Assessment of wheat yield gap in the Mediterranean:

Case studies from Morocco, Syria, and Turkey

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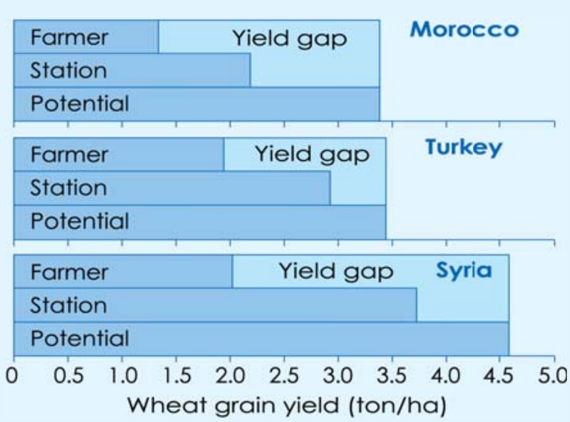

COMPREHENSIVE Assessment Of water management in agriculture

ICARDA International Center for Agricultural Research in the Dry Areas

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ASSESSMENT OF WHEAT YIELD GAP IN THE MEDITERRANEAN:

CASE STUDIES FROM MOROCCO, SYRIA, AND TURKEY

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ABSTRACT

The WANA region has 137 million hectares of arable land of which 35 million hectares are sown to wheat, mostly grown under rainfed conditions with productivity in the range of 0.5–1.5 t/ha. Wheat products are integral part of Mediterranean diet but there is already a deficit of 8 Mt of wheat which is expected to rise as population grows and people become more affluent.

In order to increase the production, there is a need to use improved land and water management practices, together with improved cultivars, to sustainably meet the increasing demand. The climate of WANA is characterized by cool (in lowlands) to cold (in highlands) winters and warm to hot arid summers with conditions differing considerably by topography and by continental (West Asia) or maritime (North Africa) effects. Precipitation is variable in space and time and often deficient in amount. Three zones - Morocco in North Africa for mild low and mild highlands, Syria in west Asia for mild lowland, and Turkey in west Asia for cold highlands were chosen for this study, and were further classified on the basis of precipitation amounts they receive. It was assumed that the wheat yields of on-farm trials by ICARDA and its national partners, state farms and research stations were higher than those achieved by the farmers mainly because of improved land and water management and superior cultivar selection. Further, CropSyst model was applied to estimate the potential yields in the zones when there was no nutrient stress. At Morocco's site with rainfall in the range of 250-350 mm, the average (1995-2004) crop yield on farmer's croplands (0-5500 kg/ha) was less than average yield measured at research station/on-farm demonstration (0-7300 kg/ha) and simulated potential yield (410-11080 kg/ha).

The main reasons identified for the yield gaps between farmers and research station/on-farm demonstrations were low fertilizer inputs, especially during wet years, and poor soil-water management during dry years. At Syrian site, the average (1994-2005) crop yield on farmer's croplands (1555-2780 kg/ha) was less than average yield measured at research station (2760-4540 kg/ha) and simulated potential yield (3610-5870 kg/ha). The farmers' yields from fields under supplemental irrigation remained low because of poor management of irrigation water, whereas, yields on research stations and on-farm demonstration fields under supplemental irrigation were higher and varied little from year to year. The yields of rainfed fields were, however, lower than those under supplemental irrigation. The cultivars used at research station and on-farm demonstration farms (Cham 3 and Cham5) produced higher crop yields than those used by the farmers. The variation in simulated potential yield was attributed to variation in the growing season rainfall. At the Turkish site, the average (1990-2001) crop yield on farmer's croplands (1675-1890 kg/ha) was less than average yield measured at research station (2365-3890 kg/ha) and simulated potential yield (2630-5915 kg/ha). The yields in this zone are lower than those in Morocco and Syria because these are dry marginal rainfed areas with degraded soil nutrient and water resources. Improvement in yields is possible with improved agronomic management practices and cultivars. The yields of coastal areas receiving higher rainfall were higher than dry areas but yields of mountainous zones receiving high rainfall were low because of steep slopes and poor soil, water and nutrient management.

The research finds that wheat yields can be increased by 1.6-2.5 times in Morocco, 1.7-2.0 times in Syria and 1.5-3.0 times in Turkey. Thus, there is large potential for increase in the wheat yields in the WANA region and improved management practices along with improved varieties and supplemental irrigation can close the wide gaps between farmers' yields and those achieved at research stations and on-farm demonstration trials. Further improvements will come from improved soil-water and nutrient management practices than those already practiced at the research stations and on-farm demonstrations.

1 INTRODUCTION

The West Asia and North Africa (WANA) region is an enormous and diverse area, with Morocco in the west, Pakistan and Afghanistan in the east, Turkey and Iran in the north, and Ethiopia and Sudan in the south. The WANA region includes: Afghanistan, Algeria, Bahrain, Djibouti, Egypt, Eritrea, Ethiopia, Gaza Strip, Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Pakistan, Qatar, Saudi Arabia, Somalia, Sudan, Syria, Tunisia, Turkey, United Arab Emirates, and Yemen. Most of the agricultural area of WANA is rainfed and a large proportion of the region's agricultural livelihoods are based on dryland farming systems, particularly in Afghanistan, Algeria, Iran, Jordan, Morocco, Sudan, Syria, Tunisia, Turkey, and Yemen, with a variable rainfall in the range of 200–600mm (Figure 1).

Most calories and protein in human diets in WANA come from plant sources – mainly cereals with some pulses – in sharp contrast with the industrialized countries, where major protein sources are meat based. Diets have improved in most of WANA over the last two decades, but still lag behind in the quantity and quality of protein. The WANA region has about 137 million hectares of arable land, of which 35 million hectares are sown to wheat (FAOSTAT 2002). About 20–30% of wheat is irrigated and the rest is under rainfed conditions. Productivity of wheat in rainfed areas is still low (0.5–1.5 t/ha). However, wheat production in the region increased from 47 Mt in 1985 to 81 Mt in 2004 (FAOSTAT 2004), which is quite a large increase and brought certain countries self-sufficiency in wheat production. this was primarily achieved by improved management practices combined with the use of improved varieties and irrigation.

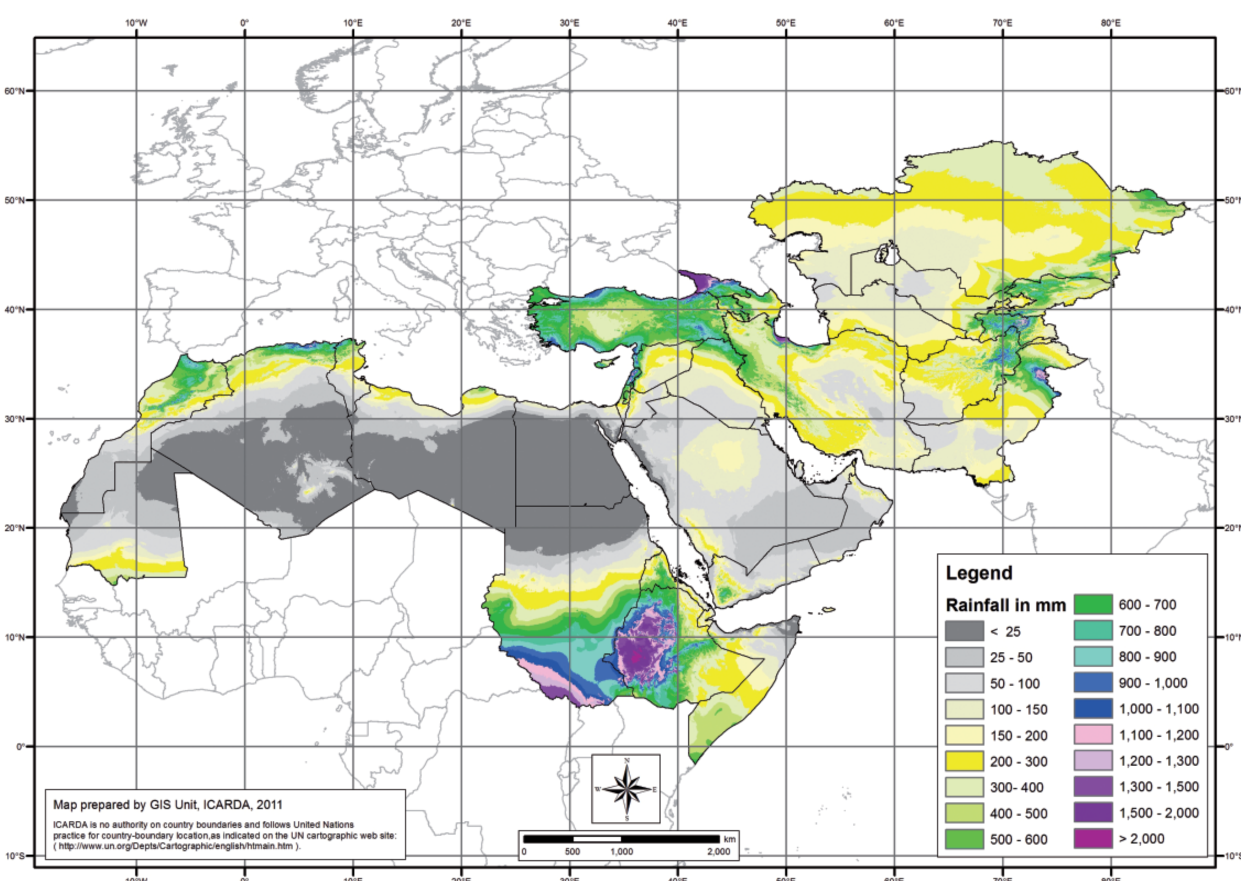

Figure 1. Rainfall zones of CWANA region

However, most countries of the region are net importers of wheat, except Syria and Turkey, which are the only net exporters of wheat in the region. About 685 million people live in the region, with a food deficit of 8 Mt of wheat (FAOSTAT 2004). Therefore agricultural growth for wheat needs to be kept at or above the level of population growth to meet increasing demand. There is a need to use improved production practices, together with improved cultivars, to meet the increasing demand for food.

Research at the International Center for Agricultural Research in the Dry Areas (ICARDA), and regional and national research institutes, has led to the development of appropriate technologies and management options for increased water use efficiency, including crop and soil management practices, and improved germplasm and on-farm water management options. One option with potential to provide large productivity gains is the use of supplemental irrigation in rainfed crops, provided that water is available for irrigation. However, many of these technologies are not widely implemented or are not seen as feasible by farmers. This can be attributed to a number of constraints, including technical, socio-economic, and policy, but most importantly the lack of community participation in the development and implementation of improved technologies. Supplemental irrigation of wheat in rainfed areas where limited water sources are available can boost crop productivity by 3 to 4 times; irrigated areas currently provide 50% of wheat production in the region (Oweis 1997).

2 MAJOR RAINFED REGIONS (ARID AND SEMI-ARID)

Wheat is mostly grown in the 300–600-mm rainfall zone throughout the WANA region. While irrigated areas may produce far higher yields and marketable surpluses, the overall value of dryland production is much greater than its market value due to social and other indirect benefits associated with these systems. Rainfed production is dependent on low and extremely variable rainfall and, therefore, productivity is low and variable. This is further affected by frequent droughts and continuing land degradation. Research has focused on ways to improve the water availability to crops in rainfed areas. Given the limited ability to utilize new sources of water in the region a major challenge is to sustainably enhance the productivity by improving the efficiency of on-farm use of the scarce water resources. Supplemental irrigation can effectively support rainfed agriculture in many countries of the WANA region. Amongst the most relevant are those countries with extensive rainfed areas including Algeria, Morocco, and Tunisia in North Africa and Iraq, Jordan, Pakistan, Syria, Turkey, and Yemen in West Asia.

Consecutive droughts in Morocco and Tunisia have forced decision makers to look for more efficient options for agricultural water use. Both countries have contacted ICARDA seeking assistance in research on the potential use of supplemental irrigation as a means to improve water use efficiency under the recent severe drought. In Syria and Iraq, to same extent as a result of research conducted by ICARDA in collaboration with National Agricultural Research Systems (NARS), policies are being framed to support the implementation of supplemental irrigation to enhance rainfed agriculture and to better use the limited available water resources. Supplemental irrigation is also a potential intervention for alleviating drought spills, improve fields and water productivity (Oweis, 1997).

3 AGRO-ECOLOGICAL CHARACTERIZATION AND PRODUCTION SYSTEMS

The soils of the WANA region are diverse, and seven major soil groups account for 86% of the abovementioned rainfed areas. Agricultural soils of the region are predominantly derived from limestone residuum, and are thus calcareous with very variable texture, depth, slope, and stoniness (Kassam 1988). The significance of these soils has been discussed from an agronomic viewpoint, with particular reference to the effects of high pH on the availability of phosphorus and micronutrients (Cooper et al. 1987). In general soil organic matter levels are low, and in some soils, particularly the salty and sandy, structural stability is poor and leads to surface crusting by rainfall and serious problems in seedling emergence and excess surface runoff. Phosphate and nitrogen (N) deficiencies are also common throughout the WANA region. Adverse responses to micronutrients deficiency have been observed but are not widespread in rainfed agriculture. Boron toxicity is a problem in some parts of WANA, e.g. major rainfed wheat-growing areas in the central plateau of Turkey (Harris 1995).

The climate of WANA is characterized by cool (in lowlands) to cold (in highlands) winters and warm to hot arid summers. Locally, conditions differ considerably by topography and by continental (West Asia) or maritime (North Africa) effects. Precipitation, whether as rain or snow in highlands areas of West Asia, is variable in space and time and often deficient in amount. In general, coastal areas are wettest, and the amount decreases rapidly with distance towards inland. On average, rain starts in fall (September–October), reaches a maximum in January or February, and decreases rapidly until April (in lowlands) or May or June (in highlands). However, year-to-year variability in rainfall distribution is often experienced. The first rains may be delayed by up to 2–3 months, with a similar uncertainty for the time the rainy season ends. The agro-ecological zones of the region are discussed in section 5 of this report.

Rainfall and other sources of water in combination with temperature, soils, and socio-economic factors are the major determinants for the multiplicity and complexity of the production systems. These systems are mainly based on cereals (barley in drier, wheat in more favorable areas) and legumes (lentil, chickpea, and faba bean and small amounts of forages) in rainfed areas, and on summer crops in irrigated areas (FAOSTAT 2004). In the region, integration with livestock, mainly sheep and goats, is important for nutrient cycling and fertilization of soils, which eventually improve the soil water use (Cooper et al. 1987). Fallow is still practiced mostly in high-elevation cold areas in rotation with cereals. Introduction of forage legume production in rotation with barley hasproved successful but adoption rate is still low due to the socio-economic conditions of the farmers (Osman et al. 1990). All winter-sown crops are, because of their small canopy and low evaporative demands in winter months, increasingly exposed to drought in the spring or early summer when evaporative demand is high, mostly at flowering and grain filling stages, and are largely dependent on the stored soil moisture to complete their growth cycles (Cooper et al. 1987). Intercropping of cereals or legumes between young olive trees (until fruit production) is becoming a common practice in the wetter areas because of economic considerations by farmers. Almost 30% of the abovementioned cropped area in the WANA is now irrigated, and over half the region's crop production is produced under irrigation, but it is unlikely that such expansion in production through irrigation can be sustained without proper management strategies.

In accordance with the terminology developed by Dixon et al. (2001), the following 'model' types of wheat-based systems occur in the non-tropical drylands of the WANA region:

Rainfed mixed: Highly diversified systems, with a wide range of rainfed crops, including tree crops (olives, fruits, and nuts) and field crops (mainly wheat, barley, lentils, chickpeas, potatoes, sugar beet, and faba beans). Terracing is common in hilly areas. Seasonal interaction with livestock, mainly sheep and goats, and use of crop residues and other fodder are common practices.

Dryland mixed: Less diverse than the rainfed mixed system, with barley and wheat as main crops grown in alternation with single or double-season fallows or with legumes (lentil and chickpea). Interactions with small livestock systems mainly take the form of barley and stubble grazing and are stronger than in the rainfed system.

Highland mixed: Dualistic land-use systems at higher altitude (1500–3000 m) with cropping pattern dominated by wheat and barley on arable land, and communal grazing on marginal land; mostly monoculture with occasional fallow, terracing is common, and sometimes supplemental irrigation.

Irrigated: Traditionally, along major river-systems downstream of dams, but recently also based on groundwater extraction. Systems can both be large-scale or small-scale, and include a wide variety of crops and cropping patterns depending on temperature regime.

A synoptic description of the non-irrigated, non-tropical dryland agricultural systems in which wheat is either the dominant or an important component of the cropping systems is given in Table 1.

The first system is common in the mountain areas of Morocco and to a lesser extent Turkey. The second system is very common on the Anatolian Plateau in Turkey. The third system is common to Morocco, Syria, and Turkey. The fourth system is common in Syria and Morocco.

The general framework for situating wheat crop zones in relation to rainfall is shown in Figure 2.

Based on case studies undertaken in the framework of the Mediterranean Rainfed Agriculture Technologies Evaluation (MEDRATE) project (De Pauw 2004), Table 2 provides a synthesis of the key characteristics of the production systems in major wheat-growing areas of Morocco, Syria, and Turkey.

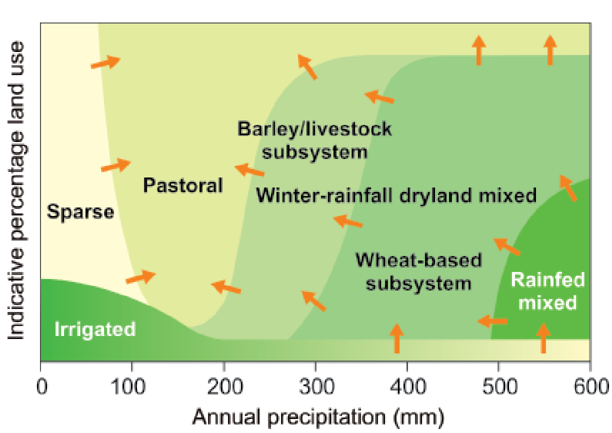

Figure 2. General 'ICARDA' framework for relationship between production systems and precipitation (ICARD, 1989).

4. METHODOLOGY FOR ASSESSING POTENTIAL YIELDS AND YIELD GAP

The total area under wheat was classified into three zones (with selected examples): Morocco in North Africa for mild low and mild highlands, Syria in west Asia for mild lowland, and Turkey in west Asia for cold highlands. The agro-climatic regions/zones within each country are given below:

Morocco: Rainfall zones are given in summary as follows (Figure 3).

Humid: > 600mm mean annual rainfall (northwest; Loukos)

Semi-humid: 450–600mm mean annual rainfall (northeast; Fes)

Semi-arid to semi-humid: 350–450mm mean annual rainfall (middle north; Marchouch, Rabat)

Semi-arid: 250–350mm mean annual rainfall (middle south; Chaouia-Doukkala, Settat)

Arid: < 250mm mean annual rainfall (south; Tessout, Marrakech; irrigated)

In the first case, the data from ICARDA durum wheat breeders in the above regions were used to calculate the yield gaps on the basis of farmers' yields around the research stations. These were compared with research station.

In the second case, a cropping systems simulation model (CropSyst–Stockle et al. 1994; Stockle and Nelson 1994) was used with the agro-climatic data from two distinct regions, Tadla (irrigated) and Settat (rainfed), from the semi-arid zone of Morocco with 250–350mm rainfall. This was used to identify the wheat yield gap during 1994–2003 cropping seasons on the basis of district/province yield means compared with potential yields from research stations and crop simulations.

Syria: The country was divided into five agricultural stability zones, according to the average annual rainfall. The zones are defined in terms of suitability for rainfed crop production, and to some extent the probability of rainfall (Figure 4).

Table 1. Important agro-ecological systems and associated land use and management practices with problems, challenges, and opportunities in WANA.

Agro-ecology	Land use and management practices	Problems and challenges	Development priorities
Highland mixed agricultural system			
Altitude 1500–3500 m; Precipitation: 400–600mm; Growing Degree Days (GDD): 2500–4000; one short growing season limited by moisture and temperature; frost risk varies according to region and elevation	Dualistic land use with cropping pattern dominated by wheat and barley on arable land, and communal grazing on marginal land. Mostly monoculture with occasional fallow, terracing common and sometimes supplemental irrigation.	Vulnerable to rainfall variability and drought. Overgrazing accompanied by land and vegetation degradation. Fertility decline by continuous cropping with low nutrient return. Isolation and poor access to markets, low producer prices, degrading farm structures (e.g. terraces). Considerable out-migration.	Reduction of soil degradation through watershed management and better integration of crops and livestock. Effective regulation of common grazing resources. Diversification of livelihoods through off-farm income.
Small-scale cereal–livestock agricultural system			
Altitude: 800–1300 m; Temperate, subcontinental thermal climate, precipitation: 200–600mm; GDD: 3000–5000	Wheat and barley are the main crops, with sheep and goats as main livestock, although many farms may have some cattle. Barley mostly used for livestock feed or export. Crop livestock integration, through stubble grazing, foraging on fallow land and uncultivable grazing areas is common. Farms under private smallholder ownership, fairly productive, diversified, and well managed.	Vulnerable to rainfall variability and drought. Small, often uneconomical, family farms. Overgrazing on the communal ranges resulting in vegetation degradation and low livestock productivity.	Land reform to create larger, more viable farm units.
Rainfed mixed agricultural system			
Altitude: 0–1000 m; Subtropical thermal climate with winter rainfall; precipitation: 400–800mm; GDD: 5500–7000	Highly diversified system, with a wide range of rainfed crops, including tree crops (olives, fruits, and nuts) and field crops (mainly wheat, barley, lentils, chickpeas, potatoes, sugar beet, and faba beans). Terracing common in hilly areas. Seasonal interaction with livestock, mainly sheep and goats, in use of crop residues and other fodder.	High population pressure combined with shortage of quality agricultural land.	Livelihood diversification through off-farm income. Exit strategies from agriculture. Crop diversification through supplemental irrigation and protected environments, such as plastic greenhouses and tunnels. Land reform to create larger, more commercial farms.
Winter-rainfall dryland mixed agricultural system			
Altitude: 0–800 m; Subtropical thermal climate with winter rainfall; precipitation: 200–600mm; GDD: 5500–7500	Less diverse than the rainfed mixed system, with barley and wheat as main crops grown in alternation with single or double-season fallows or with legumes (lentil and chickpea). Interactions with small livestock systems mainly take the form of barley and stubble grazing and are stronger than in the previous system.	Particularly vulnerable to rainfall variability and drought. Drier parts of the system are vulnerable to wind erosion. The system is increasingly unable to accommodate growing populations and, as a result, migration to urban areas and reliance on off-farm income increases.	Technologies for water conservation (water harvesting) and soil conservation (zero or minimum tillage). New crop varieties with short growth cycles and high drought tolerance. Watershed-based regulatory frameworks for access to and use of scarce land and water resources. Fodder shrubs for intensifying the livestock component.

Source: De Pauw, E. 2004. Management of dryland and desert areas. Encyclopedia for Life Support Systems. UNESCO – EOLSS Publishers (http://www.eolss.net).

Table 2. Key indicators of the production systems in wheat-growing areas of Morocco, Syria, and Turkey.

Theme	Factor	Morocco Chaouia	Syria NW	Turkey Ankara
Crop production	Yield levels	M	M, H	M, H
	Input use -Improved varieties -Fertilizer use -Weed, pest, and disease control -Mechanization	 M H L H	 M M M M, H	 M H M H
Animal production	-Intensity of production -Interaction with cropping systems	L H	L H	M, H H
Socio-economic features	-Road infrastructure and market access -Subsistence -Subsidies -Population in agriculture -Farm sizes -Population growth -Out-migration	M M M H L H H	H M, L M M L H M	H M L L L H N
Environment	Drought impact	H	M, H	M

Source: (De Pauw 2004).

Symbols used:

1. Yield levels: L: low; M: medium; H: high, in comparison to yield levels achieved under high input conditions.
2. Improved varieties: L: local varieties; M: mixture of land races and improved varieties; H: improved varieties.
3. Fertilizer use: L: low (fertility restoration by fallow mainly); M: organic/some mineral fertilizer below recommended levels; H: high.
4. Weed, pest, and disease control: L: poor; M: some; H: high.
5. Mechanization: L: low, mainly animal traction; M: medium (some tractor-driven operations); H: land management and harvesting.
6. Animal production intensity: L: extensive grazing mainly; M: grazing + feedstock fattening, or dairy, improved pastures; H: industrial production (pigs, poultry, and cattle)
7. Interaction with cropping systems: L: low (mainly manure disposal); M: barley and fodder crops for livestock; H: complementary use of high-potential and marginal lands, e.g. stubble grazing, barley and fodder feeding, feed blocks, and use of manure on farms.
8. Road infrastructure and market access: L: inadequate for rapid access from the farm gate to local and distant markets; M: rapid access between local and distant markets, but not to the farm gate; H: rapid access to major markets from the farm gate.
9. Subsistence: L: most produce sold to markets; M: substantial retention for own consumption; H: most of the produce consumed by the producers.
10. Subsidies: L: none; M: some, e.g. in the form of controlled prices and subsidized equipment; H: high price or income support, infrastructural works.
11. Population in agriculture: population employed in agriculture (L: small proportion of the rural population (sub-urbanized countryside); M: high proportion of the rural population, but not majority; H: majority of rural population employed in agriculture.
12. Farm sizes: L: small (< 20 ha); M: medium (20–50 ha); L: large (> 50 ha)
13. Population growth: L: stable or declining; M: moderate (< 2%); H: high (> 2%).
14. Out-migration: Rural to urban migration; L: low or small in-migration; M: out-migration in step with population growth; H: out-migration exceeds population growth; N: strong in-migration.
15. Drought impact: L: effects attenuated by high rainfall, low rainfall variability, or irrigation; M: moderate impact in the form of production declines; H: high impact in the form of crop failure.

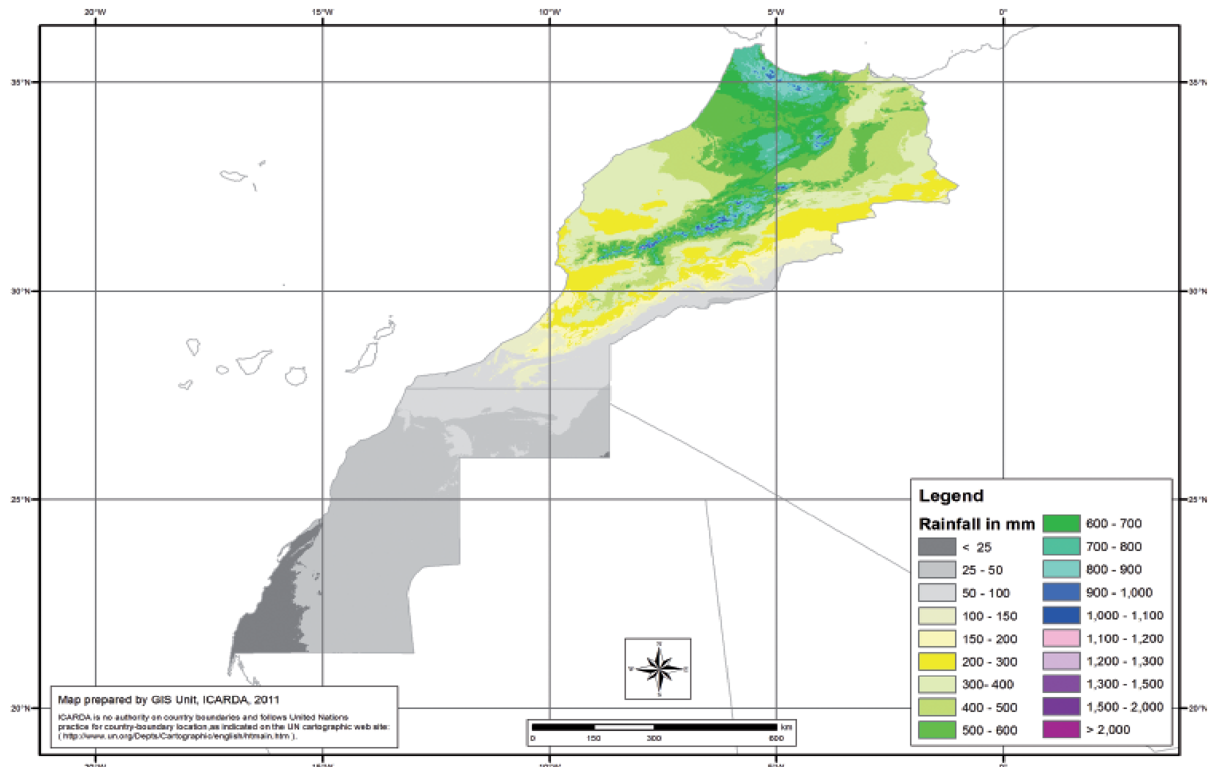

Figure 3. Rainfall zones of Morocco.

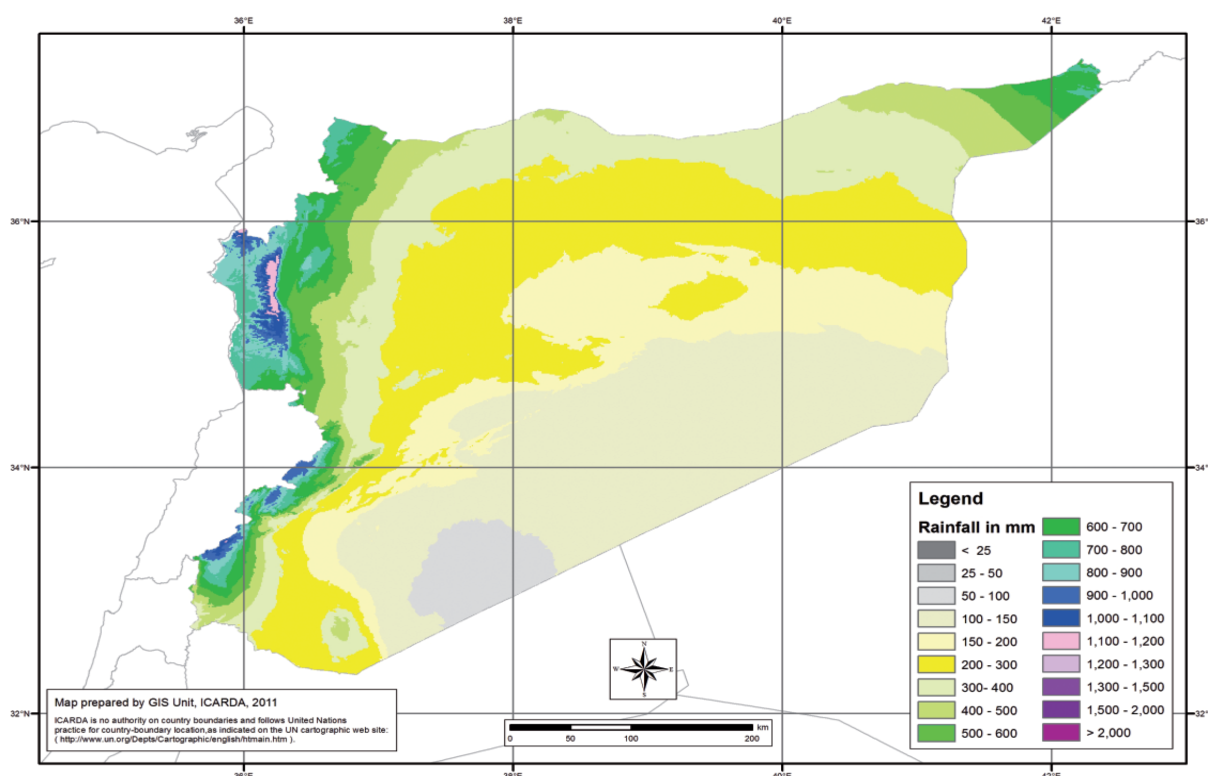

Figure 4. Rainfall zones of Syria.

Zone 1: Annual average rainfall > 350mm. The zone is divided into two areas: A. Areas with an annual average rainfall > 600mm where rainfed crops can be grown successfully. B. Areas with an annual average rainfall of 350–600mm, but ≥ 300mm during two-thirds of the monitored years, and where it is possible to grow two successful crops every three years. The main crops are wheat, legumes, and summer crops such as melon and watermelon. The area of this zone is 2698000 ha, accounting for 14.6% of the national area.

Zone 2: Annual rainfall of 250–350 mm during no less than two-thirds of the monitored years. It is possible to grow two barley crops every three years. Beside barley, wheat, and legumes, summer crops are also grown. The 2 473 000 ha of this zone represent 13.4% of the national area.

Zone 3: Annual rainfall of 250–350 mm with ≥ 250 mm rainfall during half of the monitored years. It is possible to grow one or two crops every three years. The main crop is barley but legumes may also be grown. The 1 306 000 ha of this zone represent 7.1% of the total national area.

Zone 4: A marginal zone between the arable zones and the desert zone with an annual rainfall of 200–250 mm and ≥ 200 mm during half of the monitored years. This zone is suitable only for barley or permanent grazing. The 1 823 000 ha of this zone represent 9.8% of the national area.

Zone 5: Desert and steppe zone. This area covers the rest of the country and is not suitable for rainfed cropping; the 10 218 000 ha of this zone accounts for 55.1% of the total national area. There are some areas in this zone adjacent to rivers, which permit irrigated agriculture, but most of this zone provides only sparse natural rangeland. As rainfall decreases towards the interior, the area becomes desert.

In the first case, the data from the ICARDA durum wheat breeder in Zones 1 and 2 (major rainfed wheat-growing areas) and one example from irrigated area were used to calculate the yield gaps by comparing farmers' yields around the research stations to research station yields.

In the second case, the data from General Consortium for Scientific Agricultural Research (GCSAR) for durum and bread wheat cultivars from Zone 1 (mean of Zones 1a and 1b) and Zone 2 under rainfed and irrigated areas across all zones as mean data from eight sites were used. The yield gaps were calculated by comparing farmers' yields around the stations and/or district/province yields from statistics (FAOSTAT 2003) with yields of on-farm trials and research stations.

In the third case, Zone 1b, which is a major wheat production area of Syria, the CropSyst model was used with the agro-climatic data of Tel Hadya Research Station (ICARDA) to identify the wheat yield gap during 1994–2004 cropping seasons. The yields of Aleppo farmers were compared with yields from research stations and those calculated from crop simulations.

Turkey: Has nine agro-climatic regions shows the types of wheat grown as following (long-term rainfall means are given in Figure 5):

Central Anatolia (north): Dry-cold regions with 300–500 mm of rainfall, –18°C (minimum) in winter, 40°C (maximum) in summer. Winter and winter-facultative wheats.

Central Anatolia (east): Dry and very cold regions with 400–500mm of rainfall, –25°C in winter, 40°C in summer. True winter wheats only.

Central Anatolia (south): Dry-cold regions with 250–500mm of rainfall, –20°C in winter, 40°C in summer. Winter and winter-facultative wheats.

Southeast Anatolia: Low rainfall and very warm regions with 200–500mm of rainfall, –10°C in winter, 30–45°C in summer, very dry summers. Winter-facultative and spring wheats.

Eastern Anatolia: Wet but cold regions with 450–600mm of rainfall, –30°C in winter, 35°C in summer. Only true winter wheat.

Aegean region: High rainfall and warm regions with 400–600mm of rainfall, 5°C in winter, 40° in summer, high relative humidity in summer up to 60%. Spring wheat only.

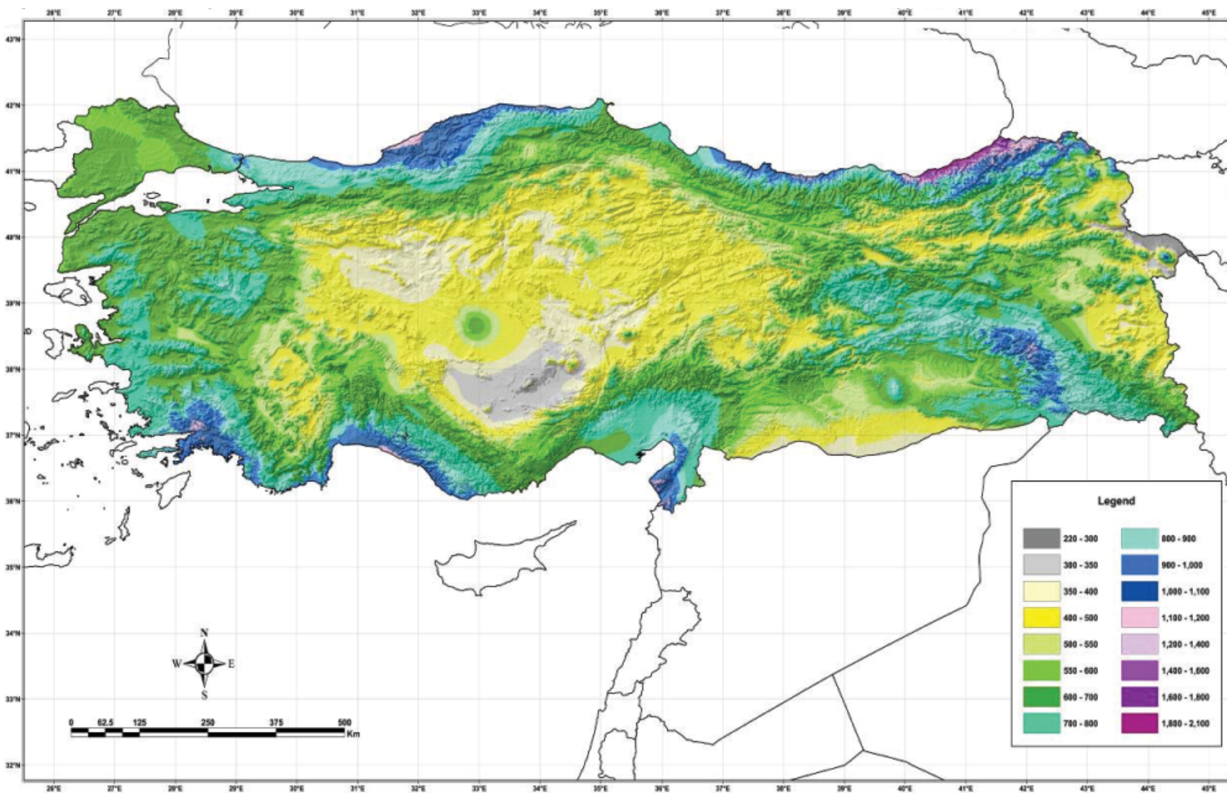

Figure 5. Rainfall zones of Turkey.

Marmara region: High rainfall and warm regions with 500–600mm of rainfall, 5°C in winter, 40°C in summer, high relative humidity in summer up to 60–80%. Winter, winter-facultative, and spring wheats.

Mediterranean region: High rainfall and warm regions with 500–600mm of rainfall, 10°C in winter, 40°C in summer, high relative humidity in summer up to 70–80%. Spring wheat.

Black Sea: High rainfall and warm regions with 600–1000mm of rainfall, 5°C in winter, 30°C in summer, high relative humidity in summer up to 80%. Winter-facultative and spring wheats.

There were two steps followed for the data evaluation of the wheat yield gap and potentials for improvement of sustainable wheat production.

<u>In the first case,</u> the first step was data from Central Research for Field Crops Institute (CRIFC) for all regions was considered for years 1990–2001 to show mean wheat yield increases by research station over the district/province yields. In the second step, the mean wheat yields from the most important wheat-growing areas in Central Anatolia (north, east, and south), Southeastern Anatolia, and Eastern Anatolia regions were used to calculate the yield gaps from mean district/province yields compared to the highest yields of state farms and research stations.

<u>In the second case,</u> the CropSyst model was used with the agro-climatic data of Ankara Rural Services Research Institute to identify wheat yield gap during 1991/92–2000/01 cropping seasons. The mean district/province yields from Central Anatolia (mean of north, east, and south), which is a major wheat production area of Turkey, were compared with potential yields from state farms, research stations, and crop simulations.

For the yield gap analysis to adequately represent the region, three different levels of classification were used as follows.

4.1 Farmers' yields

These data were obtained from farmers' fields in the vicinity of the on-farm yield trials conducted by researchers with participation of farmers (SCBS 1998; MARASTAT 2004; Pala et al. 2004; MADRPM 2005). The mean yields under farmers' conditions with local practices were recorded and further averaged over the years, and then compared with the potential yields (on-farm, research stations, and simulated yields) to estimate yield gaps (for the first case of Morocco and in the first, second, and third cases of Syria).

Historical records of the data on production and productivity of crops for the region were obtained from agricultural statistics. Total production was divided by the total area under the crop in the province to calculate the provincial average yield. Further, the average yields of each zone/region of the respective countries were calculated from average yields of their relevant provinces. Average yields were then further averaged over the years as province/region yields and compared with the yields from state farms and research stations (for both cases of Turkey) or from research stations (Settat region) and on-farm demonstrations (Tadla region) for the second case of Morocco.

Soil and crop management by farmers:

In Morocco, two contrasting pilot areas were chosen in order to determine the evolution of bread wheat grain yield and yield gap as given above. Farmers' practices are summarized as follows:

In Settat, most farmers practice low input traditional farming. It consists of one plowing operation before planting followed by broadcasting of seeds (200 kg/ha) and covering them with an offset disk. At the end of the growing season, wheat is harvested with a combine, or manually on very small and hilly plots. Usually, fertilizers are applied before sowing but in very low quantities: 0–30 kg/ha N, P2O5, and potassium (K). Small amounts of N are added at stem elongation, if it rains. Chemical (large farms) and manual (small farms) weed control is practiced but usually late in the season. Thus weeds are able to compete with wheat for the limited available soil moisture until the chemical is applied. Conservation tillage and chemical fallow technologies have not yet been adopted.

In Tadla, seedbed preparation, seeding method and rate, and harvesting technique are the same as used in the on-station production plots in Settat. However, higher inorganic inputs are used relative to other regions. In fact, for fertilizers, the rates (kg/ha) were 180–240 of N, 120 of P, and 120 of K. N was applied before planting, during tillering, during stem elongation, and sometimes even at anthesis. New cultivars are tested and certified seeds are sown. Weeds and other pests (fungi and insects) were controlled chemically. Wheat was irrigated just after sowing, during tillering, during stem elongation, and at heading.

In Syria, rainfed (Zones 1 and 2) and irrigated regions were used to determine the evolution of durum and bread wheat grain yield and yield gaps as mentioned above. Farmers' practices are summarized as follows:

Wheat-summer crop and wheat–chickpea rotation is used by most farmers in Zones 1a and 1b, but wheat–lentil rotation is common in Zones 1b and 2. Cultivation consists of one plowing operation by moldboard or disk plow in summer, and cultivation by ducks-foot before planting, followed either by broadcasting seeds (~200 kg/ha and above) and covering them with a disk-harrow or by drill planting (125–175 kg seed/ha) mostly after the first rain event between late November and late December. At the end of the growing season, wheat is harvested mostly with a combine, but about 15% of farmers manually harvest steep and stony fields or small holdings. Usually, phosphate fertilizers are applied before sowing with about 75 kg/ha P2O5 in Zone 1 and under irrigation; and 50 kg/ha P2O5 in Zone 2. N-fertilizer is applied as total of 100, 65, and 50 kg N/ha under irrigation, in Zone 1 Zone 2, respectively, with only about 30% at sowing and the rest at tillering stage according to rainfall by that time. No K is applied due to high K availability in soils. Most farmers apply chemical weed control by tractor-mounted sprayers. Farmers apply fertilizers according to the recommendations; however, depending on their economic conditions they may use fertilizers over or under the recommendation.

In irrigated areas, durum cvs Cham 1 and 7 and Bohous 5, and bread wheat cvs Cham 4, 8, and 10 and Bohous 6; in Zone 1, durum cvs Cham 1 and 3 and Bohous 7, and bread wheat cvs Cham 4 and 6 and Bohous 6; in Zone 2, durum cvs Cham 3 and 5 and Douma 1, and bread wheat cvs Cham 6 and Douma 2 were used for yield gap assessment.

In Turkey, the available data for the mean grain yields of Central Anatolia (north) were collected for the period 1990–2000. In Central Anatolia, which is the wheat basket of Turkey, most of the farmers (66%) till first by plowing to a depth of 15–25 cm in April then in mid-June using a ducks-foot cultivator at 5–10 cm depth. The remainder of the farmers apply first tillage in late May and second tillage in mid-July with the same respective implements and depths. About 90% of farmers prepare the seedbed before planting at about 5–10 cm using a ducks-foot; 70% of farmers sow wheat (about 200 kg seed/ha) during 1–15 October, and 98% use a seed drill. Usually, fertilizers are applied during sowing (about 50 kg/ha P2O5 and 20 kg/ha N) and also during March–April (30–50 kg N/ha) with a fertilizer spreading machine. Weeds are controlled chemically.

4.2 On-farm trials, state farms, and research station yields

Maximum potential yield with improved agronomic management practices were determined by researchers on research stations or as on-farm yield trials according to the countries given above. The yields obtained were averaged over each years and locations, and then compared with the potential yields to estimate yield gaps. State farm yields (Turkey only) were used as another category of potential yield as intermediate levels between farmers' and research stations' yields for the yield gap analysis.

Soil and crop management by researchers:

In Morocco, Settat, the sequence of cultural practices was plowing before planting, followed by two offset disking in fall to prepare the seedbed and cover fertilizers, sowing with a drill (120–140 kg/ha), weeding early with a herbicide and later on if needed, and finally harvesting with a combine. Fertilizers rates were higher than those used by farmers (60 kg/ha N and P). More N (20 kg/ha N) was added at tillering if there was sufficient soil moisture. In these plots, certified seeds and new cultivars were used.

In Tadla, the package was generally more intensive because of the possibility of irrigation. Consequently, there was more seedbed preparation (two offset disking). Fertilizer rates were higher than those of Settat farmers and were on average 80–120 kg/ha each of N, P2O5, and K. For N, half the amount was applied before seeding and the other at late tillering. The seeding rate was similar to that of Settat farmers. Irrigation water management is, however, controlled by ORMVAT and the amount and timing depend on the level of stored water in dams – during dry years irrigation is limited.

For the on-farm demonstration trials (Tadla region), seedbed preparation, seeding method and rate, and harvesting technique were the same as those used in the on-station production plots in Settat. However, more chemical inputs were used; for fertilizers, the rates (kg/ha) were 180–240 of N, 120 P2O5, and 120 K. N was applied before planting, during tillering, during stem elongation, and sometimes even at anthesis. New cultivars are tested and certified seeds are sown. Weeds and other pests (fungi and insects) were controlled chemically. Wheat was irrigated just after sowing during tillering, during stem elongation, and again at heading.

In Syria, management practices at research stations are summarized as follows: consisting of one plowing operation by moldboard or disk plow in summer at depth about 20–25 cm, and cultivation by ducks-foot (12–15 cm) before planting, followed by drill planting (100–125 kg/ha seed) mostly between the second half of November and first week of December. At the end of the growing season, wheat was harvested by plot combine. Usually, phosphate fertilizers were applied at sowing with about 75, 50, and 45 kg/ha P2O5 for irrigated conditions, Zone 1, and Zone 2, respectively. N-fertilizer was applied in totals of 150, 90, and 65 kg/ha for irrigated conditions, Zone 1, and Zone 2, respectively; with about 50% at sowing and the rest at tillering stage. No K was applied due to the high K availability in soils. Chemical weed control was applied at tillering stage for both broadleaf and grasses by tractor-mounted sprayers.

In Turkey, management practices for research stations and state farms are summarized as follows: experimental fields were prepared first by plowing at 18–20 cm depth in April and then cultivated in around mid-June, just after rainfall ceased, by ducks-foot cultivator at 8–12 cm to create a soil mulch layer to prevent evaporative losses and to control weeds. Later cultivation at depth of 6–8 cm was applied once more, depending on occasional rain or weeds. The seedbed preparation was done before planting at about 6–8 cm by ducks-foot with a spike-tooth harrow behind to level the field and also control weeds. Wheat was sown between late September and the first week of October using a disk-drill at 17-cm row spacing with a seed rate of 125–175 kg/ha according to the varieties planted. P and some N was applied at sowing by application of Diammonium phosphate DAP (18–46%), which gave 55–65 kg/ha P2O5 and 21–25 kg/ha N depending on soil analysis. The remainder of the N was applied during March–April as Ammonium nitrate (AN) (33%) with a plot-fertilizer spreading machine during tillering stage at 80, 45, 55, and 80 kg/ha in continuous wheat, wheat-fallow, wheat–legume, and wheat–sunflower rotations, respectively. Weed control was practiced chemically for farmers' fields.

4.3 Simulated potential yields

Process-based are increasingly being used in assessing potential, water-limited, nutrient-limited, and attainable yields for a particular area or region. The given agro-environmental conditions characterize the factors that define and limit crop growth and development (Bouman and Lansigan 1994).

Rainfed potential yields are estimated through crop simulation models when nutrients are non-limiting for crop growth – these yields are expected to be the highest. To simulate the potential yields, the crop growth simulation model CropSyst was used. CropSyst (Stockle et al. 1994; Stockle and Nelson 1994) is a management-oriented cropping systems model able to simulate a range of weather/management scenarios. CropSyst simulates the soil water budget, soil–plant N budget, crop phenology, canopy and root growth, biomass production, crop yield, residue production and decomposition, soil erosion by water, and salinity. These processes are affected by weather data (maximum and minimum temperature, precipitation, maximum and minimum humidity, solar radiation, and wind speed), soil data, crop characteristics, and cropping system management options – including crop rotation, cultivar selection, irrigation, N fertilization, soil and irrigation, water salinity, tillage operations, and residue management (Stockle et al. 2003).

The yields were simulated for the production zones of Morocco, Syria, and Turkey, where the on-farm and on-station trials were conducted.

5 ANALYSIS OF POTENTIAL YIELDS AND YIELD GAPS

To analyze the potential yields and yield gaps of wheat, data were collected from the partner institutions. These included data on experimental yields obtained with improved agronomic management (potential yields) at research stations; yields obtained from farmers' fields in the vicinity of on-farm yield trials conducted by researchers with participation of farmers; yields obtained from large-scale seed production fields of state farms (in Turkey only); and district or province-level actual yields obtained from the agricultural statistics of each country. Key representative countries of the regions were selected for yield gap analysis: Morocco in North Africa for mild lowlands and mild highlands, Syria for mild lowlands, and Turkey in West Asia for cold highlands.

Wheat area, production, and productivity are given in Table 3 for the selected major countries representing different agro-ecologies of WANA. Wheat area increased by 16.9%, while wheat production increased by 73.6% during 1985–2004 due to the yield increase of 48.3% in WANA. Since this data is an average of irrigated and rainfed regions combined, we can analyze the situation for rainfed regions as follows.

About 75% of the total wheat area in WANA (32,378 million ha) is under rainfed conditions, (24 284 000 ha) and the irrigated area 8 094 000 ha. The average of irrigated wheat yield was estimated at 3.5–4.0 t/ha. Therefore, the mean rainfed yield should be 1.27–1.41 t/ha for the entire WANA region, which is still quite low, although there has been a remarkable increase in yield and production of wheat since 1985.

There is still great potential for yield increases in rainfed wheat in the WANA region. However, this relies on the dissemination of improved varieties associated with improved soil and crop management practices: e.g. appropriate crop rotation, timely tillage with conservation practices, timely sowing associated with appropriate sowing method rate and depth, optimum fertilization, weeds and pest control, and appropriate harvest and post harvest handling.

Morocco: The wheat area of Morocco increased by 61.7%, while production and yield of wheat increased by 135 and 45.3%, respectively, since 1985 (Table 3).

Data obtained from the ICARDA durum wheat breeder for the above regions was used to calculate the yield gap and increases over the farmers' yields as given in the Methodology section of this report. There is a good potential for further increases in yield of improved wheat cultivars and agronomic management practices as shown by the yield gap (Table 4).

In Morocco, mean potential yield obtained from the research stations under improved management practices was on average 61–153% greater

Table 3. Area, production, and productivity of wheat in WANA region (1985–2004)

Wheat area harvested (10^3 ha)						
Countries	1985	1990	1995	2000	2004	Mean
Morocco	1894	2719	1968	2902	3064	2509
Syria	1265	1341	1644	1679	1831	1552
Turkey	9275	9432	9400	9400	9400	9381
WANA all	30 105	31 823	32 718	32 034	35 208	32 378
Wheat production (10^3 Mt)						
Morocco	2358	3614	1091	1381	5540	2797
Syria	1714	2070	4184	3105	4537	3122
Turkey	17 032	20 022	18 015	21 009	21 000	19 416
WANA all	46 691	58 586	62 872	66 484	81 067	63 140
Wheat yield (kg/ha)						
Morocco	1245	1330	555	475	1810	1080
Syria	1355	1545	2545	1850	2475	1955
Turkey	1835	2120	1915	2235	2235	2070
WANA all	1550	1840	1920	2075	2300	1950

Source: (FAOSTAT 2004).

Table 4. Important wheat-growing regions of Morocco and average yield gap (average for 1990–2000).

Region	Rainfall (mm)	Potential yield (kg/ha)	Farmers' yield (kg/ha)	Yield gap (kg/ha)
Loukos	> 600	8560	4700	3860
Douyet	450–600	5400	3350	2050
Marchouch	350–450	5230	3100	2130
Settat	250–350	4550	1800	2750
Tessaout	< 250*	6270	3500	2770

Source: Miloudi Nachit, durum wheat breeder, ICARDA.
*Irrigated

than farmers' yields. The highest potential yield increase was in the most important semi-arid rainfed area of Morocco, Chaouia–Doukkala region, with variable and limited rainfall.

The CropSyst model was used to determine wheat yield gap between research stations and farmers' fields as explained in the Methodology section of this report.

In Morocco, for Settat and Tadla regions the annual rainfall amount in the years 1994 to 2004 was variable (Figure 6) and wheat yields followed the same trend as annual mean rainfall in the rainfed zone. In the seasons 1998/99 and 1999/2000 there was inadequate rainfall of < 200 mm both in Settat and Tadla (Benaouda 2005; Benaouda et al. 2005).

In Settat, the rainfall distribution was high during the period 1995/96–1996/97, low in 1999/2000 and 2003/04, and medium in the remaining years. In Berrechid, the differences between potential and farmers' yields were high in 1995/96–1996/97; medium in 1997/98, 1998/99, and 2001/02; and low in 1999/2000,

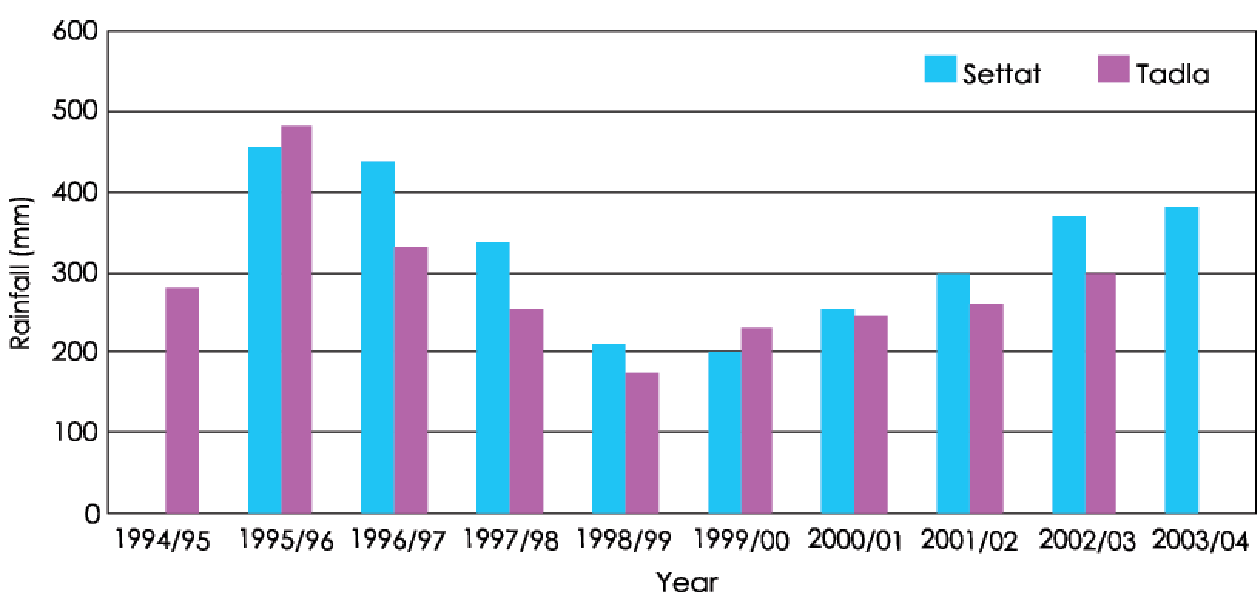

Figure 6. Annual rainfall in Settat and Tadla region during the seasons from 1994/95 to 2003/04.

2000/01, 2002/03, and 2003/04. During the last four years, yield gaps in Berrechid tended to decrease and to be lower than those for Settat. In relative terms, there was a tendency that under both very dry (1998/99 and 1999/00) and very wet (1995/96 and 1996/97) conditions, the farmers' yields remained very low compared to potential yields. It seems that farmers did not change their farming strategies to adapt to rainfall conditions-they did not increase their inputs rates during wet years and did not use water conservation techniques during dry years. Consequently, in both situations, actual yields remained low.

In the Settat–Berrechid region (rainfed), farmers' yields remained low but little higher in Berrechid (1220 kg/ha) than in Settat (1105 kg/ha); for the period 2001-2011, the respective yield ranges were 590–2550 and 380–2420 kg/ha for the two sites (Table 5). The difference in productivity was mainly due to little higher amount of rainfall at the first site. In fact, the general trend of the distribution of precipitation was similar to productivity. The lowest yield averages were in 1996/97, 1998/99, and 2000/01 with 1999/2000 almost without any production – it was a very dry year. In Tadla, the situation was different, the productivity fluctuation was lower due to the application of irrigation water. Hence, average yields were higher – 4500 (4100–5200) kg/ha in Oulad Zemam and 4900 (4000–5500) kg/ha in Bradia (Table 6) – they were stable and approximately four times those of the Settat–Berrechid zone. In Tadla plain, the yields were even higher in dry years because of the intensified use of irrigation.

During the five years of 1997/98–2002/03, farmers' yields in Bradia were higher than in Oulad Zemam. This difference was due to the impact of the extension program of regional agricultural offices; Office Regional de Mise en Valeur Agricole de Tadla (ORMVAT), in which Bradia was a pilot site for testing of new efficient water-management technologies on selected farms.

The average yields from research station trials were 2190 (1430–5430) kg/ha in Settat–Berrechid and 6800 (5400–7300) kg/ha in Tadla (Ouled Zamam–Bradia) regions (Tables 5 and 6). Irrigation water supply in Tadla provided more stable yields over years in demonstration plots (except for 1996/97); although these yields were higher than those of farmers in the two sites, they were lower than the simulated potential yields of 3390 (410–7980) and 8510 (6930–11 080) kg/ha for the two sites, respectively. The high variation from year to year in potential yields in Tadla was due to rainfall fluctuation and distribution although the same amount of irrigation was applied each year at critical stages.

Table 5. Grain yields of farmers, research station trials, and simulated potentials for bread wheat in Settat–Berrechid zone.

Year	Precipitation (mm)	Farmers (kg/ha)		Research stations (kg/ha)	Simulated potential yield (kg/ha)
		Settat	Berrechid		
1995/96	455	2420	2550	5430	7980
1996/97	436	580	670	3280	3850
1997/98	336	1720	1660	1900	2690
1998/99	209	380	590	1430	2910
1999/00	200	0	0	0	410
2000/01	255	650	1350	1830	3440
2001/02	300	1110	1070	2250	3730
2002/03	368	1640	1310	1710	2630
2003/04	382	1450	1800	1880	2860
Mean	327	1105	1220	2190	3390

Table 6. Grain yields (kg/ha) of farmers, research station trials, and simulated potentials for bread wheat in Oulad Zemam and Bradia sub-zones of Tadla.

Year	Precipitation (mm)	Farmers (kg/ha)		On-farm demonstration (kg/ha)	Simulated potential yield (kg/ha)
		Oulad Zemam	Bradia		
1994/95	280	4800	4900	-	6930
1995/96	482	4100	4000	-	11080
1996/97	332	4300	4300	5400	7690
1997/98	255	4800	5000	7300	9960
1998/99	173	5200	5500	-	9420
1999/00	232	5200	5500	7300	9630
2000/01	245	4100	5300	-	7330
2001/02	259	4100	5000	-	7260
2002/03	300	4200	4300	7000	7290
Mean	285	4500	4870	6800	8510

Consequently, for years where rainfall was high, the application of irrigation water at critical stages significantly ($P < 0.05$) increased yields (e.g. 1995/96, 1997/98, 1998/99, and 1999/00).

Yield gaps during 1994/95–2003/04 cropping seasons are presented in Table 7 for both regions. In Settat region the yield gaps of research station over farmers' yields were in the ranges of 4–466% in Settat and 4–390% in Berrechid sites. The yield gaps of simulated potentials over farmers' yields had ranges 56–666% in Settat and 59–475% in Berrechid sites. In Tadla region, the yield gaps of research station over farmers' yields had ranges of 26–67% in Oulad Zemam and 26–63% in Bradia sites; the corresponding yield gaps of simulated potentials over farmers' yields were 44–170 and 38–177%.

Table 7. Yield increase (%) by research station/on-farm demonstration and simulated potential yields over farmers' yields in semi-arid areas of Morocco.

Years	Settat–Berrechid Region (rainfed)				Tadla Region (irrigated)			
	Research station		Simulated potential		On-farm demonstration		Simulated potential	
	Settat	Berrechid	Settat	Berrechid	Oulad Zemam	Bradia	Oulad Zemam	Bradia
1994/95	-	-	-	-	-	-	44	41
1995/96	124	113	230	213	-	-	170	177
1996/97	466	390	564	475	26	26	79	79
1997/98	10	14	56	62	52	46	108	99
1998/99	276	142	666	393	-	-	81	71
1999/00	-	-	-	-	40	33	85	75
2000/01	182	36	429	155	-	-	79	38
2001/02	103	110	236	249	-	-	77	45
2002/03	4	31	60	101	67	63	74	70
2003/04	30	4	97	59	-	-	-	-
Mean	98	80	207	178	51	40	89	75

In Settat region, the difference between simulated potentials and research station yields had range of 410–2550 kg/ha with a mean of 1200 kg/ha. The highest absolute value was in the wet year 1995/96 and the lowest in the dry year 1999/2000, which was a complete failure. However, the mean yield increase of simulated potentials over research station yields was 55% with range of 17–103%, much lower than the gap between simulated potentials and farmer yields in Settat (Table 7). This indicates that improved crop and soil management was used on the research station. Nevertheless, this improvement was mainly under high moisture conditions; when it was very dry, there was total yield failure for both farmers and research stations. Water conservation techniques were not used even on research stations in very dry years.

In Settat region, in cropping season 1999/00, no yield was obtained from either site on farmers' fields. The differences between farmer and research station yields were 70–3010 (with mean 1085) kg/ha in Settat and 80–2880 (mean 970) kg/ha in Berrechid sites. The largest gaps were for 1995/96 and 1996/97 at both sites; and the smallest in 2002/03 in Settat, and 2003/04 in Berrechid. Under relatively wet conditions (high rainfall or supplemental irrigation), the absolute value of the gap increased. It is difficult to draw conclusions here, since in some years the research station plots were irrigated and hence did not experience the same weather conditions as those of the farmers.

In Tadla region, the difference between simulated potential yields and those of demonstration plots had range of 290–2660 (with mean 1710) kg/ha during only four years during 1994/95–2002/03 growing seasons. Since the wheat crop in Tadla region is irrigated, the yield did not depend only of rainfall. However, the mean yield increase by simulated potential over research station yields was 25% with range of 4–42%, which was much lower than yield increases over farmers' yields in Tadla (Table 7). This indicates that improved crop and soil management practices were used in the demonstration plots as for research stations.

In Tadla region, the differences between farmers' and research station yields were in the range 1100–2800 (with mean 2300) kg/ha in Oulad Zemam, and 1100–2700 (mean 1930) kg/ha in Bradia sites.

The yield gaps for Settat and Berrechid sites of research stations over farmers' fields were 98% and 80%, respectively (Figure 7). The corresponding yield gaps of simulated potentials over farmers' yields were 207% and 178% (Figure 7).

For Oulad Zemam and Bradia sites of Tadla region, the gaps between research stations over farmers' yields were 51% and 40%, respectively (Figure 8). The corresponding gaps of simulated potentials over farmers' yields were 89% and 75% (Figure 8).

Syria: During 1985-2004, the area under wheat production increased by 44.7%, while production and yield increased by 164% and 82.63%, respectively (Table 3).

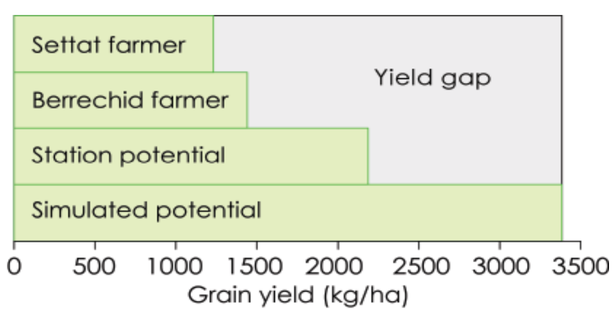

Figure 7. Average wheat yield gap under rainfed conditions in Settat–Berrechid region of Morocco during 1995–2004 seasons.

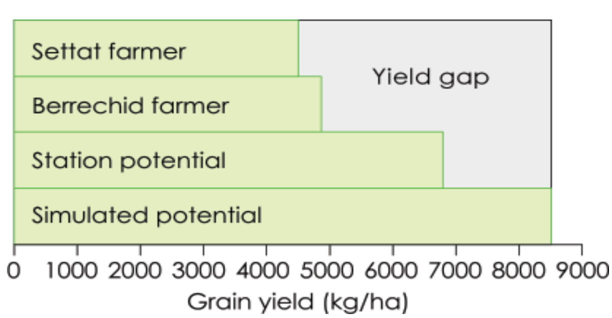

Figure 8. Average wheat yield gap under irrigated conditions in Tadla region of Morocco during 1994–2003 seasons.

Three cases were followed for wheat yield gap data analyses and potentials for improvement for sustainable wheat production as given in the Methodology section of this report.

The first case: Data from the ICARDA durum wheat breeder in the above regions were used to calculate the yield gap of research stations over farmers' yields. Similar to Morocco, the yield gap showed good potential for further increases in yield with the adoption of improved wheat varieties (Cham 3 and Cham 5) and agronomic management practices (Table 8).

In Syria, wheat yield obtained from research stations under improved management practices was on average 67–95% greater than farmers' yields. Similar to Morocco, the largest yield increase was in the driest rainfed areas of Syria: Zone 2 with variable and limited rainfall covering about 13% of the country; and similar to Zone 1a and 1b, which covers about 15% of the country. Again improved management practices, together with improved varieties, have to be adopted by farmers to close the yield gap for sustainable wheat production.

The second case: The data from GCSAR for durum and bread wheat from Zone 1 (mean of Zone 1a and 1b) and Zone 2 for rainfed and irrigated areas across all zones provided mean data of eight sites for yield gap assessment as described in the Methodology section of this report. Farmers' and research station's yields during 1994/95–2004/05 growing seasons are shown in Tables 9–11.

In the irrigated areas, the farmers' mean yields remained low irrespective of irrigation due to misuse of irrigation water: overall mean yield was 3465 and 3805 kg/ha for durum and bread wheat, respectively, compared with the corresponding mean yields of on-farm trials (6040 and 6395 kg/ha) and research stations (7320 kg and 7500 kg/ha). For 1994-2004, farmers' yields had range of about 2430–4250 and 2940–4540 kg/ha for durum and bread wheat, respectively. Use of irrigation caused lower fluctuations in production than for rainfed regions (Table 9). Yields under irrigation were uniform and much higher compared to those of farmers' rainfed yields: increases over rainfed yields were 106% in Zone 1 and 168% in Zone 2 for durum; and 94 and 188% for bread wheat, respectively. This shows the importance of supplemental irrigation in rainfed areas for improving water and crop productivity as one of the improved management practices for increasing yield stability of wheat.

Yields from irrigated on-farm trials had ranges of about 4490–6940 kg/ha for durum and 5080–7240 kg/ha for bread wheat. These yields were higher than those obtained by farmers; however, they remained lower than potential yields from research station plots with ranges of about 6400–8550 kg/ha for durum and 6440–8410 kg/ha for bread wheat (Table 9). This difference between on-farm trials and research stations

Table 8. Important wheat-growing regions of Syria and average yield gap (average for 1986–2000)

Region	Rainfall (mm)	Potential yield (kg/ha)	Farmers' yield (kg/ha)	Yield gap/increase over farmers' fields	
				Gap (kg/ha)	% increase
Zone 1a*	> 350	5855	3500	2355	67
Zone 1b*	300–350	4935	2930	2006	68
Zone 2*	250–300	2165	1170	995	85
Irrigated	200–250	5010	2750	2260	82

Source: Miloudi Nachit, Durum wheat breeder, ICARDA.
*Rainfed

Table 9. Mean durum and bread wheat grain yields (kg/ha) under irrigated conditions across all zones during 1995–2005.

Year	Durum wheat					Bread wheat				
	Farmers	On-farm trials	Research station	Yield increase over farmers (%)		Farmers	On-farm trials	Research station	Yield increase over farmers (%)	
				On-farm trials	Research station				On-farm trials	Research station
1995	2900	6068	7641	109	163	4348	6929	8289	59	91
1996	2428	6416	7150	164	195	3851	7046	7525	83	95
1997	2625	4493	6410	71	144	2940	5087	6438	73	119
1998	3697	6281	7447	70	101	3732	6965	7116	87	91
1999	2821	6139	7307	118	159	3254	6254	7535	92	132
2000	3438	5843	7793	70	127	3724	6007	7583	61	104
2001	3750	6880	7279	83	94	3643	7240	7111	99	95
2002	4251	6940	6707	63	58	4541	7101	7448	56	64
2003	4178	6162	6889	47	65	3904	5531	7212	42	85
2004	4081	5701	7347	40	80	3962	6096	7838	54	98
2005	3960	5521	8549	39	116	3960	6080	8413	54	112
Mean	3466	6040	7320	74	111	3805	6394	7501	68	97

Farmers' yields during 1995–1999 were obtained from FAOSTAT (2003); http://faostat.fao.org:8090/caf/default.htm; the other years were obtained directly from farmers' fields near the on-farm trials.

was due to the higher level of improved management practices applied on research stations. However, both increased wheat yields remarkably over farmers' yields. Increases over rainfed on-farm yields were 73% in Zone 1 and 243% in Zone 2 for durum; and 68 and 243% for bread wheat, respectively; similarly, the corresponding yield increases over rainfed research station yields were 67 and 184% for durum, and 56 and 169% for bread wheat. These significant yield increases show the importance of supplemental irrigation in rainfed areas for improving water and crop productivity as one improved management practice for increasing yield stability of wheat where irrigation water is available.

Yield gaps during 1994/95–2004/05 cropping seasons are presented in Table 9 for both wheat species under irrigation. The yield gaps of on-farm trials over farmers' yields had range of about 39–164% with mean of 74% for durum wheat, and 42–99% with mean of 68% for bread wheat. The yield gaps of research station over farmers' yields had range of about 58–195% with mean of 111% for durum wheat and 64–132% with mean of 97% for bread wheat.

In rainfed areas of Zone 1, farmers' yields were lower, with overall mean yield of 1675 kg/ha for durum wheat and 1960 kg/ha for bread wheat compared to mean yields of on-farm trials (3500 and 3800 kg/ha) and research stations (4380 and 4820 kg/ha). For 1994-2004, the ranges in yields were 950–2305 kg/ha for durum and 1220–2760 kg/ha for bread wheat (Table 10).

In Zone 1, yields from rainfed on-farm trials had ranges of about 2105–4590 kg/ha for durum and 2470–5960 kg/ha for bread wheat. Similar to irrigated areas, these yields were higher than those of the farmers; however, they remained lower than research station yields which had ranges of about 3560–5070 kg/ha for durum and 4040–5995 kg/ha for bread wheat (Table 10). The reason for the difference between on-farm trials and research station was the higher level of improved management practices applied on the research station, but both increased wheat yield remarkably over farmers' yields, similar to the observation for irrigated conditions.

Yield gaps during 1994/95–2004/05 cropping seasons are presented in Table 10 for both wheat species in Zone 1 under rainfed conditions. The yield gaps of on-farm trials over farmers' yields had range of about 45–310% with mean of 109% for durum, and 20–247% with mean of 94% for bread wheat. The yield gaps of research station over farmers' yields had range of about 117–329% with mean of 161% for durum and 73–278% with mean of 146% for bread wheat.

In rainfed areas of Zone 2, similarly to Zone 1, mean farmers' yields were lower with overall mean yield of 1290 kg/ha for durum and 1320 kg/ha for bread wheat, compared the mean yields of on-farm trials (1765 and 1865 kg/ha) and research stations (2575 and 2785 kg/ha). For 1994-2004, the farmers' yields had range of about 680–1765 kg/ha for durum and 430–2070 kg/ha for bread wheat (Table 11).

In Zone 2, yields obtained from rainfed on-farm trials had range of about 1100–2350 kg/ha for durum and 1110–2785 kg/ha for bread wheat. Similarly to Zone 1, yields were higher than those obtained by farmers; however, they remained lower than research station yields: ranges of 1650–4460 kg/ha for durum and 1950–3735 kg/ha for bread wheat (Table 11). Similar to Zone 1, the difference between on-farm trials and research station was due to the higher level of improved management practices applied on research stations, but both increased the wheat yield significantly over farmers' yields.

Yield gaps in Zone 2 during 1994/95–2004/05 cropping seasons are presented in Table 11 for both wheat species. The yield gaps of on-farm trials over farmers' yields had range of about 13–97% with mean of 37% for durum wheat and 11–197% with mean of 41% for bread wheat. The yield gaps of research station over farmers' yields had ranges of about 56–146% with mean of 99% for durum, and 51–466% with mean of 111% for bread wheat.

Bread wheat performed better than durum wheat under irrigated as well as in Zones 1 and 2 rainfed conditions. On average across all production

Table 10. Mean durum and bread wheat grain yields (kg/ha) under rainfed conditions in Zone 1 during 1995–2005.

Year*	Durum wheat in Zone 1					Bread wheat in Zone 1				
	Farmers	On-farm trials	Research station	Yield increase over farmers (%)		Farmers	On-farm trials	Research station	Yield increase over farmers (%)	
				On-farm trials	Research station				On-farm trials	Research station
1995	1863	3797	4257	104	128	2532	5958	5275	135	108
1996	1912	4020	4709	110	146	2703	3240	4673	20	73
1997	945	3870	4055	310	329	1387	3977	4041	187	191
1998	2303	3944	5005	71	117	2758	3919	5996	42	117
1999	1449	2105	4187	45	189	1703	3080	4251	81	150
2000	1219	3079	3560	153	192	1219	4225	4612	247	278
2001	1956	3828	4783	96	145	2141	4151	5253	94	145
2002	1486	3173	4694	114	216	1954	2989	4357	53	123
2003	1807	3242	3958	79	119	1773	2468	4264	39	141
2004	1537	2877	3896	87	153	1437	4197	4809	192	235
2005	1967	4587	5068	133	158	1967	3570	5453	81	177
Mean	1677	3502	4379	109	161	1961	3798	4817	94	146

* Farmers' yields were obtained from Syrian statistics for 1995–1999; the rest is from farmers' fields near the on-farm trials.

Table 11. Mean grain yields for durum and bread wheat (kg/ha) under rainfed conditions in Zone 2 during 1995–2005.

Year*	Durum wheat in Zone 2					Bread wheat in Zone 2				
	Farmers	On-farm trials	Research station	Yield increase over farmers (%)		Farmers	On-farm trials	Research station	Yield increase over farmers (%)	
				On-farm trials	Research station				On-farm trials	Research station
1995	1053	2078	2264	97	115	1583	2035	2395	28	51
1996	1310	1754	2036	34	5	1598	2784	3733	74	134
1997	680	1102	1650	62	143	872	1109	2009	27	130
1998	1241	1861	2702	50	118	1263	2037	2833	61	124
1999	1005	1038	1563	3	56	430	1278	2435	197	466
2000	992	1119	1720	13	73	557	1272	1950	128	2500
2001	1813	2352	4460	30	146	2068	2431	3574	18	73
2002	1477	2174	4005	47	171	1620	1890	2864	17	77
2003	1766	1989	3336	13	89	1624	2014	3149	24	94
2004	1373	2037	2174	48	58	1084	1657	3137	53	189
2005	1500	1906	2399	27	60	1811	2012	2535	11	40
Mean	1290	1765	2575	37	99	1320	1865	2785	41	111

* Farmers' yields were obtained from Syrian statistics during 1995–2003; the rest is from farmers' fields near the on-farm trials.

systems, bread wheat provided about 10% higher yield than durum wheat in farmers' fields, and about 7% higher in both on-farm and research station trials. Mean yield increase of farmers' fields in Zone 1 over Zone 2 was 30% for durum and 48% for bread wheat; corresponding increases were 98 and 104% for on-farm trials and 70 and 73% for research station yields. This difference between zones was due to higher rainfall in Zone 1 compared with Zone 2. However, improved soil and crop management practices are major factors for substantial yield increases by both on-farm and research station trials over farmers' fields in wheat production across all production systems.

The third case: In Zone 1b, a major wheat production area of Syria, the CropSyst model was used. Aleppo farmers' yields were used to identify the yield gap during 1994–2005 cropping seasons by comparison with yields from research stations and crop simulations based on agro-climatic data of Tel Hadya Research Station (ICARDA) (Table 12).

In Syria, annual rainfall amount was variable during 1994-2004 at Aleppo–Tel Hadya, where the long-term average rainfall was 330 mm (Figure 9). In the growing seasons of 1994/95, 1998/99, 1999/00, and 2004/05 there was inadequate rainfall, with a total seasonal (October–May) amount being less than 300 mm. However, during the consecutive three seasons of 1995/96–1997/98 and four seasons of 2000/01–2003/04 there was adequate rainfall with a total seasonal amount exceeding 400 mm.

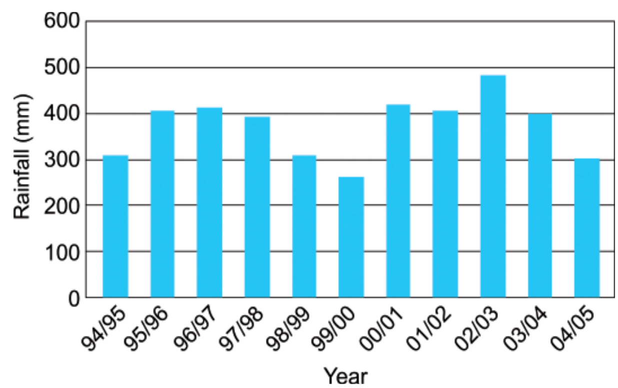

Figure 9. Annual rainfall recorded at Tel Hadya, Aleppo, Syria weather station during 1994-2004.

Table 12. Mean yields of farmers' fields, research station trials, and simulated potential grain yields of durum wheat in Aleppo Province, Syria.

Crop seasons	Oct–May precipitation, Tel Hadya (mm)	Farmers' field (kg/ha)	Research station (kg/ha)	Simulated potential (kg/ha)	Yield increase over farmers (%)	
					Research station	Simulated potential
1994/95	310	1750	4305	4885	146	179
1995/96	405	1800	4395	4955	144	175
1996/97	411	1700	3385	5080	99	199
1997/98	392	2780	3995	4170	44	50
1998/99	307	2050	2760	4015	35	96
1999/00	260	1555	2765	3610	78	132
2000/01	418	1775	4540	5230	156	195
2001/02	404	2230	4215	4320	89	94
2002/03	483	1745	3690	5870	111	236
2003/04	398	2670	3200	3885	20	46
2004/05	302	2150	3165	3935	47	83
Mean	372	2020	3675	4540	82	125

The mean farmers', research station's, and simulated potential durum grain yields under rainfed conditions are presented in Table 12. In Syria, similar to Morocco, farmers' yields remained low with a mean yield of 2020 kg/ha. During 1995–2005, in the farmers' fields in Aleppo Province, the highest yield was during the 1997/98 season (2780 kg/ha) due to relatively high rainfall with a uniform distribution; while the lowest yield (1555 kg/ha) during the 1999/00 season was due to rainfall much lower than the long-term average. Thus, the yield variation in farmers' fields generally followed rainfall variation, although for other reasons such as poor cultural practices, yield did not match the rainfall amount, e.g. in 2002/03 when yield was only 1745 kg/ha with the highest rainfall of 483 mm. In farmers' fields, management practices did not always follow the rainfall pattern for the yield levels but depended on other factors, e.g. choice of cultivar, crop rotation, tillage system, sowing date, seed rate, fertilizer use, or weed control.

Average yields from research station trials were 3675 kg/ha (2760–4995 kg/ha) in Aleppo Province (Table 12). These yields were higher than those obtained by farmers at the two sites; however, they remained lower than the simulated potential yields – with mean of 4540 (with range of 3610–5870) kg/ha. The high variation from year to year in potential yields was due to rainfall fluctuation and distribution.

Yield gaps during 1994/95–2004/05 cropping seasons for Aleppo Province of Syria are presented in Table 12. The yield gaps of research stations over farmers' yields had range of about 20–156%. Similarly, the gaps between simulated potential over farmers' yields had range of about 46–236%. The yield gap (between simulated potential and farmers yield), during the 2002/03 season, was 236% although adequate rainfall of 493mm had fallen. This gap can be attributed to poor management. Also, during the season of 1999/00, the driest year with 260 mm rainfall, the yield gap of research station over farmers' yields reached 78% and over simulated potential yield reached 132%. Under both dry and relatively favorable years, the farmers' yields remained very low compared to yields from research station trials as well as from simulations. However, the mean yield increase by simulated yields over research station yields was 24% with range of about 2–59% , and was much lower compared to yield increases by simulated potentials over farmers' yields. This indicated that improved crop and soil managements used in research stations were similar to the case of Morocco rainfed regions in Settat; nevertheless, this improvement was mainly under relatively favorable conditions.

The yield gap between the research stations over farmers' yields was 82%; similarly, yield gap of simulated yields over farmers' yields was 125% (Figure 10).

Wheat is grown on about 1.5 million hectares or 27% of the total cultivated land in Syria, mainly under rainfed conditions (300–500mm annual rainfall), which are increasingly experiencing supplemental irrigation, while drier (< 200mm) areas are fully irrigated (SCBS 1998). Improved cultivars generally combine high yield potential and stress tolerance and tend to have high yield stability, being input-efficient under limited resources in stress environments and input responsive under favorable environments. Such varieties are tested under farmers' conditions over multiple years and locations. Expansion of the wheat-cultivated area allowed Syria to be a net wheat exporter until the 1950s and, 50 years ago, Syria was self-sufficient in wheat. However, growth in domestic demand due to population increase, at 3.6% one of the highest in the world, accompanied a parallel increase

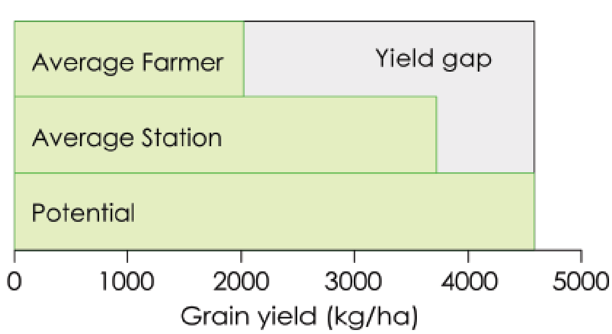

Figure 10 Average wheat yield gap in Syria during 1994–2004 seasons.

in wheat yield and/or the area planted to wheat. Thus, Syria did not produce any surplus in the late 1980s, and had to import wheat and flour; e.g. the self sufficiency rate for wheat during 1985–1989 was about 72% of the total domestic requirement (Mazid et al. 1998).

The intensive programs at the Ministry of Agriculture and Agrarian Reform staff in Syria tackled all aspects of dryland cropping and recently increased emphasis on irrigation and water use. The research involved was both basic and applied, with a large capacity-building and technology transfer component. With an initial focus on research station work across the range of rainfall zones (200–500mm), the later emphasis was on farmers' fields and farmer involvement in technology assessment.

The twin research approaches involved breeding for improved germplasm (yield stability, drought, and disease resistance/tolerance) and improved management (agronomy, fertilization, and mechanization). The doubling of wheat output in Syria within two decades and the transformation from a food-deficit economy to a self-sufficient one, which is now exporting wheat, is testament to the success of this collaborative research partnership. While many of the technologies or practices have been largely implemented, others such as adaptation of legume–cereal rotations are likely to have positive impact at the national level in future

The strategy adopted in Syrian agriculture can serve as a model for development elsewhere. The approach was one of examining a traditional low-input agriculture and promoting an alternative modern package of practices, and in doing so it involved an alternative way of thinking on the part of farmers and administrators as much as anything else.

Turkey: During 1985–2004, wheat production area of Turkey increased by only 1.3%, and production and yield increased by 23.3 and 21.83%, respectively (Table 3). However, yield increase could not attain the level of other countries of the region, since most production is in dry marginal rainfed areas, thus yield and production cannot be increased further unless improved agronomic management practices are applied by majority of farmers.

Two cases were followed for data evaluation of the wheat yield gap and potential for improvement for sustainable wheat production as given in Methodology.

The first case; first step was data gathering from CRIFC for all the regions considered for years 1990–2001 to show mean wheat yield increases by research stations over the district/province yields (Tables 13–15).

Similar to Morocco and Syria, there was good potential for further increases in farmers' yields with the adoption of improved varieties and agronomic management practices as shown by the yield gaps (Tables 13–15).

The mean wheat yields of 2020 kg/ha in farmers' fields were lower (Table 13) compared the mean yields of 2960 kg/ha for research station trials in the north region of Central Anatolia (CA). During 1989/90–2000/01 cropping seasons, the farmers' yields had range of about 1660–2150 kg/ha while research station yields were 2250–4250 kg/ha. In the south region of CA, the mean wheat yields were lower than northern CA, with overall means of farmers' yields of 1790 kg/ha and of research stations of 2605 kg/ha. During 1989/90–2000/01 cropping seasons, the farmers' yields had range of about 1515–2115 kg/ha, while research station yields were 1800–4500 kg/ha. In the east region of CA, the yield levels were close to that of southern CA, but with slightly lower farmers' yields due to less adoption of improved management practices. The mean yields of farmers were lower with overall mean of 1695 kg/ha, compared to research station trials of 2675 kg/ha. During 1989/90–2000/01 cropping seasons, the farmers' yields had range of about 1435–1865 kg/ha, while research station yields were 1875–3625 kg/ha. The difference between yields of research stations and farmers' fields was due to improved management practices applied on research stations; and thus policy measures are required for improved practices to be disseminated to farmers.

Table 13. Mean wheat grain yields (kg/ha) and yield increase (over farmers' yields) under rainfed conditions in Central Anatolia during 1990–2001.

Year	Central Anatolia North Region			Central Anatolia East Region			Central Anatolia South Region		
	Farmers' yields	Research station yield	Yield increase over farmers (%)	Farmers' yields	Research station yield	Yield increase over farmers (%)	Farmers' yields	Research station yield	Yield increase over farmers (%)
1990	2150	2750	28	1553	2956	90	1898	2265	19
1991	2128	2250	6	1757	2456	40	2116	2542	20
1992	1660	2352	42	1755	2890	65	1946	2687	38
1993	2068	2465	19	1735	2589	49	1917	2540	32
1994	1968	2850	45	1645	2595	58	1612	2315	44
1995	1980	3002	52	1735	2350	35	1617	2356	46
1996	1980	2890	46	1865	2560	37	1715	2200	28
1997	2070	3550	71	1435	3625	153	1517	4500	197
1998	2015	4250	111	1756	2900	65	1898	3360	77
1999	2057	2865	39	1589	2950	86	1785	2200	23
2000	2098	3450	64	1789	2365	32	1919	2500	30
2001	2054	2850	39	1725	1875	9	1568	1800	15
Mean	2019	2960	47	1695	2676	58	1792	2605	45

Source: N. Zencirci, Wheat Project Coordinator, Turkey.

Yield gaps during 1990/91–2000/01 cropping seasons are presented in Table 13 under rainfed conditions of CA regions. The yield gaps of research stations over farmers' yields had range of about 6–111% with mean of 47% in the north region of CA. Similarly, the yield gap had range of about 15–197% with mean 45% in the south, and 9–153% with mean 58% in the east, regions of CA.

During 1989/90–2000/01 cropping seasons, the mean wheat yields in farmers' fields were 2370 (range 1840–2755) kg/ha, lower compared to research station trials of 4680 (range 3560–5900) kg/ha in the Aegean region of Turkey (Table 14). In the Marmara region, the mean farmers' yield was 3070 with range of about 2410–3585 kg/ha, and the mean research station yield was 4945 with range of about 4325–6500 kg/ha during 1989/90–2000/01 cropping seasons (Table 14). In the Mediterranean region, the yield levels were similar to the Aegean region but little higher both in farmers' and research station yields; mean wheat yields in farmers' fields were 2800 kg/ha compared to research station trials with 4875 kg/ha.

During 1989/90–2000/01 cropping seasons, the farmers' yields had range of about 2000–3080 kg/ha while research station yields were 4000–6020 kg/ha (Table 14). However, due to higher rainfall and more improved agriculture in the coastal region the yields were higher than for CA dry areas; however, there is still potential for wheat yield increases in these regions through dissemination of improved soil and crop management practices to farmers.

During 1990/91–2000/01 cropping seasons, yield gaps of research stations over farmers' yields had range of about 44–152% with mean of 97% in the Aegean region (Table 14). Similarly, yield gaps were 26–118% with mean of 61% in the Marmara region, and 32–162% with mean of 74% in the Mediterranean region.

The mean wheat yields in farmers' fields of 1185 kg/ha were lower than for research station trials with 2970 kg/ha in northeast Anatolia region of Turkey (Table 15).

During 1989/90–2000/01 cropping seasons, the farmers' yields had range 1065–1485 kg/ha, while research station yields were 1980–3650 kg/ha. In southeast Anatolia region, the mean farmers' yield was 1630 with range of about 1420–1855 kg/ha, and mean research station yield was 3810 with range of about 2650–4685 kg/ha for 1989/90–2000/01 cropping seasons (Table 15). In the Black Sea region, the yield levels were lower than expected under the much higher rainfall. This could be because the wheat is grown in mountainous and sloping land in this region. The mean wheat yields in farmers' fields were 1625 kg/ha compared to research station trials with 3485 kg/ha.

During 1989/90–2000/01 cropping seasons, the farmers' yields had range of about 1415–1755 kg/ha, while research station yields were 2560–4700 kg/ha. However, because of lower rainfall and steep slopes areas in the northeast Anatolia region of Turkey the yields were the lowest of all regions of Turkey.

The yield gaps during 1990/91–2000/01 cropping seasons of research stations over farmers' fields had range of about 64–229% with mean of 150% in the northeast Anatolia region (Table 15). Similarly, yield gap had range of about 56–203% (mean of 134%) in Southeast Anatolia region, and 49–213% with mean of 115% in the Black Sea region (Table 15). These three regions had the lowest wheat yields, particularly under farmers' conditions due to harsh conditions of mostly sloping mountainous areas for wheat growing.

However, there is great potential for yield increases of wheat in these regions as shown by the high yield gaps of research results compared to farmers' practices.

Therefore, these regions need special attention for dissemination of improved soil and crop management practices to farmers.

Further, as a second step in the first case, mean wheat yields from the most important wheat-growing areas in CA (north, east, and south), Southeastern Anatolia, and Eastern Anatolia regions, were used to calculate the yield gaps

Table 14. Mean wheat grain yields (kg/ha) and yield increase (over farmers' yields) under rainfed conditions in Aegean, Marmara, and Mediterranean regions of Turkey during 1990–2001.

Year	Aegean Region			Marmara Region			Mediterranean Region		
	Farmers' yields	Research station yield	Yield increase over farmers (%)	Farmers' yields	Research station yield	Yield increase over farmers (%)	Farmers' yields	Research station yield	Yield increase over farmers (%)
1990	2474	3560	44	3584	4500	26	2739	6000	119
1991	2664	4300	61	3198	4650	45	2445	5505	125
1992	2455	4425	80	3239	4325	34	3062	4500	47
1993	2639	5260	99	3172	4350	37	3082	4540	47
1994	1839	3956	115	2412	5250	118	2001	5250	162
1995	2014	4300	114	3010	4500	50	2485	4250	71
1996	2025	5100	152	2856	5250	84	2896	4025	39
1997	2515	5268	109	3075	4560	48	3045	4563	50
1998	2356	5423	130	3057	5560	82	3002	4856	62
1999	2178	4365	100	3057	4350	42	2836	6020	112
2000	2754	5900	114	3156	6500	106	3000	4968	66
2001	2555	4320	69	3019	5550	84	3025	4000	32
Mean	2372	4681	97	3070	4945	61	2802	4873	74

Source: N. Zencirci, Wheat Project Coordinator, Turkey.

Table 15. Mean wheat grain yields (kg/ha) and yield increase (over farmers' yields) under rainfed conditions in Northeast, Southeast, and Black Sea Regions of Turkey during 1990–2001.

Year	North East Anatolia Region			Southeast Anatolia Region			Black Sea Region		
	Farmers' yields	Research station yield	Yield increase over farmers (%)	Farmers' yields	Research station yield	Yield increase over farmers (%)	Farmers' yields	Research station yield	Yield increase over farmers (%)
1990	1485	2852	92	1538	3250	111	1719	2560	49
1991	1233	2890	134	1548	4685	203	1583	2650	67
1992	1235	3650	196	1536	4500	193	1670	3125	87
1993	1164	3185	174	1718	2680	56	1717	3650	113
1994	1164	2856	145	1718	4500	162	1717	3260	90
1995	1163	1978	70	1602	4500	181	1413	3750	165
1996	1156	2985	158	1589	4020	153	1658	3650	120
1997	1065	3500	229	1514	4360	188	1515	3550	134
1998	1156	2950	155	1817	3800	109	1771	3850	117
1999	1064	3256	206	1418	2650	87	1317	4120	213
2000	1196	1965	64	1856	3150	70	1756	4700	168
2001	1156	3585	210	1715	3650	113	1655	2975	80
Mean	1185	2970	150	1631	3812	134	1624	3487	115

Source: N. Zencirci, Wheat Project Coordinator, Turkey.

on the basis of mean district/province yields compared with the highest yields of state farms and research stations (Table 16).

In most important wheat-growing areas of Turkey, mean potential yields (the highest yields obtained from state farms with improved management)is higher than the farmers' yields by 29–175%. Research stations yields are higher by 61–201%. These increases are comparable with mean increases at research stations as (see Tables 13 and 15) over the farmers' yields, respectively, for the regions given in (Table 16). These are translated as further yield increases of 14, 27, 21, 16, and 67% by the highest yields of research stations over the mean yields of the stations, respectively. The highest yield increase was in Eastern and Southeastern Anatolia where the dissemination of improved technologies is not as widespread as the plateau of CA.

The second case; the CropSyst model was used with the agro-climatic data of Ankara Rural Services Research Institute to identify the wheat yield gap during 1991/92–2000/01 cropping seasons. The yield gap was determined from mean district/province yields from CA (mean of north, east, and south), which is a major wheat production area of Turkey, compared with yields from research stations and crop simulations (Table 17).

In Ankara, the annual rainfall amount was variable across the selected cropping seasons of 1991/92–2000/01, with average rainfall of 359 mm (Figure 11). In the seasons of 1993/94 and 2000/01, there was inadequate rainfall for wheat growth and development with total seasonal amounts of 234 and 268 mm, respectively. However, during 1994/95 and 1997/98, there was adequate rainfall with a total seasonal amounts of 442 and 461 mm, respectively. The other cropping seasons had about average rainfall.

The mean farmers', research station's, and simulated potential durum wheat (cv. Gerek-79) grain yields under rainfed conditions are presented in Table 17. In Turkey, similar to Morocco and Syria, farmers' yields remained low with a mean of 1825 kg/ha. For the simulated years (1992–2001), in the farmers' fields in Ankara Province, the highest yield was 1935 kg/ha during the 1999/2000 season due to higher than average rainfall with good distribution; while the lowest yield of 1675 kg/ha during the 1996/97 season was due to non-uniform distribution of an average amount of rainfall. In CA, the yield pattern did not follow the rainfall variation due to factors such as choice of cultivar, crop rotation, tillage system, sowing date, seed rate, fertilizer use, or weed control, as was also the case in Syria.

Table 16. Important wheat-growing regions of Turkey and their average yield gap from the highest yields from state farms and research stations (average for 1990–2001).

Region	Rainfall (mm)	Farmers' yields (kg/ha)	State farm highest (kg/ha)	Research station highest (kg/ha)	Yield gap / increase over farmers			
					State farm		Research station	
					(kg/ha)	%	(kg/ha)	%
Central Anatolia (North)	300–500	2020	2600	3260	580	29	1240	61
Central Anatolia (East)	400–500	1695	2820	3135	1125	66	1440	85
Central Anatolia (South)	250–500	1790	2550	2970	760	42	1180	66
South Eastern Anatolia	200–500	1630	4485	4900	2855	175	3270	201
Eastern Anatolia	450–600	1185	2870	3150	1685	142	1965	166

Source: N. Zencirci, Wheat Project Coordinator, Turkey.

Table 17. Mean farmers', research station, and simulated potential grain yields (kg/ha) of bread wheat in Ankara, Turkey.

Year	Precipitation (mm)	Farmers' fields (kg/ha)	Research station (kg/ha)	Potential yield (kg/ha)	Yield increase over farmers' fields, (%)	
					Research station	Potential
1991/92	365	1785	2645	2650	48	48
1992/93	351	1905	2530	3040	33	60
1993/94	234	1740	2585	2630	49	51
1994/95	442	1775	2570	3545	45	100
1995/96	355	1855	2550	2900	37	56
1996/97	366	1675	3890	3635	132	117
1997/98	461	1890	3505	5915	85	213
1998/99	352	1810	2670	2920	48	61
1999/00	394	1935	2770	4340	43	124
2000/01	268	1890	2365	2780	25	47
Mean	359	1825	2810	3435	54	88

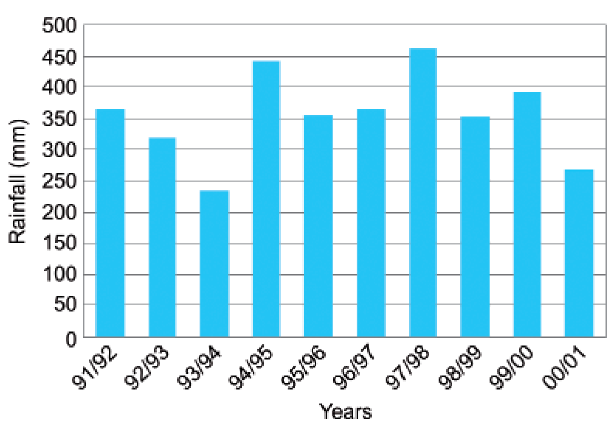

Figure 11. Annual rainfall in Ankara Province of Turkey during 1990/91–1999/2000 cropping seasons.

Average yield obtained from research station trials was 2810 (2530–3890) kg/ha in CA (Table 17). These yields were higher than those obtained by the farmers; however, they remained lower than the simulated potential yields. The mean of simulated potential yields was 3435 with range of about 2630–5915 kg/ha. The high variation from year to year in potential yields was due to rainfall variability in space and time, as well as minimum and maximum air temperature, and solar radiation that significantly affected wheat growth.

During 1991/92–2000/01 cropping seasons, the yield gaps of research stations over farmers' yields had range of about 25–132% with a mean of 54% (Table 17). Similarly, the yield gaps between simulated potentials over farmers' yields had range of about 47–213% with a mean of 88%. The yield gap of simulated potential over farmers' yields, during the 1997/98 season, reached a maximum value of 213% yield despite only adequate rainfall of 461 mm, due to the poor management of the farmers. Also, during the 1993/94 season, the driest year in the evaluation period had 234 mm rainfall, the yield increases over farmers' yields by research stations and simulated potentials were 49 and 51%, respectively. However, the mean yield increase by simulated over research station yields was 22% with range of about –7 to 69% was much lower than yield increases by simulated potentials over farmers' yields. This indicated that improved crop and soil management as used in research stations were similar to the cases of Morocco and Syria rainfed regions; similarly, this improvement was also mainly under relatively more favorable conditions for crop growth such as in 1994/95, 1997/98, and 1999/00 cropping seasons.

The yield gap between research station and farmers' yields was 54% (Figure 12); similarly, the yield gap of simulated potential over farmers' yields was 88%.

Similar to other regions of WANA, improved management practices together with improved varieties have to be adopted by farmers to narrow the yield gap for improved wheat production in Turkey.

In Turkey, wheat-growing areas reached the maximum limits (Table 3) and did not increase further in 1994-2004, but yield increased over the period by 22%. Several improved wheat varieties have been transferred to farmers. However, there is a lack of practicing of improved soil, water and crop management technologies leading to high yield gaps of state farms or research stations relative to farmers' yields.

Soils in Turkey are susceptible to erosion, which affect wheat yields. In addition, farmers do not apply enough inputs (fertilizers, certified seeds) and improved cultural practices (soil and crop management). These bottlenecks have to be considered for future production plans (Kun 1997).

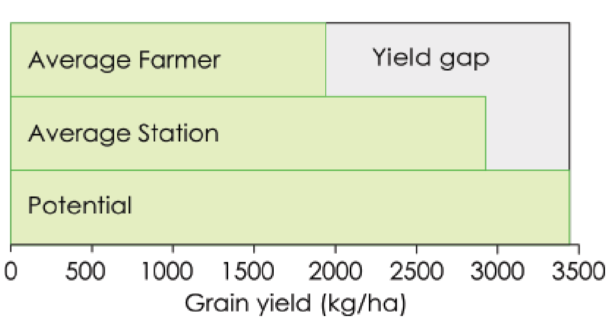

Figure 12. Average wheat yield gap in Turkey during 1991–2001 seasons.

Important wheat-growing areas of Turkey in Central, Eastern, and Southeastern Anatolian regions mostly suffer from water shortage, which lowers the mean wheat yields under inappropriate soil and crop management practices. Therefore, improved management practices as shown in the yield gap assessment will be a driving force to mitigate the negative effects of moisture deficiency and will significantly increase wheat yields over the farmers' current yield levels (Durutan et al. 1979, 1989; Guler et al. 1979, 1980; Avci et al. 1987; Karaca et al. 1987, 1989; Avci 2005).

Finally, improved soil and crop management practices with associated appropriate policies need to be brought into farmers' fields with their participation to fill the gap between state farms', research stations', as well as simulated potential wheat yields.

6 OTHER MAJOR CONSTRAINTS AND OPPORTUNITIES FOR BRIDGING THE YIELD GAPS

In the WANA region, other factors than technical aspects contribute to the low yields of wheat. In fact, continuous land fragmentation caused farm sizes to get smaller with average land holding of 0.5–2 ha. Productivity in such small areas is difficult to achieve because of high input costs. Farmers tend to migrate to urban areas for off-farm employment for their welfare, and therefore land consolidation may be a solution to land division.

In addition to land fragmentation, improved management practices have not been adopted by farmers in the region because of socio-economic considerations.

Identified constraints include: unfavorable growing conditions, unavailability of improved seed and adequate machinery, unawareness of the improved technologies, and lack of resources.

The participation of all three parties (farmer, researcher, and extension worker) in the testing, demonstration, and dissemination of improved technology will lead to better awareness of technology and its adoption by a larger number of farmers. Of course, the degree and extent of adoption will remain dependent on the availability of crucial inputs, such as machinery, fertilizer, and improved seed.

7 CONCLUSION

Currently, about 700 million people live in the WANA region, with an annual food deficit of eight million tons of wheat. The WANA population is expected to reach 1.04 billion by 2025, so agricultural production for wheat needs to be kept above the level of population growth to meet increasing demand. Most of the increase in food production will have to come from increased productivity per unit area rather than increasing the area under agriculture.

In the irrigated zones, yields are more stable due to irrigation water supply and they are, on average, four times higher than those for rainfed conditions. The gap between the potential and actual (farmers') yields is high in both rainfed and irrigated zones. It seems that most of the farmers use the same farming techniques regardless of rainfall variability and irrigation water availability. In fact, during wet years (high rainfall and irrigation possibilities), they do not use enough inputs (irrigation water, fertilizers, and pesticides) at the right time, so their yields remain relatively low. When it is too dry, they usually obtain very low productivity and sometimes even have total crop failure. Under this last situation, the adoption of water conservation practices can reduce the effects of drought and water scarcity.

In the WANA region, the productivity of rainfed wheat is low, with yield ranges of 0.5–1.5 t/ha, mostly depending on the rainfall pattern. However, higher yields have been reported in experimental fields and in on-farm demonstrations. Wheat yields can be increased 1.6–2.5 times in different wheat-growing regions of Morocco, 1.7–2.0 times in Syria, and 1.5–3.0 times in Turkey. This is possible with runoff water-harvesting, supplemental irrigation, and increased efficiency of water use, along with high-yielding varieties and improved agronomic management.

There is a clear need for reinforcement of dissemination programs and development of a more efficient participatory and integrated approach to technology transfer to encourage farmers to use existing and well adapted technologies. Finally, due to erratic conditions (drought and high fluctuations of rainfall and irrigation water) and input prices that are generally high, the yield gap needs to be measured not only in terms of grain yield, but also in terms of income. This will quantify the gains and convince farmers to adopt the new technologies, especially since they consider their intermediate farming methods (low investment techniques) to be a risk management strategy.

In summary, the results in the three representative countries of WANA show the importance of improved soil and crop management practices, combined with the use of improved crop varieties (particularly in drier areas) in reducing the yield gap for wheat crops and providing better income and livelihoods for rural communities.

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