested will be provided (Table 10).

Q: Ali Kambal

Please comment on the following points: (1) Although there are many released cultivars, they did not reach the farmer; (2) the fate of 'Habashi' (autofertile) and the 'Russian' cultivar (powdery mildew resistant); and (3) the breeder has moved from Hudeiba to Shendi, whereas the main area is the Northern State.

A: Salih H. Salih

(1) Yes, the released cultivars have not reached the farmers and this is one of our headaches. Multiplication and distribution of seeds is the responsibility of the Seed Propagation Administration. Unfortunately, for various reasons, they could not satisfy this objective. Yet, at the ARC we are trying to increase the released cultivars, and this season, for example, we had about 4.5 tons from the cultivar SM-L. (2) Unfortunately, 'Habashi' and the 'Russian' genotype are no longer in our germplasm collection. (3) Fortunately, Dongola Research Station has now been established and two agro-breeders were posted there.

Q: Mohamed A. Gabbar

We have observed faba bean and chickpea grown in Gezira around wheat fields, and their production is now available in the market. Does this mean that the crops can be successfully grown?

A: Salih H. Salih

Faba bean could be successfully grown in central Sudan including Gezira, and that was verified by the extensive research work conducted for a number of seasons in central Sudan. Chickpea is a successful crop also in Hawata area in central Sudan. An area of approximately 1680 ha is usually grown there on residual moisture when the Rahad River recedes.

Q: G.S. Youssef

I would like to know the methodology in testing or breeding for tolerance. Also, immunity has not been recorded for aphids. Does the 'Pakistani' line belong to the same species as *Vicia faba*?

A: Salih H. Salih

Assessment of aphid tolerance in faba bean is usually carried out under bee-proof cages with artificial infestation. This is thought to create a good microenvironment for aphid multiplication. The genotype 'Pakistani' was found to be highly resistant to aphids. This genotype is a *Vicia faba* cv. *minor*.

Q: Mostafa Bedier

What were the experimental designs used to select new cultivars vs. local varieties? By knowing the design, the analysis could be easily carried out and the selection of new cultivars could be clear cut from the statistical point of view.

A: Salih H. Salih

In faba bean, we found the randomized complete block design to satisfy our evaluation since we handle quite a large number of genotypes. For assessment of genotypes to stress conditions, we sometimes use a split-plot design.

Lentil Improvement

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Abstract

Lentil (*Lens culinaris* M.) improvement is confined to the introductions of advanced breeding lines and germplasm received mostly from ICARDA and the region. It involves selection based on multilocation performance. The superior performance of promising lentil genotypes for grain yield and agronomic characters under farmer conditions at Rubatab, Wad Hamid and Jebel Marra areas in the Sudan over several seasons justified the release of the lines ILL 813 and ILL 818, to farmers in the Sudan under the names Rubatab-1 and Aribo-1, respectively. The ongoing evaluation under farmer conditions showed promising large-seeded yellow cotyledon-colored lines, such as ILL 4605, ILL 6004, and ILL 6806, for potential releases as large-seeded cultivars in the Sudan. Evaluation of promising germplasm under station conditions at Hudeiba and Shendi revealed superior lines in grain yield and/or seed size, such as Flip 84-51L, Flip 84-112L, ILL 7210, ILL 7212, ILL 7617 and ILL 6465, compared to the checks.

Introduction

The relatively longer and cooler winter season in the north of the Sudan is most favorable for lentil production (El Sarrag and Nourai 1983; Sheikh Mohamed *et al.* 1989). Recently, however, the crop showed good performance at the lower *wadis* of Jebel Marra area due to the favorable microclimate generated by the effect of the high altitude (3000 m asl) (Sheikh Mohamed *et al.* 1994). The lentil improvement program in the Sudan is based on introductions, evaluation and selection within advanced breeding lines and germplasm introduced mostly from ICARDA and the region. This is simply because the lentil area in the Sudan is limited and does not justify an extensive breeding program including hybridization. The objective of this paper is to review the lentil improvement program and present cultivar recommendation for growth in the Sudan.

Release of Cultivars

In view of the evaluation of hundreds of lentil (*Lens culinaris* M.) germplasm received from ICARDA in the seventies and eighties, four small-seeded lines (ILL 788, ILL 795, ILL 813 and ILL 818) and two large-seeded lines (ILL 4606 and ILL 6004) were evaluated for grain yield and agronomic characters under farmer conditions in Rubatab area (Kudig 19°N, 33°E), Shendi area (Wad Hamid 16°N, 33°E), and Jebel Marra area (Zalengi 14°N, 25°E) in the 1990/91, 1991/92, and 1993/94 seasons for comparison with the check Selaim.

The lines showed significant differences in grain yield at Wad Hamid and Jebel Marra locations while no significant differences were observed at Rubatab. The yield data over locations and seasons showed that the best line was ILL 818 (2.9 t/ha) followed by ILL 813 (2.8 t/ha) exceeding the check Selaim (2.6 t/ha) by 11 and 6%, respectively (Table 1). The grain quality was analyzed at the Food Research Center in Shambat. The protein content of the lines was high, ranging from 26 to 30%; the best lines in protein content were ILL 818 followed by ILL 813. Grain dehulled percentage was high, ranging from 86 to 94% (Table 2). These results justified recommending the lines ILL 813 and ILL 818 in December 1993 and releasing them to farmers in the Sudan under the names Rubatab-1 and Aribo-1, respectively (Sheikh Mohamed *et al.* 1989, 1994).

Table 1. Grain yield of lentil lines in Rubatab, Wad Hamid, and Jebel Marra averaged over the 1990/91 to 1992/93 seasons.

Line	Grain yield (kg/ha)/Location			Mean	% increase over check
	Rubatab	Wad Hamid	Jebel Marra		
ILL 818	1762	4542	2450	2918	11
ILL 813	1894	4683	1823	2800	6
ILL 795	1652	4398	1950	2733	4
ILL 4605	1700	3475	2140	2438	-7
Selaim (check)	1852	4216	1630	2630	
SE (±)	212	155	116		
Signif. level		**	**		

** = Significant difference at the 1% level.

Table 2. Protein content and grain dehulling properties of promising lentil lines.

Location/line	Protein (%)	Grain dehulling properties (%)†			
		Dehulled	Undehulled	Broken	Extraction
Rubatab					
ILL 795	26	92	8	3	82
ILL 813	29	94	6	3	78
ILL 818	28	86	14	3	82
ILL 6004	27	96	4	1	82
ILL 4605	28	94	6	1	82
Selaim (check)	26	90	10	3	75
Wad Hamid					
ILL 795	29	82	18	3	79
ILL 813	28	94	6	3	78
ILL 818	30	86	14	3	79
ILL 6004	24	91	9	1	80
ILL 4605	29	87	13	2	79
Selaim (check)	28	78	22	3	74

† Dehulling was performed using the Tangential Abrasive Dehulling Device (TADD).

Selections for Desirable Traits

Along with the evaluation under farmer conditions, on-station selection of lentil material for adaptability, high yield, earliness, and large seed size has been ongoing from the early nineties at Hudeiba (17°N, 34°E) and Shendi (16°N, 33°E) research stations. The most promising lines with high yield and/or large seed size compared to the checks, shown in Table 3, were selected. Some lines such as Flip 84-5IL, Flip 84-112L, ILL 7212, and ILL 6717 outyielded the check (Selaim) by more than 50%, while other lines such as ILL 6465 and ILL 7210 were better than the check in seed size by more than 50% (Table 3). These lines will be further tested in yield trials or made use of in hybridization programs which will be initiated for better performance in earliness, seed size and high grain yield.

Table 3. Grain yield and seed weight of promising lentil lines† of advanced breeding lines and germplasm accessions.

Line	Grain yield (kg/ha)	1000-seed weight (g)
Flip 84-51L	2286	47
Flip 84-112L	2041	47
ILL 6465	1740	75
ILL 7210	760	50
ILL 7212	1458	44
ILL 7217	2188	54
ILL 7617	2208	43
H4/3/81	1543	33
H5/8/81	1743	31
Selaim (local check)	1316	30
SE (±)	150	1
Significance level	**	*

*, ** = Significant difference at the 5% and 1% levels.
† Large-seeded > 30 g.

Additional germplasm received from ICARDA and local material were evaluated in the early nineties. Four promising yellow cotyledon large-seeded lines (ILL 4605, ILL 6002, ILL 6004, and ILL 6806) and three red cotyledon medium-seeded lines (ILL 6024, ILL 6467, and ILL 795) were selected and grown under farmer conditions in various locations in two seasons (1993/94 and 1994/95) in comparison to the checks (Aribo-1, Rubatab-1 and Selaim) which are red cotyledon small-seeded types.

The lines showed significant differences in grain yield and 1000-seed weight in all locations (Tables 4 and 5). Most of the lines were significantly better than the checks in seed weight but this was not reflected in grain yield except in line ILL 4605 in 1993/94 at Rubatab (Tables 4 and 5).

Wilt/root-rot disease incidence was monitored at Hudeiba and Rubatab in 1993/94 and 1994/95. The lines evaluated showed significant differences in disease incidence in 1994/95 at Rubatab, while no significant differences were observed at Hudeiba in the two seasons (Table 6).

Table 4. Grain yield of the lentil lines in multilocations averaged over the 1993/94 and 1994/95 seasons.

Line	Grain yield (kg/ha)/Location				
	Rubatab	Hudeiba	Wad Hamid	Jebel Marra	Mean
ILL 795	1489	1129	1650	1435	1426
ILL 4605	1813	864	1265	1209	1288
ILL 6002	1650	960	850	915	1094
ILL 6004	1443	617	575	990	906
ILL 6024	1328	966	1388	1182	1216
ILL 6467	1587	1126	1738	966	1354
ILL 6806	1593	943	1100	1139	1194
Rubatab-1 (improved check)	1250	1049	1663	1525	1372
Aribo-1 (improved check)	1173	1187	1638	1520	1379
Selaim (local check)	1762	862	1762	1293	1414
Mean	1509	970	1363	1217	
SE (±)	200	100	158	60	
CV (%)	28	20	23	10	
Significance level	*	**	**	**	

*, ** = Significant difference at the 5% and 1% levels, respectively.

Table 5. Seed weight of lentil lines in multilocations averaged over the 1993/94 and 1994/95 seasons.

	1000-seed weight (g)/Location				
Line	Rubatab	Hudeiba	Wad Hamid	Jebel Marra	Mean
ILL 795	28	19	26	30	26
ILL 4605	36	32	27	40	34
ILL 6002	41	35	31	42	37
ILL 6004	44	35	31	47	39
ILL 6024	31	29	30	31	30
ILL 6467	30	26	28	31	29
ILL 6806	36	32	31	44	36
ILL 795	28	19	26	30	26
Rubatab-1 (improved check)	28	21	25	30	26
Aribo-1 (improved check)	29	23	25	29	27
Selaim (local check)	27	18	24	30	25
Mean	33	27	28	35	
SE (±)	1	1	1	1	
CV (%)	6	8	9	7	
Significance level	**	**	**	**	

** = Significant difference at the 1% level.

Table 6. Wilt/root rot disease incidence in lentil lines at two locations, 1993/94 and 1994/95.

Line	Disease incidence (%)/Location			
	Hudeiba		Rubatab	
	1993/94	1994/95	1993/94	1994/95
ILL 795	30.1†	1.6‡	2.4‡	2.6‡
ILL 4605	25.2	2.1	3	2.6
ILL 6002	26.4	1.3	3.1	1.6
ILL 6004	25.8	1.3	2.8	2.4
ILL 6024	17.7	1.5	2.6	1.6
ILL 2467	30.6	1.2	2.6	2.4
ILL 6806	22.2	2.1	2.9	2.5
ILL 795	30.1	1.6	2.4	2.6
Rubatab-1 (improved check)	31/4	1.7	2.6	1.9
Aribo (improved check)	29.4	1.5	2.5	2.1
Selaim (local check)	15.2	1.3	2.5	2.1
SE (±)	4.6	0.27	0.16	0.13
Significance level	NS	NS	NS	***

† Percentage values transformed to arc sine.
‡ Percentage values transformed to square root of (x+1).
*** = Significant difference at the 0.1% level; NS = Not significant.

Future Considerations

- Seed multiplication of released lentil cultivars is urgently needed.
- On-farm evaluation of promising lines is necessary for further flow of cultivar release.
- Germplasm enhancement on-station should be strengthened by generating variability through hybridization, pedigree and modified bulk selections..
- Evaluation of material under stress conditions such as residual moisture, high temperature, and diseases, mostly wilt/root-rots, will be given priority.

Acknowledgments

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Discussion

Q: M.S. Mohamed

Why is the cooking quality of Sudanese lentil not good and efforts are being made to improve it?

A: A. Ibrahim Sheikh Mohamed

Cooking quality is mainly a soil-type problem. If you grow lentil in good silty soils you will get good quality lentil. If grown on saline or sodic soils, hard-seeded types are produced.

Q: A. Kambal

There is emphasis in the lentil program on large seeds. Is this character related to yield?

A: A. Ibrahim Sheikh Mohamed

The large-seeded types are yellow cotyledon with low yield, but fortunately we have large-seeded red cotyledon lentil with good yield and also other yellow cotyledon types with high and reasonable yield.

Q: A.H. Nourai

In the Sudan, lentil is eaten decorticated and small-seeded lentil is very popular as it has red cotyledons. I observed that Sudanese lentil has a mixed cotyledon color varying from red to pale. Are you considering cotyledon color in your breeding program?

A: A. Ibrahim Sheikh Mohamed

Yes, cotyledon color is considered and there are two types of lentil: red cotyledon and yellow cotyledon.

Q: Abdel Galil Abdel Gabbar

The criteria for heat tolerance and moisture stress are not satisfactory. Is there any coordination between agronomists (soil/water relations) and breeders? Also, how do you deal with lentil yields since the range is relatively wide?

A: A. Ibrahim Sheikh Mohamed

Yes, there is coordination between agronomists and breeders. Regarding your second question, lentil yield is a range of yields from different locations and seasons, that is why we find a wide range of variation. However, we usually take the average and select the cultivar according to its performance over locations as well as for specific locations.

Chickpea Improvement

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Abstract

Chickpea improvement in the Sudan is based on selections made within germplasm introductions, mostly advanced breeding lines from ICARDA. Selection was for adaptation, high and stable yield, resistance to wilt/root-rot disease, earliness and large seed size. The evaluation of chickpea (*Cicer arietinum* L.) germplasm at Hudeiba and Shendi in the 1983/84–1986/87 seasons justified the release of the kabuli type line NEC 2491/ILC 1335 to be grown by farmers in northern Sudan under the name Shendi-1. On-farm evaluation of chickpea lines at Rubatab, Wad Hamid and Jebel Marra in the 1990/91–1992/93 seasons justified the release of the line ILC 915 to be grown by farmers in the Sudan under the name Jebel Marra-1. The ongoing evaluation of large-seeded and medium-seeded kabuli chickpea lines under farmer conditions in the same above locations in the 1993/94 and 1994/95 seasons showed promising genotypes such as Flip 88-36C and Flip 88-44C, which could be recommended to be grown by farmers in the Sudan as large-seeded cultivars. On-station breeding activities at Hudeiba and Shendi revealed many promising medium- and large-seeded genotypes with 50–100% higher grain yield and seed size over the checks (Shendi-1 and Jebel Marra-1). The line ICCV-2 showed wilt/root-rot disease resistance at Hudeiba and good performance under residual moisture conditions at Wad Hamid.

Introduction

The relatively long and cool winter season in the north of the Sudan is more suitable for chickpea production compared to the central and southern parts of the country. Recently, it was found that the crop is successfully grown in Hawata area in eastern Sudan and Jebel Marra in western Sudan (Faki *et al.* 1992; Sheikh Mohamed 1989, 1990, 1991).

Intensive breeding work has been ongoing at Hudeiba and Shendi research stations to develop adapted, high and stable yielding, resistant to wilt/root-rots, early and large-seeded chickpea genotypes. Because of the limited acreage of chickpea in the Sudan, the improvement program emphasized introductions, evaluation and selection within germplasm, mostly advanced breeding lines, introduced basically from ICARDA, and to a lesser extent, from ICRISAT and the region. The objective of this paper is to review the chickpea improvement program and present varietal recommendations in the Sudan.

Release of Cultivars

The evaluation of chickpea (*C. arietinum* L.) germplasm introduced from ICARDA in the late seventies and early eighties led to the selection of 19 promising lines which were grown at Hudeiba (17°N, 34°E) and Shendi (16°N, 33°E) in the 1983/84 to 1986/87 seasons for comparison with the local check (Baladi). The results indicated the superiority of the kabuli line, NEC 2491/ILC 1335, over the check (Baladi) in grain yield by 43% at Hudeiba and 24% at Shendi over the four seasons (Table l). This line exceeded the check in seed size by 50%. In view of these results, the line NEC 2491/ILC 1335 was recommended for release to farmers in northern Sudan in October 1987 and released under the name Shendi-1 (Sheikh Mohamed 1989,1990, 1991; Sheikh Mohamed *et al.* 1995).

In view of the evaluation of material received from ICARDA/ICRISAT in the late eighties and early nineties, 10 kabuli chickpea lines were selected for grain yield and desirable agronomic characters under farmer conditions at Rubatab (Kudig 19°N, 33°E), Hudeiba (17°N, 34°E), Shendi (Wad Hamid 16°N, 33°E), and Jebel Marra (Zalengi 14°N, 25°E) areas, in the 1990/91 to 1992/93 seasons for comparison with the checks (Shendi-1 and Baladi). The lines showed significant differences at Rubatab and Jebel Marra in grain yield. In both locations, the best line was ILC 915 whose average yield over locations and seasons exceeded the checks Shendi-1 by 15% and Baladi by 45% (Table 2). These results justified the recommendation of the line ILC 915 in December 1993 which was released to farmers in the Sudan under the name Jebel Marra-1 (Sheikh Mohamed and Abu Sara 1993).

Table 1. Grain yield and 100-seed weight of chickpea line NEC 2491 ILL 1335 in comparison to Baladi (average of four seasons).

Cultivar	100-seed weight (g)	Grain yield (t/ha)	
		Hudeiba	Shendi
NEC 2491/ILL 1335	18	1.0	2.1
Baladi (local)	12	0.7	1.7
Increase (%)	50	43.0	24.0

Table 2. Mean Grain yield of chickpea genotypes in Rubatab and Jebel Marra averaged over the 1990/91 to 1992/93 seasons.

Line	Yield (kg/ha)			% increase over check	
	Rubatab	Jebel Marra	Mean	Shendi-1	Baladi
ILC 915	2078	3943	3011	15	45
ILC 1327	1997	3334	2667	2	28
ILC 1631	1994	3280	2637	1	27
Shendi-1 (improved check)	1810	3403	2607		25
ILC 1353	1770	3077	2424	-7	17
ILC 1620	1612	2760	2186	-16	5
Baladi (check)	1670	2490	2080	-20	
SE (±)	160	240			
Significance level	**	**			

** = Significant difference at the 1% level.

Selections for Desirable Traits

In view of the evaluation and selection of chickpea material bred at Hudeiba and Shendi from 1990 to 1993, six large-seeded lines and three medium-seeded lines were grown under farmer conditions in the same above locations in the 1993/94 and 1994/95 seasons in order to compare them with improved and local checks (Jebel Marra-1, Shendi-1 and Baladi) which were medium-seeded lines. The lines showed significant differences in grain yield and 100-seed mass in all locations. All the Flip lines had significantly heavier seed size than the checks but were not superior in grain yield except in Flip 88-44C at Wad Hamid (Table 3). The line Flip 88-36C showed relatively stable grain yield and good seed size in all the locations.

Table 3. Grain yield and 100-seed weight of chickpea lines over in Rubatab, Hudeiba and Wad Hamid averaged over the 1993/94 and 1994/95 seasons.

Line/pedigree	Rubatab		Hudeiba		Wad Hamid		Mean	
	GY† (kg/ha)	SW‡ (g)	GY (kg/ha)	SW (g)	GY (kg/ha)	SW (g)	GY (kg/ha)	SW (g)
Flip 88-30C	1723	38	1496	41	1469	34	1563	37
Flip 88-32C	1265	40	1592	39	1303	34	1387	38
Flip 88-36C	1750	44	1736	46	1650	41	1712	44
Flip 88-39C	1546	38	2080	40	1651	34	1769	37
Flip 88-44C	1418	41	1659	43	2244	39	1774	41
Flip 88-56C	1901	36	1800	38	1481	33	1727	36
ILC 378	1570	19	2511	19	1750	18	1944	19
ILC 1327	1638	20	2610	19	1828	19	2025	19
ILC 2910	1597	17	2291	19	1775	17	1888	18
Jebel Marra-1 (improved check)	1935	18	2675	21	1979	17	2196	18
Shendi-1 (improved check)	2072	18	2534	20	2032	19	2213	19
Baladi (local check)	1625	14	1983	17	1838	11	1815	14
Mean	1673	28	2080	30	1750	26		
SE (±)	180	1	230	1	150	1		
Significance level	**	**	**	**	**	**		

† GY = Grain yield; ‡ SW = 100-seed weight.
** = Significant difference at the 1% level.

Wilt/root-rot and stunt diseases incidence was monitored at Hudeiba and Rubatab locations in the two seasons. At Hudeiba, wilt/root-rot disease was observed in the two seasons with significant differences among the lines in 1993/94 only, while the stunt disease was observed in 1993/94 only with significant differences among the lines. At Rubatab the stunt disease was observed in the two seasons while the wilt/root-rot disease was observed in 1993/94 only with significant differences among the lines in both diseases (Table 4). In both diseases the advanced breeding (Flip) lines were generally more affected than the world germplasm collection (ILC) lines and checks.

Table 4. Disease evaluation of chickpea lines at Hudeiba and Rubatab, 1993/94 and 1994/95.

Line/pedigree	Hudeiba			Rubatab		
	Wilt/root-rot		Stunt	Wilt/root-rot	Stunt	
	1993/94	1994/95	1993/94	1993/94	1993/94	1994/95
Flip 88-30C	3.3†	2.1†	2.5†	1.6†	3.2†	35.3‡
Flip 88-32C	3.4	2.2	2.5	1.5	2.8	28.0
Flip 88-36C	3.1	1.8	2.5	1.1	2.3	39.0
Flip 88-39C	3.2	2.2	2.2	1.5	5.4	40.9
Flip 88-44C	3.2	2.0	1.7	1.8	3.3	32.9
Flip 88-56C	3.6	2.1	2.3	1.4	2.2	38.3
ILC 378	1.8	1.4	2.0	1.1	1.4	26.7
ILC 1317	1.8	1.4	2.1	1.2	1.6	26.5
ILC 2910	2.2	1.5	1.7	1.2	1.3	26.8
Jebel Marra-1 (improved check)	1.7	1.4	1.8	1.1	1.2	30.2
Shendi-1 (improved check)	1.9	1.9	2.4	1.0	1.4	27.2
Baladi (local check)	2.3	1.8	2.2	1.2	1.5	29.1
SE (±)	0.3	0.3	0.3	0.2	0.2	3.2
Significance level	***	NS	NS	***	***	**

† Infection percentage values transformed to square root of (x+1).
‡ Infection percentage values transformed to arc sine.
, * = Significant difference at the 1% and 0.1% levels, respectively.
NS = Not significant.

Because of the limited acreage of chickpea in the Sudan, the improvement program emphasized the evaluation of germplasm, mostly advanced breeding lines introduced from ICARDA, and to a lesser extent, from ICRISAT. Many new introductions were evaluated and yield-tested in preliminary and advanced yield trials in the 1990/91–1994/95 seasons. The material was divided into medium-seeded (< 30 g/100-seeds) and large-seeded (> 30 g/100-seeds) lines. The most promising lines with higher grain yield and/or larger seed size than the improved checks (Jebel Marra-1 and Shendi-1) are presented in Tables 5 and 6. Many medium-seeded lines exceeded the checks by 10–40% in grain yield and many large-seeded lines exceeded the checks by 50–100% (Table 5 and 6). The line ICCV-2, although not higher in grain yield than the checks, showed good resistance to wilt/root disease in a sick plot at Hudeiba. It also showed good performance under residual moisture conditions at Wad Hamid and under prolonged irrigation intervals at Hudeiba. More information will be presented in the pathology and soil-water relation reviews.

Table 5. Grain yield and 100-seed weight of chickpea lines in the breeding program at Hudeiba and Shendi (medium-seed size).

Line	Grain yield (kg/ha)	100-seed weight (g)
ICCV-2	1667	28
ICCV -3	2228	24
ICCV-89501	2514	25
ICCV-89503	2775	21
ICCV-89504	3203	28
ICCV-89506	2867	26
ICCV-89507	3431	23
ICCV-89509	3721	20
ICCV-89510	2844	28
ICCV-91301	1851	27
ICCV-91302	2298	25
ICCV-91303	2846	26
ICCV-91306	2031	29
ICCV-91307	3293	23
ICCV-91308	3407	23
Jebel Marra-1 (improved check)	2744	20
Shendi-1 (improved check)	2674	20
Baladi (local check)	2217	15
SE (±)	200	1
Significance level	**	**

** = Significant difference at the 1% level.

Table 6. Grain yield and 100-seed weight of chickpea lines in the breeding program at Hudeiba and Shendi (large-seeded).

Line	Large-seeded trial 1 Grain yield (kg/ha)	Large-seeded trial 1 100-seed wt. (g)	Line	Large-seeded trial 2 Grain yield (kg/ha)	Large-seeded trial 2 100-seed wt. (g)
Flip 89-81C	2555	36	ICCV-92304	1204	35
Flip 89-82C	3229	38	ICCV-92307	1030	34
Flip 89-117C	3229	40	ICCV-92308	1115	35
Flip 89-120C	2778	37	ICCV-92310	1189	89
Flip 90-12C	1260	34	ICCV-92311	1123	35
Flip 90-28C	2029	35	ICCV-92315	852	40
Flip 90-71C	2393	34	ICCV-92316	862	34
Flip 90-12C	2506	30	ICCV-92318	885	33
Flip 90-12C	3376	36	ICCV-92320	1121	33
Flip 90-163C	2380	38	ICCV-92321	927	34
Flip 90-182C	1847	34	ICCV-92324	758	34
Flip 91-35C	1458	34	ICCV-92328	1098	35
Flip 91-69C	3438	42	ICCV-92329	1302	35
Flip 91-71C	3438	42	ICCV-92331	1195	32
Flip 91-75C	3194	36	ICCV-92332	1396	34
Flip 91-76C	3958	35	ICCV-92334	1001	32
Flip 91-77C	3646	32	ICCV-92336	956	36
Flip 91-80C	3542	38	ICCV-92337	960	31
Flip 91-88C	4063	42			
Flip 91-142C	941	35			
Flip 91-193C	1563	40			
Flip 92-9C	2916	46			
Flip 92-92C	3958	39			
Jebel Marra-1 (improved check)	2138	20		1413	20
Shendi-1 (improved check)	2078	20			
SE (±)	200	1		200	1
Significance level	**	**		NS	**

** = Significant difference at the 1% level.
NS = Not significant.

Future Improvement Prospects

- Seed multiplication of released cultivars is urgently needed to ensure the availability of improved seeds to farmers.
- On-farm yield verification of promising material is essential for more flow of cultivar recommendations.
- The breeding programs should be strengthened through single plant selections and progeny evaluation from segregating populations introduced from ICARDA.
- Evaluation under stress conditions, such as disease, limited moisture, and soil salinity, are important. More emphasis is needed to develop cultivars resistant to wilt/root-rot disease and tolerant to moisture stress and with early maturity.

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Chapter 3
Agronomy and Microbiology

Agronomy of Faba Bean

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Abstract

Faba bean is grown as an irrigated winter crop mainly in the northern part of the Sudan where environmental conditions suit its production better than in other parts of the country. The growing season is restricted to a short period of time by high temperatures prevailing at the beginning and end of winter. Under such conditions, planting time is critical for achieving high yields. Biotic factors (insect pests and diseases) also play a significant role in determining the optimum sowing time. Due to the plastic nature of faba bean, large variations in seed rate, plant spacing and plant population were not accompanied by sizeable changes in grain yield. Irrigation at 7- to 10-day intervals throughout the growing season proved good, but longer irrigation intervals (up to 15 days) were adequate under high soil fertility (Gurier soils) and/or cool temperatures in the Selaim basin. Studies showed that the reproductive phase (flowering and pod formation) is the most sensitive to water stress, followed by the grain filling phase. In the traditional faba bean growing areas there was no need for *Rhizobium* inoculation or nitrogen application, but in new areas inoculation was needed. Chicken manure alone or in combination with split applications of nitrogen fertilizer increased yield on saline and alkaline soils. Phosphorus fertilizer, when placed with the seed, increased yield. Salinity reduced faba bean yield and 50% reduction in grain yield occurred at a salinity level of 9 mmhos/cm. Mulching increased soil moisture availability during the first six weeks from planting and reduced soil temperature which improved plant stand and grain yield. Seed grading did not affect grain yield. Seed storage under laboratory conditions for five years had no adverse effect on seed germination, but after eight years germination reduced to 20%. The optimum time to harvest faba bean was between 100 to 110 days after sowing for the cultivars H 72 and BG 2/2.

Introduction

Faba bean is grown as an irrigated winter crop mainly in the northern part of the Sudan (Northern and River Nile states and, to a limited extent, Khartoum) where environmental conditions suit its production. Lately, efforts were made to extend its production to other nontraditional areas (i.e., Gezira, New Halfa and Rahad schemes). Research work has been conducted at research stations and in on-farm trials to tackle various agronomic problems, which are summarized in this paper.

Planting Time

Faba bean production is restricted to a short period of time by the high temperatures prevailing at the beginning and end of the winter season. The high temperatures occurring during the growing season limit the yield. Biotic factors (i.e., diseases and insect pests), which are themselves influenced by the weather conditions, affect the optimum sowing time for the crop (Last and Nour 1961).

At Shambat the highest yield was given by crops sown in early November; crop sown earlier than this period was more likely to be affected by insect pests. Similarly, rapid yield drop was recorded when sowing was delayed after mid-November, mainly due to disease infection (powdery mildew). Heipko (1966) noted that plants sown in mid-October or early November formed most of their fruits before powdery mildew infection became serious, while the late-sown plants became infected in the budding or early flowering stage, resulting in increased flower and pod shedding and decreased seed size. Abu Salih *et al.* (1973) showed that delaying sowing of faba bean beyond October greatly lowered the seed yield as a result of increased infestation with aphids and broad-bean mosaic virus.

Ageeb (1977b) recorded highly significant effects of sowing date, irrigation interval and their interaction on grain yield. The optimum sowing date varied with irrigation interval, being in the second half of October when the crop was irrigated every week and in the first week of November when the crop was irrigated every two weeks (Table 1). Irrigation at weekly intervals in October, when temperatures were relatively hot, created a micro-climate less favorable for disease development and more favorable for plant growth and survival (Freigoun 1980). The number of plants per unit area, number of pods per plant, 1000-seed weight and, to a lesser extent, the number of seeds per pod were also affected by sowing date and watering interval (Ageeb 1977b).

Table 1. Effect of sowing date and irrigation interval on grain yield of faba bean.

Irrigation interval (days)	Sowing date/Grain yield (kg/ha)													Mean
	October				November					December				
	4	11	18	25	1	8	15	22	29	6	13	20	27	
7	1308	2081	2386	2209	2043	2150	1820	1653	1377	1250	1000	787	547	1585
14	333	927	1338	1379	1459	1578	1344	1289	847	928	763	572	413	1013
21	231	512	889	1017	1033	1083	921	896	695	476	449	344	282	679
SE (±)							81.5							111
Mean	624	1173	1538	1535	1512	1604	1362	1279	973	885	737	568	414	
SE (±)							25.6							

Source: Ageeb (1977b).

Taha *et al.* (1983), summarizing the results of a sowing date-variety trial conducted over three seasons at six different locations from Shambat in Khartoum State to Selaim in the Northern State, observed that the optimum date varied with locality. For Selaim it ranged from 10 to 20 October; for Zeidab, Aliab, and Shendi between 20 October and 10 November; and for Shambat between 30 October and 10 November. The negative effect of early sowing in the south was attributed to the higher incidence of wilt and root-rots as a result of the warmer weather compared with the northern part of the country.

Ibrahim and Ali (1993) reported that the optimum sowing date for Hudeiba ranged between 13 October and 17 November and that the variation in grain yield was highly associated with the variation in biomass at maturity, harvest index, plant height at maturity, single kernel weight and the number of seeds per pod.

The results of a factorial experiment conducted at Hudeiba, Shendi and Shambat over three seasons to study the effect of four production factors, each at two levels (improved vs. farmers' practice), revealed that sowing on 1 November consistently outyielded the farmers' practice of sowing towards the end of November (Mohamed *et al.* 1983b).

Method of Sowing

The standard method of sowing faba bean in research stations (Hudeiba, Shambat and Shendi) is space-planting on 60 cm ridges. This method was compared with the traditional farmers' practice at various locations (Aliab, Shendi, Saiyal, Hagar El Asal and Basabeer) in farmers' fields by the author from 1983 to 1986. These trials showed that the ridge method of sowing was not superior to the farmers' practice in the traditional faba bean growing areas where adequate land preparation was carried out.

Seed Rate

Last and Nour (1961) found that increasing the seed rate from 81.6 to 163.2 kg/ha increased the grain yield of a local variety (B.F.M.) by 48% and that of an introduced variety (Rebaya 34) by 18%. On the other hand, Heipko and Dafalla (1961, 1962) found no significant differences in the grain yield of two varieties

(B.F.M. and R40) when seed rates of 73.3, 110.5 and 147.4 kg/ha were used. El Saeed (1968) found that the yield of a local variety increased with increase in the seed rate from 40.8 to 327.4 kg/ha, but yield increment diminished beyond the seed rate of 163.2 kg/ha. Mohamed et al. (1984) studied the effect of seed rate, method of planting and weed control, each at two levels, for two seasons at Shendi and Aliab. The higher seed rate (160 kg/ha) consistently produced higher grain yields compared with the lower rate (60 kg/ha). Later, in the 1985/86 season, a comparison conducted by the author between two seeding rates (120 vs. 160 kg/ha) under farmers' conditions at three different locations showed no yield differences. Considering the above results, the optimum seed rate for faba bean in the traditional growing areas appears to be around 120 kg/ha.

Spacing and Plant Population

Ageeb (1977a) reported that the variation in row spacing (60, 40 and 20 cm), plant spacing (20, 10 and 5 cm) and number of plants per hole (1 or 2) had no significant effect on grain yield of the H 72 cultivar grown at Hudeiba Research Station for two consecutive seasons. These findings reflected the plastic nature of the cultivar which makes it insensitive to wide variation in plant population as a result of the compensatory change in the number of pods per plant. This was also evident in the work of Ishag (1971) who did not find any significant change in grain yield when plant spacing was varied between 10 and 30 cm or when two or three plants per hole were used, but grain yield was significantly decreased in comparison to the above treatments when a plant spacing of 40 cm or single plant per hole were used.

Taha *et al.* (1982) studied the effect of plant population in relation to sowing date at Selaim, Hudeiba and Zeidab sites. The yield under the three seeding densities (16.6, 33.3 and 49.9 seeds/m^2) were similar at Selaim and Zeidab, but at Hudeiba the highest density recorded significantly higher yield compared to the other two densities (Table 2).

However, the actual plant population was far less than the theoretical plant population as averaging over all sowing dates showed that percent plant establishment for the 16.6 and 49.9 seeds/m^2 varied between 88 to 53.7% in Selaim, between 84 to 57% in Zeidab and between 51 to 36% in Hudeiba, respectively.

Table 2. Effect of sowing date and plant population on faba bean grain yield and some yield components at three different sites in the Northern Region.

Treatment	Selaim			Hudeiba			Zeidab		
	Grain yield (kg/ha)	No. of pods/plant	No. of seeds/pod	Grain yield (kg/ha)	No. of pods/plant	No. of seeds/pod	Grain yield (kg/ha)	No. of pods/plant	No. of seeds/pod
Sowing date									
10 Oct.	2631	14.1	1.7	2241	23.9	2.3	1960	13.9	2.0
20 Oct.	2891	14.5	1.9	2398	21.6	2.3	1964	11.4	2.3
30 Oct.	2726	13.7	1.9	2491	18.1	2.3	2206	12.9	2.5
10 Nov.	2238	15.6	2.0	2270	16.0	2.6	2060	10.8	2.4
20 Nov.	1390	15.1	2.4	1560	16.0	2.3	1861	9.3	2.5
SE (±)	200	7.2	0.2	86	2.0	0.2	76		0.2
Population (plants/m^2)									
16.6	2253	20.5	1.9	2162	27.6	2.4	1905	17.0	2.4
33.3	2495	13.1	2.1	2195	17.0	2.3	2055	9.8	2.3
49.9	2381	10.3	2.0	2339	12.8	2.4	2070	8.3	2.2
SE (±)	155	5.6	0.2	67	1.6	0.2	59	0.9	0.1

Source: Taha *et al.* (1982).

In central Sudan (Gezira and Rahad agricultural schemes), which is a marginal area for faba bean, response to variations in plant population was different. Ageeb (1980) found that decreasing the plant spacing from 20 to 10 cm and increasing the number of plants per hole from one to two or three, significantly increased grain yield at Gezira Research Station. It was suggested that the difference in the response to plant population between the traditional and marginal faba bean growing areas could be due to the fact that plants in central Sudan were smaller and, therefore, a larger number of them could be accommodated per unit area.

Row and plant spacing interaction was studied by Ageeb *et al.* (1984) for three seasons at Gezira Research Station in Wad Medani (Table 3). Seed yield increased as row spacing was decreased from 60 to 20 cm, but the difference between 20 and 40 cm row spacing was not significant.

Moreover, at the narrowest row spacing of 20 cm, grain yield increased as the plant spacing was increased from 10 to 20 cm and the reverse happened at the widest row spacing of 60 cm. In contrast, average effects of variation in plant spacing were not significant.

Table 3. Average effect of plant and row spacing on the seed yield of faba bean at Gezira Research Station, Wad Medani.

Treatment	Seed yield (kg/ha)	Plants/m^2 at harvest	Pods/ plant	100-seed weight (g)	Plant height (cm)
Row spacing (cm)					
20	2641	51.0	6.0	38.2	103.0
40	2455	26.0	9.9	38.2	100.0
60	2150	19.0	12.4	38.1	102.0
SE (±)	75	0.3	0.3	0.2	1.4
Plant spacing (cm)					
10	2433	38.0	7.7	38.3	102.0
14	2488	32.0	8.9	38.0	105.0
20	2366	25.0	11.7	38.2	99.0
SE (±)	78	0.3	0.3	0.2	1.4

Source: Ageeb *et al.* (1984).

Water Management

Ageeb (1976, 1977b) studied the effect of three irrigation intervals in relation to two phases of plant development (vegetative and reproductive phases, the latter starting from pod set) of two faba bean cultivars on a heavy montmorilonitic clay soil at Hudeiba Research Station. The results indicated that the reproductive phase was more sensitive to water stress than the vegetative phase. Increasing the irrigation interval during the second phase from 7 to 14 and 21 days reduced grain yield by 893 and 1183 kg/ha, respectively, but application of similar treatment during the vegetative stage decreased grain yield by only 394 and 570 kg/ha, respectively.

Ayoub (1972, 1973) found that an 8-day irrigation regime increased grain yield by 22, 63 and 108% over 13-, 18- and 23-day regimes, respectively, at Hudeiba Research Station. Babiker (1975) reported that irrigating faba bean at weekly intervals increased grain yield by 92% over irrigating every two weeks.

Mohamed (1981) studied the effect of irrigation frequency in relation to the stage of plant development. Three watering regimes (7-, 10- and 14-day intervals) were applied continuously or interchanged in different combinations according to the phase of plant development. Three phases of development were defined: (1) vegetative (from sowing to the start of flowering); (2) reproductive (from the start of flowering to 100% pod setting); and (3) grain filling (from 100% pod setting to maturity). The reproductive phase was the most sensitive to moisture supply, followed by the vegetative stage, but the late grain filling phase was the least sensitive (Table 4).

Table 4. Mean effect of irrigation frequency at three phases of faba bean development on grain yield and yield attributes at Hudeiba.

Yield and attributes	Irrigation frequency (days)								
	Phase I			Phase II			Phase III		
	7	10	14	7	10	14	7	10	14
Grain yield (kg/ha)	1354	1180	1170	1414	1226	1065	1243	1227	1235
No. of pods/plant	15.2	16.4	16	18.4	16.4	13	16.6	16.2	15.1
No. of seeds/pod	2.33	2.2	2.3	2.38	2.2	2.3	2.19	2.29	2.36
1000-seed weight (g)	394.4	368.5	380	381	386.5	375	382	382	378.4

Source: Mohamed (1981).

It was suggested that the best irrigation regime under Hudeiba conditions was a 10-day interval during the vegetative stage and a 7-day interval during the reproductive stage.

Mohamed *et al.* (1983a) looked into the possibility of some saving in irrigation water with minimal or no loss in faba bean grain yield by withholding irrigation once, twice or three times at various stages of plant growth in a crop that was basically irrigated at 10-day intervals. Comparison was made with the performance of the crop that received continuous 10- and 15-day regimes up to maturity. This trial was conducted at Hudeiba, Shambat and Wad Medani for two seasons. But in the second season, the basal irrigation interval was changed from a 10- to a 7-day regime at the Wad Medani site, as the former interval proved to be too dry for the Gezira environment. Grain yield response to moisture stress was highly significant at the Hudeiba site. The highest yield was recorded by regular irrigation at 10-day intervals up to maturity, while the lowest yield was given by the plots where water stress was imposed at both the reproductive and the grain filling stages of growth. The reproductive stage proved to be the most critical as omission of one irrigation cycle during this period resulted in grain yield reduction of 1029 kg/ha, while missing one irrigation during the vegetative and the grain filling phases reduced yield by only 292 and 188 kg/ha, respectively (Table 5).

Regular watering at 15-day intervals resulted in better seed yield and saved three irrigations compared to watering at 10-day intervals and omitting one irrigation cycle during the reproductive stage. This showed that preconditioning the plants by short periods of water stress is less damaging to the crop than when a single water stress is applied at a critical phase of a crop that is well supplied with irrigation water. Water-use efficiency was highest when one irrigation was omitted during the late grain filling stage and lowest when one irrigation was omitted during the reproductive stage.

Gravimetric determination of soil moisture in the active root zone of the crop just before each irrigation at Hudeiba showed that the continuous 10-day regime maintained the available water in the range of 2.4 to 22.9 mm, with the lowest availability coinciding with the stage of maximum pod formation. Omission of one irrigation in the early stage of vegetative growth maintained the soil moisture just above the permanent wilting point or resulted in water deficit of not more than 2.4 mm. In contrast, omission of irrigation during the reproductive stage induced water deficits ranging from 10.3 to 16.3 mm below the permanent wilting point (PWP). Omission of irrigation during the grain filling

Table 5. Effect of water stress on faba bean grain yield, yield components and water-use efficiency (WUE) at Hudeiba (H) and Shambat (S).

Treatment	Grain yield (kg/ha)		WUE (kg grain /ha/irrigation)		Plant height (cm)		No. of pods /plant		1000-grain weight (g)	
	H	S	H	S	H	S	H	S	H	S
Watering every 10 days†	2455	2986	245.5	298.6	77	93	15	25.2	355	388
Watering every 15 days	1693	2494	241.8	356.2	66	89	12.4	22.3	320	417
As in † but 3rd irrigation omitted	2163	2696	240.3	299.5	72	87	16.2	23.3	335	395
As in † but 7th irrigation omitted	1426	2873	158.4	319.2	72	89	12.7	21.9	334	384
As in † but 9th irrigation omitted	2267	2954	251.8	328.2	76	90	13.1	20.1	344	406
As in † but 3rd and 7th irr. omitted	1549	2056	193.6	257.0	66	82	10.1	19.1	353	412
As in † but 7th and 9th irr. omitted	1375	2182	173.8	272.7	67	82	10	18.9	326	424
As in † but 3rd and 9th irr. omitted	1639	2743	204.8	342.8	75	93	15	22.9	323	387
As in † but 3rd, 7th and 9th irr. omitted	1505	2080	215	297.1	63	82	10	15.8	332	423
Mean	1766	2135			70.4	87.4	12.7	21.1	337	404
SE (±)	137	146			2.4	2.9	1.3	2.2	10.9	15.4

Source: Mohamed *et al.* (1983a).

phase resulted in water deficits ranging from 5.8 to 9 mm. The regular 15-day irrigation regime recorded gradual increase in soil moisture deficit from 4 mm below PWP on December 9 up to a maximum of 11 mm below PWP on January 8, and thereafter the water availability rose to 19 mm.

The response of faba bean to water stress at Shambat site was generally similar to that at Hudeiba. At Wad Medani the highest yield (2747 kg/ha) was produced by irrigating every 7 days throughout the growing season. This yield was 300 and 1054 kg/ha greater than the yield from the 10- and 15-day irrigation regimes, respectively. However, the effect of water stress in relation to the phase of plant development during the second season in Wad Medani was different from that of the first season. It showed that the grain filling stage was more sensitive to water stress during the second season, mainly due to the prevalence of warmer weather during the first three weeks of February, and this magnified the effect of the water stress and resulted in reduced grain size and hence lower grain yield.

Ibrahim (1986) examined the effect of differential irrigation on faba bean grown under more favorable agroclimatic conditions in the Selaim basin where weather is cooler and soils are fertile. He found that irrigating every two weeks throughout the growing season was the most productive regime in terms of seed yield, consumptive water use, and water-use efficiency. A similar irrigation regime was found appropriate for faba bean grown under fertile soils (Gurier) characterized by high water-holding capacity.

Plant Nutrition

Rhizobial Inoculation

In the traditional faba bean growing areas in the Sudan there was no response to inoculation as the local rhizobial population was adequate to develop effective symbiosis (Mahadi 1983). However, in the nontraditional areas, such as those south of Khartoum, the population of native *R. leguminosarum* was low resulting in a positive response to inoculation with effective strains.

Fertilizer Requirement

Nitrogen

Ayoub (1971), Babiker (1975) and Salih (1977, 1978) did not find significant response to nitrogen addition in faba bean grown at various locations in the northern part of the Sudan.

Yousif (1987) examined the effect of chicken manure and split nitrogen application on faba bean under saline conditions at Soba Research Station (Khartoum State) for three seasons. Results showed that chicken manure at the rate of 12 t/ha increased grain yield by more than 25% compared with the control treatment (Table 6). Nitrogen fertilizer was only effective when applied with chicken manure. More than 50% increase in grain yield was recorded for a crop that received chicken manure combined with two doses of nitrogen (20 kg N/ha at sowing and 20 kg N/ha one month later).

Table 6. Effect of chicken manure and nitrogen application on faba bean grain yield and yield components at Soba Research Station.

Treatment	Grain yield (kg/ha)	No. of pods/plant	No. of seeds/plant	No. of shoots/plant	Plant height (cm)
Control	1125	8.1	17.0	2.3	53.9
40 kg N/ha at sowing	1143	8.9	17.8	1.8	58.2
40 kg N/ha in two doses†	1312	8.1	16.1	2.1	71.8
40 kg N/ha in three doses‡	1114	10.5	21.2	2.5	61.1
12.8 t/ha chicken manure	1268	8.0	14.7	2.4	69.0
12.8 t/ha chicken manure + 40 kg N at sowing	1330	8.6	16.5	2.5	65.1
12.8 t/ha chicken manure + 40 kg in 2 doses†	1929	13.6	29.9	2.5	70.2
12.8 t/ha chicken manure + 40 kg in 3 doses‡	1392	10.7	17.5	2.3	69.2
SE (±)	148	1.2	2.6	0.2	3.4

† 20 kg N at sowing + 20 kg N after one month.
‡ 13 kg N at sowing + 13 kg N after one month + 13 kg N after two months.
Source: Yousif (1987).

Phosphorus

Soils of northern Sudan are known to have adequate amounts of total phosphorus, but these soils are in general alkaline in reaction (pH > 8.0). Small amounts of phosphorus are found in labile form because of chemical fixation. Salih and Ageeb (1987) found no grain yield response to the level and method of phosphorus application in Shambat. In contrast, El Karouri (1979) obtained a positive response to phosphorus when it was placed in holes with the seed.

Potassium

The clay soils of the Sudan are known to be rich in potassium and, therefore, faba bean did not respond to the application of potassium fertilizers (Ayoub 1972; Babiker 1975).

Soil salinity

Faba beans are traditionally grown in the fertile 'Gurier' soils which are silty loams deposited in a narrow strip along the banks of the Nile. Due to the scarcity of good soils and the high demand for faba bean, new lands of inferior quality (such as 'Karu' and 'Terrace') are coming into production. These lands are affected to various degrees by alkalinity and salinity. El Karouri (1979) showed that the salinity level at which 50% reduction in faba bean yield occurred was 9 mmhos/cm. The correlation between yield and ECe was significant and negative ($r = -0.88$).

Shelter Crop and Intercropping

Various experiments were conducted at Shambat and Wad Medani Research Stations with the main objective of reducing soil temperature and, therefore, decreasing the incidence of root-rot/wilt disease complex which normally affects faba bean plant stand largely under the marginal agroclimatic zone, south of Khartoum.

Grass mulching improved plant establishment and increased the number of plants that survived to maturity at both Shambat and Wad Medani (Salih and Ageeb 1983) and this was reflected in yield increases of 100 and 200 kg/ha, respectively. Mulching also improved soil moisture status during the first six weeks from planting and reduced the soil temperature through partial insulation, resulting in vigorous plant growth.

Using pigeon pea (*Cajanus cajan*) as a shelter crop for the whole season or up to the flowering stage of faba bean, Salih and Ageeb (1987) found no improvement in plant stand. The plant population was reduced when the shelter crop remained in the field for the whole season. The shelter crop significantly reduced faba bean seed yield by 53% and 64% when retained for the short and long duration, respectively. This could be due to the smothering effect of pigeon pea on faba bean.

Intercropping faba bean with sorghum (*Sorghum bicolor* L.) or maize (*Zea mays* L.) significantly reduced faba bean yield at both Wad Medani and Shambat compared to the pure stand (Ageeb *et al.* 1989), mainly due to etiolation of plants and reduction in plant stand.

Seed Quality

Seed Size

Salih and Salih (1980) indicated that grading faba bean for seed purposes did not result in any economic benefit to farmers because the crop establishment from smaller and larger grades was similar to that from ungraded seed.

Seed Age

Salih and Salih (1976) found that the storage of faba bean seed under ordinary laboratory conditions between 1 to 5 years had little effect on germination percentages (92–87%) but, when stored for longer periods, the percentage of germination declined rapidly reaching 20% after 8 years. Grain yield changed little, from 1738 to 1105 kg/ha, when 1 and 5-year old seeds were used. The drop in yield was more rapid as the duration of storage increased and the yield was only 105 kg/ha when 8-year old seeds were sown (Table 7).

Table 7. Effect of seed age on germination and yield of faba bean.

Seed age (years)	Germination (%)	Field emergence (%)	Seed yield (kg/ha)
1	92.3	92.1	1738
2	91.3	86.1	1567
3	93.5	75.1	1410
4	94.8	71.3	1238
6	44.0	40.8	210
7	34.6		
8	19.9	13.7	105

Source: Salih and Salih (1976).

Harvesting Time

Ageeb (1980) showed that the optimum time for the harvest of cultivar H72 was 110 to 120 days from sowing, as harvesting 10 days earlier or later resulted in significant reduction in grain yield (Table 8). Grain yield increased at a linear rate as the time of harvest increased between 90 and 110 days as a result of the increase in grain size. The yield levelled off at 110 and 120 days after which it significantly dropped because of pod shedding. The percentage of hard seed, which greatly affects cooking quality, was at its lowest when harvest was done after full maturity.

Table 8. Effect of time of harvest on seed yield and other characteristics of faba bean at Hudeiba.

Time of harvest (days after sowing)	Grain yield (kg/ha)	Pods/ plant	100-seed weight (g)	Seed hardness (%)
90	559	29	20	19
100	1377	30	29	15
110	2186	28	33	10
120	2149	25	34	11
130	1793	24	34	6
140	1627	20	35	8
SE (±)	94.4	3	0.7	1.4

Source: Ageeb (1980).

Future Perspectives

Research work showed that the yield potential is high. Nevertheless, the gap between research station and farmers' yields is considerable. Extension work is needed to transfer improved technologies to farmers. The Nile Valley Regional Program (NVRP) of ICARDA has done a commendable job in this area. Future work on agronomy of faba bean should concentrate on stress physiology, i.e., on factors leading to excessive flower and bud shedding. Additionally, research should be targeted more towards definite agroclimatic zones.

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Discussion

Q: Mohamed El-Borai

You mentioned the effect of different agronomic factors on faba bean yield. What are the main factors, included in the recommended package, for maximizing yield on farmers' fields?

A: G. El Sarrag Mohamed

The agronomic factors that mostly determine the level of production under farmers' conditions are sowing date and irrigation. The interaction between these two factors is highly significant as early planting requires shorter watering regimes.

Review of Agronomic Research on Lentil

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Abstract

Review of lentil agronomic research conducted in northern Sudan in the period 1982–1994 indicated that the optimum sowing date for Shendi area was between late October and late November, while at Hudeiba, Rubatab and Selaim, it was the first half of November. Yields were reduced drastically when sowing was delayed to 10 December. Broadcasting the seed and then ridging was the best sowing method in light soils which have low weed infestation, while *Nigaha* sowing method (sowing in hills 25–30 cm apart with a hand hoe) is suitable for weedy areas as it facilitates hand-weeding. Results of testing a range of seeding rates (24–214 kg/ha) showed that a high seeding rate (107 kg/ha) appears to be optimum for the 'broadcasting-and-ridging' method of sowing, while for *Nigaha* method a lower rate of 36 kg/ha was sufficient. Studies on N and P nutrition and rhizobial inoculation showed the absence of response to these treatments. In the southern part of the region, where the winter is shorter and relatively warmer, frequent irrigation (every 10 days) was necessary, particularly on light soils. In the northern part of the region, where the winter is longer and cooler, a 15-day irrigation interval was sufficient.

Introduction

Lentil is one of the traditional cool-season food legumes grown in northern Sudan where it is raised after flood recession in Dongola area or under pump irrigation in Rubatab area. On-station research on lentil crop was initiated in the late sixties with the main objective of selecting high yielding cultivars and developing the best management practices which boost lentil yields. In the early eighties, on-farm research was started in different sites in northern Sudan in order to verify the technology and then transfer it to farmers and get feedback on the constraints which face lentil production so that they could be subjected to further research.

Since the area grown to lentil in the past was very small, the country imported all its required lentil. Table 1 shows Sudanese lentil imports and their value for the period 1960–1989. The quantity of lentil imported in the period 1980–1989 (10 years) was higher than the quantity imported in 1960–1979 (20 years), indicating an increased lentil consumption. However, the price of lentil has shown a substantial increase; the cost per metric ton increased from LS 60 paid for imports during the period from 1960 to 1979, to LS 1248 per metric ton paid for lentil imported in the period 1980–1989. In the early nineties, the Sudanese government launched a campaign to encourage lentil production so as to attain self-sufficiency with respect to this important commodity. The components of the campaign were the provision of credit to the producers, improved seed, and technical support and extension, and the declaration of a fair product price. Due to this policy the area grown to lentil remarkably increased and the Sudan was declared self-sufficient in lentil in April 1993. However, in 1994 and 1995, the production of lentil decreased due to adverse climatic conditions, primarily high temperature, and the reduction in government support.

Table 1. Sudan lentil imports for the period 1960–1989.

Period	Quantity (metric tons)	Total value (LS 1000)	Average imports (metric tons/year)	Price/metric ton (LS)
1960–69	33,523	2,003	3,352	60
1970–79	37,241	4,610	3,724	124
1980–89	73,131	91,272	7,313	1,248

Source: Department of Statistics and the Sudan Bank.

The present paper reviews the findings of agronomic research on lentil conducted from 1982/83 to 1993/94 and highlights areas which need further research.

Sowing Date

Studies on sowing dates were conducted in four major production or potential areas at Shendi, Hudeiba, Rubatab and Selaim (Taha *et al.* 1984, 1985a, 1986b; Mohamed 1994; Nourai *et al.* 1994). The optimum sowing date varied with location. In Shendi area the optimum sowing date lied between the end of

October and the end of November, while at Rubatab high grain yields were realized from lentil sown on 29 October and 12 November (Table 2). At Hudeiba and Selaim, the optimum sowing period was during the first half of November. At all locations, drastic reductions in lentil yields were recorded when sowing was delayed to 10 December (Table 2). The high yields obtained from early-sown crop were associated with increased number of pods per plant and larger seed size. The low yields with late-sown (10 December) crops were mainly due to reduced vegetative growth and early termination of the crop season because of the rise in temperature early in the reproductive phase (Mohamed 1988).

Sowing Method

The effects of various sowing methods on lentil yield were tested. These included: seeding in twin rows in ridges 60 cm apart; drilling in rows 20–30 cm apart; broadcasting the seed and then ridging (either with an oxen-drawn plough or tractor) into 40 or 60 cm ridges; broadcasting the seed and covering it with *Kardek*; and flat planting in hills 25 or 30 cm apart—the *Nigaha* method, commonly used by farmers in Rubatab area—(Taha *et al.* 1984, 1985a, 1986b; Nourai and Ali 1991; Nourai *et al.* 1992, 1993; Mohamed and Mohamed 1994). Table 3 shows that the response to sowing method varied with the type of soil. At Rubatab, where the soils are sandy loam, there was no apparent difference between raising lentil in twin rows in ridges 60 cm apart, in rows 20 cm apart, or 'broadcasting-and-ridging' into 60 cm ridges. However, at Shendi, 'broadcasting-and-ridging' was superior to the two other methods (Table 3). 'Broadcasting-and-ridging' increased grain yield by 47% and 22% over sowing in ridges or drilling in rows, respectively, when averaged over the three seasons.

Table 4 shows the results of an experiment comparing two sowing methods (broadcasting and oxen-ridging into 40 cm ridges and seed-sowing in hills 25 cm apart—the *Nigaha* method) conducted at Rubatab for three consecutive seasons (1990/91, 1991/92 and 1992/93). 'Broadcasting-and-ridging' resulted in a highly significant ($P = 0.001$) increase in lentil grain yield in one out of three seasons with an overall 11% increase in grain yield (Nourai and Ali 1991; Nourai *et al.* 1992, 1993). Results of different sowing methods (sowing in hills 30 cm apart, drilling in rows 30 cm apart and 'broadcasting-and-covering' the seed using *Kardek*) conducted at Selaim in the 1993/94 season indicated that drilling lentil in rows 30 cm apart gave the highest grain yield (775 kg/ha) (Mohamed and Mohamed 1994).

Table 2. Effect of sowing dates and seeding rates on grain yield of lentil grown at two locations, 1982/83–1984/85:

	Location/Grain yield (kg/ha)							
	Rubatab				Shendi			
	1982/83	1983/84	1984/85	Mean	1982/83	1983/84	1984/85	Mean
Sowing date								
29 Oct.	2807	1647	1119	1858	1295	995	176	822
12 Nov.	2473	1806	1122	1800	1195	884	258	779
26 Nov.	2196	1479	617	1431	1604	975	193	924
10 Dec.	1297	773	166	745	1120	435	7	521
SE (±)	63.3	41.1	46.7		97.0	75.7	30.7	
Significance level	***	***	***		*	***	***	
Seed rate (kg/ha)								
107.1	2150	1388	687	1408	1400	720	132	751
142.9	2178	1457	786	1474	1128	868	163	720
178.6	2251	1434	796	1494	1382	879	180	814
SE (±)	54.4	35.6	40.0		84.0	65.6	26.6	
Significance level	NS	NS	NS		NS	NS	NS	

*, *** = Significant at the 5 % and 0.1% levels, respectively.
NS = Not Significant at the 5% level.

Table 3. Effect of sowing method and seeding rate on grain yield of lentil grown at two locations, 1982/83–1984/85.

	Location/Grain yield (kg/ha)							
	Rubatab				Shendi			
	1982/83	1983/84	1984/85	Mean	1982/83	1983/84	1984/85	Mean
Sowing method								
Broadcasting and ridging	2647	1610	1017	1758	1763	1335	271	1123
2 rows/60 cm ridges	2478	1651	1019	1716	1446	800	52	766
Drilling in rows 20 cm apart	2803	1461	1034	1766	1763	869	131	921
SE (±)	131.1	76.7	76.6		46.8	117	45.7	
Significance level	NS	NS	NS		**	*	*	
Seed rate (kg/ha)								
107.1	2517	1454	1002	1658	1599	858	108	855
142.9	2596	1548	1050	1731	1629	1007	135	924
178.6	2771	1650	1047	1823	1752	1007	127	962
214.3	2688	1642	996	1775	1650	1134	235	1006
SE (±)	54.4	54.4	57.8		70.9	95.1	29.6	
Significance level	*	NS	NS		NS	NS	*	

*, ** = Significant at the 5 % and 1% levels, respectively.
NS = Not Significant at the 5% level.

Table 4. Effect of sowing method and seeding rate on grain yield of lentil grown at Rubatab, 1990/91–1992/93.

	Grain yield (kg/ha)				
	Season			Mean	% change
	1990/91	1991/92	1992/93		
Sowing method					
Flat planting in holes 25 cm apart	1152	1833	1420	1468	
Broadcasting and ridging	982	2169	1725	1625	
SE (±)	109	143	63		
Significance level	NS	NS	***		
Seed rate (kg/ha)					
35.7	1377	1860	1536	1591	
53.6	779	1913	1338	1343	-16
71.4	979	1962	1541	1494	-6
89.3	1020	2144	1675	1613	1
107.1	1117	2126	1773	1672	5
SE (±)	172	226	99		
Significance level	NS	NS	NS		

*** = Significant at the 0.1% level; NS = Not Significant at the 5% level.

It is worth mentioning that 'broadcasting-and-ridging' is a cheap method suitable for light soils which are relatively free of weeds or when chemical weed control is available, but its disadvantage is that it requires higher seed rate. The *Nigaha* method of sowing has the advantage of low seed requirement and facilitates hand-weeding (man days/ha needed for the first and second hand-weedings were 13 and 4, respectively, for *Nigaha* sowing as compared to 19 and 7, respectively, for 'broadcasting-and-ridging' sowing). However, the disadvantages of the *Nigaha* method are that it is more expensive (as it requires intensive labor for plot levelling, making water ties and sowing) and its canopy coverage of the soil is poor so the plants are exposed to bird damage at pod formation. 'Broadcasting-and-covering' the seeds by *Kardek* is not a suitable sowing method for lentil planting as the seeds will not be buried properly and hence will be exposed to birds and also hand-hoeing is tedious and laborious.

Seeding Rate

A range of seeding rates varying from 71 to 214 kg/ha were tested at different locations in northern Sudan, namely, Shendi, Zeidab, Rubatab and Selaim in the period 1982−1985. The results of a trial in which the treatments comprised a factorial combination of two seeding rates (71 and 143 kg/ha), two sowing dates, two irrigation frequencies and two sowing methods, indicated that significant increases in lentil grain yield at all sites were realized when the higher seed rate (143 kg/ha) was used (Mohamed *et al.* 1983; Taha *et al.* 1985b, 1986a). In further studies conducted at Shendi and Rubatab, in which the effects of sowing dates and seeding rates (107, 143, and 179 kg/ha), and sowing methods and seeding rates (107, 143, 179 and 214 kg/ha) were examined, there was, in most seasons, only a nonsignificant (P = 0.05) increase in grain yield with the higher seeding rates (Tables 2 and 3).

Based upon the above research findings and as a result of feedback from on-farm research conducted at Rubatab where low seeding rates are used as the *Nigaha* method is adopted, low levels of seeding rates varying from 24 to 167 kg/ha were tested (Nourai and Ali 1990, 1991; Nourai *et al.* 1992, 1993; Mohamed and Mohamed 1994). In a study conducted at Rubatab in the 1989/90 season, investigating the effects of varying seeding rates (54, 71, 89, 107, 125 and 143 kg/ha) on grain yield of three promising lentil genotypes, results indicated that highly significant (P = 0.001) increases in grain yield were recorded when the high levels of seeding rates (71 up to 143 kg/ha) were used (Nourai and Ali 1990). In another trial conducted at Selaim in 1993/94 with varying seeding rates (24, 60, 95, 131 and 167 kg/ha), a highly significant increase in lentil grain yield was obtained when the seeding rate of 131 kg/ha was adopted (Mohamed and Mohamed 1994). However, in a further study conducted at Rubatab for three seasons, with a factorial treatment combination of two sowing methods and five seeding rates (36, 54, 71, 89, and 107 kg/ha), grain yield increase with increasing seeding rate was significant in one out of three seasons (Table 4).

It could be inferred from the above results that the seeding rate depends upon the sowing method. A high seeding rate of 107 kg/ha could be used when the 'broadcasting-and-ridging' method is adopted in order to compensate for losses in plant population due to burying of some seeds deep while ridging. In areas where the *Nigaha* method is adopted, a seeding rate of 36 kg/ha appears to be satisfactory.

Crop Nutrition

Monitoring of *Rhizobium* nodulation of lentil plants grown at Rubatab at the earlier stages of growth of this crop indicated that, in most cases, nodulation was absent. Studies at Rubatab, however, indicated that there was no increase in yield by application of nitrogen or inoculation with *Rhizobium* culture either alone or in combination with phosphorus application (Mukhtar and Nourai 1984, 1985). The results of a study conducted in the 1988/89 season at three locations (Shendi, Hassa and Rubatab), the treatments of which comprised a factorial combination of two nitrogen treatments (0 and 43 kg/ha) and two weedings and two insect pest control treatments, indicated that nitrogen application resulted in a significant (P = 0.05) increase in grain yield at Rubatab only (Nourai *et al.* 1989). However, further studies at Rubatab, in which N and P fertilization application (Nourai *et al.* 1990) and *Rhizobium* inoculation (Ahmed and Nourai 1990; Mukhtar and Nourai 1991) were tested, showed no effect of these treatments on lentil yield. It appears that the native rhizobia are effective in supplying N to the lentil crop in quantities high enough to meet N requirement and consequently attain the potential yield of the crop.

Water Management

Earlier studies in water management, conducted at Shendi and Hudeiba for three consecutive seasons (Taha *et al.* 1984, 1985a, 1986b) comprised a factorial combination of three watering frequencies (1, 2 and 3 weeks) imposed at two plant developmental stages (from crop establishment to flowering and from flowering to maturity). Results indicated that frequent irrigation during the vegetative stage resulted in significant reduction in seed yield at Hudeiba, while at Shendi, frequent irrigation during both the vegetative and reproductive stages resulted in marked increases in grain yield. The variations in the response of lentil to irrigation regimes at the two locations was attributed to the variation in soil type. At Hudeiba, frequent irrigation caused some waterlogging damage because the soils were heavier. Results of another trial, in which the treatments comprised a factorial combination of two irrigation frequencies (10 and 15 days), two sowing dates, two seeding rates and two sowing methods, and which was conducted for two seasons at Zeidab and three seasons at Shendi, Rubatab and Selaim (Mohamed *et al.* 1983; Taha *et al.* 1985b, 1986a), showed that high lentil grain yields were realized from frequent irrigation every 10 days. In a recent study at Hudeiba and Rubatab (Ahmed and Nourai 1991, 1992, 1993), in which a factorial combination of two irrigation regimes (10 and 20 days) during the vegetative stage and three irrigation regimes (10, 15 and 20 days) during the reproductive stage were tested on two lentil cultivars, lentil grain yield was reduced significantly when water stress was imposed during the reproductive stage by increasing the irrigation interval to 20 days from 10 days (Table 5). Yield was also decreased to a lesser extent when irrigation interval was increased from 10 to 20 days at the vegetative stage.

In a further study conducted at Selaim for two seasons (1992/93 and 1993/94), the effects of watering regimes imposed at different developmental stages on lentil grain yield were examined. The treatments comprised a factorial combination of three watering regimes (10, 15 and 20 days) imposed at the vegetative stage followed by four watering regimes (10, 15, 20 and 25 days) imposed at the reproductive stage. Results indicated that significant increases in lentil grain yield were obtained when the crop was irrigated every 15 days during the vegetative stage while there was no apparent effect of variation in irrigation frequency during the reproductive stage (Mohamed and Ahmed 1993, 1994). This is probably related to the good water-holding capacity of the fertile silty loam soils of Selaim and to the cool winter weather.

Future Research

From the above review, it appeared that the following areas need further research:

- Identification of the optimum seeding rates for varying sowing methods.
- Screening genotypes tolerant to moisture and heat stresses.
- Strengthening research in the areas of insect pests, diseases and weed control and water management.
- Intensification of research on rhizobial inoculation for more effective *Rhizobium* strains.

Table 5. Effect of frequency of irrigation imposed at two developmental stages on grain yield of lentil genotypes grown at two locations, 1990/91–1992/93.

	Location/Grain yield (kg/ha)								
	Hudeiba				Rubatab				
	1991/92	1992/93	Mean	% change	1990/91	1991/92	1992/93	Mean	% change
Frequency of irrigation during the vegetative stage (days)									
10	770	1220	995		1096	1875	2776	1916	
20	510	1060	785	-21	835	1924	2731	1830	-4
SE (±)	36	59			84	89	115		
Significance level	***	NS			*	NS	NS		
Frequency of irrigation during the reproductive stage (days)									
10	800	1335	1068		1247	2025	3267	2180	
15	644	1166	905	-15	994	2062	2720	1925	-12
20	476	918	697	-35	956	1612	2274	1614	-26
SE (±)	45	72			103	85	177		
Significance level	***	**			**	**	**		
Genotype									
Selaim	671	1082	877		987	1871	2654	1837	
ILL 795	609	1197	903		943	1828	2853	1875	
SE (±)	35	41			51	84	85		
Significance level	NS	NS			NS	NS	NS		

*, **, *** = Significant at the 5 %, 1% and 0.1% levels, respectively; NS = Not Significant at the 5% level.

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Review of Chickpea Agronomic Studies

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Abstract

During the past decade (1985/86–1994/95), the major agronomic aspects of the chickpea crop were effectively addressed by many research studies. These aspects included the determination of the optimum sowing time, crop establishment, nutrition and irrigation. The optimum sowing time was found to be mid-November. The studies revealed that for yield maximization, the crop should be planted on ridges at a plant density of 33.3 plants/m^2 or a seed rate of 60 kg of seed/ha. Crop nutrition studies addressed nitrogen and phosphorus fertilization and *Rhizobium* inoculation. Results on these inputs were inconsistent. Response to N fertilization indicated the need for a starter dose, while the response to P was negligible. Response to *Rhizobium* inoculation studies generally showed that local strains were quite effective. Irrigation studies showed that frequent irrigation (7- to 10-day interval) through the crop cycle always resulted in the highest grain yield. The studies also indicated that early termination of irrigation water drastically reduced (40–60%) grain yield. Looking at the crop cycle as being composed of vegetative and reproductive phases, with the latter being the most sensitive stage to water stress, the optimum irrigation schedule for chickpea was to apply irrigation water at 20- and 10-day intervals during the vegetative and reproductive stages, respectively.

Introduction

Chickpea is an important cash crop grown in the Northern Region of the Sudan. The crop faces strong competition with other winter grain legumes like faba bean and lentil as well as other cash crops like spices. Therefore, maximization of crop yield becomes a necessity to maintain its rank in the existing cropping complex. Yield maximization is only possible through adoption of optimum crop management practices and use of improved high-yielding cultivars.

During the past decade (1985/86–1994/95), the various production factors were satisfactorily addressed on-station as well as on farmers' fields. The objectives of these studies were to find the optimum cultural practices that could boost chickpea productivity.

The reviewed studies dealt with the major agronomic aspects of chickpea production. The subjects covered included sowing time, crop establishment, and crop nutrition and irrigation.

Sowing Time

Fig. 1 shows the effects of sowing date on grain yield of chickpea (1987/88–1989/90). The optimum sowing date for chickpea was found to be mid-November (2524 kg/ha). Sowing earlier (25 October) than mid-November reduced yield by 34%, and sowing later (5 December) than mid-November reduced grain yield by 9%.

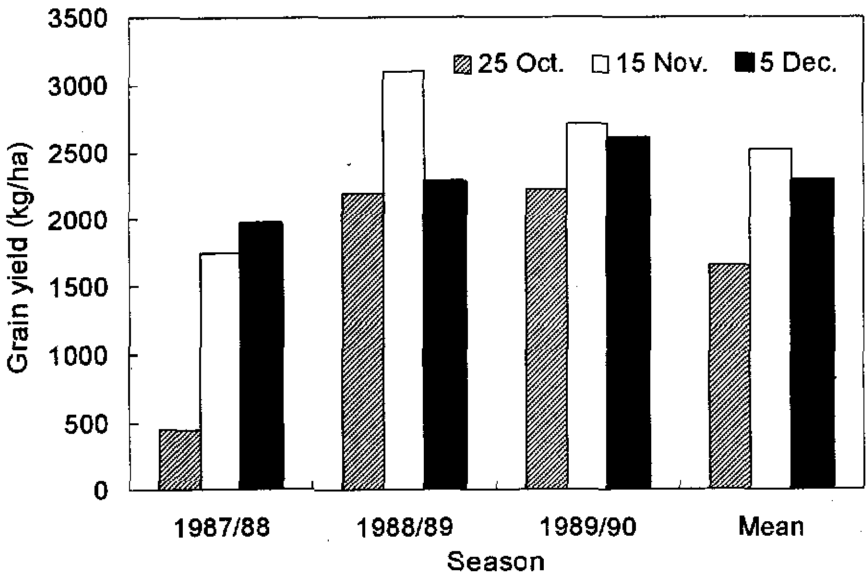

Fig. 1. Effect of sowing date on grain yield of chickpea (Taha 1990).

Crop Establishment

The crop establishment aspect was approached in two ways, either as crop architecture or as seeding rate. Tables 1 and 2 show the influence of plant population and seed rate, respectively, on grain yield of chickpea over various seasons. Results of these studies revealed that a plant population of 33.3 plants/m^2 or a seed rate of 60 kg/ha was satisfactory for good crop establishment and, consequently, for maximum grain yield.

Table 1. Effect of plant population on grain yield of chickpea.

Plants/m^2	Grain yield (kg/ha)						
	Season			Season			
	1985/86	1986/87	Mean	1987/88	1988/89	1989/90	Mean
16.6	1562	3102	2332				
26.7				1260	2430	2496	2062
33.3	1790	3331	2561	1314	2534	2492	2113
44.4				1690	2619	2560	2290
SE (±)	48.8	54.3		73.4	NS	NS	

NS = Not significant.
Source: Taha (1987, 1990).

Table 2. Effect of seed rate on grain yield of chickpea.

Seed rate (kg/ha)	Grain yield (kg/ha)			
	Season			Mean
	1985/86	1988/89	1989/90	
30	1073†	2679	1344	1699
60	1469	3076	1618	2054
SE (±)	169.4	117.7	84.1	

† First seed rate in 1985/86 was 26 kg/ha instead of 30.
Source: Nourai (1986b); Taha *et al.* (1989, 1990a).

Sowing Method

Two methods, sowing on-ridge or on-flat, were studied over four seasons (1987/88–1990/91). Results showed that sowing on-ridges was superior to planting on-flat (Fig. 2).

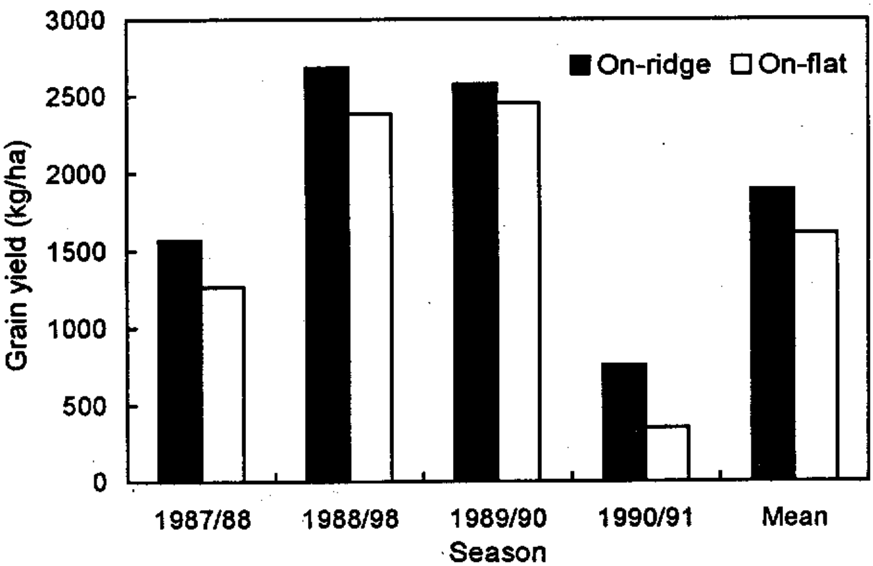

Fig. 2. Influence of sowing method on grain yield of chickpea (Taha 1990; Taha and Ali 1991).

Crop Nutrition

The effects of fertilizer (N and P) application and *Rhizobium* inoculation on yield performance of chickpea were studied over different seasons and locations (Tables 3, 4 and 5). Results showed that the response to P was negligible (Table 3). Grain yield response to N fertilization, on the other hand, was inconsistent (Tables 6 and 7), but indicated the need for a starter dose (10–20 kg N/ha). *Rhizobium* inoculation studies (Table 5) indicated that local strains were quite effective.

Table 3. Effect of phosphorus fertilization on grain yield of chickpea.

P level ($kg\ P_2O_5/ha$)	Grain yield (kg/ha)			
	Season			
	1984/85	1985/86	1986/87	Mean
0	657	1498	2155	1436
71	702	1748	2136	1529
143	645	1783	2145	1524
SE (±)	13.8	59.8	NS	

NS = Not significant.
Source: Taha (1987).

Table 4. Effect of nitrogen fertilization on grain yield of chickpea.

N level (kg N/ha)	Grain yield (kg/ha)		
	Season		
	1988/89	1989/90	Mean
0	1558	1505	1532
43	1910	1450	1680
86	1913	1488	1701
SE (±)	88	NS	

NS = Not significant.
Source: Noufai (1989); Taha *et al.* (1990a).

Table 5. Effect of *Rhizobium* inoculation on grain yield of chickpea, 1988/89.

Treatment	Location/Grain yield (kg/ha)			
	Rubatab	Hudeiba	Wad Hamid	Mean
Control	3396	2695	2430	2840
120 kg N/ha	2993	2989	2613	2865
Inoculation	3104	2949	2702	2918
SE (±)	NS	NS	NS	

NS = Not significant.
Source: Taha *et al.* (1989).

Table 6. Effect of irrigation interval on grain yield of chickpea.

Irrigation interval (days)	Grain yield (kg/ha)					
	Season				Season	
	1984/85	1985/86	1986/87	Mean	1985/86	1988/89
7					1888	
8	817	2057	2502	1793		
10						2096
12	667	1690	2252	1536		
14					1457	
16	524	1283	1679	1162		1491
20					1038	
21					501	
28						
SE (±)	14	60	67		138	72

Source: Taha (1987); Nourai (1986a, 1989).

Table 7. Effect of terminal water stoppage on grain yield of chickpea.

Terminal water stoppage†	Grain yield (kg/ha)						
	1991/92			1992/93	1993/94	1994/95	Mean
	Hudeiba	Rubatab	Mean	Hudeiba			
To maturity	690	1130	910	1870	2692	3001	2521
90 DAS	750	820	790	1459	2495	2476	2143
80 DAS				1238	2239	2016	1831
70 DAS	410	790	600	1092	1591	1887	1523
50 DAS	380	350	370				
SE (±)	77	11		102	78	126	126

† DAS = Days after sowing.
Source: Taha and Ali (1991); Ibrahim (1993, 1994, 1995).

Irrigation Regime

Application of irrigation water to chickpea was studied in three ways: (1) imposing different irrigation intervals throughout the crop cycle; (2) timing of last irrigation; and (3) irrigation schedule during both vegetative and reproductive stages of the crop.

Results showed that frequent (7−10 day intervals) irrigation during the whole crop cycle always resulted in the highest grain yield (Table 6). It was also found that early termination of irrigation water drastically reduced grain yield (Table 7). Grain yield losses of 59 and 40% occurred when irrigation water was terminated 50 and 70 days after sowing, respectively.

Dealing with the crop life cycle as being composed of vegetative and reproductive phases, it was found, as expected, that the reproductive stage was the most sensitive stage to moisture stress developed through expanded irrigation intervals (Table 8). Consequently, the optimum irrigation schedule was established so as to irrigate the crop at 20- and 10-day intervals during the vegetative and reproductive stages, respectively (Table 8).

Table 8. Influence of irrigation regime (varied by irrigation intervals in days) on grain yield of chickpea.

Schedule (veg. + rep.)†	Grain yield (kg/ha)					
	1989/90		1992/93	1993/94	1994/95	Mean
	Hudeiba	Rubatab	Hudeiba			
10 + 10	2310	1751	1481	2439	2169	2030
15 + 10			1332	2263	2429	2008
20 + 10	2096	1985	1430	2059	2438	2002
10 + 20	1375	1633				1504
20 + 20	1153	1645				1399
SE (±)	128	156	NS	71	NS	

† (veg. + rep.) = Irrigation interval in days during the vegetative and reproductive phases, respectively.
NS = Not significant.
Source: Taha *et al.* (1990b); Ibrahim (1993, 1994, 1995).

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Water Relations of Faba Bean, Chickpea and Lentil

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Abstract

Available literature on water relations of common food legumes (faba bean, chickpea and lentil) in the Sudan was reviewed. Results were based mainly on studies of the effects of different fixed or interchanged irrigation intervals during two or more growth stages. Results indicated that crop response to irrigation treatments is site-specific and subject to seasonal weather fluctuations. However, with the exception of lentil on heavy clay soils, the vegetative growth stages for the three crops were less sensitive to water stress compared to later growth stages. Some savings in irrigation water during the early stages with minimal loss in seed yield are possible. Genotypic differences with regard to tolerance to water stress were detected. These were tested by subjecting different genotypes of the three crops to suboptimal irrigation conditions in the field. Crop water requirements were measured by the neutron probe at Hudeiba. Faba bean, chickpea and lentil require about 430, 380 and 365 mm of water, respectively.

Introduction

Faba bean, chickpea and lentil are grown mainly in the Northern Region of the Sudan where environmental conditions (relatively cooler and longer winter seasons) are more suitable for production. Faba bean and lentil are produced exclusively under irrigation while a large area of chickpea is grown on residual soil moisture content after flood recession (Wad Hamid basin).

Faki (1991) reported that irrigation water is the most important single constraint to agricultural production in northern Sudan. He further stated that expensive water pumping from the Nile coupled with limited pump sizes, and energy and spare part availability problems render irrigation water a costly resource that justifies optimal allocation among the different crops grown. For these reasons, frequent irrigation is generally the least adopted component of packages in on-farm trials.

Discussion

Comment: Prof. Abdalla Abdalla

In the organization of the conference, I would have liked to see the achievements within each crop grouped together. Also, there is a need to integrate the work of individual scientists. And my question is: Where do we go from here in agronomy?

A: O.H. Ibrahim

I fully agree with Prof. Abdalla's suggestions to integrate efforts and improve efficiency of output.

Comment: M.B. Solh

I would like to comment on Prof. Abdalla Abdalla's comment on the need for the organizers to have had a presentation on each crop on the impact of research under NVRP. With respect to the organization, the last session of the workshop will be on technology transfer and socioeconomic studies. Technology transfer will specify the improved production packages developed in every one of the four crops of concern to NVRP. In addition, adoption and impact studies of improved technologies will be presented. In these studies, the farmers' perception of these technologies will be discussed. Certain components of the improved packages may be turned back over to the researchers to make them more acceptable to farmers. After the last session, there will be one day of discussions to highlight the future guidelines in order to have more impact on national production.

The main objective of this work was to review existing information on crop-water relations of faba bean, chickpea and lentil in the Sudan. Neutron probe studies at Hudeiba showed that faba bean, chickpea and lentil require about 430, 380 and 365 mm of water, respectively (Ahmed 1994).

Faba Bean

Studies on water relations of faba bean during the first phase of the ICARDA/IFAD Nile Valley Project in the Sudan were reviewed by Saxena and Stewart (1983). Results of trials conducted at different locations are given in Tables 1, 2, 3 and 4.

Table 1. Effect of irrigation frequency during different growth stages on faba bean seed yield at Hudeiba, 1979/80.

Irrigation interval (days)†			Seed yield (kg/ha)
S1	S2	S3	
7	7	7	1466
10	10	10	1016
14	14	14	1004
7	7	14	1466
7	14	7	1038
7	14	14	916
14	7	7	1333
14	7	14	1345
14	14	7	1211
SE (±)			193

† S1 = From planting to start of flowering; S2 = From start of flowering to 100% pod setting; S3 = From 100% pod setting to maturity.

Table 2. Effect of irrigation frequency during different growth stages on faba bean seed yield at different locations, 1980/81.

Irrigation interval (days)†			Location/Seed yield (kg/ha)		
S1	S3	S3	Zeidab	Aliab	Hudeiba
7	7	7	2793	2664	2976
7	7	14	2298	2310	2319
7	14	7	2636	2402	2193
7	14	14	2090	2312	2074
14	7	7	2290	2576	2617
14	7	14	2221	2064	2126
14	14	7	2364	2494	2300
14	14	14	2105	1986	2126
SE (±)			160	136	167

† S1 = From planting to start of flowering; S2 = From start of flowering to 100% pod setting; S3 = From 100% pod setting to maturity.

Table 3. Effect of differential irrigation during different growth stages on faba bean seed yield at Shambat, 1980/81.

Irrigation interval (days)†			Number of irrigations	Seed yield (kg/ha)
S1	S2	S3		
10	10	10	11	1811
15	15	15	8	1183
10	10	15	10	1450
10	15	15	9	1200
15	10	10	10	1464
15	10	15	9	1378
15	15	10	9	1308
10	15	10	10	1394
SE (±)				93

† S1 = From planting to start of flowering; S2 = From start of flowering to 100% pod setting; S3 = From 100% pod setting to maturity.

Table 4. Effect of water stress during different growth stages on faba bean seed yield at different locations, 1981/82.

Treatment	Location/Seed yield (kg/ha)		
	Wad Medani	Shambat	Hudeiba
Irrigating every 10 days to maturity†	974	2840	2571
Irrigating every 15 days to maturity	646	1847	1919
As in † but 3rd irrigation missed	957	2612	2596
As in † but 7th irrigation missed	678	2025	1389
As in † but 9th irrigation missed	801	1962	2017
As in † but 3rd and 7th irrigations missed	593	1856	1547
As in † but 7th and 9th irrigations missed	561	1655	1387
As in † but 3rd and 9th irrigations missed	646	543	1387
As in † but 3rd, 7th and 9th irrigations missed	513	1652	1374
SE (±)	63	112	86

A trial was conducted at Hudeiba Research Station to study the effects of different irrigation intervals at three plant growth stages: (1) from planting to the start of flowering (S1); (2) from the start of flowering to 100% pod setting (S2); and (3) from 100% pod setting to maturity (S3). Irrigation interval had a significant effect on seed yield (Table 1). Irrigating every 7 days significantly outyielded the 10- and 14-day intervals by 44%. Water stress between the start of flowering and 100% pod setting was detrimental to seed yield as it reduced the number of seeds per plant. When the trial was repeated during the next season at two more sites, the continuous 7-day regime outyielded the 14-day regime by 40, 34 and 33% at Hudeiba, Aliab and Zeidab, respectively (Table 2). Results of a similar trial conducted at Shambat showed that irrigating every 10 days throughout the season was significantly superior to irrigating every 15 days (Table 3). Results also indicated that water stress is less critical to seed yield during the early vegetative growth stage as compared to later growth stages.

The possibility of saving irrigation water with minimal losses in seed yield was studied in a field trial replicated at Hudeiba, Shambat and Wad Medani during the 1981/82 season. The trial examined the effects of withholding irrigation once, twice and three times at different growth stages compared to irrigating every 10 and 15 days throughout the season. Plant growth stages were: early vegetative stage (17–27 days from planting), pod development (47–67 days), late grain filling (67–87 days) and their different combinations. Results clearly indicated that water stress during the early vegetative stage had no effect (Wad Medani and Hudeiba) or very little effect (7% reduction at Shambat) on seed yield. Water stress during seed formation decreased seed yield by 30% (Shambat and Wad Medani) and 46% (Hudeiba) compared to continuously irrigated crops at 10-day intervals. Omitting the ninth irrigation reduced seed yield by 18, 22 and 31% at Hudeiba, Wad Medani and Shambat, respectively (Table 4).

Following the same objective of saving irrigation water with minimal loss in seed yield, a series of trials were conducted at Wad Medani (Farah 1992). During the first two seasons (1982/83 and 1983/84) of the trial, the effects of irrigating every 7 and 14 days throughout the season were tested. Irrigating every 7 days compared to every 14 days reduced seed yield by 18 and 31% during the first and second seasons, respectively. A third treatment, where the crop was irrigated every 14 days until flowering and every 7 days thereafter, was included in the 1984/85 season. This treatment produced the highest seed yield and also saved two irrigations before flowering. In the following season (1985/86), the 7-day treatment was omitted and 14 or 21 days were imposed during the preflowering stage followed by every 7 or 10 days during the postflowering period. Again, the highest seed yield was obtained from the 14-7 regime followed by the 21-7 irrigation regime (Table 5).

Table 5. Effect of irrigation intervals during two growth stages (vegetative and reproductive) on faba bean yield at Wad Medani, 1985/86.

Attribute	Irrigation intervals† (days)				
	14-7	14-10	21-7	21-10	SE (±)
Seed yield (kg/ha)	1957	1460	1702	1505	67
CWU‡ (mm)	666	560	492	504	
Number of irrigations	14	11	13	10	
Number of pods/plant	10.2	9.7	11.2	10.5	0.6
100-grain weight (g)	37.8	35.7	33.9	37.3	0.5

† During the vegetative and reproductive stages, respectively.
‡CWU = Consumptive water use.

Faba bean growers in the Northern Region of the Sudan generally apply lower numbers of irrigations than recommended. In an attempt to identify genotypes that may produce reasonable yields under suboptimal irrigation conditions, Salih *et al.* (1993) tested the performance of 10 promising genotypes under different irrigation regimes. The irrigation treatments were every 10, 15 and 21 days during the first two seasons (1990/91 and 1991/92) and factorial combinations of irrigating every 10 and 20 days were interchanged during the vegetative and reproductive developmental stages in the third season (1992/93).

Response of the different genotypes to water stress was assessed using the methods of Fisher and Maurer (1978). This was accomplished by regressing mean yields of the different genotypes against an environmental index consisting of the means of all tested genotypes at each water level. Table 6 shows linear regression parameters, seed yields under wet (Yp) and stress (Ys) conditions, together with a drought susceptibility index (S) for the different genotypes. Genotypes Bulk 1/3, BB 7 and ZBF 9/4 attained the best yields under stress conditions and the lowest S values, and were thus rated as most tolerant. Genotypes BB 7 and Bulk 1/3 were accepted for release to farmers in December 1993.

Table 6. Regression parameters of grain yield of 10 faba bean genotypes against an environmental index for the means of all genotypes at each water level.

Genotype	Intercept	Slope	R†	SE (±)	Yp‡ (kg/ha)	Ys§ (kg/ha)	S¶
Bulk 1/3	396	0.868	0.95	0.099	4302	700	0.922
BB 7	395	0.940	0.98	0.075	4625	724	0.929
SML 85/1/1	173	0.997	0.98	0.075	4660	522	0.978
BF 2/2/8/1	-107	1.000	0.87	0.201	4393	243	1.040
ZBF 1/1	-308	1.101	0.97	0.094	4607	37	1.092
Bulk 1/1	113	0.962	0.99	0.047	4442	450	0.990
F402	132	1.059	0.99	0.062	4898	503	0.988
Hudeiba 72	-17	1.023	0.99	0.059	4587	341	1.019
ZBF 9/4	213	1.010	0.98	0.080	4758	567	0.970
ZBF 3/3	-259	1.040	0.98	0.083	4421	105	1.075

† R = Coefficient of correlation.
‡ Yp = Seed yield under wet conditions.
§ Ys = Seed yield under water stress conditions.
¶ S = Fisher drought susceptibility index.

Chickpea

Ageeb (1975) studied the effects of factorial combinations of two nitrogen levels (0 and 86 kg N/ha), three irrigation intervals (7, 14 and 21 days) and three intra-plant spacings (7, 10 and 14 cm) on chickpea yield. Irrigation treatments had no significant or appreciable effect on grain yield. Average seed yield was 727, 717, and 680 kg/ha for the three irrigation treatments, respectively.

The effects of three irrigation intervals (8, 12 and 16 days) in combination with two seed rates and three phosphorous levels were further investigated by Taha (1985, 1986, 1987). Within the range tested, irrigation treatments had a significant effect (P = 0.01) on seed yield (Table 7). Irrigating every 12 and 16 days reduced seed yield by 14 and 35%, respectively, relative to irrigating every 8 days.

Table 7. Effect of three irrigation intervals on chickpea yield in three crop seasons, 1984/85–1986/87.

Irrigation interval (days)	Crop season/Grain yield (kg/ha)			
	1984/85	1985/86	1986/87	Mean
8	817	2057	2502	1793
12	667	1690	2252	1536
16	524	1283	1679	1162
SE (±)	14	60	67	
Significance level	**	**	**	

** = Significant at the 1% level.
Source: Taha (1985, 1986, 1987).

Response of the crop to different irrigation treatments at different growth stages was reported by Mohamed (1985). Three watering treatments (7, 14 and 21 days) were interchanged during two stages of growth: (1) vegetative (from sowing to 50% flowering), S1; and (2) reproductive (from 50% flowering to physiological maturity), S2.

Significant differences in seed yield and total biological yield in response to the different irrigation treatments were recorded (Table 8). The highest seed yield was obtained with the continuous 7-day interval followed by 14 days during the vegetative stage and 7 days during the reproductive stage. It was concluded that chickpea is very responsive to irrigation and that the 7-day irrigation regime seems to be optimal under Hudeiba conditions if irrigation water is available.

Table 8. Effect of irrigation frequency during two growth stages (vegetative and reproductive) on chickpea yield and yield components, 1985/86.

Irrigation intervals† (days)	Yield (kg/ha)	Number of pods/plant	Number of seeds/pod	1000-seed weight (g)
7-7	1883	75	1.1	172
7-14	1050	56	1.0	177
7-21	1042	51	1.2	170
14-7	1528	78	1.2	165
14-14	1035	72	1.0	162
14-21	926	59	1.1	165
21-7	871	71	1.1	150
21-14	835	61	1.0	170
21-21	1054	46	1.2	164
SE (±)	176	11	0.1	4

† During the vegetative and reproductive stages, respectively.
Source: Mohamed (1985).

Ahmed (1988) presented data showing that the crop is very sensitive to water stress during the reproductive stage. Treatments were factorial combinations of irrigating every 8, 16 and 20 days interchanged during the vegetative and reproductive stages. Irrigating every 14 and 20 days during the vegetative stage reduced seed yield by 7 and 15%, respectively, relative to the 8-day interval. The same respective irrigation treatments reduced seed yield by 39 and 58% when the stress was imposed during the reproductive stage (Table 9). The best seed yield was obtained with the continuous 8-day interval which was not significantly different from seed yield of the 14-8 and 20-8 treatments. Seed size and number of seeds per pod were the most affected yield components.

The fact that the irrigation interval may be extended to every 20 days during the vegetative stage—i.e., saving irrigation water—with more frequent irrigation during the reproductive stage was further verified at Hudeiba and Rubatab (Taha *et al.* 1990). The treatments included factorial combinations of irrigating every 10 and 20 days during the vegetative and reproductive stages, respectively, and two methods of sowing (broadcasting and then ridging or sowing on flat beds).

Table 9. Effect of irrigation frequency during two growth stages (vegetative and reproductive) on chickpea yield and yield components.

Irrigation intervals† (days)	Yield (kg/ha)	Number of pods/plant	Number of seeds/pod	1000-seed weight (g)
8-8	2795	61	1.4	153
8-14	1779	50	1.1	194
8-20	1179	45	1.1	189
14-8	2617	60	1.2	179
14-14	1610	48	1.2	178
14-20	1119	39	1.2	192
20-8	2488	49	1.4	144
20-14	1402	40	1.4	180
20-20	1010	39	1.3	203
SE (±)	136	11	0.003	9
Significance level	***	NS	**	***

† During the vegetative and reproductive stages, respectively.
, * = Significant at the 1% and 0.1% levels, respectively.
NS = Not significant.
Source: Ahmed (1988).

At Hudeiba, the effect of the different irrigation treatments on seed yield and total biological yield was highly significant (P = *0.001*). The 10-day interval during the vegetative stage with 10 or 20 days during the reproductive stage produced more or less the same yields but significantly outyielded the other two treatments with 20-day intervals during the reproductive stage. Reduction in seed yield was accompanied by lower number of pods per plant and significantly (P = 0.001) higher seed size (Table 10). At Rubatab, the effect of the irrigation treatments on seed yield, number of pods per plant and number of seeds per pod followed similar trends to those reported at Hudeiba but the differences were not significant. The interaction (location x irrigation) was significant with the highest seed yield obtained from the continuous 10-day treatment at Hudeiba and the 20-10 treatment at Rubatab. This may be attributed to the relatively cooler winter season at Rubatab compared to Hudeiba.

Table 10. Effect of irrigation frequency during two growth stages (vegetative and reproductive) on chickpea yield and yield components at Hudeiba and Rubatab, 1989/90.

Irrigation intervals† (days)	Yield (kg/ha)	Number of pods/plant	Number of seeds/pod	1000-seed weight (g)
		Hudeiba		
10-10	2310	56	1.10	194
20-10	2096	57	1.10	199
10-20	1375	36	1.00	214
20-20	1153	36	1.00	210
SE (±)	128	6	0.04	3
Significance level	***			***
		Rubatab		
10-10	1751	49	1.00	185
20-10	1985	50	1.00	174
10-20	1633	39	0.90	201
20-20	1645	34	1.00	202
SE (±)	156	5	0.03	6
Significance level	NS	NS	NS	

† During the vegetative and reproductive phases, respectively.
*** = Significant at the 0.1% level; NS = Not significant.

The same trial was repeated at both locations but treatments were modified with the main objective of determining the optimum date of terminal irrigation (Taha and Ali 1991). The treatments included: (1) W0: continuous irrigation till maturity; (2) W90: irrigation terminated 90 days after sowing; (3) W70: irrigation terminated 70 days after sowing; and (4) W50: irrigation terminated 50 days after sowing. The irrigation interval was 20 days during the vegetative stage and every 10 days during the reproductive stage.

At both locations, the date of terminal irrigation had a significant effect on seed yield (Table 11). The continuous irrigation regime (W0) at Rubatab gave the highest seed yield, while at Hudeiba the best yield was obtained when irrigation water was terminated 90 days after sowing. Reduction in seed yield in response to early water stoppage was mainly attributed to poor pod setting as indicated by the fewer number of pods per plant.

Table 11. Effect of terminal irrigation on chickpea yield and yield components at Hudeiba and Rubatab, 1990/91.

Treatment†	Yield (kg/ha)	Number of pods/plant	Number of seeds/pod	1000-seed weight (g)
		Hudeiba		
W0	685	19	1.00	160
W90	752	28	0.80	156
W70	409	13	1.00	152
W50	379	7	1.30	151
SE (±)	77	4	0.12	4
		Rubatab		
W0	1129	22	1.30	159
W90	820	18	1.30	157
W70	794	18	1.30	149
W50	351	9	1.20	152
SE (±)	107	3	0.03	4

† W0 = Continuous irrigation till maturity; W90 = Irrigation terminated 90 days after sowing; W70 = Irrigation terminated 70 days after sowing; W50 = Irrigation terminated 50 days after sowing.

More information on the effect of terminal irrigation date was reported by Ibrahim and Ahmed (1993) and Ibrahim (1994). Treatments included irrigating every 10, 15 and 20 days during the vegetative stage and a continuous irrigation after flowering unless terminated by a water stoppage treatment, in which case irrigation at a 10-day interval was adopted. Four water stoppage treatments were imposed: no water stoppage till maturity (W0), and W90, W80 and W70, corresponding to terminating water 90, 80 and 70 days after sowing, respectively.

For the first season of the experiment (1992/93), the irrigation interval during the vegetative stage had no significant effect on seed yield (Table 12). However, a significant (P = 0.001) reduction in seed yield in response to early water stoppage was detected. Variation in seed yield across the different water stoppage treatments was a reflection of variation in the number of pods per plant, ratio of empty to total pods and harvest index. In the second season, both the irrigation interval during the vegetative stage and the terminal water stoppage treatments had a significant effect on seed yield and most of the yield components (Table 13). Irrigating every 15 and 20 days during the vegetative stage reduced seed yield by 7 and 16%, respectively, relative to irrigating every

10 days. Terminating irrigation water 90, 80 and 70 days after sowing lowered seed yield by 7, 17 and 41%, respectively, relative to the no water stoppage treatment. Differences were associated with significant differences in the number of pods per plant, seed size and harvest index.

Table 12. Effect of irrigation regime and terminal water stoppage on chickpea yield, 1992/93.

Irrigation interval (vegetative stage) (days)	Terminal water stoppage†/Yield (kg/ha)				
	W0	W90	W80	W70	Mean
10	1896	1564	1385	1080	1481
15	1834	1348	1152	996	1332
20	1881	1465	1176	1200	1430
Mean	1870	1459	1238	1092	

† W0 = Continuous irrigation till maturity; W90 = Irrigation terminated 90 days after sowing; W80 = Irrigation terminated 80 days after sowing; W70 = Irrigation terminated 70 days after sowing.

Table 13. Effects of irrigation regime† and terminal water stoppage on chickpea yield and yield components, 1993/94.

Treatment	Seed yield (kg/ha)	Number of pods/plant	Number of seeds/pod	1000-seed weight (g)
Irrigation regime (days)				
10	2439	36	1.0	167
15	2263	36	1.1	161
20	2059	34	1.0	159
SE (±)	71			
Water stoppage‡				
W0	2692	47	1.0	172
W90	2495	31	1.1	168
W80	2239	33	1.0	164
W70	1591	29	1.0	146
SE (±)	78	2.7		2.4

† During the vegetative stage.
‡ W0 = Continuous irrigation till maturity; W90 = Irrigation terminated 90 days after sowing; W80 = Irrigation terminated 80 days after sowing; W70 = Irrigation terminated 70 days after sowing.

Genotypic differences with regard to tolerance to prolonged irrigation intervals were tested at Hudeiba from 1987 to 1990. Ahmed (1988, 1989a, 1990) tested the performance of four chickpea genotypes: NEC 2491 (released as Shendi-1), NEC 2486, NEC 2701 and the local check (Baladi) under four irrigation regimes: (1) well watered control treatment (WW); (2) water-stressed during the vegetative stage (DW); (3) water-stressed during the reproductive stage (WD); and (4) water-stressed during both stages (DD).

In the first season (1987/88) of the trial, water stress treatments were imposed by withholding irrigation water for 30 and 21 days during the vegetative and reproductive stages, respectively. In the WW treatment, irrigation was applied every 8–10 days. For the 1988/89 and 1989/90 seasons, the four irrigation treatments were factorial combinations of irrigating every 10 and 20 days interchanged during the vegetative and reproductive stages.

Results indicated that the irrigation interval may be extended to 20 days during the vegetative stage with no significant or appreciable reduction in seed yield (Table 14). Significant differences in seed yield of the different genotypes were detected with the best yield obtained with the released cultivar Shendi-1. Differential response of the different genotypes to water stress was assessed by regressing mean yields of individual genotypes on an environmental index consisting of the mean of all tested genotypes at each water level (Ahmed 1989b). Potential yield (Yp) and yield under stress (Ys) for the different genotypes were estimated from regression equations using an environmental index of 2400 kg/ha for the well watered treatments and 300 kg/ha for the water-stressed treatments. Table 15 shows the slope, intercept, Yp and Ys for the different genotypes. The best yield under both the well watered and water-stressed conditions was obtained with the released cultivar Shendi-1 and was thus rated as most tolerant.

More recently, Ahmed and Mohamed (1995a) studied the performance of 13 chickpea genotypes under two watering regimes: W1 (irrigating every 9–10 days), and W2 (irrigating every 18–20 days). The watering treatment had a significant effect ($P = 0.01$) on seed yield. Stressing the crop reduced seed yield by 48% relative to the control (Table 16).

Table 14. Effect of different irrigation regimes on seed yield (kg/ha) of four chickpea genotypes, 1987/88–1989/90.

Treatment†	Shendi-1	NEC 2701	NEC 2486	Baladi	Mean	SE (±)
			1987/88			
WW	1347	866	1119	1505	1209	
DW	838	594	772	794	750	102
WD	782	443	635	274	534	
DD	530	573	418	305	457	
SE (±)		102				
			1988/89			
WW	1858	1722	1753	1769	1845	
DW	1972	1591	1896	1590	1762	100
WD	1066	631	785	663	786	
DD	711	905	902	683	801	
SE (±)		62				
			1989/90			
WW	2348	1841	2062	1275	1881	
DW	1741	1783	1945	1350	1705	78
WD	1193	1105	1191	565	1014	
DD	1163	1014	953	557	922	
SE (±)		69				

† WW = Well watered control treatment; DW = Water-stressed during the vegetative stage; WD = Water-stressed during the reproductive stage; DD = Water-stressed during both stages.

Table 15. Regression† parameters for the four chickpea genotypes, 1987/88–1989/90.

Genotype	Slope	Intercept	Yp‡ (kg/ha)	Ys§ (kg/ha)
Shendi-1	1.06	96.2	2633	413
NEC 2486	1.06	-2.6	2539	315
NEC 2701	0.99	-22.2	2359	275
Baladi	0.89	-71.4	2069	196

† Regression of mean yields of inidvidual genotypes on an environmental index over yield levels at different stressed conditions.
‡ Yp = Seed yield under wet conditions.
§ Ys = Seed yield under water stress conditions.

Table 16. Effect of irrigation regime on seed yield of different chickpea genotypes, 1994/95.

Genotype	Irrigation regime†/Seed yield (kg/ha)		
	W1	W2	Mean
Flip 88-30C	2592	1377	1985
Flip 88-32C	2498	1264	1881
Flip 88-36C	3295	1652	2474
Flip 88-39C	2907	1700	2304
Flip 88-44C	2680	1668	2174
Flip 88-56C	2781	1514	2147
ILC 378	3217	1846	2532
ILC 915 (Jebel Marra-1)	3474	1381	2428
ILC 1327	2664	1425	2044
ILC 2910	2761	1419	2090
Shendi-1	3584	2006	2795
Baladi (local check)	3518	1346	2432
ICCV-2	2241	1331	1786

† W1 = Irrigating every 9–10 days; W2 = Irrigating every 18–20 days.
SE (water) (±) = 55; SE (genotypes) (±) = 200.
Source: Ahmed and Mohamed (1995a).

Differences in seed yield of the different genotypes were significant (P = 0.05) with the best yield obtained with cultivar Shendi-1 (2.8 t/ha) and the poorest with genotype ICCV-2 (1.8 t/ha). Seed yield of the released cultivar Jebel Marra-1 and the local check (Baladi) were not significantly different compared to Shendi-1 under wet conditions, but both had 32% lower seed yield under water stress conditions. Genotype ICCV-2 attained the lowest average seed yield but also the lowest percent reduction in seed yield in response to water stress, i.e., poor adaptability but probably some tolerance to water stress. Being an early maturing genotype, ICCV-2 may have some promise under residual soil moisture content, i.e., in Wad Hamid and Hawata areas.

Lentil

The effects of different irrigation intervals (7, 14, 21 and 28 days) were studied on lentil at Hudeiba by Ageeb (1976). Irrigation intervals had a highly significant effect (P = 0.001) on grain yield. Extending the irrigation interval to every 14, 21 and 28 days reduced seed yield by 15, 38, and 44% relative to irrigating every 7 days, respectively. (Table 17).

Table 17. Effect of irrigation frequency on lentil seed yield and yield components at Hudeiba, 1975/76.

Irrigation interval (days)	Seed yield (kg/ha)	Number of pods/plant	Number of seeds/pod	1000-seed weight (g)
7	1703	24.5	1.5	23.3
14	1440	19.1	1.4	23.7
21	1063	17.7	1.2	25.7
28	947	14.2	1.2	24.5
SE (±)	42***	2.1	0.03	0.2

*** = Significant at the 0.1% level.

Taha *et al.* (1984, 1985, 1986) reported data on the effect of irrigating every 7, 14 and 21 days interchanged during the vegetative and reproductive stages on lentil yield at Shendi and Hudeiba. At Hudeiba, seed yield was significantly lower with frequent irrigation, especially during the vegetative stage. Best yields were obtained with the 21-day interval during the vegetative stage and more frequent irrigation during the reproductive stage. On the other hand, the crop was more responsive to frequent irrigation during both growth stages at Shendi. The highest seed yield was recorded with the 7-day interval (during both stages) and the biweekly intervals at the vegetative stage plus every 7 days for the reproductive growth stage at Shendi (Table 18). The damaging effect of frequent irrigation during the first stage of growth at Hudeiba was mainly attributed to waterlogging as a result of the heavier soil texture compared to Shendi.

Table 18. Effect of irrigation frequency on lentil seed yield at Shendi and Hudeiba, 1982/83–1984/85.

Irrigation interval† (days)	Location/Seed yield (kg/ha)					
	Shendi			Hudeiba		
	1982/83	1983/84	1984/85	1982/83	1983/84	1984/85
7-7	2216	1403	359	223	150	389
14-7	2219	1208	228	394	420	455
21-7	1922	1167	118	773	715	356
7-14	1896	1090	118	407	230	485
14-14	1912	799	206	636	565	464
21-14	1537	972	127	564	340	205
7-21	1606	854	121	454	200	377
14-21	1526	820	20	512	260	423
21-21	1218	736	37	505	820	396
SE (±)	146	30	63	92	158	66

† During the vegetative and reproductive stages, respectively.

The response of two lentil genotypes (ILL 795 and Selaim) to different soil moisture levels was investigated at Hudeiba and Rubatab (Ahmed and Nourai 1991, 1992, 1993). Irrigation treatments were factorial combinations of irrigating every 10 and 20 days during the vegetative stage and every 10, 15 and 20 days during the reproductive stage. Soils of the experimental sites were a loamy sand at Rubatab and a sandy clay loam at Hudeiba.

Results of the first season of the experiment at Hudeiba showed that the watering treatments at both growth stages had a highly significant effect ($P = 0.001$) on seed yield. During the second season, irrigating every 10 or 20 days during the vegetative stage had no significant effect on seed yield. However, a significant ($P = 0.01$) reduction in seed yield in response to longer irrigation intervals during the reproductive phase was detected (Table 19).

Table 19. Effect of irrigation frequency on seed yield of two lentil genotypes at Hudeiba and Rubatab in different crop seasons.

Irrigation interval (days)	Location/Seed yield (kg/ha)				
	Hudeiba		Rubatab		
	1991/92	1992/93	1990/91	1991/92	1992/93
Vegetative					
10	770	.1220	1096	1875	2776
20	510	1066	835	1924	2731
SE (±)	36	59	84	89	115
Significance level	***	NS	*	NS	NS
Reproductive					
10	800	1335	1247	2025	3267
15	644	1166	994	2062	2720
20	476	918	956	1612	2274
SE (±)	45	72	103	85	177
Significance level	***	**	**	**	**
Genotype					
Selaim	671	1082	987	1871	2654
ILL 795	609	1197	943	1828	2853
SE (±)	35	41	51	84	85
Significance level	NS	NS	NS	NS	NS

*,**, *** = Significant at the 5%, 1% and 0.1% levels, respectively.
NS = Not significant.

At Rubatab, significant differences (P = 0.05) in seed yield as a result of irrigating every 10 or 20 days were only detected during the first season of the study. Similar to Hudeiba, the three season results showed that less frequent irrigation during the reproductive stage had a significant (P = 0.01) depressive effect on seed yield (Table 19). In general, irrigating every 20 days during the vegetative stage as compared to every 10 days reduced seed yield by 21 and 4% at Hudeiba and Rubatab, respectively. Also, extending the irrigation interval to 15 and 20 days relative to the 10-day watering regime reduced seed yield by 15 and 35% at Hudeiba and 12 and 26% at Rubatab, respectively. Differences in seed yield in response to less frequent irrigation were associated with significant differences in the number of pods per plant and seed size. At both sites, differences in seed yield of the two genotypes were not significant (Table 19). Also, the interaction, genotype x water, was not significant.

The performance of 12 promising lentil genotypes under limited soil moisture conditions was studied at Hudeiba by Ahmed and Mohamed (1995b). The genotypes were subjected to two irrigation regimes: W1 (irrigating every 9–10 days), and W2 (irrigating every 18–20 days). The irrigation treatments were imposed 36 days after sowing and the two treatments, W1 and W2, received a total of 7 and 5 irrigations, respectively.

A significant (P = 0.05) reduction (35%) in seed yield in response to the irrigation treatments was detected over all genotypes. The interaction term (water x genotype) was also significant (P = 0.002), indicating differential response of the different genotypes to water stress. The highest seed yield under both wet and water stress conditions was attained by the newly released cultivar Aribo-1 followed by genotypes ILL 6467, ILL 795, ILL 6024 and then the newly released cultivar Rubatab-1 (Table 20). Differences in seed yield among genotypes were highly significant (P = 0.001) at the different irrigation treatments and were associated with significant differences in the number of seeds per pod, seed size and harvest index.

Table 20. Performance of promising lentil genotypes under different irrigation regimes, 1994/95.

Genotype	Irrigation regime†/Seed yield (kg/ha)		
	W1	W2	Mean
ILL 795	1515	1544	1530
ILL 4605	1556	871	1213
ILL 6002	1785	800	1293
ILL 6004	744	669	707
ILL 6024	2107	952	1529
ILL 6025	423	229	326
ILL 6459	645	375	511
ILL 6467	1902	1383	1642
ILL 6806	1502	550	1026
Rubatab-1	1663	1259	1461
Aribo-1	2135	1540	1837
Selaim	1329	1136	1232
Mean	1442	942	
Significance level	***	***	***

† W1 = Irrigating every 9–10 days; W2 = Irrigating every 18–20 days.
*** = Significant at the 0.1% level.
SE (water) (±) = 49; SE (genotypes) (±) = 103.

Concluding Remarks

Available information showed that faba bean, chickpea and lentil are very responsive to frequent irrigation especially during the reproductive stages of growth. One exception to this general statement is the expected waterlogging ill-effects on lentil grown on heavy textured soils. Although data indicated that savings in irrigation water during less sensitive growth stages are possible, there is not enough information on quantity and cost of applied water for the different treatments. Research in the future should focus on quantification of crop water requirements, water-use efficiency and the economics of different crop water management practices.

Data also indicated that screening different genotypes for tolerance to less frequent irrigation may be promising, especially for faba bean and lentil. For chickpea, there seem to be two target environments: (1) Rubatab (irrigated), and (2) Wad Hamid and Hawata (under residual soil moisture content). The potential of the promising genotype ICCV-2 under residual soil moisture content should be evaluated.

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Discussion

Q: El Amin Mohamed El Amin

Were there any effects of irrigation interval on the incidence of insect pests and diseases?

A: S.H. Ahmed

Yes, and this will be covered in more detail in the pathology section of the meeting.

Comment/Q: Prof. Hassan M. Ishag

(1) Using fixed intervals of irrigation every 7, 10, 12 days, etc. is not appropriate. It is better to use phasic development or % soil moisture depletion instead. (2) What about the economics of prewatering? Would it be better to use this water to expand the area of water?

A: S.H. Ahmed

(1) I agree with you that irrigation intervals should be interchanged during different phasic developments of the plant. Soil moisture depletion (as a treatment) has the advantage of comparing different results from different seasons and locations. (2) Prewatering proved to be of great advantage for weed control and improving crop establishment in the Gezira (see the mechanization and weed management sessions for more detail). Some of the water will be stored in the profile and the plant may make use of it.

Q: M.A. Rizk

Are irrigation practices of lentil on farmers' fields affected by clay content? And what is the effect of the irrigation/soil type interaction on crop response?

A: S.H. Ahmed

Yes, irrigation practices are affected by clay content, especially in case of lentil. Crop response depends on the soil type. On light soils, the crop is very responsive to irrigation, while on heavy clay soils, yield is reduced as a result of waterlogging.

Comment: Hamid Faki

It is important to bring faba bean cultivars, which tolerate long irrigation intervals, to on-farm trials. Such cultivars are needed, given the limitations on the use of more irrigations due to economic efficiency criteria within the farming systems in the north.

A: S.H. Ahmed

I totally agree with you and this will be suggested to the on-farm group.

Q: M.B. Solh

Can farmers adopt recommendations on irrigation interval considering the fixed cycle of water availability to the farmers?

A: S.H. Ahmed

Yes and no, depending on the scheme. Farmers with small water pumps in private schemes can adopt these recommendations. However, in large schemes where many crops are grown, water in the irrigation canal may be less than actual crop water requirements.

Comment: Hassan Tambal

Farmers in the Northern Province are used to irrigating once at sowing and withhold water to flowering. They claim that this saves water and controls aphids and white flies. This should be considered in comparing the recommended package with the local practice to ease the adoption process. Also, the effect of different water regimes should be economically evaluated.

Biological Nitrogen Fixation Research on Faba Bean, Lentil and Chickpea

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Abstract

From 1979 to 1985/86, faba bean microbiology research concentrated on *Rhizobium* strain survey, isolation and screening, and the need for inoculation tests. After 1986, it concentrated on testing effective strains with and without starter doses of nitrogen (10–20 kg N/ha), and application of phosphorus fertilizer. In the presence of phosphorus with inoculation and N-fertilization, yield of faba bean significantly increased; inoculated faba bean outyielding N-fertilized faba bean. Research in lentil also addressed strain testing, starter N-dose and both P and N combination with seed inoculation; but the crop did not respond to fertilization with N or N added with P. Again, the significant effect of phosphorus on lentil yield was evident. In 1987/88, a survey of different areas growing chickpea was carried out. Nodules and soil samples were collected for isolation and testing of these isolates. This was followed by using the best isolates, singly and in multistrain inoculants, for field experiments at Wad Hamid (traditional area). Chickpea did not nodulate in the new areas unless inoculated, and its response to inoculation was excellent in both traditional and new areas.

Introduction

Though the importance and beneficial effects of biological nitrogen fixation (BNF) was recognized in the Sudan as early as 1925 when *Dolichos lablab* was introduced in the Gezira rotation and later replaced by groundnuts in 1961, work on BNF was fragmentary with research priorities given to cash crops (Burhan and Mansi 1967; Musa 1974). In the last decade, leguminous crops like faba bean and others gained importance with the growing demand of the poor population sectors for cheaper protein sources and with demand outstripping production. These cool-season legume crops are traditionally grown on small holdings with lift irrigation along the banks of the Nile north of Khartoum, where lateral expansion in areas is limited by land and water availability and rise in cost of production.

As part of the efforts of the Nile Valley Project (NVP), and later the Nile Valley Regional Program (NVRP), to make these essential commodities—particularly faba bean—available to the consumer at reasonable prices, serious research attempts were made over the period 1979–1991 to expand the faba bean growing area south of Khartoum, characterized by warm winters and semi-arid conditions, including Gezira, Rahad and New Halfa, where land, irrigation water and agricultural inputs are reasonably available. As the three crops are leguminous, it was deemed necessary to rely in their production on biological nitrogen fixation (BNF) for their nitrogen needs. Thus, an ambitious program of BNF for the three crops was included in the NVP.

Experimental Methods

Faba bean (*Vicia faba* L.), mainly variety BF2/2, lentil (*Lens culinaris* Med.) and chickpea (*Cicer orietinum* L.) were grown at Rubatab, Hudeiba, Zeidab and Wad Hamid (traditional areas), and at Wad Medani, Turabi, Rahad and New Halfa (new areas). Faba bean and chickpea were sown between 31 October and 20 November, while lentil was sown from 20 November. Sowing was done using 60 cm ridges by 15 cm between holes and 2–4 seeds per hole. Seed inoculation with *Rhizobium* was one of the variables in all experiments. Inoculation was done by mixing the seed thoroughly with a slurry of peat-based or bagasse-, Nile silt- or charcoal-based inoculant in a 6% solution of Arabic gum. In some treatments, nitrogen (urea) and phosphorus (triple superphosphate) were also included. Irrigation was applied every 7–10 days.

All experiments were conducted in a randomized complete block design with four replications. In all experiments, the parameters studied included yield and yield components, nodule number and/or dry weight, shoot dry weight, and shoot N-content at different time intervals during crop development (mainly, 4, 6 and 8 weeks, and at harvest). Shoot P% was studied in some trials.

Results

Faba Bean

Effect of fertilization and inoculation on nodulation, N_2-fixation and yield of faba bean

The experiment was carried out at Wad Medani in 1979/80 and repeated at Shambat in 1980/81. The treatments included: T_1 (uninoculated); T_2 (inoculated with Wad Medani culture); T_3 (inoculated with Aleppo culture); T_4 (as in T_3 +

36 kg P_2O_5/ha); T_5 (as in T_3 + 72 kg P_2O_5/ha); T_6 (as in T_3 + 18 kg N/ha + 72 kg P_2O_5/ha); T_7 (as in T_3 + 36 kg N/ha + 72 kg P_2O_5/ha); T_8 (uninoculated + 100 kg N/ha, half of which at sowing and half at flowering + 72 kg P_2O_5/ha); T_9 (inoculated with Egyptian culture); and T_{10} (inoculated with Shambat culture). There was no significant effect on yield in both experiements.

Testing strain efficiency
This experiment was conducted in 1981/82 at Wad Medani, Shambat and Zeidab areas. It tested six strains in the following treatments: T_1 (uninoculated); T_2 (inoculated with Wad Medani culture); T_3 (inoculated with Egyptian culture); T_4 (inoculated with BB 48a); T_5 (inoculated with BB 54b); T_6 (inoculated with BB 80b); T_7 (inoculated with SL 23); and T_8 (uninoculated + 120 kg N/ha in three splits: at sowing, and 1 and 2 months after sowing).

In this experiment, inoculation with the Aleppo cultures, in particular BB 80b and SL 23, resulted in significantly improved nodulation, plant dry matter production and shoot tissue N-content, evaluated 4 weeks from sowing at all three locations. This effect was most prominent at Wad Medani, a new area (Mahdi *et al.* 1983), as shown in Table 1. At Wad Medani, significant increases in seed yield and total biological yield (TBY) were also obtained with BB 80b and SL 23. At Zeidab and Shambat (traditional areas), no significant treatment effects on seed yield were obtained.

Table 1. Effect of inoculating faba bean at Wad Medani with different strains of *Rhizobium leguminosarum* on nodulation, plant dry weight and nitrogen content 4 weeks after sowing, 1981/82.

Treatment	Nodules/plant		Plant dry weight (g)	N% of plant
	Number	Dry weight (g)		
T_1 (control)	4.2	0.010	0.86	2.76
T_2	1.8	0.010	0.86	2.68
T_3	0.2	0.003	0.83	2.68
T_4	11.9	0.070	1.17	2.68
T_5	9.1	0.040	0.92	3.75
T_6	11.8	0.020	0.89	3.32
T_7	16.2	0.100	1.49	2.96
T_8	2.0	0.010	1.29	3.94
SE (±)	2.97**	0.015**	0.114**	0.223**

** = Significant at the 1% level.

Effect of method and frequency of inoculation on strain efficiency

This experiment was executed at the above three locations in the 1981/82 season with a basal application of 50 kg P_2O_5/ha. The treatments were: T_1 (uninoculated); T_2 (seed-inoculated with Wad Medani culture); T_3 (soil-inoculated with Wad Medani culture); T_4 (seed- + soil-inoculated with Wad Medani culture); T_5 (seed-inoculated at sowing + soil-inoculated 15 days later); T_6 (soil-inoculated at sowing + soil-inoculated 15 days later); T_7 (seed-inoculated with SL 23); T_8 (soil-inoculated with SL 23 at sowing); and T_9 (120 kg N/ha in three splits: at sowing, and 1 and 2 months later). Though soil inoculation was slightly better than seed inoculation, the results were generally erratic. All treatments including the control were, however, significantly better than T_5 and T_9 (Mahdi *et al.* 1983).

Effect of inoculation with a starter N-dose on nodulation, nitrogen content and yield

This experiment was carried out at Wad Medani in 1982/83. It included the following treatments: T_1 (uninoculated); T_2 (120 kg N/ha in three splits: at sowing, and 1 and 2 months after sowing); T_3 (inoculated with SL 24 Aleppo culture); T_4 (inoculated with local strain); T_5 (inoculated with SL 24 + 20 kg N/ha); and T_6 (inoculated with local strain + 20 kg N/ha).

The strain SL 24 was a composite of the Aleppo strains BB 80b, BB 54b and SL 23, which performed well at this location the previous season. Results are shown in Table 2. After 40 days from sowing, significantly more nodule dry matter was produced by all inoculated treatments compared to T_2 (120 kg N/ha), i.e., the higher dose of N reduced nodule formation. The inoculated treatments T_5 and T_6, aided with a starter N-dose, produced less nodules than the control treatment, while more inoculation without N produced significantly more nodular dry matter than the control, i.e., even the small dose (20 kg N/ha) had an adverse effect on nodule formation. Eighty days after sowing, all treatments produced significantly more nodules than the nitrogen treatment T_2. Inoculation with the local strain (T_4) gave the highest nodulation.

As far as seed yield is concerned, even T_2 (120 kg N/ha) failed to produce any increase in yield, indicating that the particular plot planted with faba bean that season had a high population of faba bean *rhizobia*.

Table 2. Effect of inoculating faba bean with and without starter N-dose on seed yield, nodule dry weight and shoot N% at Wad Medani, 1982/83.

Treatment	Seed yield (t/ha)	Nodule dry weight (g/plant)		N% 40 days from sowing
		40 days from sowing	80 days from sowing	
T_1 (control)	1.84 a†	0.35 cd	1.09 abc	3.93 c
T_2	1.76 a	0.12 d	0.31	4.76 a
T_3	1.56 a	0.68 ab	1.51 ab	4.46 ab
T_4	2.12 a	0.77 a	1.64 a	4.23 bc
T_5	1.62 a	0.50 abc	0.86 dc	4.43 bc
T_6	1.52 a	0.61 abc	1.00 abc	4.20 bc
SE (±)	0.18^{NS}	0.09*	0.18*	0.16*

† Values within a column followed by the same letter(s) are not significantly different at the 5% level according to DMRT.
* = Significant at the 5% level.
NS = Not significant.

Effect of inoculation, starter N-dose and phosphorus application

The experiment was conducted during 1983/84 at two locations, Wad Medani (new area) and Rubatab (traditional area, but not grown to faba bean before). The following treatments were applied: T_1 (uninoculated); T_2 (uninoculated + 50 kg P_2O_5/ha); T_3 (inoculated with SL 24); T_4 (inoculated with SL 24 + 50 kg P_2O_5/ha); T_5 (inoculated + 10 kg N/ha); T_6 (inoculated + 10 kg N/ha + 50 kg P_2O_5/ha); T_7 (inoculated + 20 kg N/ha); T_8 (inoculated + 20 kg N/ha + 50 kg P_2O_5/ha); T_9 (120 kg N/ha in three splits: at sowing, and 1 and 2 months later); and T_{10} (as in T_9 + 50 kg P_2O_5/ha).

The treatment effects on nodulation are shown in Table 3. T_4 resulted in the best nodulation at all stages at both locations. The effect of P application on improving the performance of the inoculant became more clear as the crop age increased.

The effect on grain yield and shoot N-content are shown in Table 4. The yield was significantly improved by P application at Rubatab at all other treatment combinations of inoculation and starter-N application. At Wad Medani also, the trend for the improvement in yield with P application was clear. The effect of treatments on N-content was not significant.

Table 3. Effect of inoculation (with best available strain), starter N-dose and P application on faba bean nodule dry weight at Wad Medani and Rubatab, 1983/84.

Treatment	Time from sowing/Nodule dry weight (g/plant)								
	4 weeks			6 weeks			8 weeks		
	Wad Medani	Rubatab	Mean	Wad Medani	Rubatab	Mean	Wad Medani	Rubatab	Mean
T_1 (control)	0.12 c†	0.09 c	0.10 c	0.44 b	0.38 c	0.41 b	0.82 a	1.13 bc	0.98 c
T_2	0.12 c	0.17 cd	0.15 bc	0.25 b	0.37 c	0.31 b	1.16 a	0.68 cd	0.92 c
T_3	0.18 bc	0.34 a	0.26 ab	1.08 a	0.83 bc	0.96 a	0.72 a	1.58 ab	1.15 bc
T_4	0.31 a	0.35 a	0.33 a	1.04 a	0.81 bc	0.93 a	1.50 a	2.15 a	1.83 a
T_5	0.27 ab	0.32 ab	0.30 ab	0.73 ab	0.81 bc	0.77 a	1.11 a	1.49 abc	1.30 ab
T_6	0.13 bc	0.39 a	0.26 ab	0.58 bc	1.11 ab	0.85 a	0.97 a	1.87 ab	1.42 ab
T_7	0.23 ab	0.32 ab	0.27 ab	0.68 bc	0.76 bc	0.69 a	1.09 a	1.54 abc	1.35 ab
T_8	0.13 bc	0.27 ab	0.20 bc	0.75 ab	0.98 b	0.87 a	1.09 a	1.70 ab	1.39 ab
T_9	0.07 d	0.18 bcd	0.13 c	0.18 c	0.23 c	0.20 b	0.63 a	0.63 c	0.63 c
T_{10}	0.11	0.13 de	0.12 c	0.12 c	0.37 c	0.24 b	0.36 a	0.70 cd	0.53 c
SE (±)	0.04*	0.04*	0.44*	0.15*	0.14*	0.16	0.23^{NS}	0.30*	0.29*

† Values within a column followed by the same letter(s) are not significantly different at the 5% level according to DMRT.
* = Significant at the 5% level.
NS = Not significant.

Table 4. Effect of inoculation (with best available strain), starter N-dose and P application on seed yield and shoot N% of faba bean at Wad Medani and Rubatab, 1983/84.

Treatment	Seed yield (t/ha)			Shoot N% 6 weeks from sowing	
	Wad Medani	Rubatab	Mean	Wad Medani	Rubatab
T_1 (control)	1.63 bc†	1.45 d	1.54	5.16 a	4.43 a
T_2	1.80 abc	2.01 c	1.95	5.19 a	4.51 ab
T_3	1.60 bc	1.01 d	1.56	4.92 a	4.36 a
T_4	1.75 abc	2.07 bc	1.91	5.23 a	4.53 a
T_5	2.27 a	1.59 d	1.93	5.19 a	4.57 a
T_6	1.79 abc	2.37 ab	2.08	5.29 a	4.58 a
T_7	1.77 abc	1.46 d	1.62	5.02 a	4.55 a
T_8	1.56 abc	2.48 a	2.02	5.30 a	4.58 a
T_9	1.35 c	1.62 d	1.49	5.50 a	4.63 a
T_{10}	2.11 ab	2.28 bc	2.20	5.35 a	4.79 a
SE (±)	0.17*	0.14*	0.16*	0.12	0.11

† Values within a column followed by the same letter(s) are not significantly different at the 5% level according to DMRT.
* = Significant at the 5% level.

The above experiment was repeated in 1984/85 at three locations. In addition to Wad Medani and Rubatab, Turabi in the Gezira Scheme was included. There was no effect of the treatments on yield, nodulation and nitrogen content of the shoot.

On-farm evaluation of the best available *Rhizobium* isolate in the new areas
This was done in 1985/86 at Wad Medani, Turabi, Rahad and New Halfa. The treatments included: uninoculated, nonfertilized control; inoculation using a bagasse carrier); and a high dose of N (60 kg N/ha at sowing, and 60 kg N/ha at flowering). None of the treatments could significantly outyield the control.

Nevertheless, inoculation and nitrogen produced 13 and 16% more seed, respectively, compared to the control at Wad Medani, and 25 and 31%, respectively, at Turabi. At Rahad, N gave 13% more seed than both inoculation and the control.

The above experiment was repeated in 1986/87 at all locations except Turabi. Nodule formation results showed that significantly more nodulation throughout the season was produced by inoculation at New Halfa (Table 5). Both the high dose of N and inoculation treatments gave significantly more ($P = 0.05$) shoot dry matter at 8 weeks than the control, at Wad Medani and Rahad, while at New Halfa both the control and N gave significantly ($P = 0.05$) more shoot dry matter than the inoculated treatment.

Both the high dose of N and inoculation treatments outyielded the control by 25% at Wad Medani (Table 5). No differences were observed at Rahad, while at New Halfa the N treatment outyielded inoculation and the control by 21 and 13%, respectively.

During the 1987/88 season, the experiment was conducted only at the Wad Medani location. No significant differences in shoot dry matter, shoot N-content and seed yield were observed, suggesting that there was an adequate natural *Rhizobium* population at the test site.

Response to *Rhizobium* inoculation in pilot production and demonstration plots in the new areas

Seed inoculation of faba bean was included in the improved production package of faba bean in the new areas (Gezira, Rahad and New Halfa) in 1987/88. Inoculated plots were given 43 kg N/ha while uninoculated plots were given 86 kg N/ha. The *Rhizobium* inoculant (counting 2-7 x 10^9 cells/g) was provided from Egypt. About 60 farmers received inoculants and were shown how to use them. These farmers belonged to three groups within the Gezira Scheme: 9 farmers from the Southern Group; 27 from the Center Group; and 24 from the Northern Group.

Two visits were made to the fields 4 and 8 weeks from sowing where inoculated and uninoculated crops were inspected for the status of nodulation, plant dry matter and tissue N%. Inoculation increased nodulation except in a few situations. Some uninoculated crops were also well nodulated. However, scanty nodulation was the rule for the uninoculated crops.

Table 5. On-farm evaluation of best available strain: Nodule dry matter, shoot dry matter and shoot N% at 8 weeks from sowing, and seed yield of faba bean, 1986/87.

Treatment†	Wad Medani				Rahad				New Halfa			
	NDW§	SDW	SN%	SY	NDW	SDW	SN%	SY	NDW	SDW	SN%	SY
C (control)	0.14 a‡	4.44 b	4.34 a	1.10 a	0.19 ab	11.17 b	3.84 a	1.44 a	0.04 a	10.97 a	3.70 a	1.15 a
R	0.14 a	10.00 a	4.30 a	1.38 a	0.37 a	13.25 a	3.81 a	1.40 a	0.57 a	8.39 b	3.76 a	1.17 a
N	0.22 a	8.65 ab	4.28 a	1.14 a	0.28 ab	15.25 ab	3.89 a	1.59 a	0.36 a	11.49 a	3.76 a	1.14 a
SE (±)	0.03	1.28		0.13	0.04	1.03	0.06	0.11	0.20	6.94	0.04	0.12

† C = Uninoculated, nonfertilized control; R = Inoculated using a bagasse carrier; N = Given a high dose of N: 60 kg N/ha at sowing, and 60 kg N/ha at flowering.
‡ Values within a column followed by the same letter(s) are not significantly different at the 5% level according to DMRT.
§ NDW = Nodule dry weight (g/plant); SDW = Shoot dry weight (g/plant); SN% = Shoot N%; SY = Seed yield (t/ha).

Small scale production of *Rhizobium* inoculant for faba bean and its evaluation in farmers' fields
While about 60 farmers inoculated their crops in 1987/88, only 10 received inoculants in the 1988/89 season. Peat-based inoculants prepared in the laboratory were distributed and the methodology for their use demonstrated by laboratory technicians. All farmers' fields were treated with herbicides for weed control and received 43 kg N/ha and 10–12 irrigations at intervals of 7–15 days. Three different faba bean cultivars were grown at the different locations.

Two isolates were tested on-station against a high dose of N and a control. The data for the measured variables indicated no significant influence of inoculation or fertilization. Nodulation seemed to be related to the type of cultivar. Although cv. 00104 was sown 10 days later than cv. 00503 and in spite of the high combined N in the soil, it gave the highest nodule matter. Cultivar 00503 ranked second and SM-L last. Seed yield of cv. 00104 was highest with high nodulation. The lowest yields were obtained for cv. 00503 at Wad Adam where both nodulation and plant dry matter were lowest though soil NO_3-N was very high. The high soil NO_3-N areas indicated that farmers in these areas applied more than the allowed 43 kg N/ha.

Lentil

Studies of biological nitrogen fixation in lentil started in 1982/83, and covered the crop response to rates of inoculation, starter nitrogen application and application of phosphorus fertilizer.

Effect of rate of inoculant application and starter dose of N
This experiment was conducted in 1982/83 at Hudeiba Research Station. It included the following treatments: T_1 (uninoculated, nonfertilized control); T_2 (inoculated with SL 23 in the amount of 25 g inoculant/kg seed); T_3 (as in T_2 + 10 kg N/ha); T_4 (as in T_2 + 20 kg N/ha); T_5 (inoculated with SL 23 in the amount of 50 g inoculant/kg seed); T_6 (as in T_5 + 10 kg N/ha); T_7 (as in T_5 + 20 kg N/ha); and T_8 (120 kg N/ha in three splits: at sowing, and 1 and 2 months later). The site was highly saline, hence no worthwhile results could be obtained. It was, therefore, decided to conduct future inoculation studies at Abu-Hasheem location in Rubatab which is better-suited for lentil production.

Lentil inoculation and fertility trial

This experiment was conducted at Rubatab in 1983/84 and included eight treatments: T_1 (uninoculated, nonfertilized control); T_2 (86 kg N/ha); T_3 (inoculated); T_4 (inoculated + 21.5 kg N/ha); T_5 (inoculated + 43 kg N/ha); T_6 (inoculated + 43 kg P_2O_5/ha + 21.5 kg N/ha); T_7 (inoculated + 86 kg P_2O_5/ha + 43 kg N/ha); and T_8 (86 kg P_2O_5/ha).

Treatment T_2 gave significantly more nodule dry matter than all other treatments only after 6 weeks. All inoculated treatments, except T_4, gave significantly higher nodule matter than the control. After 6 weeks, T_3 and T_7 produced significantly more nodule dry matter than T_2 and T_5. After 8 weeks, no response was evident (Table 6). There was no significant effect of treatments on the shoot dry matter, N% of shoot, yield attributes and yield of seed. Straw yield was increased by inoculation and P application.

The experiment was repeated at Rubatab in 1984/85. Inoculation with a starter dose equal to 21.5 kg N/ha gave significantly ($P = 0.05$) higher nodule dry matter at 8 weeks after sowing than most treatments except when 86 kg P_2O_5/ha was applied. All treatments produced significantly ($P = 0.05$) more nodules than the uninoculated control and the 86 kg N/ha treatments (Table 6).

Shoot tissue N% was generally high. It seemed that adequate amounts of N were available for the smaller plants. No response was observed in grain and straw yields and yields were low perhaps because of unfavorable weather conditions.

Lentil international fertility-cum-inoculation trial

The aim of the trial was to answer questions such as: Is the symbiosis with local rhizobial population adequate and is there a need for inoculation? Is BNF limited by P deficiency and/or K? Is the symbiotic N_2-fixation adequate to meet the N need of the crop.The experiment was conducted at Wad Medani.

The treatments applied in this trial were: T_1 (the control); T_2 (P at 50 kg P_2O_5/ha); T_3 (K at 60 kg K_2O/ha); T_4 (inoculated with *Rhizobium*); T_5 (inoculation + P); T_6 (inoculation + K); T_7 (inoculation + P + K); and T_8 (100 kg N/ha + P + K). Local Selaim was sown in 22 cm rows on 26 November 1983 in a RCBD and harvested on 10 March 1984.

Table 6. Lentil inoculation and fertility trial: Nodule dry weight, shoot dry weight, shoot N% and total biological yield (TBY), 1983/84–1984/85.

Treatment†	Nodule dry wt. at 8 weeks (g/plant)		Shoot dry wt. at 8 weeks (g/plant)	Shoot N% at 8 weeks		Seed yield (t/ha)		TBY (t/ha)	
	1983/84	1984/85	1983/84	1983/84	1984/85	1983/84	1984/85	1983/84	1984/85
T_1 (control)	0.048 a†	0.010 c	4.15 a	3.19 a	5.31 a	1.72 a	0.70 a	4.45 b	1.51 a
T_2	0.053 c	0.010 c	5.19 a	5.30 a	5.15 a	2.18 a	0.68 a	6.50 b	1.56 a
T_3	0.038 a	0.018 b	3.82 a	3.29 a	5.25 a	2.17 a	0.55 a	6.42 b	1.39 a
T_4	0.088 a	0.028 a	4.78 a	3.48 a	5.54 a	2.18 a	0.72 a	6.34 b	1.54 a
T_5	0.065 a	0.013 bc	3.48 a	3.27 a	5.36 a	2.25 a	0.71 a	5.82 b	1.59 a
T_6	0.098 a	0.015 bc	5.33 a	3.23 a	4.79 a	2.39 a	0.60 a	7.56 a	1.38 a
T_7	0.083 c	0.025 ab	5.35 a	3.35 a	5.51 a	2.45 a	0.54 a	7.78 a	1.38 a
T_8	0.055 a	0.025 ab	4.90 a	3.28 a	5.37 a	2.41 a	0.67 a	7.76 a	1.56 a
SE (±)	0.017	0.003	0.75		0.34	0.13	0.60	0.32	0.45

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

Nodulation started after 4 weeks and nodules were scanty. The control gave one of the highest nodule dry weights after 8 weeks. No response of shoot dry weight to inoculation or fertilization with P, K or combinations was observed. At 4 weeks, all treatments gave significantly higher shoot N% than T_5, while T_8 was significantly better than T_2 and T_7 (both receiving P) and T_5. Treatment 3 (K alone) was significantly better than T_2 and T_5. In general, the treatments receiving potash seemed to give better results than those receiving phosphate. Grain yield did not respond to the treatments and was generally low.

Effect of starter N-dose and P on the efficiency of BNF by lentil

The following treatments were tested in 1990/91 at Rubatab in a RCBD: phosphorus at 50 kg P_2O_5/ha (P); nitrogen at 150 kg N/ha + P; inoculated with local isolate + P; and inoculated with ICARDA strain + P. Local cultivar Selaim was sown on 16 November 1990 on 60 cm ridges and was irrigated every 10 days leading to a total of 10 irrigations.

It is evident from Table 7 that neither inoculation alone nor inoculation aided with P or even fertilization with N at 150 kg N/ha alone or aided with 50 kg P_2O_5/ha were able to result in increased grain or straw yields or TBY of lentil.

Table 7. Lentil inoculation trial at Rubatab: Effect of starter N-dose and P on the efficiency of BNF, 1990/1991.

Treatment†	Grain yield (kg/ha)	TBY‡ (kg/ha)	Nodule dry weight (g/plant)	Shoot dry weight (g/plant)
T_1	913.90 a§	4993.10 a	11.0 b	20.6 a
T_2	886.80 a	4227.80 a	13.0 b	18.0 a
T_3	902.80 a	4491.70 a	34.0 a	21.7 a
T_4	741.70 a	3848.60 a	34.0 a	17.1 a
SE (±)	268.06	668.75	3.1	5.3

† T_1 = Phosphorus at 50 kg P_2O_5/ha (P); T_2 = Nitrogen at 150 kg N/ha + P; T_3 = Inoculated with local isolate + P; T_4 = Inoculated with ICARDA strain + P.

‡ TBY = Total biological yield.

§ Values within a column followed by the same letter are not significantly different at the 5% level according to DMRT.

Nodule dry matter was significantly more in case of inoculation plus P application for both isolates used. This increase in nodulation had no positive effect on other variables studied. Shoot dry weight, shoot N% and P%, number of pods per plant, number of seeds per pod, 1000-seed weight and lentil harvest index were not influenced by any of the treatments.

Chickpea

Survey of nodulation and N_2-fixation of chickpea in the Nile Province
This survey, done in 1989/90, covered the areas of Rubatab, Hudeiba, Shendi and the Wad Hamid basin (traditional chickpea growing areas). The survey, carried out at three sites in each location, aimed at investigating the presence and size of the chickpea *Rhizobium* population; collecting nodules and soil sample for isolation of *Rhizobium*; and visual examination of the symbiotic efficiency in terms of nodule size, shape, position on the root and color of the inside, and shoot dry matter and N% of the surveyed crops.

In order to conduct the nodulation test with all isolates, the plants were grown on sterile sand in pots and watered with the proper nutrient solution. In addition, soils collected from the different locations were potted and chickpea was sown for possible nodulation and further isolation of *Rhizobium* from the nodules.

Nodules were present, mostly on the main root of all the sampled plants, in all the areas surveyed. Nodule number varied between few and numerous, depending on location. Although the nodules were small in size (1–2 mm), the inside was red to pink, indicating effectiveness of fixation. Of the 33 sites (11 locations) studied, three were well nodulated, four poorly nodulated and the rest moderately so. Table 8 illustrates the above results as well as nodule dry matter of the crop samples. Testing of the isolates indicated that, out of the large number of isolations made, only eight isolates formed nodules. Chickpea grown on soils collected from the different locations also gave varying amounts of nodules according to the type of soil.

Analysis of the soils collected from the different locations showed that the soils differed in the content of clay (12.2–27.0%); carbon (0.29–0.71%); total N (373–821 ppm); available P (4.7–10.0 ppm); and salts (0.04–0.08%); pH (8.2–8.6); and NO_3-N (5.7–82.3 ppm). All these variations, however, did not result in clear differences in nodulation, N_2-fixation or plant dry matter. It seems that the detected differences in nodulation could be related to the size of the indigenous *Rhizobium* population.

Table 8. Nodule dry weight of chickpea at different sites of the locations surveyed, 1989/90.

Location	Nodule dry weight (g/plant)	Nodulation
Hagar Elter	1.21	Very good
$Shendi_1$	0.58	Very good
$Hudeiba_3$	0.40	Very good
$Hudeiba_1$	0.27	Moderate
$Rubatab_5$	0.05	Poor
Hasa	0.06	Poor
$Shendi_2$	0.07	Poor
Hagar $Elter_1$	0.09	Poor

The need for inoculation tests

Two experiments were carried out using the three best effective isolates from the previous seasons' surveys: R_1 from Wad Medani, R_2 from Rubatab and R_3 from Messiab.

In the first experiment, the three isolates were screened for nodulation and N_2-fixation efficiency in the presence and absence of P at 50 kg P_2O_5/ha. Chickpea was sown on 22 November 1989 on flat beds (60 x 30 cm), 2 seeds per hole, and received 6 irrigations. The crop was harvested on 10 March 1990.

In general, grain yield increased with applied P (Table 9). Inoculation with R_1 + P; R_3 + P increased grain yield significantly (P = 0.05) over the uninoculated control (with and without P). Application of 120 kg N/ha with and without P also increased yield significantly over the uninoculated control.

Nodule number was greater with inoculation but was not significant. The exception was R_3 + P which gave significantly (P = 0.05) more nodules than all other treatments. Nodule dry matter seemed to decrease with added P but only significantly in case of R_1 with respect to R_2 + P. R_1 could actually produce significantly more nodular matter than all treatments except R_2. Alteratively, R_2 itself gave significantly more nodule dry matter than the control treatment without P.

Table 9. Screening of *Rhizobium* isolates with and without P on chickpea at Wad Hamid, 1989/90.

Treatment†	Grain yield (kg/ha)	Nodule number	Nodule dry weight (g/plant)	Shoot dry weight (g/plant)
R_1	93.3	7.8 b‡	0.89 a	36.6 a
R_1 + P	197.1	8.5 b	0.58 b	27.0 a
R_2	185.3 ab	7.8 b	0.76 ab	28.0 a
R_2 + P	164.7 abc	7.5 b	0.33 bc	26.9 a
R_3	179.4 ab	7.0 b	0.54 bc	22.6 a
R_3 + P	191.2 a	16.4 a	0.51 bc	19.1 a
N	194.1 a	5.6 b	0.45 bc	25.4 a
N + P	208.8 a	6.0 b	0.51 bc	23.7 a
Control	100.0 c	4.3 b	0.06 c	19.3 a
Control + P	114.7 b	5.4 b	0.29 bc	28.4 a
SE (±)	21.7	1.7	0.16	3.96

† R_1 = Isolate from Wad Medani; R_2 = Isolate from Rubatab; R_3 = Isolate from Messiab; N = 43 kg N/ha; P = 50 kg P_2O_5/ha.
‡ Values within a column followed by the same letter(s) are not significantly different at the 5% level according to DMRT.

In the second experiment, a composite of the three best isolates (R_1 + R_2 + R_3) was tested with N, K and N + K at 43 kg N/ha and 43 kg K_2O/ha. A basal dressing of phosphorus (50 kg P_2O_5/ha) was used. Significantly more grain yield was obtained with inoculation than the control. Urea at the rate of 43 kg N/ha also caused a significant increase above the control and N + K. All other treatments were only significant over the uninoculated, nonfertilized control.

Seed inoculation increased the number of nodules per plant. This increase was only significant, however, when inoculation was aided by both N and K. Nodulation was present even without inoculation but was less than that which occurred when the seed was inoculated. Nodule dry matter showed only a trend of improvement with inoculation. Plant shoot dry matter was not influenced by treatment.

Effect of starter dose of N and P on the efficiency of N_2-fixation by chickpea
This experiment was sown on 20 November 1990 at Wad Hamid. The best tested isolate (local) together with another one (E) from Egypt (provided by ICARDA) were both subjected to this field trial. Twelve treatments were applied: the control (C); the control + P (50 kg P_2O_5/ha); 120 kg N/ha (N); N + P; inoculated (local); inoculated (local) + P; inoculated (E); inoculated (E) + P; inoculated (local) + 21.5 kg N/ha; inoculated (local) + 21.5 kg N/ha + P; inoculated (E) + 21.5 kg N/ha; and inoculated (E) + 21.5 kg N/ha + P.

All treatments tested failed to influence any of the parameters measured, e.g., grain yield, number of pods per plant, number of seeds per pod, number of seeds per plant, plant dry matter and tissue N and P percentages.

Acknowledgements

The following scientists have contributed to the original work on which this review was based: Drs. A.H. Nourai (Hudeiba Research Station), G.E. Mohamed (Shendi Research Station), M.B. Mohamed (Rahad Research Station), and A.M. Gurashi (New Halfa Research Station).

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Discussion

Q: M.C. Saxena

(1) There was no nodulation in chickpea at Hudeiba and Shendi research stations, where major work on this food legume is carried out. Can you comment on the reason? (2) In view of the fact that lentil does not respond to inoculation and fertilizer N application, one should expect that the local *Rhizobium* population is quite effective. There is a possibility that nodulation of lentil does not look impressive because of our inability to properly uproot the plants. We should aim at quantifying the symbiotic N_2-fixation by using the ^{15}N-technique.

A: Nuri O. Mukhtar

(1) When the areas mentioned were surveyed for the presence of nodules on crops already in the fields, both Shendi and Hudeiba fell within the very well nodulated crops in one location and the poorly nodulated in another ($Shendi_1$ 0.58 g nodule dry matter/3 plants, $Shendi_2$ only 0.07 g/3 plants, while $Hudeiba_3$ gave 0.40 g/3 plants, $Hudeiba_1$ 0.27 g/3 plants). It was only in soil samples taken from those areas, potted and grown to chickpea, that nodules did not come up for reasons unknown. (2) It is true that the uprooting of lentil is difficult and may be the reason for the unimpressive results. The exact efficiency of lentil rhizobia can only be determined by the use of ^{15}N-dilution methodology; a thing we intend to do, hopefully soon.

Q: Mohamed Safaa Eldin Sharshar

What is the relationship between soil pH and *Rhizobium* inoculation?

A: Nuri O. Mukhtar

The optimum pH range for rhizobia, and indeed for most bacteria, lies between pH 6.5 and 7.5. This does not mean that above and below that range N is not fixed, but that fixation efficiency is adversely affected and that inoculants coated with lime are applied in acid soils.

Comment: G.S. Youssef

We should be aware that scientists in the US and in other countries have been able to produce *Rhizobium* strains that are able to double the amount of N that is fixed. Other strains have also been produced that attack new crops like cereal and transform genes for nitrogen fixation.

A: Nuri O. Mukhtar

Yes, biotechnology in the field of N_2-fixation has succeeded in transferring genes from an effective *Rhizobium* to an ineffective one. The induction of N_2-fixation by other nonleguminous crops entails biological engineering and DNA manipulation, a technology for which we have neither the expertise nor the millions of dollars needed to establish such laboratories.

Comment: Dr. A.H. Nourai

Nitrogen nutrition indicated significant responses in some areas (e.g., Hassa). Response to P was positive, particularly in case of straw yield. I think, since natural nodulation is observed to be very poor, that research on P nutrition and inoculation using different indigenous and exogenous rhizobia should be conducted and testing that in different soil types should be carried out.

A: Nuri O. Mukhtar

Our survey of nodulation at Hassa showed that nodulation was very poor in that area (0.06 g/3 plants compared to 1.21 g/3 plants at Hagar Elter). I agree that that area and others need the introduction of effective tested strains and the use of P to boost the process of fixation.

Q: Osman A.M. Eltom

How do you account for your statement that lentil did not respond to fertilization in spite of low nodulation? Also, your tables show that fertilization increased yields in Rubatab area.

A: Nuri O. Mukhtar

It is true that lentil did not respond to fertilization with N or inoculation with *Rhizobium*, yet nodule size and amount were not impressive. That does not mean, however, that those nodules were not effective. Efficiency of nodules can only be exactly decided using ^{15}N-dilution methodology; a thing we intend to do in the near future.

Q: Ahmed Ali Salih

Is there a response to molybdenum application?

A: Nuri O. Mukhtar

Work using Mo was not done, mainly because of molybdenum's availability in our alkaline soils. Nevertheless, we know that Mo is an important nitrogenase constituent and that no N can be fixed in the absence of Mo except in very rare cases where it can be replaced by vanadium.

Comment: Hassan A. Tambal

The insignificant response of lentil in Rubatab area to N fertilizer or inoculum could be either due to applying the wrong inoculum or to the presence of an indigenous unknown *Rhizobium* strain. So, more work is needed on crop-strain specificity.

A: Nuri O. Mukhtar

The fact that the crop did not respond to nitrogen as high as 120 kg N/ha is an indication of the efficiency of the indigenous rhizobia. If only the response to N was positive, then your suggestion should be taken care of. However, other cultivars and genotypes could be tried.

Chapter 4
Crop Protection

Insect Pests of Cool-Season Food Legumes and Their Control

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Abstract

Insect pests are one of the major constraints that limit the production of cool-season food legumes (faba bean, chickpea and lentil) in the Sudan. This paper summarizes the results of the work undertaken in different parts of the Sudan to alleviate the insect pest problems. A number of surveys showed that the insect pest populations vary from one area to another and also between seasons. The natural enemies were observed late in the season and their numbers were generally low. Screening for host resistance showed that some faba bean genotypes were resistant to the leaf miner (*Liriomyza trifollii*). Resistance to aphids (*Aphis craccivora*) was also observed in some faba bean lines. Late sowing of faba bean on both sides of the ridge decreased the infestation by the leaf miner. Chemical control studies resulted in the recommendation of Danitol-S for the control of leaf miner on faba bean at an economic threshold level of 25% infested leaflets. *Neem* extracts, although less effective against insect pests, proved to be soft for the natural enemies. Larvin, Sevin and Baythroid were found to be effective in reducing pod borer damage. In the stores, protection of food legumes could be achieved by using phostoxin at a rate of 10 tablets/t of seed.

Introduction

Faba bean, chickpea and lentil are the major cool-season food legume crops grown in the northern part of the Sudan. They provide cheap and high quality protein and are (especially faba bean) major sources of family income.

One of the major biotic constraints that limits legume production in the Sudan is the insect pest problem. The insect-pest complex of faba bean, chickpea and lentil is generally of the same nature with slight differences in host preference. The rate of infestation and the magnitude of damage also vary depending on area, season and cultural practice.

The wide range of herbivores which attack every part of the plant can cause tremendous losses in crop yield. These are the cutworm (*Agrotis ipsilon*), army worm (*Spodoptera exigua*), leaf miner (*Liriomyza trifollii),* aphid (*Aphis craccivora* and *Acyrthosiphon gossypii*), pod borer (*Helicoverpa armigera*), and thrips (*Caliothrips sudanensis* and *Thrips tabaci*). Bruchids (*Bruchidius incarnatus*) and the Khapra beetle (*Trogoderma granarium*) can do large-scale damage to stored produce. The whitefly (*Bemisia tabaci*), jassid (*Jacobiasca lybica*) and white-ant (*Microtermes* sp.) are of minor importance in legume crops. Among vertebrates, birds are a major pest on lentil.

Entomological research carried out during the last decade aimed at formulating simple, safe and affordable integrated pest management (IPM) strategies. Such strategies place minimum reliance on chemical insecticides which, in any case, are getting very expensive besides being hazardous to the environment and to nontarget organisms. This paper reviews the research carried out from 1985 to 1994 which addressed the following aspects:

- Survey of insect pests of legumes and their natural enemies.
- Screening of insecticides with different formulations as well as *neem* extracts for the control of major insect pests of legumes and the study of their selectivity to natural enemies.
- Study of the economic threshold for spraying against the leaf miner.
- Screening for host resistance.
- Testing the effect of sowing date and plant population on the leaf miner population.
- Control of store pests.

Insect Survey

Faba Bean

A survey in the Gezira area indicated that the leaf miner (*L. trifollii*) infestation level was higher in the north of the Gezira Scheme than in the south (Fig. 1). In another survey, carried out in northern Sudan in the 1992/93 and 1993/94 seasons, the results revealed that insect pest populations were very low and consequently their natural enemies had low populations as well (Mohamed 1993, 1994; Musa and Mohamed 1994). The species of the natural enemies encountered were *Coccinella* sp., *Chrysoperlla carnea, Camplylomma* sp. and the Syrphid fly. High populations of *Chrysoperlla carnea* were particularly observed in Rubatab area. The pheromone-trap catch showed that the population of the pod borer (*H. armigera*) reached its peak in mid-February (Fig. 2).

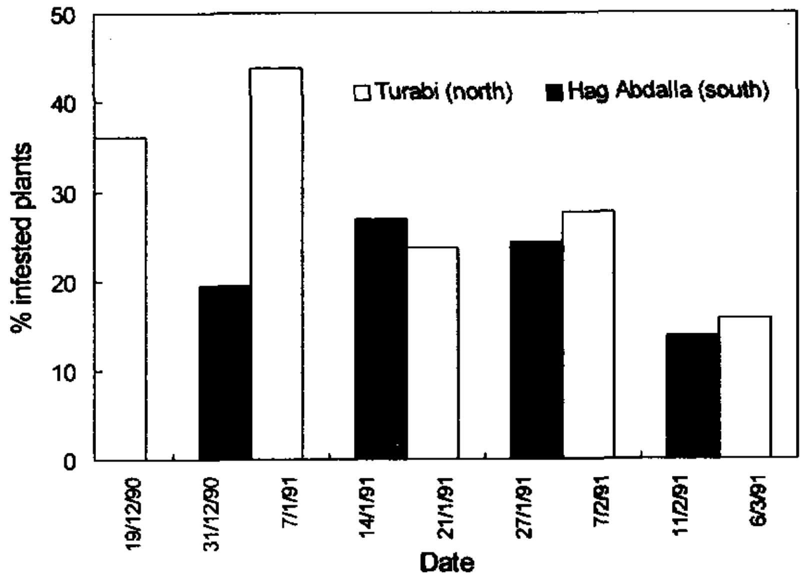


Fig. 1. Incidence of leaf miner in Gezira, 1990/91 (Sharaf Eldin 1991).

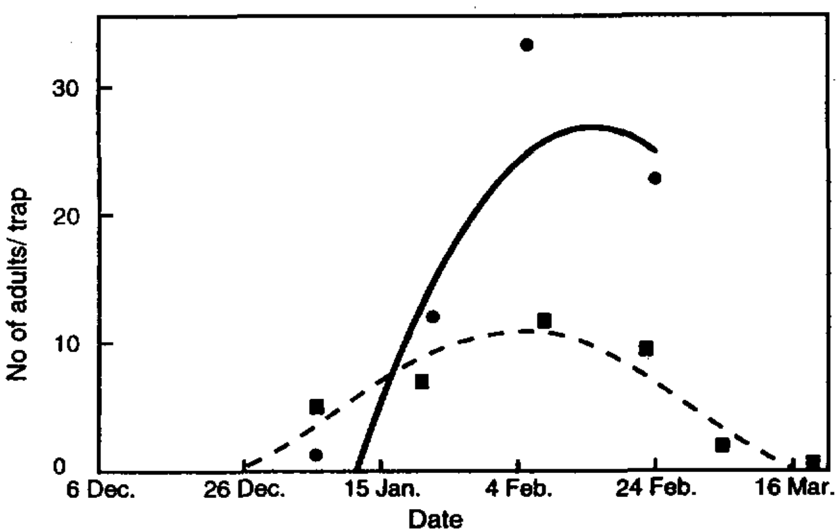


Fig. 2. Pheromone trap catch of adults of *Helicoverpa armigera* at Wad Hamid (Bushara 1990a).

Chickpea

A survey of the insect pests of chickpea carried out in the 1989/90 season in the River Nile State indicated that *S. exigua* infestation was higher at Wad Hamid (58.5–82.4%) than at Rubatab (20%) (Bushara 1990b). On the other hand, the incidence and build-up of the pod borer were higher in Wad Hamid compared to Rubatab and Shendi areas (Fig. 3). In Shendi, both the percent infested plants and percent damaged pods were very low (Figs. 3 and 4). The highest percent of infested plants at the three locations was recorded around mid-February. This coincided with the peak of the pod borer population recorded by the pheromone-trap catch (Fig. 2). Mole cricket, unidentified *Coleoptera* spp., *Spodoptera exigua* and *Helicoverpa armigera* were reported on chickpea in Hawata area (Babiker *et al.* 1994).

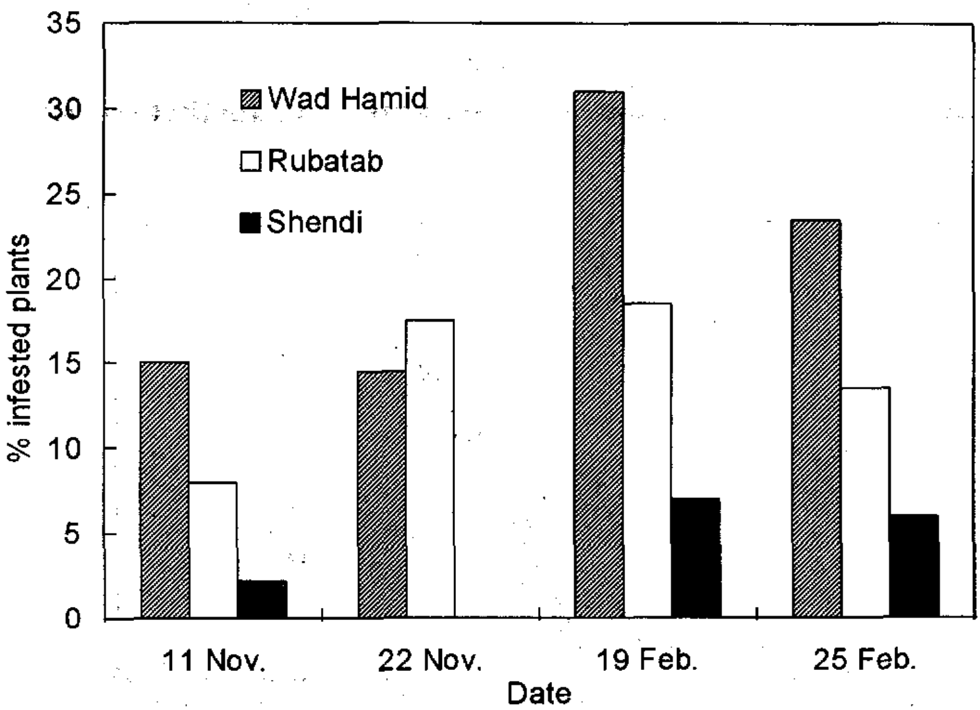


Fig. 3. Percent chickpea plants infested by *Helicoverpa armigera* (Bushara 1991).

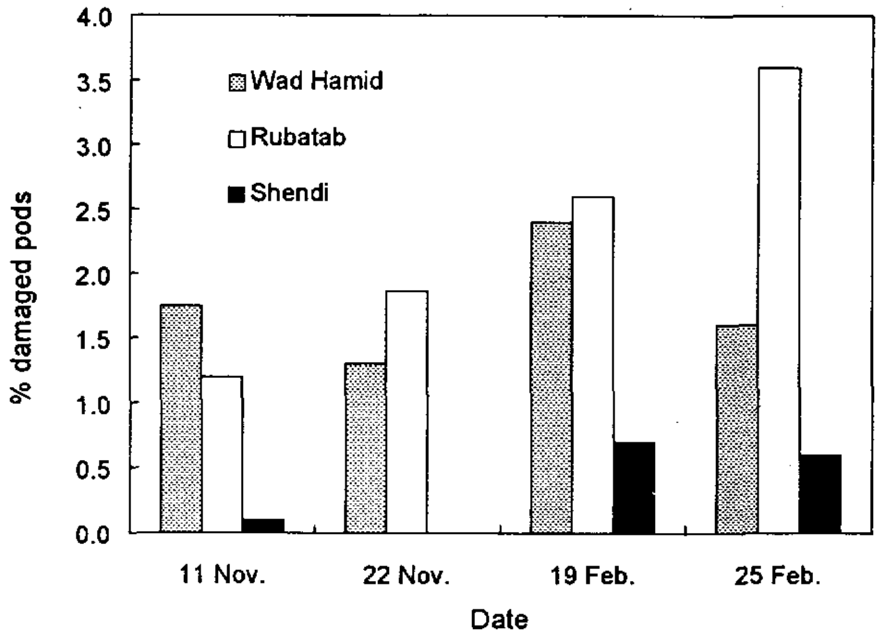


Fig. 4. Percent chickpea pods damaged by *Helicoverpa armigera* (Bushara 1991).

Lentil

Surveys of insect pests on lentil revealed that this crop is less affected than other cool-season legumes, as very low numbers of insect pests were recorded on it (Nourai *et al.* 1989a; Bushara 1990c; Mohamed 1993). However, in the 1984/85 and 1993/94 seasons, *S. exigua* reached damaging levels necessitating spraying with insecticides (Nourai *et al.* 1985, 1994). Besides the other insects reported on legume crops, loopers (*Tricoplusia* sp.) and the apion fly (*Apion* sp.) were also reported on lentil (Nourai *et al.* 1989b). Among vertebrate pests, birds were reported to cause enormous crop losses at Rubatab (Nourai *et al.* 1989a).

Pest Management

Faba Bean

Chemical control of leaf miner

A number of chemicals were evaluated for the control of leaf miner in faba bean in central Sudan. The economic threshold level for spraying against leaf miner was found to be 25% infested leaflets (Sharaf Eldin 1989). Among the insecticides tested, Evisect, Hostathion, Sumithion, and Danitol-S showed good control of the leaf miner. The two rates of application of the insecticides were tested in the 1994/95 season. Both rates gave equivalent control of the pest (Table 1). Sumithion gave comparable performance at the higher rate to that of Danitol-S, which is the only recommended chemical for the control of the leaf miner and was included as a standard check. Low residue levels were detected in treatment with Danitol-S (Zorgani *et al.* 1989). Gaucho and Furadan, as soil-applied insecticides, were also tested for the control of leaf miner and for their selectivity to the natural enemies, but their activity against insect pests was found to be poor. On the other hand, *neem* extracts and Evisect were reported to be softer for the parasites of the leaf miner as they permitted relatively high percentages of parasitism (Sharaf Eldin 1992), but *neem* extracts showed moderate activity against the pest.

Table 1. Chemical control of leaf miner on faba bean.

Treatment	Rate per hectare	% infested leaflets	Yield† (t/ha)
Evisect 50 W.P.	1440.0 g	35.78	1.14 ab
Evisect 50 W.P.	960.0 g	36.96	0.98 bc
Hostathion 50 E.C.	2.4 L	36.00	1.13 ab
Hostathion 50 E.C.	1.2 L	36.61	0.99 bc
Sumithion 50 E.C.	2.4 L	36.00	1.07 b
Sumithion 50 E.C.	1.2 L	34.34	1.01 bc
Danitol-S 50 E.C.	2.4 L	33.24	1.40 a
Control		39.71	0.75 c

† Numbers followed by the same letter(s) were not significantly different.
Source: Sharaf Eldin (1995).

Chemical control of aphids

The efficacy of the soil-applied insecticides Gaucho, Confidor and Furadan could not be proved due to the very low aphid infestation (Sharaf Eldin 1995; Mohamed 1995). These chemicals are expected to be less harmful to the beneficial fauna than the foliar-applied insecticides, and could be useful in IPM programs if found effective. Therefore, further testing of these chemicals is needed.

Cultural control of the leaf miner

Testing the effect of different sowing dates on the population density of the leaf miner revealed that the density decreased with the delay in sowing (Table 2). Therefore, the late-sown crop needed no spraying of insecticide. However, early sowings (15–20 November) were reported to give higher yields (Sharaf Eldin 1995) compared to late sowings and, therefore, alternative control measures of the leaf miner would be needed to get full benefit from early sowing. Infestation levels decreased with increasing plant population (double row planting, Table 2).

Screening for resistance to the leaf miner and aphids

Host-plant resistance is an important component in developing IPM programs. The use of resistant varieties resulted in reducing or eliminating the need for insecticide application and would consequently result in decreased production cost and environmental pollution. Some faba bean genotypes were reported to be resistant to the leaf miner. However, these lines when further tested proved to be susceptible. The breakdown of resistance was attributed to the change in the environmental conditions which might affect the plant resistance to the insect pest (Sharaf Eldin 1992). Recent studies, however, indicated that the lines 00385, E26/2 and SM-L showed some resistance to the leaf miner (Sharaf Eldin 1995). On the other hand, resistance to aphids was also recorded on some faba bean genotypes at Shambat (Salih *et al.* 1992) and at Hudeiba (line Pakistani).

Chickpea

Chemical control of the pod borer

Bushara (1991) reported that Larvin and Baythroid were the best chemicals for controlling the pod borer. Sevin was also found to be effective in reducing pod damage (Mohamed 1993).

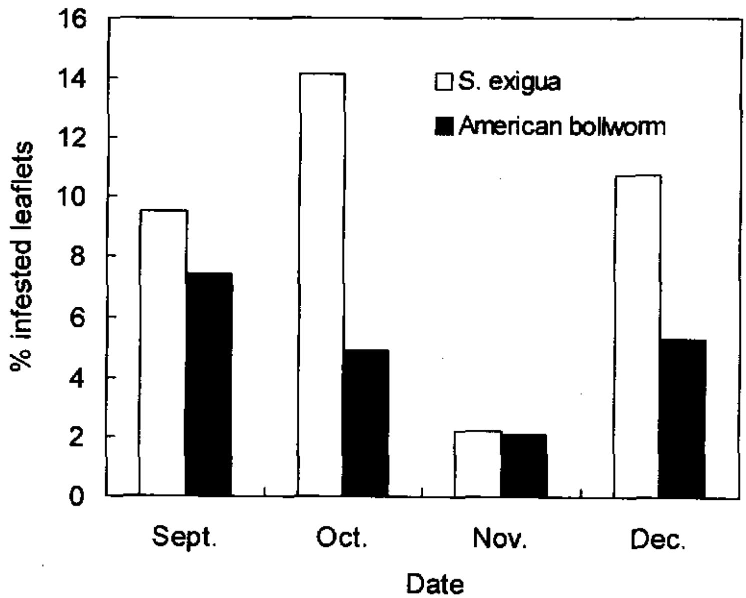
Cultural control of the army worm and pod borer

Low incidences of both the army worm (*S. exigua)* and the American bollworm *(H. armigera*) were reported in Hawata area when the crop was sown in November (Figs. 5a and 5b).

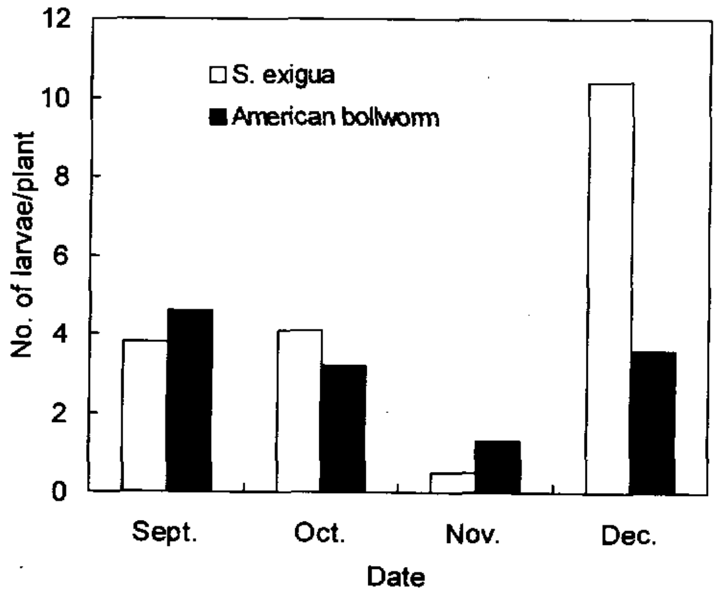
Table 2. Effect of sowing date and plant population on leaf miner incidence and grain yield of faba bean at Gezira Research Station.

Date	1992				1993				1994			
	% infest.		Yield (kg/ha)		% infest.		Yield (kg/ha)		% infest.		Yield(kg/ha)	
	S†	D†	S	D	S	D	S	D	S	D	YS	YD
1 Nov.	36.0	34.6	1678	1820	19.4	18.3	409	509	41.9	40.0	95	160
10 Nov.	32.8	31.6	1328	1394	18.9	17.4	453	584	41.2	40.1	158	175
20 Nov.	30.1	29.2	1490	1668	17.0	15.6	307	287	37.2	39.9	336	366
30 Nov.	28.0	27.6	1449	1506	15.5	14.6	212	339	40.4	38.3	175	330
SE (±)			83.3					NR‡			NR	

† S = Single row planting; D = Double row planting.
‡ NR = Not reported.
Source: Sharaf Eldin (1992, 1993, 1994).



(a)



(b)

Fig. 5. Effect of sowing date on seasonal abundance of *S. exigua* and American bollworm on chickpea in Hawata area: (a) % infestation; (b) number of larvae/plant (Babiker and Kannan 1994).

Storage Insect Pests

The most serious insect pest of stored legumes in the Sudan is the small broad bean beetle (*Bruchidius incarnatus*). Chickpea is also attacked by the Khapra beetle (*Trogoderma granarium*). A survey of store pests of chickpea in the River Nile State indicated that the infestation with *B. incarnatus* varied from 0–96.5% in Rubatab area and from 8–70.5% in Shendi area (Bushara 1990b). On the other hand, *T. granarium* was not encountered in farmer stores in both areas (Bushara 1990b).

Testing two chickpea cultivars, 'Baladi' and 'Shendi-1', for their resistance to the two insect pests showed that there was no difference in the infestation rate of the two cultivars by either pest (Bushara 1990b).

Control of store insect pests

Phostoxin at the rate of 10 tablets/t was recommended for the control of store pests. A package consisting of spraying the store with insecticides, keeping the product in a well-built store with completely sealed doors and windows, and using proper hygiene together with applying fumigants at recommended dosage rates was extended to the farmers in the Northern State. An acceptability study of the new recommended storage practices showed 100% level of adoption (Saeed and Bushara 1989). The recommendation has been highly profitable to farmers as it allows them to retain their produce in store and sell it when prices are higher.

Suggestions for Future Research

- Research on host-plant resistance to the major insect pests of legumes should be carried out by a multidisciplinary team consisting of entomologists, breeders and biochemists.
- Reliable resistance screening techniques should be developed so that resistant genotypes could be identified.
- Research on bioagents should be strengthened.
- Research on different types of *neem* seed extracts should continue.
- Indigenous beneficial fauna should be conserved and augmented.
- The economic threshold level of the major insect pests should be determined.
- Studies on cultural practices, such as intercropping and growing trap crops, should be initiated to test their effect in controlling pests.
- Study of pheromones and alleochemicals should be strengthened.

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A Review of Wilt and Root-Rot Diseases of Food Legumes

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Abstract

Wilt and root-rots are the most important diseases of food legumes in the Sudan. A brief review on disease etiology, pathogen variability, cultural and chemical control measures, and resistance screening against these diseases is presented. Several fungi have been reported to be associated with diseased plants suggesting that wilt and root-rots are of complex etiology. Among these, *Fusarium oxysporum*, *F. solani*, *Rhizoctonia bataticola* and *R. solani* are the most important ones. There is evidence of races or pathotypes in the Sudan among populations of *F. oxysporum* f. sp. *ciceri*, the chickpea wilt pathogen. The role of crop management practices in reducing disease incidence is discussed. The seed-dressing fungicides, Tecto-TM and Quinolate, greatly improve the crop stand of chickpea at emergence. However, they are ineffective in protecting chickpea from wilt/root-rots. Resistance screening work against chickpea wilt/root-rots have culminated in the identification of a few resistant genotypes.

Introduction

Wilt/root-rots are the most important diseases of cool-season food legumes (faba bean, chickpea and lentil) in the Sudan, especially in areas where farmers do not adhere to crop rotations. They are particularly damaging in early-sown crops where they adversely affect crop stand and, hence, crop productivity (Hussein 1982). High temperature has been considered the most important predisposing factor for development of wilt/root-rot disease complex in faba bean (Salt 1982; Saeed *et al.* 1989). This review attempts to summarize the work conducted in the Sudan on wilt/root-rot diseases of cool-season food legumes.

Causal Organisms

Faba Bean Wilt/Root-Rots

Several fungal pathogens have been reported to be associated with diseased plants. *Fusarium solani* f. sp. *fabae* (Ibrahim and Hussein 1974) and *F. oxysporum* (Ibrahim and Owen 1981) were reported as causal agents of root-rot diseases. *F. moniliforme* var. *intermedium, F. acuminatum, Pythium* sp., *Rhizoctonia solani* and *Macrophomina phaseolina* were also reported to be associated with wilt/root-rot diseases of faba bean (Saeed *et al.* 1989; Ali 1991).

Chickpea Wilt/Root-Rots

Freigoun (1980b) reported *Fusarium oxysporum* as the causal agent of wilt, and *F. solani* and *R. bataticola* as root-rot pathogens of chickpea. In addition, *R. solani* was considered the causal agent of the wet root-rot disease in chickpea (Ali 1991).

Lentil Wilt/Root-Rots

From the limited number of isolations carried out so far, *Fusarium oxysporum* and *Rhizoctonia solani* were reported as the causal agents of wilt and wet root-rot, respectively (Nourai *et al.* 1993).

Pathogen Variability

Variability among populations of *F. oxysporum* f. sp. *ciceri*—the chickpea wilt pathogen—was studied in the 1994/95 season at Hudeiba Research Station in the screen-house. Based on the reactions of the ten differential chickpea cultivars to the six isolates of *F. oxysporum* f. sp. *ciceri* obtained from Hudeiba Research Farm (HRF-1, HRF-2, HRF-3 and HRF-4), Wad Hamid (WH) and Rubatab (Rub), the six isolates were grouped into three races (pathotypes), tentatively designated 7, 8 and 9 (Table 1). These races are distinct from races 1, 2, 3 and 4 identified in India (Haware and Nene 1982), races 0 and 5 in Spain (Cabrera de la Colina *et al.* 1985) and race 6 in California (Phillips 1988). These findings suggest that chickpea cultivars should be thoroughly screened against all possible races in the country before being released for commercial production.

Table 1. Reaction of differential genotypes of chickpea to six isolates of *Fusarium oxysporum* f. sp. *ciceri* from the Sudan.

Genotype	Reaction to isolate†					
	Race 7			Race 8		Race 9
	HRF-1	WH	Rub	HRF-3	HRF-4	HRF-2
JG - 62	S	S	S	M	M	M
C - 104	M-S	S	M-S	R	R	R
JG - 74	M	M	M	R	R	R
CPS - 1	M	M	M	R	R	M
BG 212	M	M	M	R	R	M
WR - 315	M-S	S	M-S	R	R	R
Annigeri	M-S	S	S	R	R	M
Chaffa	M-S	S	S	M	M	R
L-550	S	S	S	R	R	M
850-3/27	S	S	M-S	M	M	R

† R = Resistant (0–20% mortality); M = Moderately susceptible (21–50% mortality); S = Susceptible (> 50% mortality).
Source: Ali (1994, 1995).

Control Measures

Several strategies for the control of wilt/root-rot diseases of food legumes have been advocated. These include: cultural control, chemical control and host resistance.

Cultural Control

Faba bean wilt/root-rots

Most of the work that has been done in faba bean was directed towards crop management practices that decrease the soil temperature and, hence, reduce disease incidence. In accordance with this, several experiments were conducted to study the effects of sowing date, irrigation interval, plant population, mulching, ridge direction and plant orientation, and intercropping on the incidence of wilt/root-rot diseases.

Several studies have shown that delaying the sowing date of faba bean to late October or early November remarkably reduced disease incidence (Tables 2, 3, 4, 5 and 6). The reduction in disease incidence correlated well with the decrease in temperature (Hussein *et al.* 1982).

Table 2. Effect of sowing date and irrigation interval on incidence (% infection) of wilt/root-rot diseases of faba bean.

Sowing date	Irrigation interval/% disease infection		
	1 week	2 weeks	3 weeks
3 October	39.5	46.4	53.0
13 October	31.4	37.7	46.3
23 October	26.8	38.0	41.0
2 November	25.7	26.5	34.0
12 November	17.6	20.2	24.8
22 November	12.5	19.5	18.7
2 December	7.0	12.3	10.6
12 December	9.7	10.0	10.5
SE (±)		3.1	

Source: Freigoun (1980a).

Table 3. Effect of sowing date, mulching and irrigation interval on incidence of wilt/root-rot diseases of faba bean at Wad Medani.

Treatment	Mean dead plants (%)†
Sowing date	
10 October	22.2
20 October	14.6
30 October	11.1
SE (±)	1.0
Mulching	
Mulch	12.5
No mulch	19.5
SE (±)	0.9
Irrigation interval (days)	
7	28.1
14	37.6
SE (±)	0.9

† Mean percentage dead plants transformed into degrees.
Source: Hussein *et al.* (1982).

Table 4. Effect of the duration of shading, sowing date, and plant population on incidence of faba bean wilt/root-rot disease complex at Shambat.

Treatment	Mean dead plants (%)†
Shading treatment (duration)	
Short	1.97
Long	1.48
Unsheltered	2.34
SE (±)	0.29^{NS}
Sowing date	
13 October	2.44
4 November	1.44
SE (±)	0.23
Plant density (plants/m^2)	
16.6	2.46
49.9	1.41
SE (±)	0.23

† Mean percentage dead plants transformed into degrees.
NS = Not significant.
Source: Salih and Ageeb (1987).

Frequent irrigation (7-day intervals) has been reported to reduce the incidence of wilt/root-rot diseases (Tables 2, 3 and 5). Salih and Ageeb (1987) reported that the incidence of wilt/root-rot diseases was significantly higher in the low compared to the high plant population (Table 4). Mulching has been reported by Hussein *et al.* (1982) to reduce the incidence of wilt/root-rot diseases (Table 3). Experiments on ridge direction and plant orientation have indicated that faba bean plants growing on the eastern side of north-south ridges are more affected by wilt/root-rot diseases (Hussein 1983).

The effect of intercropping on disease incidence in Wad Medani and Shambat (Table 5) was contradictory (Ageeb *et al.* 1989). The faba bean pure stand at Shambat had the highest disease incidence, whereas at Wad Medani it showed the lowest incidence.

Table 5. Effect of sowing date, irrigation interval and intercropping with sorghum and maize on wilt/root-rot disease complex of faba bean at Shambat and Wad Medani.

Treatment	Mean dead plants (%)†	
	Shambat	Wad Medani
Sowing date		
10 October	8.65	19.33
7 November	3.87	7.18
SE (±)	0.45	0.88
Irrigation interval (days)		
7	5.18	12.83
14	7.34	13.68
SE (±)	0.45	0.88^{NS}
Intercropping		
Sorghum	6.46	15.2
Maize	3.87	13.57
Pure stand	8.44	10.82
SE (±)	0.59	0.99

† Mean percentage dead plants transformed into degrees.
NS = Not significant.
Source: Ageeb *et al.* (1989).

Chickpea wilt/root-rots

Little work has been done on the effects of crop management practices on the incidence of wilt/root-rots of chickpea. Taha and Ali (1991) reported that the incidence of wilt/root-rots at Hudeiba was significantly higher in flat planting as compared to ridge planting, whereas at Rubatab the difference between the two sowing methods was not significant (Table 7). At both locations, the highest disease incidence was observed on the chickpea crop in which the irrigation water was stopped 50 days after sowing.

Lentil wilt/root-rots

Delaying the sowing date of lentil from October to November has been reported by Nourai *et al.* (1992) to reduce the incidence of wilt/root-rots (Table 8). However, the effects of seed rate, sowing method and irrigation interval on disease incidence were either inconsistent or not significant (Taha *et al.* 1985; Nourai *et al.* 1992).

Table 6. Effect of sowing date on the incidence of wilt/root-rots of faba bean.

Sowing date	Wilt/root-rot incidence (%)†	
	1992/93	1993/94
17 September	84.54	77.3
29 September	79.03	65.0
13 October	9.67	13.9
20 October	5.54	NT
27 October	3.06	4.1
3 November	1.64	1.4
10 November	0.33	0.1
17 November	0.97	0.1
24 November	0.04	0.1
1 December	0.03	NT
8 December	0.03	0.1
15 December	0.03	NT
22 December	0.03	0.1
5 January	0.04	0.1
19 January	0.03	0.1
2 February	0.03	NT
SE (±)	1.021***	0.8***

† Percentage values transformed to arc sine.
NT = Not tested.
*** = Significant at the 0.1% level.
Source: Ibrahim and Ali (1993, 1994).

Table 7. Effect of sowing method and date of terminal irrigation on wilt/root-rots of chickpea at Hudeiba and Rubatab, 1990/91.

Treatment	Mortality (%)†	
	Hudeiba	Rubatab
Sowing Method		
Ridge planting	4.8	2.09
Flat planting	6.51	1.86
SE (±)	0.24**	0.07[NS]
Days to terminal irrigation		
Till maturity	5.05	1.69
90	5.51	1.77
70	5.52	1.77
50	6.08	2.73
SE (±)	0.14*	0.08***

† Percentage values transformed to square root of (x+1).
*, **, *** = Significant at the 5%, 1% and 0.1% levels, respectively.
NS = Not significant.
Source: Taha and Ali (1991).

Chemical Control through Seed Treatment

Faba bean wilt/root-rots

The seed-dressing fungicides, Benlate, Topsin and Udonkor, were found to be ineffective in controlling wilt/root-rot diseases in faba bean (Freigoun 1978).

Chickpea wilt/root-rots

The seed-dressing fungicides, Raxil, Baytan, Monceren Combi and Captan, were ineffective in improving crop stand or in controlling the disease (Ali 1992). Ali (1994) reported that the crop stand at emergence was almost doubled when the chickpea seeds were dressed with the fungicides Quinolate or Tecto-TM (Table 9). However, none of these fungicides was effective in protecting chickpea plants from wilt/root-rots. In an on-farm verification trial at Wad Hamid, Hussein and Mohamed (1994) clearly demonstrated the effectiveness of the seed-dressing fungicide, Tecto-TM, in improving crop stand.

Table 8. Effect of sowing date and cultivar on the incidence of wilt/root-rots of lentil at Hudeiba and Rubatab.

Treatment	Wilt/root-rot incidence (%)†	
	Hudeiba	Rubatab
Sowing date		
15 October	39.0	29.5
29 October	27.2	22.3
12 November	16.8	15.0
26 November	14.6	14.7
12 December	17.6	14.7
SE (±)	1.1***	1.5***
Cultivar		
Selaim	23.3	19.4
Rubatab-1	23.7	19.5
ILL 60074	22.0	18.9
SE (±)	1.0[NS]	0.7[NS]

† Percentage values transformed to arc sine.
*** = Significant at the 0.1% level; NS = Not significant.
Source: Nourai *et al.* (1994).

Lentil wilt/root-rots
So far, no work has been done on the effect of seed-dressing fungicides on wilt/root-rot diseases of lentil.

Host Resistance

Sowing of resistant cultivars is probably the most practical, economical, and effective method to control wilt/root-rots. A major prerequisite for the identification of sources of resistance is the development of a reliable and effective screening methodology.

Faba bean
Earlier resistance screening work against wilt/root-rot diseases was done under natural conditions of infection in the field. No conclusive results have been achieved, largely because the inoculum level was low at that particular spot of the field or the temperature was not high enough to predispose the plants to infection as is the case in cooler seasons (Hussein 1985).

Table 9. Effect of fungicidal seed treatment on crop stand and incidence of wilt/root-rots of chickpea.

Seed treatment	Fungicide dosage rate (g/kg)	Plants/m² at emergence	Mortality (%)†
Control	—	15	9.9
Benlate	2	12	10.0
Benlate	3	13	9.9
Benlate	4	13	9.9
Quinolate	2	26	10.0
Quinolate	3	27	9.9
Quinolate	4	27	9.8
Tecto-TM	2	26	9.9
Tecto-TM	3	24	9.9
Tecto-TM	4	27	9.9
SE (±)		0.8***	NS

† *Percentage values transformed to square root of* (x+1).
*** = Significant at the 0.1% level.
NS = *Not significant.*
Source: Ali (1994).

Recently a sick-plot was developed at Shambat Research Farm for screening faba bean germplasm for resistance to wilt/root-rot diseases. In the 1989/90 season, four faba bean selections (00634, 325/127/80, 00340 and 00305) were reported free of the disease (Salih *et al.* 1990). In the 1990/91 season, seven selections (S-O-27, A-O-66, A-O-86, 00605, Hagar El Asal No. 26, 00198 and Hagar El Asal No. 19) were reported disease-free (Salih *et al.* 1991). In the 1991/92 season, only two faba bean selections (00605 and line 8/6, a selection from Selaim) were disease-free (Salih *et al.* 1992). In the 1993/94 season, nine lines (E. 26/2, E. 61/2, E. 86/2, E. 86/4, 00104/15, T 6/2, Sy/4, Sy/10/1 and H. 12/1) were disease-free (Salih *et al.* 1994). Of all these disease-free lines, the faba bean selection 00605 was the only entry to be reported disease-free in two seasons. Therefore, the reaction of the other lines needs further confirmation.

Chickpea

Resistance screening work was initiated in the 1988/89 season. Over the past seven years more than 330 chickpea genotypes were evaluated for resistance to wilt/root-rots in the sick-plot at Hudeiba Research Farm. Results of the screening work have clearly indicated the susceptibility of the released cvs. Shendi-1 (NEC 2491) and Jebel Marra-1 (ILC 915) and the local cv. Beladi to wilt/root-rot diseases (Ali 1994). So far, the resistance of nine chickpea genotypes (Table 10) has been confirmed for more than two seasons of testing. The other resistant genotypes identified in the 1994/95 season will be retested in the coming season for confirmation of resistance.

Table 10. Chickpea genotypes resistant to wilt/root-rots in the Sudan.

Chickpea line	Type	Source
ICCV-2	Kabuli	CIFWN-ICARDA
Flip 85-20C	Desi	CIFWN-ICARDA
Flip 85-29C	Desi	CIFWN-ICARDA
Flip 85-30C	Desi	CIFWN-ICARDA
UC 15	Kabuli	CIFWN-ICARDA
ICCX 850498-3P-BPN-5H	Kabuli	ICRRWN-ICRISAT
ICCX 850496-BP-7H-BH	Kabuli	ICRRWN-ICRISAT
X†	Kabuli	ICRISAT
ICCL-82001	Kabuli	ICRISAT

† Chickpea line with unknown pedigree.

Lentil

So far, no work has been done on resistance screening against wilt/root-rot diseases of lentil. This is mainly because a sick-plot has not yet been developed.

Integrated Management of Wilt/Root-Rots of Chickpea

The performance of the resistant genotype, ICCV-2, and the seed-dressing fungicide, Tecto-TM, was verified in the 1994/95 season in four farmers' fields in Wad Hamid Basin. Results showed that the farmer cultivar was severely affected by wilt/root-rots as compared to the resistant one, ICCV-2 (Table 11). Furthermore, the seed yield of ICCV-2 was almost twice that of the farmer cultivar. Although seed treatment improved crop stand, the differences in crop stand between treated and untreated plots were not significant at the 5% level.

Table 11. Effect of genotype and seed treatment on crop stand, wilt/root-rots incidence and yield of chickpea at Wad Hamid, 1994/95.

Treatment	Plants/m^2 at emergence	Mortality (%)†	Seed yield (kg/ha)
Genotype			
Farmer cultivar	20.0	47.6	560.0
ICCV-2	16.0	0.6	1092.0
SE (±)	2.1^{NS}	4.7***	59.1***
Seed treatment			
Tecto-TM	21.0	25.1	891.0
Untreated control	16.0	23.2	762.0
SE (±)	2.1^{NS}	4.7^{NS}	59.1^{NS}

† Percentage values transformed to arc sine.
*** = Significant at the 0.1% level.
NS = Not significant.
Source: Ali *et al.* (1995).

Recommendations for Future Research

- There is an urgent need for systematic disease surveys in the production areas of the three crops to quantify the economic importance of wilt/root-rot diseases and to determine the relative importance of the causal organisms.
- The work on crop management practices that reduce yield losses due to these diseases should continue and be further emphasized.
- Development of effective and reliable screening techniques for identifying resistant germplasm is necessary. This could be achieved through development of uniformly infested sick-plots. There is an urgent need now for the development of a sick-plot for wilt/root-rots of lentil.
- There is a need to continue work on the variability of the chickpea wilt pathogen by testing a large number of isolates from different geographical areas.
- The chickpea germplasm should be thoroughly screened against all possible races of the chickpea wilt pathogen in the country.
- Emphasis should be given to the identification of reliable sources of resistance to major causal organisms causing wilt/root-rots in faba bean.

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Discussion

Q: M.C. Saxena

How would you explain the presence of three races of *Fusarium* wilt in chickpea in Hudeiba itself? Have you tested the reaction of the 'resistant lines' that you presented in your paper to all these three races?

A: Mohamed E.K. Ali

This could be explained by the fact that the isolates collected from the sick-plot at Hudeiba Research Farm were originally obtained from the chickpea production areas of Wad Hamid and Rubatab and then incorporated in the sick-plot a few years back. The resistant lines were not yet tested against all the three races. However, there is a plan to do that in pots in the screenhouse in the coming season.

Comment: M.B. Solh

Apparently the experiments on the effect of cultural practices on wilt/root-rots were done in fields where the disease incidence was not high, thus, the results of comparing treatments with disease incidence will be misleading and, hence, we cannot draw conclusions.

A: Mohamed E.K. Ali

Your comment is very well taken.

Q: Abdelaziz I. Sidahmed

Do you think that a resistant cultivar would solve the problem of diseases, and is it rather applicable in the case of Wad Hamid area where the resources are limited?

A: Mohamed E.K. Ali

Of course a resistant chickpea cultivar would be the best solution for the wilt/root-rot problem in Wad Hamid basin where the nature of the farming system will not permit manipulation of crop management practices that alleviate the disease problem.

Survey and Monitoring of Faba Bean Virus Diseases

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Abstract

Many viruses are reported worldwide to affect faba bean. Only a few of them have been reported so far on faba bean in the Sudan. Among these, Bean Yellow Mosaic Virus (BYMV), Bean Leaf Roll Virus (BLRV), Broad Bean Mottle Virus (BBMV) and, to a lesser extent, Broad Bean Stain Virus (BBSV) are the most prevalent. Previous studies indicated that virus diseases, particularly the mosaic group, usually appear late in the season, coinciding with the onset of cooler weather and the build-up of insect vector populations. Of these, BYMV seemed to be the most prevalent (about 80%). Mixed infections also occur naturally, leading to substantial yield losses. The yellows group on the other hand, represented by BLRV, usually occurs early in the season. Yield losses due to this group could be heavy in view of the severe symptoms they induce ranging from yellowing to stunting, to necrosis and ultimate collapse of the whole plant. In recent years and due to the excellent facilities provided by the Nile Valley Regional Program in terms of mobility and other logistics, extensive surveying and monitoring of these viruses were carried out in the research farms and production centres all over the country. This generated a good deal of information and knowledge about faba bean and other legume viruses and identified priorities for future work.

Introduction

Some 44 viruses are reported worldwide to affect faba bean (Makkouk *et al.* 1988); only ten of them have been reported so far on faba bean in the Sudan. Among these, Bean Yellow Mosaic Virus (BYMV), Bean Leaf Roll Virus (BLRV), Broad Bean Mottle Virus (BBMV) and, to a lesser extent, Broad Bean Stain Virus (BBSV) are the most prevalent.

Previous surveys by the author indicated that virus diseases, particularly the mosaic group, usually appear late in the season, coinciding with the onset of cooler weather and the build-up of insect vector populations. Of those, BYMV seems to be the most prevalent (about 80%). Mixed infections could also occur naturally, leading to substantial yield losses. The yellows group, on the other hand, usually occurs fairly early in the season.

This paper describes monitoring of virus diseases in certain breeding trials as well as in germplasm screening nurseries conducted at Shambat Research Farm. It also describes surveys carried out in the production areas to assess the situation of virus diseases in faba bean all over the country.

Work Conducted at Shambat Research Station

Monitoring of Virus Diseases

Monitoring of virus diseases has been conducted in certain breeding trials where a number of breeding lines from local and exotic origins were tested together with two local checks for their yield and yield components. In all the trials considered, 4-5 disease counts were carried out at regular intervals throughout the season.

In 1992/93, a total of 55 entries were monitored for leaf roll disease infection. Although the level of infection was very low (Table 1), all of them were susceptible to varying degrees. The incidence was higher in earlier sowing dates. Infection by leaf roll disease was observed to predispose the plants to infection by wilt/root-rot diseases. Highly susceptible plants to leaf roll were often readily attacked by wilt/root-rot diseases.

Table 1. Mean average incidence of leaf roll disease as recorded in certain breeding trials at Shambat Research Farm, 1992/93.

Type of trial	Sowing date	No. of entries tested	Mean average incidence (%)
Preliminary yield trial No. 1	10 Nov. 1992	18	0.98
Preliminary yield trial No. 2	8 Nov. 1992	14	0.70
Advanced yield trial	3 Nov. 1992	16	1.50
National verification trial	2 Nov. 1992	7	1.60

In 1993/94, a total of 66 breeding lines were monitored for natural infection by three diseases: leaf roll, mosaic and phyllody. The latter, which is caused by a mycoplasma-like organism, had often been mistaken for a virus disease. Although the level of infection was again very low (Table 2), very few of the entries were free from leaf roll or phyllody diseases. The incidence of mosaic disease was nil.

Table 2. Mean average incidence of leaf roll, mosaic and phyllody diseases as recorded in certain breeding trials at Shambat Research Farm, 1993/94.

Type of trial	Sowing date	No. of entries	Mean average incidence (%) of		
			leaf roll	phyllody	mosaic
Preliminary yield trial No. 1	31 Oct.	18	0.4	0.3	0.01
Preliminary yield trial No. 2	3 Oct.	18	0.7	0.6	0.01
Advanced yield trial	17 Nov.	15	0.1	0.3	0.03
National verification trial	11 Nov.	7	0.2	0.7	0
National verification trial	8 Nov.	8	0.3	0.1	0

Screening Nurseries

Faba bean leaf roll disease screening nursery

In 1992/93, 90 different selections and breeding lines from progenies of certain crosses and from new introductions were grown in single rows repeatedly intercepted by rows of three local checks in an augmented design with six blocks. Single seeds per hole were sown in the centre of 6 m long rows at 10 cm between holes to give a calculated stand of 60 plants per row (or per entry). The nursery was sown on 1 November and watered at intervals of 10–14 days. Data was collected on plant stand and number of infected plants, which was recorded at regular intervals throughout the season.

Both types of symptoms, the transient and persistent symptoms, were observed and counted as leaf roll disease. The overall incidence ranged between zero and 17%. Twenty-eight entries were free from infection, 30 entries scored less than

5%, 23 between 5 and 10% and nine entries scored more than 10%. The three checks were all susceptible. All the nine entries which scored above 10% incidence similarly scored high incidences of wilt/root-rot diseases.

Faba bean mosaic disease screening nursery

The same nursery described above was planted with the same specifications at a later date (30 November) to screen for mosaic disease, which, unlike the leaf roll disease, occurs fairly late in the season. The disease symptoms appeared with the onset of cooler temperatures and the spread was highest between 1 to 10 February coinciding with a marked drop in temperature. The symptoms observed were almost exclusively mosaic. The overall incidence ranged between 10 and 73%. All the 90 entries tested, except one (Line 00631), were infected, so were the three checks. Eight entries had less than 5% incidence, 27 between 5 and 10% and 58 entries more than 10% incidence. Out of 44 mosaic-infected samples tested for the common mosaic viruses of faba bean by ELISA, 33 samples were positive for BYMV and 11 were negative.

In the next season (1993/94), 108 entries were included in the mosaic disease screening nursery with the same specifications as mentioned earlier. Sowing date was 28 November (4 weeks later than optimum) to subject the plants to maximum virus attack at a younger physiological age for effective screening. Mosaic symptoms appeared very late in the season and the incidence ranged between zero and 85%. Twenty-nine entries were symptomless, two scored less than 5% incidence, 14 between 5 and 10%, and 66 more than 10%. It is noteworthy that the incidence of leaf roll and phyllody disease was nil.

Identification of Faba Bean Mosaic Viruses from Shambat

Since diagnosis of viruses in the field by noting the symptoms is not often reliable, especially for the mosaic group, infected leaf samples from different plots on the research farm at Shambat were collected and taken to the Agricultural Research Center (ARC) in Giza, Egypt to be tested using the ELISA technique. Identification was done by personnel from ICARDA's Virology Laboratory who were at the ARC in Giza on a Nile Valley Regional Program (NVRP) mission to survey faba bean viruses in Egypt. Out of a total of 90 samples, 75 (83%) were positive for BYMV and the rest were negative for all the common faba bean mosaic viruses tested.

Work Conducted in Production Areas

Justification and Objective

The outbreak of the virus disease epidemic in Egypt in 1991/92 resulted in a total loss of almost half the faba bean acreage. The virus involved was identified later as Faba Bean Necrotic Yellows Virus (FBNYV) which has the same characteristic leaf rolling and yellowing symptoms as BLRV but is far more prevalent than BLRV in faba bean in Egypt.

In the planning session of the NVRP in October 1993, it was decided to conduct systematic surveys for faba bean viruses in the Sudan similar to the one conducted earlier in Egypt, to assess the situation of faba bean viruses in the Sudan and to find out whether FBNYV exists in the Sudan or not.

Methodology

Two major surveys were conducted to cover the faba bean production and experimental areas in the Sudan. Each field visited was evaluated according to a prepared format (Fig. 1). Disease incidence was determined on the basis of visual symptoms and by counting the percentage of infected plants at different spots in each field. Virus symptoms observed were classified for convenience into two major categories: (1) mosaic/mottle, and (2) yellowing/rolling/stunting/ necrosis.

Samples representing these symptom-categories were collected from the top part of infected plants for laboratory testing later. The number of samples collected from each category depended on its frequency in the field. About 15–25 samples were collected from each field, blotted on a nitrocellulose membrane and tested later by the tissue blot immunoassay (TBIA) technique at the Plant Pathology Laboratory at the University of Gezira and the University of Khartoum. Antisera used in the first survey were provided by the Virology Laboratory at ICARDA and the Institute for Biochemistry and Plant Virology, BBA, Braunschweig, Germany. Those used in the second survey were provided by ICARDA's Virology Laboratory.

Sudan Faba Bean Virus Disease Survey, February 1994

Surveyors ____________________

Survey route ________ to ____________

Starting point ________ km ____________

Date ___________ Stop no. __________

Kilometer car reading ______________

Collection No.

Route initials-Yr-Stop no.-Sample no.

_________ -94- _____ - ______

Crop ____________________ Cultivar ______________________

Crop condition ☐ Poor ☐ Average ☐ Excellent

Growth stage ☐ Seedling ☐ Young plant ☐ Early flowering

☐ Pod setting ☐ Mature

Virus Disease Symptoms

Type ☐ Mosaic ☐ Mottling ☐ Yellowing

☐ Stunting ☐ Leaf and stem necrosis ☐ Other

Estimate of disease incidence (%)

____

Severity of symptoms: Lightest (1) to most severe (9)_______________

Comments ____

Aphid Population

☐ High ☐ Low ☐ Absent

General Comments ______________

____

For Laboratory Use

Fig. 1. Form used to collect information from faba bean fields during the survey conducted in the Sudan in February 1994.

First Survey (February 1994)

Field work

A total of 33 faba bean fields were selected to represent the following different production regions: Gezira/Rahad and Khartoum regions (both in the new areas), and Shendi/Berber region (in the traditional areas). The location of the fields visited are shown in Fig. 2 and the number of samples collected are presented in Table 3.

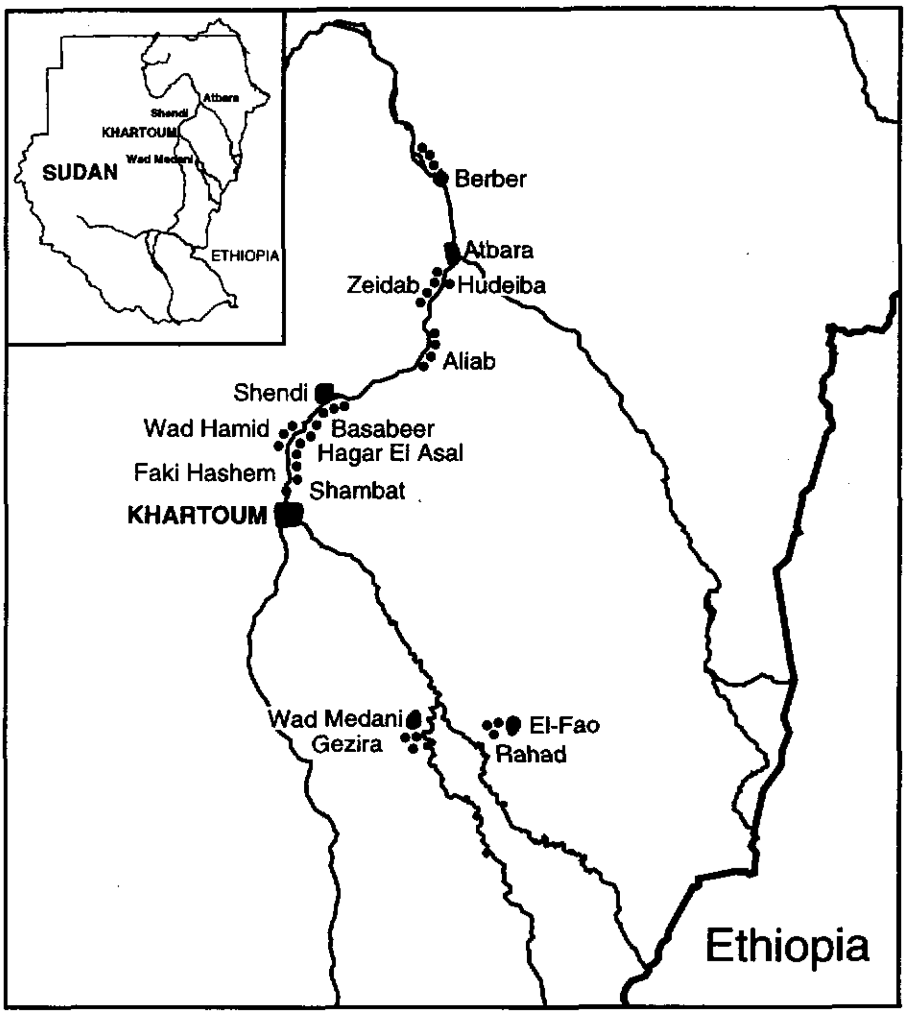

Fig. 2. Map of the Sudan showing the location of faba bean fields surveyed in February 1994.

Table 3. Distribution of faba bean samples collected from three regions in the Sudan on the basis of visible symptoms of virus infection, 1993/94.

Region	No. of fields surveyed	No. of collected samples with symptoms of	
		leaf roll/yellowing	mosaic/mottle
Khartoum	6	145	44
Gezira and Rahad	6	115	30
Traditional areas (north)	21	166	265
Total	33	426	339

Observations showed that 50% of the fields surveyed had, at the time of the survey, a virus disease incidence of 5% or less. As the crop maturity was approaching, it was unlikely that such fields would have any yield reduction due to virus disease infection. The majority of these fields were in the new areas (Table 4).

Table 4. General distribution of faba bean fields surveyed in three regions in the Sudan on the basis of virus disease incidence categories, 1993/94.

Incidence category	Number of fields			
	Khartoum	Gezira and Rahad	Shendi/Berber	Total
0–1 %	3	1	0	4
1–5 %	3	3	7	13
6–20 %	0	2	4	6
21–50 %	0	0	6	6
> 50 %	0	0	4	4
Total	6	6	21	33

In the traditional areas, virus diseases encountered were those that induce mosaic and/or mottle symptoms. About 20% of the fields had a virus disease incidence of 6–20%, about 18% had 21–50% and about 12% had 51–100%. In such fields yield losses due to virus infection were likely and, based upon previous studies, could reach 20%.

Laboratory work

A total of 765 samples were collected from the 33 fields surveyed for laboratory testing. Antisera used were of Faba Bean Necrotic Yellow Virus (FBNYV), Bean Leaf Roll Virus (BLRV), Bean Yellow Mosaic Virus (BYMV), Broad Bean Wilt Virus (BBWV), Broad Bean Mottle Virus (BBMV), Alfalfa Mosaic Virus (AMV), Broad Bean Stain Virus (BBSV), Pea Seed-Borne Mosaic Virus (PSBMV) and Broad Bean True Mosaic Virus (BBTMV).

Results obtained are presented in Table 5. The viruses detected were BYMV (38.7%), BBMV (8.8%), BLRV (0.26%), PSBMV (0.13%) and AMV (0.13%). These results clearly indicated that BYMV was the most frequently encountered virus in infected plants showing mosaic/mottle category of symptoms, followed by BBMV. However, and surprisingly, the majority of the samples showing yellowing and leaf rolling symptoms did not react with FBNYV nor with BLRV antisera. It was also observed that some diseased plants showed leaf yellowing and thickening in the lower part and normal healthy leaves in the upper part indicating latency or, possibly, recovery.

Table 5. Results of laboratory tests conducted on 765 faba bean samples with symptoms suggestive of virus infection collected from different locations in the Sudan, 1993/94.

Region/ location	No. of fields surveyed	Avg. virus disease incidence (%)	No. of samples tested	No. of samples found positive for				
				BYMV	BBMV	AMV	PSBMV	BLRV
Khartoum and new areas								
Shambat	3	4	101	30	0	1	1	0
Faki Hashim	3	1	88	12	1	0	0	0
Gezira	3	5	80	8	0	0	0	0
Rahad	3	5	65	7	2	0	0	0
Northern								
Wad Hamid	2	3	47	3	28	0	0	0
Hagar El Asal	3	3	70	24	16	0	0	0
Basabeer	1	3	16	1	6	0	0	0
Hudeiba	1	100	25	25	0	0	0	0
Zeidab	4	45	81	63	7	0	0	2
Berber	3	6	49	5	6	0	0	0
Aliab	4	55	83	66	0	0	0	0
Shendi	3	18	60	52	1	0	0	0
Total	33		765	296	67	1	1	2

Second Survey (January 1995)

This was carried out, in continuation to the previous survey, in the remaining parts of the faba bean production regions, to have a complete picture of the virus disease situation in faba bean in the Sudan. The regions covered included: Hudeiba, Merawi/Nouri/Gurare, Dongola/Debba, and last but not least, Selaim/Burgaig region, which is by far the largest single production region of faba bean in the Sudan (Fig. 3). All these regions are within the traditional production zone.

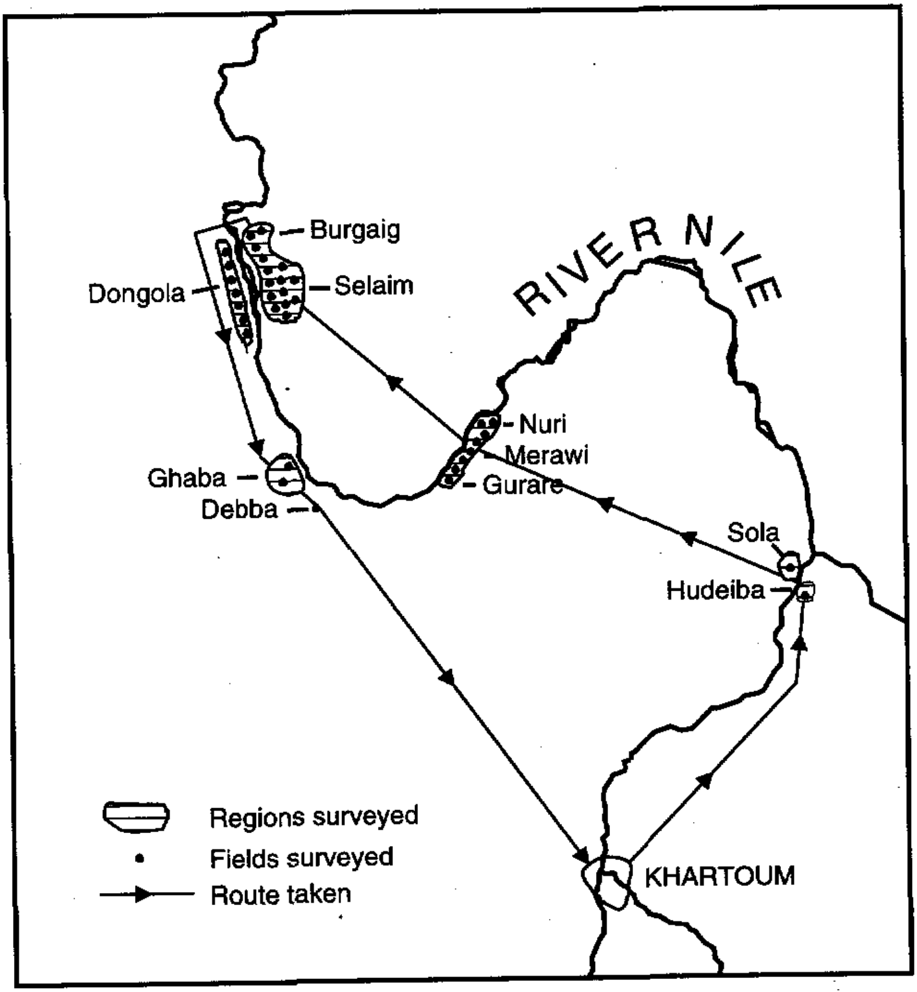

Fig. 3. Map showing the location of faba bean fields in the four regions surveyed in January 1995.

Field work

A total of 35 fields were selected at random to represent the four regions covered. The virus disease incidence in the fields surveyed is summarized in Table 6 for the mosaic/mottle group. About 45% of the fields surveyed had, at the time of the survey, an incidence of 5% or less mosaic/mottle disease symptoms. The majority of these fields were in excellent crop condition and advanced podding stage with the symptoms confined to the top of the infected plants. Thus, any reduction in yield due to further spread of the disease was unlikely, despite high aphid population recorded particularly in Selaim region.

Table 6. Distribution of faba bean fields surveyed in the Sudan on the basis of mosaic/mottle disease incidence, 1994/95.

Incidence category	Number of fields†				
	Hudeiba	M/G	S/B	D/D	Total
0–1%		2	4	3	9
1–5%		3	2	2	7
6–20%	1	1	5	2	9
21–50%	1	2	4	2	9
> 50%		1			1
Total	2	9	15	9	35

† M/G = Merawi/Nouri/Gurare; S/B = Selaim/Burgaig; D/D = Dongola/Debba.

The remaining fields were in poor or average growth conditions and were already suffering badly from weed infestation and other problems. About 26% of these fields had an incidence of 6–20%, another 26% had an incidence of 21–50% and about 3% had more than 50% incidence. Some of these fields showed evidence of primary infection through seed, and the farmers spoke of an aphid attack earlier in the season. In some cases, as in Merawi/Gurare and Dongola/Debba regions, the neighboring alfalfa (*Medicago sativa*) fields were observed to have 100% mosaic/mottle disease symptoms. Considerable yield loss in such fields due to the disease was not unlikely.

The incidence of the yellowing and stunting disease is summarized in Table 7. The disease was observed in all the regions surveyed but was most prevalent in Selaim region. About 57% of the fields surveyed had an incidence of 5% or less, about 14% had 6–20%, about 26% had 21–50% and about 3% had an incidence of more than 50%.

Table 7. Distribution of faba bean fields surveyed in the Sudan on the basis of yellowing and stunting disease incidence, 1994/95.

Incidence category	Number of fields†				
	Hudeiba	M/G	S/B	D/D	Total
0–1%	1	6	3	7	17
1–4%		1	1	1	3
6–20%			5		5
21–50%	1	1	6	1	9
> 50%		1			1
Total	2	9	15	9	35

† M/G = Merawi/Nouri/Gurare; S/B = Selaim/Burgaig; D/D = Dongola/Debba.

Of the 14 fields showing 6–50% incidence, 11 (79%) were in Selaim region. In two of these fields, foci or pockets of severely infected and stunted plants were observed which were strikingly similar to what had been described in the case of FBNYV in Upper Egypt. The crop in both fields was otherwise in an excellent condition and in an advanced podding stage. Severely affected plants were infected by wilt and root-rots and eventually died. Apparently, plants in these pockets were infected early in the season.

In one of the fields at Selaim, severe infestation by dodder (*Cuscuta campestris*) was observed and the incidence of the yellowing disease was estimated at 50%, clearly indicating the apparent role of dodder in the spread of the disease. The crop was in a very poor condition and with hardly any flowers or pods. Symptoms of early infection and recovery were also observed at Selaim.

Ten out of 15 fields surveyed in Selaim were in excellent crop condition and advanced podding stage, mostly because of adherence by farmers to the optimum sowing date of late October/early November. On the other hand, most of these fields (70%) showed high incidence of the yellowing and stunting disease which apparently occurred early in the season. Considerable losses in yield due to this disease in these fields were likely. Although the identity of the causal agent in the Sudan is not yet fully explored, epidemiologically the situation is very similar to that of FBNYV in Egypt.

Laboratory testing

A total of 457 samples collected from the 35 fields (Table 8) were tested against antisera of FBNYV, BYMV, BBMV and AMV in the Plant Pathology Laboratory at the University of Gezira, using the TBIA technique. The results obtained are given in Table 9. Out of the 278 samples showing mosaic symptoms, about 56% were due to BYMV, 26% due to BBMV and 14% due to AMV. Mixed infections of BYMV with BBMV or AMV were also detected. Samples with mosaic symptoms suggestive of seed transmission proved, in most cases, to be due to BYMV and, less frequently, to BBMV.

Table 8. Distribution of faba bean samples collected from the Sudan on the basis of visual symptoms, 1994/95.

Region	No. of fields surveyed	No. of collected samples with symptoms of	
		mosaic/mottle	yellowing/stunting
Hudeiba	2	42	9
Merawi/Gurare	9	98†	19
Selaim/Burgaig	15	102	116
Dongola/Debba	9	51‡	20
Total	35	293	164

† Six of them from alfalfa; ‡ Two of them from alfalfa.

Samples with yellowing, necrosis and stunting symptoms collected from Hudeiba and Merawi did not react to FBNYV. About 5% of the samples collected from Selaim region gave what was taken as positive reaction to FBNYV. However, when duplicate samples of those were sent to the Virology Laboratory at ICARDA for confirmatory tests against FBNYV, none gave a positive reaction. Instead, about four samples were positive to Chickpea Chlorotic Dwarf Virus (CCDV) and three were positive to a monoclonal virus with broad specificity for luteo viruses (K.M. Makkouk, personal communication, May 1995).

Table 9. Results of laboratory tests conducted on 457 infected samples collected from random fields in four faba bean growing regions in the Sudan, 1994/95.

Region	No. of samples tested		No. of samples positive for			
	Mosaic/ mottle	Yellowing/ stunting	BYMV	BBMV	AMV	FBNYV
Hudeiba	42	9	42	21	12	0
Merawi/Gurare	98	19	33	18	21	0
Selaim/Burgaig	90	128	59	22	0	7
Dongola/Debba	48	23	31	16	7	0
Total	278	179	165	77	40	7

These results clearly indicated that BYMV is predominant in the four regions surveyed. The wide occurrence of this virus in alfalfa (*M. sativa*) crops as well as its ability to be transmitted through seed, need to be considered when advocating methods for control. The most intriguing result, however, is the occurrence of CCDV in Selaim area. The disease symptoms and the pattern of spread undoubtedly resembled what had been observed in the case of FBNYV in Egypt (Dafalla *et al.* 1994). High incidence was mostly associated with early sowing, thus indicating the possibility of having outbreaks, especially since most of the farmers traditionally stick to early (optimum) sowing dates.

General Conclusions

In the Sudan, bean leaf roll and phyllody diseases occur fairly early in the season while mosaic disease occurs late in the season coinciding with marked drop in temperature. This confirms previous findings and indicates close association of the three diseases with insect-vector activity. All the incidences were generally low, yet most of the entries were susceptible. However, a noticeable degree of variability is indicated and rigorous screening may yield fairly tolerant lines. Infection by leaf roll disease predisposes the plants to infection by wilt/root-rot diseases.

It is evident from the surveys that the mosaic/mottle group of symptoms is far more frequent in faba bean fields in the Sudan and that BYMV is the predominant component of this group. Given that this virus is seed-transmitted, readily aphid-transmitted and easily carried over in perennial alfalfa (*M. sativa*) crops, it could pose a serious production constraint. This refers to Selaim area in particular, where evidence of seed transmission was observed and where aphids were prevalent in most of the fields and where alfalfa constituted an important perennial fodder in the cropping pattern. The effect of BYMV on yield could be tremendous especially if the attack is early in the season (Makkouk *et al.* 1988).

All the samples with yellowing/stunting/necrosis group of symptoms did not react to either FBNYV or BLRV despite the identical visual symptoms to those induced by both viruses. There is however a strong evidence that similar symptoms could be induced by CCDV (Makkouk *et al.* 1995; Makkouk, personal communication). Efforts to obtain antiserum for CCDV from ICRISAT before conducting the second survey were not successful. However, in-depth etiological studies are needed to ascertain the organism(s) involved in this yellowing/stunting/necrosis disease syndrome and to formulate possible methods of control.

The use of TBIA for large-scale testing has proved very instrumental and efficient, since tissue blotting of infected stems can be done in the same day of sample collection and processed weeks or even months later without affecting the sensitivity of the test.

The outcomes of both surveys now provide a fair picture of the faba bean virus disease situation in the Sudan.

Acknowledgements

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Weed Control in Legumes

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Abstract

The production of legumes in northern Sudan is greatly constrained by weeds. The traditional methods of weed control in northern Sudan involve late hand-weeding done voluntarily by animal owners for collecting fodder for livestock. A series of experiments on weed management in cool-season legumes were carried out in different parts of northern Sudan from 1985 to 1995. Unrestricted weed growth and delayed weeding reduced seed yield of faba bean, lentil and chickpea by up to 80%. Weed competition and weeding regime studies showed that the critical period of weed/lentil competition appeared to be between two and four weeks from sowing and that the best weeding regime included one hand-weeding (at four weeks after sowing) or two hand-weedings (at four and six weeks after sowing). Experiments with pre-emergence herbicide and herbicide mixtures showed that Pursuit, Igran and Gesagard, in a tank-mixture with Stomp or Goal, gave adequate control of weeds and increased the grain yield of faba bean, lentil and chickpea. However, in some locations, the herbicide Pursuit was phytotoxic to chickpea. In areas where the leguminous weeds *Tephrosia apollinea, Melilotus indicus* and *Rhyncosia memnonia* were dominant, one supportive hand-weeding along with pre-emergence herbicide treatment gave excellent weed control throughout the season and resulted in high yield. The effectiveness of Pursuit, alone or in a tank-mixture with Stomp or Goal, was verified for weed control in faba bean in different locations in northern Sudan. The herbicide, alone or in a tank-mixture with Goal or Stomp, maintained adequate control of weeds and resulted in up to 50% higher yield than the yield from the traditional practice of weeding adopted by farmers and was highly profitable. The effectiveness of presowing irrigation, two methods of sowing, and different weed control treatments were evaluated for integrated weed management in lentil in northern Sudan. The herbicide Goal, with presowing irrigation and one supportive hand-weeding (four weeks after sowing), was an effective integrated weed-management practice for lentil.

Introduction

The major problem facing the production of legumes in northern Sudan is weeds. Weeds create serious competition for water, nutrients and light because of the low competitive ability of legume crops during the early stages of their growth. There are wide variations in the population and distribution of individual weed species in northern Sudan. The most important weed species reported from the region are: *Malva* sp., *Chenopodium* sp., *Melilotus* sp., *Convolvulus arvensis* and *Sinapis arvensis* in Dongola and Marawe; *Tephrosia apollinea, Panicum hygrocharis, Amaranthus* sp. and *Melilotus* sp. in Rubatab; *Beta vulgaris, Sinapis arvensis*, wild sorghum (*Sorghum sudanensis*), *Brachiaria eruciformis* and *Rhyncosia memnonia* in Aliab and Damer; and *Melilotus* sp. *Chenopodium* sp., *Datura* sp.,wild sorghum and *Amaranthus* sp. in Shendi and Wad Hamid. The traditional methods of controlling weeds in legumes in northern Sudan involve late hand-weeding done voluntarily by animal owners to collect fodder for their animals. This late removal of weeds does not mitigate the adverse effect of weeds on yield; causes physical damage to the crop, including flower shedding; and as only those weeds that are palatable to the animals are removed, the problematic weeds persist and become noxious.

Early hand-weeding is difficult and expensive as labour is becoming scarce. Herbicides are, therefore, of great potential importance to eliminate the early competition of weeds in legumes. Very little work on chemical weed control in legumes has been done. The work reviewed in this paper was carried out from 1985 to 1995 and includes weed control in faba bean, lentil and chickpea.

Weed Control in Faba Bean

A series of experiments with pre-emergence herbicides were conducted (El Badawi 1983, 1986, 1987) to test their activity against diverse weeds and their selectivity to faba bean. Of the herbicides tested (Topogard, cyanazine, Igran, Gesagard, Goal, Stomp, Kerb, Maloran, and Pursuit), cyanazine, Igran (terbutryn), Gesagard (prometryn), Goal (oxyfluorfen), Stomp (pendimethalin), and Pursuit (imazethapyre) were found to be the most promising for weed control in faba bean. Experiments carried out from 1985/86 to 1989/90 (El Badawi 1986, 1987; Ali and Babiker 1989; Babiker and Mohamed 1989; Babiker *et al.* 1991a, 1991c) indicated that the pre-emergence application of

Goal or Stomp was quite effective on grassy weeds, but their activity against broad-leaf weeds was poor. Igran, Gesagard and cyanazine adequately controlled broad-leaf weeds in Selaim and Shendi areas. Effectiveness of Igran or Gesagard in a tank-mixture with Goal or Stomp was evaluated from 1991/92 to 1993/94 at Dongola (Mohamed and Mohamed 1992a), Aliab (Mohamed *et al.* 1992b; Mohamed 1993) and Hudeiba (Mohamed *et al.* 1992b; Mohamed 1993, 1994). These combinations gave adequate control of grassy and broad-leaf weeds (Tables 1 and 2). However, these herbicides, at higher rates, were phytotoxic to faba bean at Hudeiba.

Table 1. Effect of herbicide treatment on weed control and faba bean yield at Dongola, 1991/92.

Treatment	Rate (kg a.i./ha)	% control 30 days after sowing		Yield (t/ha)
		Grasses	Broad-leaf weeds	
Goal + Igran	0.24 +1.0	61	92	2.2
Goal + Igran	0.24 + 1.5	62	94	2.1
Goal + Gesagard	0.24 + 0.5	63	73	1.5
Goal + Gesagard	0.24 + 1.0	87	90	1.6
Goal + Pursuit	0.24 + 0.025	64	77	2.1
Goal + Pursuit	0.24 + 0.05	47	83	1.8
Stomp + Igran	1.20 + 1.0	79	97	2.2
Stomp + Igran	1.20 + 1.5	73	91	1.9
Stomp + Gesagard	1.20 + 0.5	85	90	1.9
Stomp + Gesagard	1.20 + 1.0	58	94	2.4
Stomp + Pursuit	1.20 + 0.025	81	88	3.1
Stomp + Pursuit	1.20 + 0.05	56	85	2.1
Hand-weeded		100	100	2.9
Unweeded		0	0	1.0
SE (±)				0.2

Table 2. Effect of herbicide treatment on growth and yield of faba bean at Hudeiba, 1993/94.

Treatment	Rate (kg a.i./ha)	% control 60 days after sowing		Yield (t/ha)
		Grasses	Broad-leaf weeds	
Stomp + Gesagard	1.2 + 0.5	96	65	1.0
Stomp + Gesagard	1.2 + 0.5 + HW†	98	73	1.2
Stomp + Gesagard	1.2 + 1.0	98	68	0.5
Stomp + Igran	1.2 + 0.5	96	65	1.1
Stomp + Igran	1.2 + 0.5 + HW	98	79	1.1
Stomp + Igran	1.2 + 1.0	98	76	0.7
Hand-weeded (HW)		100	100	1.2
Unweeded		0	0	0.6
SE (±)				0.2

† HW = Hand-weeded four weeks after sowing.

The herbicide Pursuit, alone or in a tank-mixture with Goal or Stomp, was evaluated at Wad Hamid and Aliab from 1988/89 to 1990/91 (Ali and Babiker 1989; Babiker and Mohamed 1989; Babiker *et al.* 1991c). In general, satisfactory control of broad-leaf weeds occurred, but control of grasses was very poor. However, when Pursuit was tank-mixed with Goal or Stomp or its application combined with a supportive hand-weeding (at four weeks after sowing), adequate control of all weeds was obtained and, hence, the yield was increased significantly (Table 3). In 1991/92, the application of Pursuit in a tank-mixture with Stomp or Goal gave a yield which was comparable to the weed-free treatment (Table 4) at Wad Hamid, Aliab and Hudeiba (Mohamed *et al.* 1992b). When supported by one hand-weeding at four weeks after sowing, this herbicide treatment resulted in excellent suppression of weeds throughout the season and significant increase in grain yield over the weedy check (Table 4).

The efficacy of Pursuit, alone or in a tank-mixture with Goal or Stomp, was verified on farmers' fields in Aliab, Wad Hamid and Dongola (Ali *et al.* 1991; Babiker *et al.* 1991c; Mohamed *et al.* 1992a, 1993b, 1994a). The herbicide treatments gave adequate control of weeds and resulted in 50% increase in seed yield as compared to the traditional weed control practice of farmers (Table 5). Economic evaluation indicated that herbicide use in faba bean was highly profitable.

Table 3. Effect of herbicide treatment on weed control and faba bean yield at Wad Hamid and Aliab, 1990/91.

Treatment	Rate (kg a.i./ha)	% control 40 days after sowing at Wad Hamid		Yield (t/ha)	
		Grasses	Broad-leaf weeds	Wad Hamid	Aliab
Pursuit	0.025	29	91	1.26	2.01
Pursuit + HW†	0.025	84	100	2.64	2.49
Pursuit	0.050	66	91	1.56	2.23
Pursuit + HW	0.050	88	100	2.29	2.35
Pursuit + Goal	0.025 + 0.24	87	82	2.69	2.01
Pursuit + Goal	0.050 + 0.24	93	91	2.99	2.00
Pursuit + Stomp	0.025 + 1.20	100	73	3.19	2.19
Pursuit + Stomp	0.050 + 1.20	99	91	3.38	2.14
Hand-weeded (HW)		100	100	3.76	2.23
Unweeded		0	0	1.06	1.97
SE (±)				0.18	0.17

† HW = Hand-weeded four weeks after sowing.

Table 4. Effect of herbicide treatment on weed control and faba bean yield at Hudeiba, Aliab and Wad Hamid, 1991/92.

Treatment	Rate (kg a.i./ha)	% control 60 days after sowing at Aliab		Yield (t/ha)		
		Grasses	Broad-leaf weeds	Aliab	Hudeiba	Wad Hamid
Pursuit	0.05	63	99	2.4	3.9	3.6
Pursuit + HW†	0.05	91	100	2.8	4.2	3.0
Pursuit + Stomp	0.05 + 1.20	69	99	2.6	3.4	4.1
Pursuit + Stomp + HW	0.05 + 1.20	81	100	3.0	4.0	3.4
Pursuit + Goal	0.05 + 0.24	92	100	3.1	3.9	2.8
Pursuit + Goal + HW	0.05 + 0.24	91	100	3.1	4.1	3.7
Hand-weeded (HW)		100	100	3.0	3.7	3.5
Unweeded		0	0	2.5	2.7	2.5
SE (±)				0.1	0.2	0.2

† HW = Hand-weeded four weeks after sowing.

Table 5. On-farm verification of chemical weed control of faba bean at Wad Hamid, Aliab and Dongola in different years.

Treatment	Rate (kg a.i./ha)	Yield (t/ha)				
		Wad Hamid	Aliab	Dongola		
		1990/91	1991/92	1992/93	1993/94	1994/95
Pursuit	0.05	2.2			1.9	2.1
Pursuit + HW†	0.05				2.3	2.5
Pursuit + Goal	0.05 + 0.24	2.3	3.0	3.0		
Pursuit + Stomp	0.05 + 1.20		2.6	3.1		
Farmer practice		1.0	2.0	2.4	1.6	1.6
SE (±)			0.15	0.2	0.12	0.15

† HW = Hand-weeded four weeks after sowing.

Weed Control in Lentil

Studies were carried out at Rubatab to determine the magnitude of yield losses due to weeds and to determine the critical period of weed/lentil competition (Mohamed and Nourai 1993a, 1994a). Weeds were retained in the field for two, four, six, eight and ten weeks after sowing. Other plots were maintained weed-free for the same periods. Weedy and weed-free checks were also included for comparison. The results of the study showed that unrestricted weed growth and delayed weeding accounted for up to 80% loss in lentil grain yield (Table 6). The critical period of weed/lentil competition appeared to be between two and four weeks after sowing (Fig. 1). Experiments conducted at Dongola and Wad Hamid to determine an economic weeding regime treatment for lentil (Mohamed *et al.* 1994b, 1994c) revealed that unrestricted weed growth accounted for 56% loss in grain yield. Weeding late, six or eight weeks after sowing, resulted in yield which was lower than that under weed-free treatment. But one hand-weeding at four weeks after sowing or two hand-weedings at four and six weeks after sowing proved to be the best treatments for weed control in lentil (Table 7).

Table 6. Weed competition in lentil, effect on grain yield at Rubatab, 1992/93 and 1993/94.

Treatment	Yield (t/ha)		
	1992/93	1993/94	Mean
Weed-free check	1.66	2.00	1.83
Weedy check	0.94	0.32	0.63
Weed-free for 2 weeks	1.05	1.14	1.10
Weed-free for 4 weeks	1.62	1.90	1.35
Weed-free for 6 weeks	1.65	2.10	1.83
Weed-free for 8 weeks	1.69	2.10	1.90
Weed-free for 10 weeks	1.66	2.10	1.88
Weedy for 2 weeks	1.73	1.80	1.76
Weedy for 4 weeks	1.63	1.42	1.52
Weedy for 6 weeks	0.95	0.65	0.80
Weedy for 8 weeks	0.90	0.25	0.58
Weedy for 10 weeks	0.71	0.06	0.39
SE (±)	0.14	0.12	

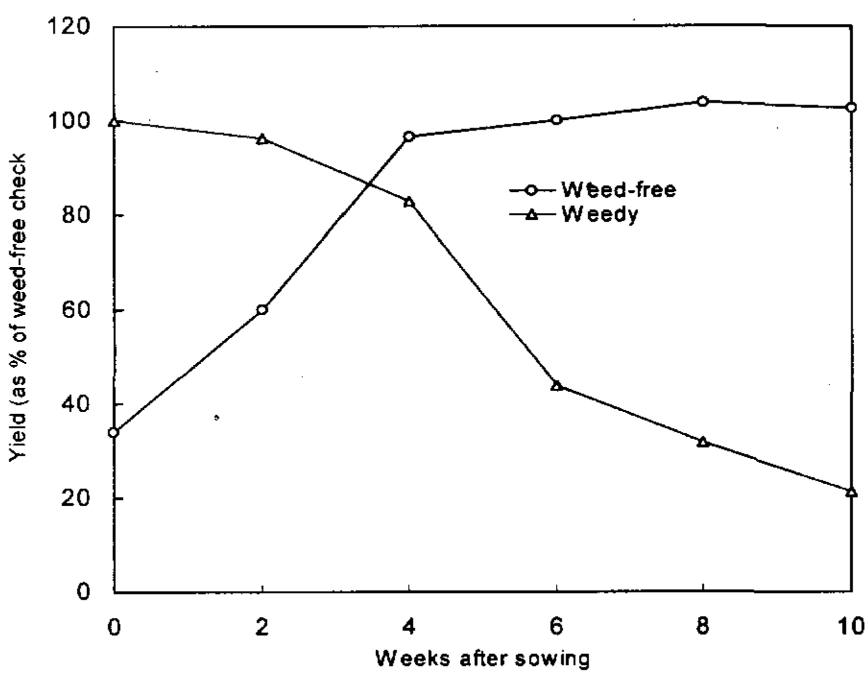

Fig. 1. Effect of duration of weed-infested and weed-free period on the mean productivity of lentil at Rubatab, 1992/93–1993/94 (critical period of weed/lentil competition is between 2 and 4 weeks after sowing).

Table 7. Effect of weeding regime on grain yield of lentil in northern Sudan, 1993/94.

Treatment	Yield (t/ha)		
	Wad Hamid	Dongola	Mean
One weeding at 4 WAS†	3.08	0.65	1.87
One weeding at 6 WAS	2.39	0.65	1.52
One weeding at 8 WAS	2.22	0.45	1.34
Two weedings at 4 and 6 WAS	2.58	1.05	1.82
Two weedings at 4 and 8 WAS	2.56	0.57	1.56
Weed-free check	3.08	1.01	2.06
Weedy check	1.36	0.46	0.91
SE (±)	0.15		0.10

† WAS = Weeks after sowing.

A number of experiments with herbicide mixtures were conducted at Wad Hamid, Dongola, Hassa and Rubatab from 1990/91 to 1992/93 (Babiker *et al.* 1991b; Mohamed and Mohamed 1992b; Mohamed *et al.* 1992d, 1993a). The treatments included the herbicides Pursuit, Igran or Gesagard in a tank-mixture with Goal or Stomp. All herbicide treatments provided excellent wide-spectrum weed control and resulted in yields significantly higher than the unweeded control treatment (Table 8). However, Igran or Gesagard at 1.5 kg a.i./ha adversely affected the growth and yield of lentil crop. Therefore, these chemicals were further evaluated at Rubatab and Wad Hamid at lower rates in a tank-mixture with Stomp (Mohamed *et al.* 1993a; Mohamed and Mohamed 1994) (Tables 9 and 10). The herbicide Stomp, in a tank-mixture with Pursuit at 0.025 kg a.i./ha, Igran at 1.0 kg a.i./ha, or Gesagard at 1.0 kg a.i./ha gave adequate control of grassy and broad-leaf weeds and, hence, increased grain yield of lentil significantly over the unweeded control. However, the leguminous weeds, *Tephrosia apollinea* and *Melilotus indicus* were not controlled. A supportive hand-weeding at four weeks after sowing was necessary to get an excellent control of weeds throughout the season with the above herbicide treatments (Table 10).

Table 8. Effect of herbicide treatment on weed control and grain yield of lentil at Wad Hamid, Dongola and Hassa, 1991/92 and 1992/93.

Treatment	Rate (kg a.i./ha)	% control at Dongola		Grain yield (t/ha)		
		Grasses	Broad-leaf weeds	Wad Hamid	Dongola	Hassa
Stomp + Pursuit	1.2 + 0.025				1.6	1.3
Stomp + Pursuit	1.2 + 0.05				1.3	1.4
Stomp + Igran	1.2 + 1.0	94	91	3.5	1.3	1.1
Stomp + Igran	1.2 + 1.5	95	93	2.2	1.5	1.0
Stomp + Gesagard	1.2 + 1.0	91	88	2.8	1.2	1.1
Stomp + Gesagard	1.2 + 1.5	94	91	2.7	1.4	1.2
Goal + Pursuit	0.24 + 0.025				2.0	1.3
Goal + Pursuit	0.24 + 0.05				1.6	1.3
Goal + Igran	0.24 + 1.0	83	82	3.2	1.8	0.9
Goal + Igran	0.24 + 1.5	95	93	2.9	1.9	1.3
Goal + Gesagard	0.24 + 1.0	91	89	2.8	1.6	1.2
Goal + Gesagard	0.24 + 1.5	92	92	1.7	1.2	1.3
Hand-weeded		100	100	2.1	2.0	1.0
Unweeded		0	0	0.9	0.1	0.6
SE (±)				0.2	0.1	0.1

Table 9. Effect of herbicide treatment on weed control, growth and yield of lentil at Wad Hamid and Rubatab, 1992/93.

Treatment	Rate (kg a.i./ha)	% control at Rubatab		Grain yield (t/ha)		
		Grasses	Broad-leaf weeds	Rubatab	Wad Hamid	Mean
Stomp + Pursuit	1.2 + 0.025	86	43	1.2	3.0	2.1
Stomp + Pursuit	1.2 + 0.05	84	53	1.3	2.5	1.9
Stomp + Igran	1.2 + 0.5	92	36	1.5	2.5	2.0
Stomp + Igran	1.2 + 1.0	89	67	1.4	2.9	2.2
Stomp + Gesagard	1.2 + 0.5	88	47	1.3	2.9	2.1
Stomp + Gesagard	1.2 + 1.0	83	25	1.3	3.5	2.4
Hand-weeded		100	100	1.4	4.4	2.9
Unweeded		0	0	0.8	2.0	1.4
SE (±)				0.1	0.2	

Table 10. Effect of herbicide treatment on growth and yield of lentil at Wad Hamid and Rubatab, 1993/94.

Treatment	Rate (kg a.i./ha)	Yield (t/ha)		
		Rubatab	Wad Hamid	Mean
Stomp + Pursuit	1.2 + 0.025	1.3	1.9	1.6
Stomp + Pursuit + HW†	1.2 + 0.025	1.7	2.4	2.1
Stomp + Pursuit	1.2 + 0.05	1.2	2.7	2.0
Stomp + Igran	1.2 + 0.5	0.8	2.4	1.6
Stomp + Igran + HW	1.2 + 0.5	1.9	2.4	2.2
Stomp + Igran	1.2 + 1.0	1.1	2.1	1.6
Stomp + Gesagard	1.2 + 0.5	1.1	1.7	1.4
Stomp + Gesagard + HW	1.2 + 0.5	1.5	2.9	2.2
Stomp + Gesagard	1.2 + 1.0	1.3	2.1	1.7
Hand-weeded (HW)		1.9	2.7	2.3
Unweeded		0.8	1.2	1.0
SE (±)		0.14	0.26	

† HW = Hand-weeded four weeks after sowing.

The effectiveness of presowing irrigation, two methods of sowing (broadcast sowing/ridging or flat sowing), and different methods of weed control was evaluated, as integrated management of weeds in lentil at Rubatab (Mohamed and Nourai 1993b, 1994b). The results of this experiment are shown in Table 11. Presowing irrigation reduced weed population by up to 60%. The herbicide Goal gave satisfactory wide-spectrum weed control. Methods of sowing showed no effect on weed population. The presowing irrigation increased grain yield by more than 26%. No significant differences in yield between the methods of sowing were obtained. Goal, with one supportive hand-weeding, resulted in higher yield than the unweeded control (Table 11). In general, Stomp, in a tank-mixture with Pursuit, Igran or Gesagard gave adequate control against weeds and increased yield of lentil significantly in northern Sudan. On the other hand, the herbicide Goal, with one supportive hand-weeding, can be used with presowing irrigation as an integrated weed management practice in lentil in Rubatab area.

Table 11. Integrated weed management in lentil, effects on weeds and grain yield at Rubatab, 1992/93.

Treatment	% control 60 days after sowing				Yield (t/ha)	
	1992/93		1993/94		1992/93	1993/94
	Grasses	Broad-leaf weeds	Grasses	Broad-leaf weeds		
Presowing irrigation						
No	0	0	0	0	1.40	0.80
Yes	60	60	42	0	1.80	1.00
SE (±)					0.10	0.05
Method of sowing						
Broadcast and ridge	10	20	0	0	1.50	1.00
Sowing on flat	20	20	0	0	1.70	0.90
SE (±)					0.10	0.07
Weed control						
Unweeded	0	0	0	0	1.20	0.40
Hand-weeded	83	86	80	80	1.70	1.20
Goal at 0.24 kg a.i./ha	75	70	82	85	1.80	1.20
SE (±)					0.12	0.06

Weed Control in Chickpea

Experiments were conducted at Rubatab and Wad Hamid to determine the magnitude of yield losses due to weeds and to assess the efficacy and selectivity of some herbicides in chickpea. The results indicated that weed competition reduced seed yield of chickpea by more than 80%. Pursuit, alone or in a tank-mixture with Goal or Stomp, was found to be injurious to the chickpea plant and reduced yield.

Igran, Gesagard, Goal and Ronstar were evaluated for weed control in chickpea at Hudeiba and Wad Hamid (Mohamed *et al.* 1992c). The results showed that Igran and Gesagard gave poor control of grassy weeds, but their activity against broad-leaf weeds was excellent. Goal, however, displayed excellent activity against grassy weeds (Table 12). Other experiments were conducted at Hudeiba and Wad Hamid (Mohamed and El Sarrag 1993; Mohamed and Mohamed

1994) from 1992/93 to 1993/94 to evaluate the efficacy and selectivity of the herbicide Goal, alone or in a tank-mixture with Igran or Gesagard, for weed control in chickpea. Unrestricted weed growth accounted for up to 80% loss in chickpea yield (Table 13). Goal, alone or in a tank-mixture with Igran or Gesagard, gave satisfactory control of weeds and increased yield over the weedy check treatments. One hand-weeding at four weeks after sowing to support the herbicide treatment gave excellent suppression of weeds throughout the season and gave higher or comparable yield to the weed-free checks (Table 13).

Table 12. Effect of herbicide treatment on weed control and grain yield of chickpea at Hudeiba and Wad Hamid, 1991/92.

Treatment	Rate (kg a.i./ha)	% control at Wad Hamid		Yield (t/ha)	
		Grasses	Broad-leaf weeds	Wad Hamid	Hudeiba
Igran	1.00	33	63	2.4	0.9
Igran	1.50	17	78	1.7	1.6
Igran	2.00	17	86	2.5	1.4
Gesagard	1.00	37	50	3.1	1.2
Gesagard	1.50	37	59	2.8	1.7
Gesagard	2.00	53	78	1.5	1.4
Ronstar	0.75	25	12	2.0	1.0
Ronstar	1.00	53	0	2.3	1.1
Ronstar	1.25	53	49	1.9	
Goal	0.24	33	48	1.5	1.3
Goal	0.36	3	57	2.3	1.4
Goal	0.48	37	54	2.2	1.6
Hand-weeded		100	100	2.2	2.4
Unweeded		0	0	1.6	1.0
SE (±)				0.14	0.11

Table 13. Effect of herbicide treatment on weed control and grain yield of chickpea at Wad Hamid and Hudeiba, 1992/93 and 1993/94.

Treatment	Rate (kg a.i./ha)	Yield (t/ha)			
		Wad Hamid		Hudeiba	
		1992/93	1993/94	1992/93	1993/94
Goal + Igran	0.24 + 0.5	2.8	1.1	0.8	3.4
Goal + Igran + HW†	0.24 + 0.5	2.9	3.4	2.6	1.7
Goal + Igran	0.24 + 1.0	2.8	1.2	1.3	1.6
Goal + Igran + HW	0.24 + 1.0	2.8		2.1	
Goal + Gesagard	0.24 + 0.5	3.4	1.8	1.7	1.5
Goal + Gesagard + HW	0.24 + 0.5	2.2	3.6	3.2	1.5
Goal + Gesagard	0.24 + 1.0	3.2	2.1	1.7	1.5
Goal + Gesagard + HW	0.24 + 1.0	2.5		2.8	
Goal	0.24	2.0	1.3	1.6	1.5
Goal + HW	0.24	3.2	3.5	2.9	1.6
Goal	0.36	2.4	2.2	1.3	1.5
Goal + HW	0.36	2.8		1.8	
Hand-weeded (HW)		3.2	3.2	2.2	1.5
Unweeded		1.4	0.8	1.0	1.0
SE (±)		0.17	0.29	0.29	0.16

† HW = Hand-weeding four weeks after sowing.

Conclusions

Unrestricted weed growth and delayed weeding accounted for considerable losses in grain yield of the cool-season food legumes. Timely weeding is essential. Late weeding does not mitigate the adverse effect of weeds on yield, causes mechanical damage to the crop and exposes crops, like lentil, to damage by birds. The use of herbicides is of great importance to eliminate competition of weeds during the critical period. Faba bean, chickpea and lentil showed very good tolerance to the herbicides Stomp, Goal, Pursuit, Igran and Gesagard. However, Pursuit was phytotoxic to chickpea. There are wide variations in the soil and in the weed flora in northern Sudan. The effectiveness of the tested herbicides depends on the types of soils and weeds. The use of herbicide mixtures can ensure wide-spectrum weed control. Some leguminous weeds (*Tephrosia apollinea, Melilotus indicus* and *Rhyncosia memnonia*), are morphologically and physiologically similar to the cool-season food legume crops; so they are not affected by the herbicides. Therefore, one supportive hand-weeding is needed wherever those weeds are present. The soils of Selaim, Dongola, Zeidab, Hudeiba and Wad Hamid are heavy, whereas the soils of Rubatab and, to some extent, of Shendi areas are light. On light soils the dose of the herbicides Pursuit and Gesagard has to be reduced as doses appropriate on heavier soils could damage the crop on light soils.

Presowing irrigation gave satisfactory control of *Tephrosia apollinea, Amaranthus* sp., *Tribulus* sp., *Rhyncosia memnonia* and most grasses. However, in case of *Malva* sp., *Chenopodium* sp., *Melilotus indicus* and other winter weeds, the control was not effective because these weeds need lower temperatures to germinate than what are available when presowing irrigation is given. Therefore, time and frequency of presowing irrigation need to be further studied. A proper control strategy is the adoption of an integrated weed management policy that includes cultural and chemical methods. Time and frequency of presowing irrigation, method of sowing and plant population need to be further studied and integrated with chemical methods of weed control.

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Discussion

Q: Mohamed Adlan

Does the presence of leguminous weeds in medium to low population densities have any effect on soil fertility conservation both on the short- and long-term, provided that their ability to fix N is improved?

A: El Sadig Mohamed

Since the crop is a legume crop, the effect of leguminous weeds on soil fertility is negligible compared to that of the crop.

Q: Mohamed El-Borai

How many hand-weedings are used in lentil trials and is it easy to do this in lentil? Also, have you used any post-emergence herbicides in lentil, especially for grasses?

A: El Sadig Mohamed

The number of hand-weedings is two at 3 and 6 weeks after sowing. It is not easy to do this in lentil. No post-emergence herbicides were used on lentil.

Q: Dr. Musa Abdalla

How would you comment on the fact that ridging is not practical in sandy and light loamy soils?

A: El Sadig Mohamed

Ridging is of great value in heavy clay soils, therefore, ridging in Rubatab area (where the soil is light) has no significant effect on lentil yield, compared to that in Zeidab and Hassa.

Q: Dafalla A. Dawoud

Farmers at Dongola delay the weeding treatment (till flowering) to use the weeds as animal feed. Is there any economic evaluation of the delayed hand-weeding and its contribution to animal feeding compared to the yield loss due to delayed hand-weeding?

A: El Sadig Mohamed

Yield loss due to the delay of weeding is very high. The benefit of weeds as fodder compared to crop loss due to the delay of weeding still needs to be economically evaluated.

Q: Dr. Shama Elamin Dawelbeit

Weeds are sometimes controlled in Europe by burning one or two days before plant germination. How about the possibility of such application in the Sudan? And if that is not possible, what are the limitations? Is it crop type or what?

A: El Sadig Mohamed

This method is not possible in wheat, lentil, faba bean and other field crops. It might be possible in cotton and fruit trees.

Chapter 5
Technology Transfer

Food Legume Technology Transfer

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Abstract

The major constraints to production of food legumes—faba bean, chickpea and lentil—are: limited cultivable land, poor management practices, low yielding traditional cultivars, insect pest and disease damage, inadequate credit and marketing, and traditional crop-sharing arrangements. The Nile Valley Regional Program (NVRP) is working towards improving production of these crops by means of a stepwise research approach from on-station to on-farm levels. Packages that comprised different combinations of improved inputs and practices were developed by the program and recommended for wider on-farm trials for verification and demonstration. The demonstrations were exclusively managed by farmers and administered by research or extension personnel. Detailed timing and quantification of technology components were collected by farmer interviews using structured questionnaires. The sampling was targeted to participating farmers and an equal number of their closest neighbors for comparison reasons. Analysis of variance was used for the agronomic data, and partial budgets were constructed for economic evaluation. Marginal rate of return (MRR) constituted the basic measure of return on investment in the technology. The improved technology showed agronomic superiority and economic feasibility across the three crops, reflected by considerable yield advantage and high MRRs, respectively. The ranges of technology yield increase over farmers from 1989/90 to 1993/94 were 20 to 155%, 24 to 168% and 20 to 62% for faba bean, chickpea and lentil, respectively. MRR ranges for the same period were 130 to 5562%, 120 to 2592% and 329 to 8779% for faba bean, chickpea and lentil, respectively. Adoption studies, carried out to trace and predict farmers' acceptability of the improved technology, revealed that farmers were aware of most of the recommended technologies and their advantages over traditional practices. Resource availability was the major constraint. The irrigation regime was the least adopted component and farmers were using suboptimal technology levels. This was related to the limited pump capacity and to the traditional production relations. Results also showed that lentil production had low chances for expansion because its yields were discouragingly low despite its high price. To stimulate farmers and to accelerate technology adoption, stronger extension-farmer linkages and input and finance availabilities were the most important issues needing attention and policy intervention.

Introduction

Faba bean, chickpea and lentil are the most important cool-season food legumes produced in the Sudan. The Northern Region of the country is the main production area for the three crops because of its favorable climatic conditions, particularly the relatively cooler winters. The three crops are also main cash earners for their growers.

The major factors limiting the production of cool-season food legumes are: (1) low competition ability of these crops to other high value crops for the limited area of arable land; (2) poor management practices; (3) low yields of traditional cultivars which are susceptible to insect pests and diseases; (4) insect pest and disease damage; and (5) inadequate credit and marketing facilities and the continuation of traditional crop-sharing arrangements which often prevent adoption of improved production technologies because of conflict of interest of tenants, landowners and owners of water pumps.

Research on food legumes has been ongoing at Hudeiba Research Station since the early sixties. The main focus of that research has been to improve productivity and quality of these crops through plant breeding and crop husbandry programs. However, a systems-research approach, which was started in faba bean in 1979 through the ARC/ICARDA/IFAD Nile Valley Project (NVP), and has continued in the current ARC/ICARDA/The Netherlands Nile Valley Regional Program (NVRP), covers all cool-season food legumes and wheat. The program follows a stepwise research approach from on-station to on-farm. The main steps of that approach are: on-station trials, on-farm researcher-managed trials, farmer-managed trials and on-farm demonstrations. In new areas covered by the program, research usually starts by exploratory field surveys to investigate farmers' production problems, on which on-station work has to be carried out to generate information for on-farm evaluation.

Based on past research findings and the outcomes of surveys, 'improved' levels of many production factors which have been evaluated at many levels in comparison to the farmers' own practices were identified. After several seasons' testing, packages of production practices were developed for wider evaluation and verification in the farmer-managed on-farm trials. Finally, on-farm demonstrations have been conducted to disseminate the recommended technologies on a wider scale.

Adoption of demonstrated technologies has been studied through field surveys to trace farmers' acceptability of the demonstrated production technology and to identify factors that limit or encourage farmers' adoption. Adoption studies have also provided feedback to researchers for their back-up research. This report reviews the NVRP technology development and transfer for the three cool-season food legumes in the period from 1988/89 to 1994/95.

Technology Demonstration

Field-verified, improved production packages were demonstrated in major production areas on farmers' fields. The demonstration fields were planted and managed by farmers under the direction of a guiding committee representing research, extension and crop protection departments and the production scheme administration. Farmers were chosen on the basis that they were willing to implement the package and that their fields were representative of the recommendation domain for which the package was developed. The performance of the package on the participating farm was compared with the crop performance on the neighboring, nonparticipating farm to evaluate the comparative advantage of the demonstrated technology.

Using structured questionnaires, designed to collect detailed information on timing and quantities of application of various inputs, data were collected from participating farmers (PF) and an equal number of their closest neighbors (neighboring farmers or NF). Data were also collected on yield levels and variable production costs to permit the evaluation of the improved package in terms of physical and monetary benefits. Interviews were conducted by trained enumerators or the technical staff at the site or by local extension agents. The technical staff was also responsible for monitoring and recording data on insect pests and diseases in addition to monitoring the required management practices.

Participating farmers constituted the replications within a production region, while 'improved production packages' on participating farms and 'local production practices' on neighboring farms formed the two treatments for comparison.

An analysis of variance was done for the agronomic data, and partial budgets were constructed for economic evaluation. Using average grain yield and farm-gate price at harvest, gross benefits were computed. Variable costs were computed for the improved technology. 'Net benefits' were computed by deducting variable costs from the difference in the gross benefits on the participating farms and neighboring farms. Thus the 'net benefits' reported here are the net renumeration to the adopted improvements in the technology rather than the net returns of the whole crop production. Computation of marginal rates of return (MRR) was done to assess the reward associated with investment in the technology. MRR is the percentage of change in net benefits to change in variable costs. High MRR would indicate that prospects for technology adoption would be high. Break-even analysis was used in some seasons to test the stability of the package and its tolerance to cost increase or crop price decrease. Mean comparison was done to examine the effect of individual package components on yield. To examine the effect of an individual factor in the presence of others, regression analysis was carried out.

Faba Bean

Based on the results of several seasons' testing, a package of four factors was recommended for on-farm demonstration. The recommended package included:

- Early sowing (during the first week of November) in contrast to farmers' practice of late sowing which often extends to December.
- Irrigation at 10- to 14-day intervals as against farmers' practice of adopting wider intervals and subjecting the crop to moisture stress after the second irrigation.
- Chemical control of *Spodoptera*, aphids, pod borers and semi-loopers compared to farmers' practice of no control.
- Proper weed control by two hand-weedings or pre-emergence application of a mixture of Stomp and Pursuit or a mixture of Goal and Pursuit in contrast to late hand-weeding common amongst farmers.

The outcome of the on-farm demonstration in the period 1989/1990–1994/95 is summarized in Table 1.

Table 1. Outcome of faba bean on-farm demonstration plots in different locations in the Northern Region of the Sudan, 1989/90–1994/95†.

Season/ Location‡	Sowing date§		Number of irrigations		Number of sprayings		Weed control#		Yield (kg/ha)		% yield increase	% cost increase	MRR (%)
	PF¶	NF¶	PF	NF	PF	NF	PF	NF	PF	NF			
1989/90													
Selaim (6)	30O-6N	15-28O	8.6	8.3	0.1	0.1	1.3	1.0	2894	2127	32	9	952
Kali (10)	3N	11-20N	8.0	5.5	1.0	0.3			2259	1600	41	27	1037
1990/91													
Shendi (19)	4-7N	1-10N	8.8	5.7	1.5	0.2			1856	1017	82	45	1465
Selaim (7)	1-15N	14-28O	7.4	8.9	0.6	0.1	1.7	1.9	1747	1452	20	2	5562
1992/93													
Aliab (8)							HRB	FP	3243	1509	155	50	588
Wad Hamid (10)							HRB	FP	3745	2951	27	22	381
1993/94													
Shendi area (6)	7-12N	7-20N	7.2	5.5	1.0	0	HRB	FP	2166	769	182	21	2677
Wad Hamid (8)	5-10N	10-18N	6.0	4.3	2.0	0	HRB	FP	1987	438	362	55	1724
Aliab (3)	1N	15-21N	8.1	6.2	1.0	0	HRB	FP	1471	671	192	262	533
1994/95													
Shendi (8)	4-15N	7-30N	5.9				HRB	FP	3301	2364	40	32	945
Wad Hamid1 (5)	12-14N	14N-1D	5.0	4.0			HRB	FP	3473	2190	59	28	1118
Wad Hamid2 (5)	12-14N	14N-1D	5.0	4.0			HW	FP	2769	2190	26	25	501

† In 1989/90 at Kali and in 1990/91 at Shendi, weed control was not a factor; in 1992/93 data on sowing date, number of irrigations and number of sprayings were not reported; in 1994/95 there were no serious insect pest problems, thus spraying was not practiced.
‡ *Numbers in parentheses are the numbers of sites.* § O = October; N = November; D = December. ¶ PF = Participating farmers; NF = Neighboring farmers. # Numbers in columns represent number of weedings; HRB = Herbicide; FP = Farmers' practice, HW = Hand-weeding.
Source: G. Mohamed *et al.* (1990a, 1991); Taha *et al.* (1990a, 1991a); E. Mohamed *et al.* (1992, 1993); El Sarrag *et al.* (1994b, 1995).

The improved package was agronomically superior to farmers' traditional practices as it resulted in higher yield in all seasons and locations. The advantage in yield because of the improved package over that of farmers' practices ranged between 20 and 155%. The cost of the improved package was 2 to 85% higher than that of farmers' practices. MRR ranged between 130 and 5562% indicating that net returns to each LS invested in the package ranged between LS 1.30 and LS 55.62, depending on the season and location. This is a reflection of the high profitability of the package. Both methods of weed control—chemical and manual—were superior to farmers' practices, with the chemical one being better than the manual weed control.

Profitability of the package was found to be stable and would tolerate high cost increase and lower crop prices. The effect of individual components was also examined by comparison of means and multiple regression analysis, and statistically significant effects were found for most components.

Chickpea

Research on chickpea under the NVRP started in the late eighties. A package of four factors has been demonstrated in Rubatab area where chickpea is grown under irrigation. The package consists of (1) the cultivar Shendi-1 (NEC 2491); (2) a seed rate of 60 kg/ha; (3) sowing in the first half of November; and (4) chemical control against insect pests, if necessary. Another three-factor package has been demonstrated in Wad Hamid area where chickpea is grown under residual moisture. This package includes: (1) the cultivar Shendi-1; (2) two supplementary irrigations; and (3) chemical control of insect pests, if necessary.

The results of the chickpea pilot production demonstration plots in the two locations for the period 1989/90–1994/95 are summarized in Table 2. The package gave a substantial yield increase (24 to 168%) in all seasons in both areas. The additional cost of the improved package ranged between 21 and 109% that of farmers' practices. However, that cost increase was more than compensated for by the higher yield of the improved package as reflected by a MRR of 120 to 2592%.

Table 2. Outcome of chickpea on-farm demonstration plots in different locations in the Northern Region of the Sudan, 1989/90–1994/95†.

Season/ Location‡	Cultivar		Seed rate (kg/ha)		Sowing date¶		No of sprayings		Number of irrigations		Yield (kg/ha)		% yield increase	% cost increase	MRR (%)
	PF§	NF§	PF	NF	PF	NF	PF	NF	PF	NF	PF	NF			
1989/90															
Rubatab (6)	Shendi-1	Local	60	50	16N-2D	10D-4J	1.3	0	NR††	NR	1579	1275	24	21	274
Wad Hamid (12)	Shendi-1	Local					2.4	0.5	1.3	0.3	1940	1369	42	28	602
1990/91															
Rubatab (6)	Shendi-1	Local	60	48	15N	NR	1.0	0.2	7.8	5.5	1644	614	168	109	1158
Wad Hamid (10)	Shendi-1	Local					2.0	0	4.4	2.5	1190	761	56	38	767
1991/92															
Wad Hamid (5)	Shendi-1	Local	74	86			2.0	0	2.1	0	1639	975	68	37	546
1992/93															
Rubatab (8)	Shendi-1	Local	60	63	28N	8D	0.3	0.3	7.0	5.0	1358	1007	35	74	213
Wad Hamid (7)	Shendi-1	Local					1.0	0			1680	1247	35	40	120
1993/94															
Rubatab (8)	Shendi-1	Local	60	27	15N	4D	0.9	0.4	7.1	4.3	883	328	63	21	2592
Wad Hamid (6)	Shendi-1	Local			10N	20-30D			1.3	0	1429	793	45	36	328
1994/95															
Wad Hamid (6)	Shendi-1/JM#	Local									952	655	45	21	526
Rubatab (10)	Shendi-1	Local	60	36	12N-18D	7-27D	1.0	0.7	6.5	4.7	1581	951	66	30	544

† Seed rate and sowing date are not factors in chickpea packages at Wad Hamid, though sometimes reported; spraying was not practiced at Wad Hamid in 1993/94 and 1994/95. ‡ Numbers in parentheses are the numbers of sites.
§ PF = Participating farmers; NF = Neighboring farmers. ¶ N = November; D = December; J = January.
# JM = Jebel Marra-1 (newly released). †† NR = Not reported.
Source: Taha *et al.* (1990b, 1991b); G. Mohamed *et al.* (1990b, 1995a) ; El Sarrag *et al.* (1992a); El Sarrag and Ahmed (1993a); Ibrahim (1994, 1995).

Lentil

Lentil research under the NVRP started also in the late eighties. An improved package was demonstrated in Rubatab area, consisting of: (1) the cultivar Selaim; (2) early sowing (during the first half of November); (3) a seed rate of 107 kg/ha; (4) irrigation at a 10-day interval; and (5) weed and insect pest control. A similar package with a lesser seed rate (47 kg/ha) was demonstrated in Wad Hamid area.

The outcome of demonstrations for several years is summarized in Table 3. The improved package gave a yield advantage of 20 to 148%, with an additional cost of 8 to 30% as compared to the farmers' practice. The MRR ranged from 329 to 8779%, reflecting the high returns on investment in the package.

Adoption Studies

Approach

Adoption studies within the NVRP started in 1988/89 when adoption of various components of improved production technology for faba bean in the Nile State of northern Sudan was investigated. They covered different faba bean producing areas in that region where on-farm research was conducted for several years in the past under NVP. Two types of adoption studies were conducted, both based on on-farm surveys: (1) cross sectional measure of adoption at one point in time by direct interviewing of farmers, and (2) prediction of farmers' adoption behavior by using farm models built to simulate the whole farming system within the policy framework in which it operates.

In earlier surveys, selective sampling was pursued where the sample was confined to those farmers who participated in past on-farm demonstration trials as well as their closest neighbors. The objective was to trace levels of adoption of technology by past participants and any 'spill-over' of adoption to nonparticipants. Farmers attitudes towards the technology and factors that influence adoption were monitored. The factors included the type of farming system, production relations and other socioeconomic characters which may affect farmers' receptiveness to the adoption of the technology. Comparison between the participant and nonparticipant farmer groups was useful in reflecting the rate of technology diffusion and detecting the scale of technology transfer in the area. This would be attributed to the effectiveness of extension services and the level of informal exchange of information among farmers.

Table 3. Outcome of lentil on-farm demonstration plots in different locations in the Northern Region of the Sudan, 1989/90–1994/95.

Season/Location†	Sowing date‡		Seed rate (kg/ha)		Number of irrigations		Weed control¶		Number of sprayings#		Yield (kg/ha)		% yield increase	% cost increase	MRR (%)
	PF§	NF§	PF	NF	PF	NF	NF	PF	PF	NF	PF	NF			
1989/90															
Rubatab (4)	27N	2-15D	143.0	48.0	9.3	6.5	1.0	0.5	0.25	0	1645	1234	33	8	461
1990/91															
Rubatab (4)	25N-2D	20N-29N	107.0	37.0	9.8	7.5	1.8	2.0	1.00	0	1889	1471	28	16	643
1991/92															
Rubatab (6)	9N-14N	10N-26D	107.0	93.0	9.0	6.0	1.0	1.0	NR††	NR	2359	1457	62	17	2458
1992/93															
Rubatab (8)	17N-3D	17N-4D	107.0	107.0	8.3	6.7	1.7	1.3			2137	1499	43	10	528
Wad Hamid (16)	15N	08N	15.9	16.5	5.7						1525	1270	20	10	1447
1993/94															
Shendi (7)					6.3	5.5	HRB	FP	1.00	0	1033	416	148	4	8779
Rubatab (8)	14-19N	17N-19D	107.0	32.0	8.1	5.0	1.8	1.0	0.90	0	414	181	56	30	329
1994/95															
Rubatab	18-20N	20N-5D		variable	6.4	6.1	2.0	1.1			270	307		11	
Wad Hamid1 (5)	NR	NR		NR	NR	NR	HRB	FP			1192	857	39	-2	
Wad Hamid2 (5)	NR	NR		NR	NR	NR	HW	FP			786	857	-8	-9	

† Numbers in parentheses are the numbers of sites. ‡ N = November; D = December.
§ PF = Participating farmers; NF = Neighboring farmers.
¶ *Numbers in columns represent number of weedings*; HRB = Herbicide; FP = Farmers' practice, HW = Hand-weeding.
# No serious insect pest or disease problems in 1992/93 and 1994/95, thus spraying was not practiced.
†† NR = Not reported.
Source: G. Mohamed (1990c, 1995b); Nourai *et al.* (1990, 1991, 1992, 1993, 1994, 1995); El Sarrag and Ahmed (1993b); El Sarrag *et al.* (1992b, 1994a).

In later seasons, random sampling was followed in areas of similar on-farm research activities. These studies started with emphasis on faba bean, but attempts were made to consider important aspects of the farming systems and their interactions that were expected to influence adoption. These could be constraints within the farm, such as input limitations (water, land and labor), and those outside the farm, such as the institutional role in input supply and policy issues. Farm modelling was regarded as a suitable tool for such analysis. The need for this emerged from the results of the first type of adoption studies on faba bean. For example, the recommended irrigation regime was found to be the least adopted component. It was hypothesized to be so because of system constraints rather than because of the technology performance. Modelling was used to verify this hypothesis and to identify measures that could be taken to enhance adoption.

In later studies other crops, namely, chickpea, lentil and wheat were also included as improved technologies for these crops developed in the area. This enabled the consideration of wider interactions with respect to crops and constraints related to different types of technology.

A linear programming model was employed for the analysis of technology adoption. The model structure was meant to be simple, where different activities of each crop were identified according to the levels of technology and the associated input requirements and benefits. Various technology combinations and their levels were derived from past on-farm trials results. The levels comprised traditional, intermediate and high technology. The model results were expected to show the optimum farm organization with respect to crop areas and technology levels that were feasible, subject to prevailing constraints. Different scenarios were developed to examine the effects of possible relaxation of constraints that were likely to improve adoption. The model provided good insight as to the directions in production that farmers are likely to pursue with different options of institutional services and policy. It also provided quantification of cropping structures and needed interventions. Table 4 shows the procedure for the conduct of adoption studies in food legumes during the period 1988/89–1994/95.

Results

The improved package used for faba bean has already been described above. The recommended irrigation regime calls for 9 to 11 irrigations, but this level was not observed in all farm surveys. The recommended regime was therefore modified to a medium level of 7 irrigations (or more) which is still higher than farmers' levels.

Table 4. Procedure for the conduct of adoption studies in food legumes.

Season	Location	Crop(s)	Technology	Sampling	Sample size
1988/89	South Shendi: Basabeer, Hagar El Asal	Faba bean	Irrigation, sowing date, pest control	Selective	11 farmers
1990/91	Shendi area: Sayal, Messeiktab	Faba bean	Irrigation, sowing date, pest control	Selective	36 farmers
1990/91	Shendi area: Basabeer, Hagar El Asal	Faba bean, other crops	Faba bean package	Random	13 schemes
1990/91	Gezira: Rahad	Faba bean	Crop introduction, production practices	Random, selective	64 farmers
1991/92	Shendi area: Wad Hamid	Faba bean	Faba bean package	Selective	36 farmers
1991/92	Shendi area: Wad Hamid	Faba bean, chickpea, other crops	Faba bean and chickpea packages, other crops	Random	38 schemes
1992/93	Ed-Damer area: Zeidab, Aliab	Faba bean	Faba bean package	Selective	60 farmers
1992/93	Wad Hamid area	Faba bean, chickpea, lentil, wheat, other crops	Packages for faba bean and chickpea, wheat technology and introduction, lentil introduction	Random	15 schemes
1993/94	Shendi area	Faba bean	Faba bean package	Selective	38 farmers
1993/94	Rubatab area	Faba bean, chickpea, lentil, wheat, other crops	Chickpea package, wheat and lentil technology and introduction	Random	15 schemes
1994/95	Shendi area	Faba bean, chickpea, lentil, wheat, other crops	Faba bean package, wheat and lentil technology and introduction	Random	15 schemes

Adoption of recommendations

Studies were carried out in four production schemes (Sayal, Wad Hamid, Zeidab and Aliab) where faba been recommendations had been demonstrated for several years (Ahmed 1991a, 1991b, 1992, 1993a, 1993b, 1995). Across locations and over time, the irrigation regime was the least adopted component of the package (Table 5). Other recommendations, however, were well adopted by farmers. Adopters of the irrigation regime were using a medium level of technology which was lesser than the recommended level and higher than the traditional practice. The alternative was to reduce the area, which was irrational given the fact that marginal returns on land were higher than on irrigation (Faki and Ahmed 1992, 1993). Nonadopters of different components attributed not adopting to the unavailability of inputs (water, pesticides and labor), their high costs and financial difficulties.

Determinants of adoption

Acceptability of a technology is dependent on factors not only related to the technology itself but also to the socioeconomic circumstances of the farmers. The new technology has to be more profitable, its profitability must be known to the farmers, and it should be accessible to them. The on-farm demonstration had already established the profitability of the package. To find out whether the technology was extended, comparison was made between two groups of farmers: the participants and the nonparticipants. The adoption behavior of the two groups is summarized in Table 6.

Except for the earlier study in Sayal Scheme which revealed higher adoption of sowing time and irrigation regime by participant farmers, there was no major difference in the adoption behavior of the two groups. The irrigation technology continued to be the least adopted component for the two groups.

Another factor which could affect adoption behavior is socioeconomic conditions of the farmers, such as the type of their farming system and the ownership of resources. These can affect farmers' adoption behavior by influencing their resource base and accessibility to input and extension information. Adoption rates of different farmer groups are given in Table 7. There were differences amongst farmer groups in the adoption of some technologies. For example, in Shendi area, adoption rates for tenants of the public schemes were relatively higher than those of private farmers. This was partly because most of the earlier on-farm research in that area was conducted in public schemes rather than on private farms. Also, private schemes are dispersed and have weaker extension contacts. Pump owners in Wad Hamid area have higher adoption rates than farmers in the same area, perhaps because pump owners are financially better off than farmers and can afford higher input needed in the improved package.

Table 5. Percentage of farmers adopting various components of faba bean recommended package in different production areas in northern Sudan.

Recommendation	% farmers adopting practices				
	Sayal (36)†	Wad Hamid (36)	Zeidab (30)	Aliab (30)	Shendi (38)
Sowing date	69	98	100	90	69
Irrigation regime	50	36	30	17	31
Insect pest control	92	83			
Weed control			57	85	40

† Numbers in parentheses are the sample sizes.

Table 6. Percentage of participant (PF) and nonparticipant (NF) farmers adopting various components of improved production package in northern Sudan, 1990/91–1994/95.

Season/ Location	% farmers							
	Sowing date		No. of irrigations		Insect pest control		Weed control	
	PF†	NF†	PF	NF	PF	NF	PF	NF
1990/91								
Sayal Scheme	89	43	77	20	88	100		
1991/92								
Wad Hamid	100	95	36	35	100	74		
1992/93								
Zeidab Scheme	56	62	33	29	38	65		
Aliab Scheme	46	64	27	11			100	77
1994/95								
Nile State	37	56	26	9	52	32	52	56

† PF = Participating farmers; NF = Neighboring farmers.

Table 7. Percentage of farmers in different categories adopting various components of the recommended package in different seasons and production systems in northern Sudan, 1990/91–1994/95.

Season/System	% farmers adopting practices: Sowing date	Number of irrigations	Pest control	Weed control
1990/91				
Shendi area				
Public schemes	74	57	100	
Private schemes	56	33	75	
1991/92				
Wad Hamid area				
Pump owners	100	56	100	
Farmers	95	29	75	
1992/93				
Ed-Damer area				
Public schemes	75	18		80
Private schemes	85	35		53
Full-time farmers	82	33		71
Part-time farmers	50	22		67
1993/94				
Shendi area				
Cooperatives	46	100		8
Big schemes	93	62		77
Small schemes	67	70		43
1994/95				
Nile State				
Wad Hamid	39	6	44	50
Basabeer	0	29	0	86
Zeidab	12	18	12	59
Hagar El Asal	0	0	0	100
Sayal	25	40	70	45

Prospects of technology use in pump schemes in northern Sudan

Adoption studies reviewed above revealed different implementation levels of the technology components by farmers. Specific socioeconomic conditions of farmers and the nature of existing production relations and input availability were among the factors that affected technology use. Competition for scarce resources among the crops grown represents a major determinant of technology use. This is particularly true for recommendations on irrigation adoption which is limited by the pump size, energy availability and finance problems. Consideration of constraints within the whole system is crucial for technology adoption.

Linear programming was used to predict farmers' behavior towards crop activities and technology levels (Faki and Ahmed 1993, 1994a, 1994b, 1994c). The model activities reflect production of major crops in the area with emphasis on faba bean, chickpea, lentil and wheat which were the targets of monitoring technology adoption. Different levels of technology were defined for the target crops depending on the state of technology development at the time and the information available on farmers behavior towards those technologies. Three technology levels were identified for faba bean as: (1) the traditional practice (low); (2) the application of seven irrigations and one insecticidal spray (medium); and (3) nine irrigations in addition to two sprays (high). Two technology levels (low and high) were defined for chickpea, lentil and wheat, reflecting the traditional practices and the recommended technology, respectively. The model constraints were land (scheme area), irrigation water (pump capacity) and family labor. Different scenarios were developed in order to examine the effects of possible relaxation of constraints and to reflect institutional and policy options that are likely to affect adoption.

The results of the model in Wad Hamid area are presented in Tables 8 and 9, and that of South Shendi in Table 10. The model results in Table 8 reflect the conflicting perception of pump owners and farmers towards the improved irrigation regime. While farmers who have limited control on irrigation water would like to adopt the high technology, pump owners who have full control on water provision would prefer the medium technology. This is due to fact that irrigation water cost is fully incurred by pump owners only.

Table 8. Optimum allocation of land area to different crop-technology combinations for pump owners and tenant farmers in Wad Hamid.

Crop mix	Land allocation (ha)	
	Pump owners	Farmers
Faba bean: high	0	4.33
Faba bean: medium	4.33	0
Faba bean: low	0	0
Chickpea: high	0.42	0.42
Chickpea: low	0	0
Potato	0.92	0.92

Table 9. Optimum allocation of land area (ha) to different crop-technology combinations under varying land-water resource availability in Wad Hamid.

Crop mix	Scheme size (ha)			50% more water supply
	5.72	8.41	15.14	
Faba bean: low	0	0	0	0
Faba bean: medium	0	5.00	6.22	11.77
Faba bean: high	4.20	1.31	0	0
Chickpea: low	0	0	0	0
Chickpea: high	0	0	0.85	0.85
Potato	1.47	1.47	1.47	1.47
Coriander	0.04	1.06	1.06	1.06

Table 10. Optimum allocation of land area (ha) to different crop-technology combinations for different levels of land resource in Shendi area.

Crop mix	Scheme size (ha)			
	5.97†	5.97‡	8.41	15.14
Faba bean: low	0	0	0	0
Faba bean: medium	0	0	5.6	6.89
Faba bean: high	4.91	4.08	0.92	0
Phaseolus	1.06	1.06	1.06	1.06
Onion	0	0.85	0.85	0.85

† With *Phaseolus* fixed at 1.06 ha.
‡ With onion and *Phaseolus* fixed at 0.85 and 1.06 ha, respectively.

The results in Table 9 show that with increased land availability there would be an expansion in faba bean area with a shift to a lower level of technology. This could be explained by the higher marginal rates of return to land compared to water. However, still the medium technology is being adopted. Farmers would continue to apply less than the recommended number of irrigations, but higher than the traditional number, as long as water represents a constraint to the whole system. Adoption of insect pest control would follow a similar trend to that of water. Chickpea production, on the other hand, would be effected at a high technology level because the marginal value product of the extra irrigation water is substantial in this crop and the water requirement is low.

For South Shendi area, a similar trend to that of Wad Hamid area could be noticed with respect to the technology level (Table 10). With increased land availability, the shift would be towards lower levels of technology use. Still, a medium level of technology in faba bean would be maintained.

For Rubatab area, three versions of the model were developed to accommodate various scheme sizes in the area (small, medium and large). Different scenarios were examined with respect to irrigation water supply which is the major constraints and crop prices that call for policy interventions. The results of the model for Rubatab area are presented in Table 11.

Table 11. Optimum allocation of land area to different crop-technology combinations at different resource levels in Rubatab.

Crop mix	Allocation of land area (ha)							
	Limited minimum area			Relaxed water		Higher wheat and lentil prices		
	Small	Medium	Large	Small	Medium	Small	Medium	Large
Chickpea: high	0.21	5.94	52.99	0.85	1.52	0.85	15.48	0
Chickpea: low	0.64	9.51	0	0	0	0	0	0
Lentil: high	3.78	0.97	63.10	3.78	14.89	0	0.97	0
Lentil: low	0	0	0	0	0	0	0	0
Wheat: high	0	0	0	0	1.68	3.78	1.68	439.08
Wheat: low	0	1.68	211.90	0	0	0	0	0
Lupin	0.64	0.42	8.41	0.64	0.42	0.64	0.42	8.41
Cumin	0.64	0	14.72	0.64	0	0.64	0	14.72

With no restriction on crop areas and constraints, chickpea would dominate the cropping pattern of the three scheme sizes. Its production would be under high technology and, to a lower extent, under low technology levels. This could be due to its higher relative prices, higher yields and low demand for water and labor. Under a realistic situation of minimum crop areas dictated by the need for diversification and risk aversion, and with various scenarios of crop prices and input supply, chickpea was still a highly competitive crop. With restricted chickpea areas, wheat and lentil will compete for area. Their areas depend on their relative prices. High technology would be used in most situations except under the current situation of limited input availability. In all situations, however, irrigation water appears to be the most limiting factor.

From the above modelling analysis, the following can be concluded:

- Conflicting strategies between pump owners and farmers with respect to the level of technology use are because of the current arrangement between them on resource participation. It is time to set a policy so that these traditional arrangements are amended so that clear resource rental terms are established.

- Higher irrigation levels will only be used under limited land availability. As the land resources are increased, the shift would be towards lower levels of technology. On the other hand, as the cost of water provision increases, the chances of using higher levels would be reduced. In both cases, however, medium levels of technology would still be preferred over the traditional practice.
- Under the current situation, wheat and lentil would have low chances to be expanded. Lentil yields were discouragingly low because of adverse conditions. Prices of the two crops would need to rise so that their cultivation is encouraged under high technology levels. This is justified by the interest in increased production of the two crops for self-sufficiency targets.
- Provision of inputs, especially irrigation-related supplies, such as fuel and spare parts for pumps, etc., are important factors in promoting technology use. Efficient extension services are a prerequisite for higher adoption of improved technology.

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Capacity Building and Institutional Development

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Institutional development, for the purpose of enhancing the capabilities of the Agricultural Research Corporation (ARC) in effective technology development and transfer, was a major component of NVRP. Institutional development and technical capacity building included human resource development, establishing research and technology transfer 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: 72 in nondegree training (both short and long-term), 5 in degree training and 312 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 food legumes and wheat 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 food legumes through the support of 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	2	-	-	-		-	3
Short courses†	2	2	-	6	6	21	1	38
Individual training	3	5	1	3	1	4	-	17
Professional visits	2	2	5	-	4	-	1	14
Subtotal	**14**	**6**	**6**	**3**	**10**	**30**	**8**	**86**
Degree training								
(ongoing)				3¶	2¶			5
Workshops/meetings/conferences								
Travelling Workshops‡	3	7	11	6	4	18	21	70
Conferences	-	1	1	4	1	4	3	15
Regional CM§	1	1	8	10	9	9	8	45
National CM	44	28	20	19	20	16	35	182
Subtotal	**25**	**40**	**43**	**42**	**36**	**65**	**59**	**310**

† Including in-country and regional training courses.
‡ Excluding annual travelling workshops in the Sudan in which all NVRP program scientists were involved.
§ CM = Coordination Meeting.
¶ Beginning of M.Sc. program.

In degree training, the five M.Sc. graduates—now members of the research teams of the food legumes program at the ARC—were involved in activities in the fields of agronomy, stress physiology, food legume and wheat 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 food legumes and wheat.

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 food legume and wheat 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 the 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. The developed technology to solve those problems was then 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.

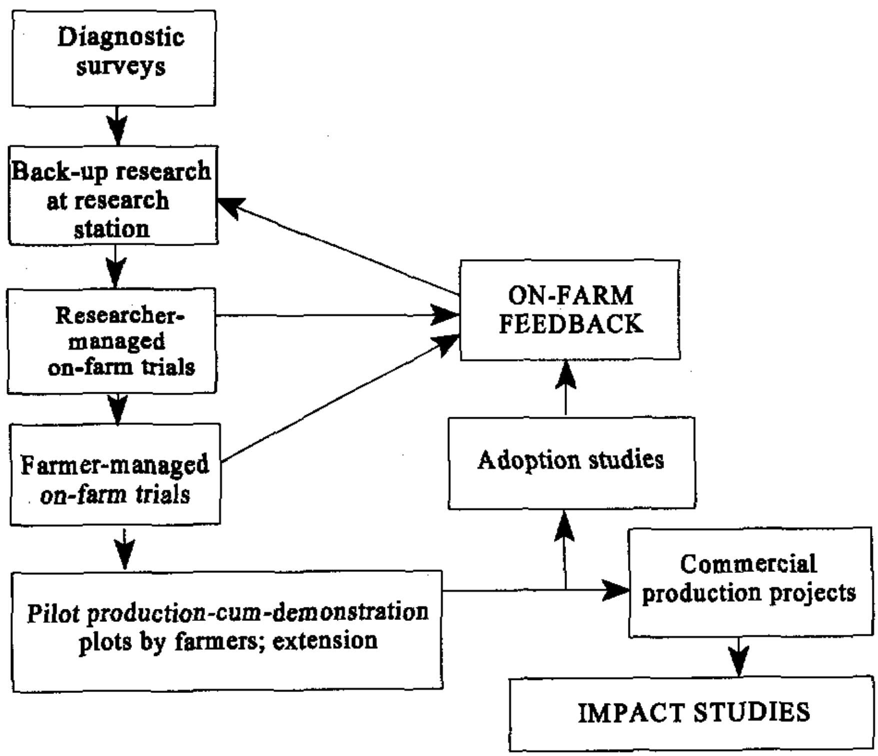

Fig. 1. NVRP strategy for the development and transfer of improved technology.

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) on Faba Beans 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 food legume production areas in the country. The ARC published several extension leaflets through the NVRP support 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 cool-season food legumes and wheat. 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 Netherlands Government. 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 support of the Netherlands Government, 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 importance of cool-season food legumes in the Sudan, which occupy about 70,000 ha, is rising as a result of the escalating meat prices and also as many rural people are settling in towns and cities. Faba bean, in particular, constitutes the main breakfast dish for the mass of Sudanese people. Cool-season food legume crops, which provide a good portion of the daily protein requirements, are the main source for cash to farmers in northern Sudan. Their important role to sustain soil fertility in the cropping system, as a result of the biological N_2-fixation and consequently the residual effect on subsequent crops, cannot be overlooked. Thus their role in agricultural production is expected to increase in the future.

Most of the information presented in this review was generated at Hudeiba Research Station in the River Nile State. The bulk of cool-season food legume production is either in the southern part of that state or far away in the Northern State which constitutes a different agroecological zone. With the recent establishment of Dongola Research Station, intensifying back-up research there, mainly on faba bean, in order to develop the appropriate technology suitable for that zone is well-grounded. This also holds for Jebel Marra area which is another different agroecological zone.

The studies carried out to quantify farmers' adoption of the improved technologies indicated that the recommended irrigation regime was the least adopted for various reasons. This necessitates the need to breed improved cultivars that could tolerate limited moisture application.

Most of the on-farm activities were demonstrated in Rubatab/Shendi areas. It is now high time to extend such work to other potential areas like Merawi/Karima, Upper Atbara River, Jebel Marra and Hawata areas where sizeable amounts of the food legumes are produced.

The bulk of chickpea in Sudan is produced under residual moisture conditions in Wad Hamid/Salawa and Hawata areas. It is felt that more work is needed to develop the appropriate technology suitable for this basin irrigation system.

Work on biological nitrogen fixation (BNF) has been generally weak. It is recommended to direct more research toward the production of efficient *Rhizobium* strains and large-scale production of rhizobial inocula for the farmers.

At the beginning, the release of improved cultivars was slow, especially for lentil; thus, this activity should be enhanced as the program includes a wide range of adapted high-yielding germplasm through NVRP efforts. Lentil production has also suffered a setback in the past two seasons. It would be appropriate to diagnose the reasons behind this problem. There is also a need to refine the production factors contributing to the productivity of lentil in the Sudan.

The seed production activity is very poor in legumes and that is why most of the newly released cultivars did not reach the farmers. This activity should receive due attention by the Seed Production Unit which has been newly created at the ARC. All of the eight food legume cultivars, newly released during the NVRP period, should be given priority in seed multiplication in order to make high quality seeds available to the farmers.

Germplasm collection campaigns for landraces should be properly organized especially for faba bean. In fact, all the released faba bean genotypes are either direct selections from or crosses with landraces.

Jebel Marra area in Western Sudan is unique in that it has some locations having an altitude of 2000 m above sea level. These locations have moderately cool weather all year and, as such, could be used as off-season growing sites by breeders to enhance the release of improved genotypes.

In northern Sudan, where most of the grain legumes are produced, there is a lack of well defined crop rotations which creates many problems. For example, the continuous cropping of one legume in one area helps in building up diseases that could sometimes be disastrous. Thus, research should be directed towards establishing proper cropping sequences for the sake of bettering sustainability of production.

Food legume production is now extending to new marginal lands which have their own problems. This situation necessitates initiating research in these marginal areas to develop suitable production technologies.

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Weeds, insect pests and pathogens form a major constraint against production. Work on such problems should concentrate on integrated management. Weed scientists should be alert to the serious weed, *Orobanche*, so that the damaging species are not imported to the Sudan.

Practically all cool-season food legume research in the Sudan is now undertaken by the ARC. It is felt that collaboration should be sought with other centers, especially the regional universities and in particular the Faculty of Agriculture in Dongola to decentralize some of these efforts to major produciton areas where the ARC does not have research stations. Through the efforts within such cooperation, the production and improvement of these important crops can be enhanced, thus, approaching the ultimate goal of increasing the productivity of these crops in the different agroecological zones in the Sudan and enhancing the socioeconomic status of the Sudanese farmers.

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Recommendations for faba bean production in nontraditional areas.

Recommendations for lentil production in northern Sudan.

Recommendations for chickpea production in northern Sudan.

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