Crop Production and Management in Semi-Arid and Arid Environments

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Abstract

Saudi Arabia is an arid country having limited water resources coupled with a hot and dry climate. Important factors, affecting crop production in an arid environment, include soil type, water availability, rainfall intensity, high evaporative conditions, high infiltration rate of soil, crop selection, fertilizer use and crop management practices. Recently, research has indicated that optimum crop production in an arid environment can only be achieved if improved soil, water and crop management practices are adopted. For example: average wheat production in Saudi Arabia has reached up to 7-8 Mg ha^{-1} due to the adoption of improved crop production technology and management. Overall wheat production in the Kingdom of Saudi Arabia ranged from 0.28 million tons (1977) to 1.75 million tons (1998). The main objective of this paper is to identify factors important for increased crop production and to discuss different soil, water and crop management practices adopted for optimal crop production, sustainable agriculture and higher water use efficiency. Overall, there exists an excellent potential for a reasonable crop production if certain soil, water and crop management practices are considered in an arid environment.

Introduction

The total land area of the Kingdom of Saudi Arabia is about 2.25 million km^2 which accounts for approximately 1.8% of total global land and covers about 80% of the Arabian Peninsula. It is situated between 35°-56° east longitude and 16°-32° north latitude bordering on the west by the Red Sea on the south by Yemen and Oman and on the north by Jordan, Iraq and Kuwait. The western coast, which extends from the Gulf of Aqaba to the Yemen border, is more than 1,750 km long. The eastern coast, from Qatar to Kuwait, is about 480 km long. The southern frontier is 1,360 km long.

The country experiences a very hot and dry climate where pan-evaporation usually exceeds that of precipitation which is scarce and very low. This has led to practice irrigated agriculture for sustainable production. The water needs are mainly met by pumping groundwater and applied through improved irrigation systems such as central pivot, solid set sprinklers and various drip irrigation systems. The size of the farm covered by a given system of irrigation depends on the kind of crop under cultivation. For example: one central pivot irrigates between 35-75 ha depending on the length of its panels and the crop under consideration (Bashour, 1987).

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Climate of Saudi Arabia

Saudi Arabia is characterized by a hot and dry climate and is classified as an arid region occupying about 5% of the world's arid zone (Bashour *et al.*, 1983). The relative humidity is low except along the coastal zone where sometimes it reaches 90%. The average annual temperature is 33°C in winter and 40°C~in summer with a wide seasonal variation (El-Khatib, 1980). The mean minimum temperature was 22°C in January and 8°C for the Riyadh region, while in June the diurnal mean maximum temperature was 42°C and minimum 26°C. Wind speed ranges between 6 and 25 km $hour^{-1}$. In some other regions of the Kingdom, wind speed reached sometimes up to 90 km $hour^{-1}$. Sunshine measured by the total number of bright hours varies due to seasons and the latitude. The seasonal range of sunshine hours in the Kingdom is between 6 hours during winter and 12 hours during summer. Solar radiation in Riyadh was reported to be 550 cal cm^{-1} day^{-1} for 1975-1984 for the months of July and August and 325 cal cm^{-1} day^{-1} in December and January (Water Resources Department, Ministry of Agriculture and Water, 1988).

Measurement of climate parameters shows that the pan-evaporation rates are low along the coast and high in the interior. Evaporation rates were 540 mm in the month of July at Hail at 988 m elevation, 270 mm in Buljurshi (2,400 m elevation), and 310 mm in Qatif with an elevation of 5 m. During January, the values were about 100 mm at all the three stations. The rainfall variations between the years are high and long periods of drought without rainfall have been experienced.

Crop production in Saudi Arabia

In the past, oasis-based agricultural production was the main source of income for sustainable population. The exploration of oil resources in the Kingdom encouraged the Government to embark on many development projects in various fields for the improvement of the social structure of the country. Among the various projects, agriculture expansion took the major share of the oil-based revenue for the exploitation of groundwater resources. This brought a radical change in the life style of all sectors of the society because many regions in the Kingdom have adequate water resources and good land for crop production. Major agriculture production areas are located in Al-Kharj, Al-Aflaj, Wadi Dawaser, Jizan, Najran, Al-Hasa, Al-Qateef, Al-Qaseem, Hail, Tabouk and Al-Jouf.

Government of the Kingdom of Saudi Arabia in the Third National Development Plan (1980-1985) placed a major emphasis on the development of indigenous resources, with special reference to water and agriculture. The main objective of the plan was to achieve self-sufficiency in food production utilizing local resources. Significant progress has already been made in all aspects of agricultural activities. Recently self-sufficiency has been achieved in the production of some major agricultural commodities including wheat. As a result, there was a surplus in certain commodities, which were exported to other countries. Major crops grown include field crops (wheat, barley, alfalfa, sorghum, and sudan grass), vegetable crops (tomato, cucumber, potato, squash, onions, and carrot) and fruit trees (date palm, grapes, citrus, peaches, melons, water melons, pomegranate, lemon and figs).

Agricultural land availability and use

The total agricultural land availability and use are presented in Table 1 which indicates the potential land resources available for agriculture expansion and increase of food production to meet social needs, thus improving the economic conditions of the community.

Table 1 Agricultural land availability and use

Description	Area (1,000 ha)
Cultivable land	48,899
Reclaimable land	3,785
Total cultivable & reclaimable	5,268
Land distributed up to end 1999	2,986
Total holding area (farms)	4,969
Forest	2,700
Pastures	170,000

Source: Land Management Department, Ministry of Agriculture and Water, 1985.

Water resources

There are no perennial streams or rivers in Saudi Arabia. The main sources of water are underground water aquifers, rainfall and desalination. According to Al-Jaloud (1999), a brief detail of these resources is given below:

1 Groundwater

The quantity and quality of groundwater depend on the geological formation of underlying strata, the size of aquifer and the site location. The groundwater is classified into four hydrogeological zones, i.e. confined aquifers, main aquifers, free flowing aquifers and the springs. Agriculture sector largely draws water from the main aquifers. In total, there are nine main aquifers (Noory, 1983; Water Resources Department, Ministry of Agriculture and Water, 1985). The flow rate and water salinity of these acquifers are presented in Table 2.

Table 2 Salient features of major aquifers in Saudi Arabia

Aquifer	Location	EC $dS\ m^{-1}$	Depth (m)	Discharge $L\ s^{-1}$
Al-Saq	Central North	1.0 - 1.5	100 - 1,500	20 - 110
Al-Manjur	Central	1.0 - 1.5	1,200 - 2,000	60 - 120
Al-Wajeed	South	0.5 - 1.5	150 - 900	40 - 80
Al-Wasi	Central East	1.5 - 5.0	100 - 800	85 - 110
Tabouk	North	1.0 - 6.0	60 - 2,500	15 - 20
Al-Biyadh	North	0.8 - 1.2	30 - 200	25 - 50
Um-Er-Rudma	East	1.5 - 3.0	100 - 400	50 - 100
Neogene	East	1.5 - 7.0	50 - 100	50 - 100
Dammam	East	1.3 - 3.0	160 - 200	5 - 15

2 Rainfall

Rainfall which occurs usually between October and April in most of the Kingdom is highly unpredictable and the seasonal variations are also very high. The mean annual rainfall is 100 mm or less in major parts of the country, except in the mountainous part of the northern region (Asir) where it exceeds 500 mm in some small areas.

3 Desalination

There has been a tremendous increase in the demand for water supply over the last decade due to extensive development both at rural and urban levels. In order to meet the growing water needs, construction of desalination plants was inevitable. The quantity of water supplied by the desalination plants increased from 17 x 10^3 m^3 day^{-1} in 1970 to 2041 x 10^3 m^3 day^{-1} in 1990. The capacity of the desalination plants at Jubail and Al-Khobar located on the Arabian Gulf is 907 x 10^3 m^3 day^{-1} and 217 x 10^3 m^3 day^{-1}, respectively. The capacity of the desalination plant in Jeddah on the Red Sea is 335 x 10^3 m^3 day^{-1}.

4 Other sources

There is a potential source of reclaimed wastewater for use in agriculture as a supplemental source of irrigation water. The use of treated water should be encouraged as a supplemental source of irrigation in agriculture and landscape development to meet the increasing demand of water.

Total cropped area

Total cropped area includes the areas under temporary winter and temporary summer crops and areas under permanent crops (Fig. 1). Total cropped area in 1998 was estimated at about 1.22 million hectares compared to 0.61 million hectares in 1980. There was an increase of around 200% from 1980. This indicates the level of expansion in the field of agriculture. There were some fluctuations in the total cropped area in some years as compared to others, which could be subjected to variability in crop growth factors such as climate, etc.

Due to increased productivity per unit area of most agricultural products, the decline in the total area in 1981 did not affect the total output (Fig. 2). The year 1981 is considered to represent the beginning of the

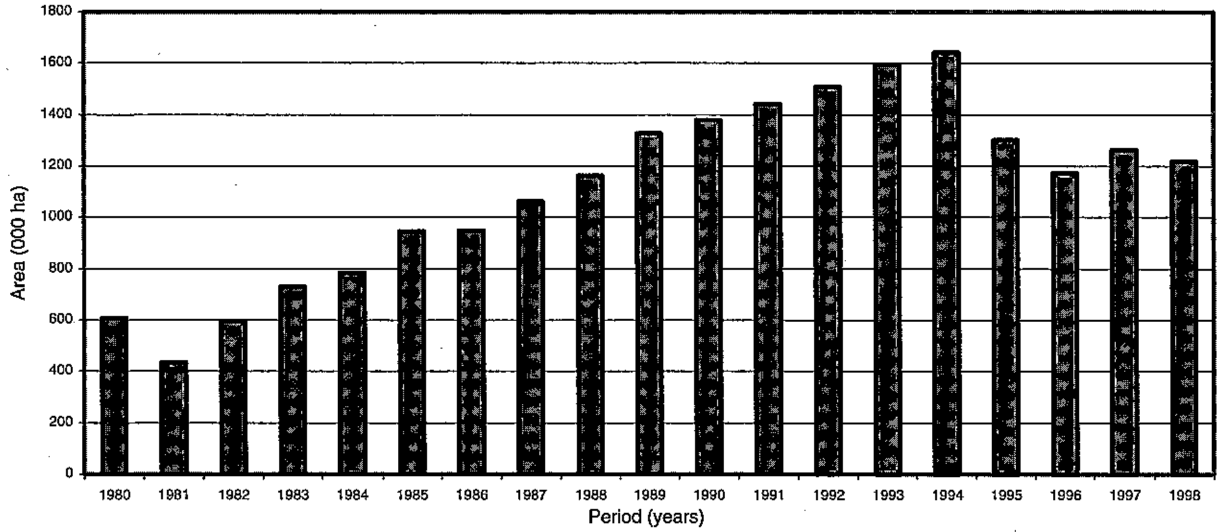

Fig.1 Total cultivated area in Saudi Arabia.

change in agricultural production patterns by the adoption of new agriculture technology. The next seven years have witnessed a marked increase in per unit productivity of crop areas, which led to a gross increase in agricultural output. Figure 1 shows the total cropped area in the Kingdom during the period 1980 - 1998 (Department of Economic Studies and Statistics, Ministry of Agriculture and Water, 1999). The increase in the percentage of wheat production is much higher than the corresponding increase in the cultivated area. This is due to the adoption of modern agricultural methods coupled with government incentives in the form of subsidies for farm machinery, light and heavy agricultural equipment, fertilizers and interest-free loans for different agriculture inputs. Additionally, the Saudi Government encourages and advises farmers to use improved crop varieties, better planting and plant protection methods to obtain higher quality crops.

Cereal production

Cereal output in 1998 was estimated at around 2.20 million tons compared to 0.282 million tones in 1977, showing an increase of 780% over a period of 18 years. This tremendous increase in cereal production was due to increased wheat production, which accounts for between 85-90% of the total cereal production in the Kingdom.

Wheat production

The total wheat output in 1998 was 1.75 million tons as compared to 0.142 million tons in 1980, showing an increase of 1,232% (Fig. 2). This success of wheat production earned appreciation of the world for the Kingdom. Although, there was a tremendous increase in wheat production in the late 1990s, there was a decline in total wheat production, which is attributed mainly to the change in government policy to diversify resources for the cultivation of new crop varieties. This decline in production was due to the decrease in the total area under wheat crop and not due to the decline in yield per unit area. The kingdom achieved self-sufficiency in wheat production resulting in a sizeable buffer-stock and surplus for export The Food and

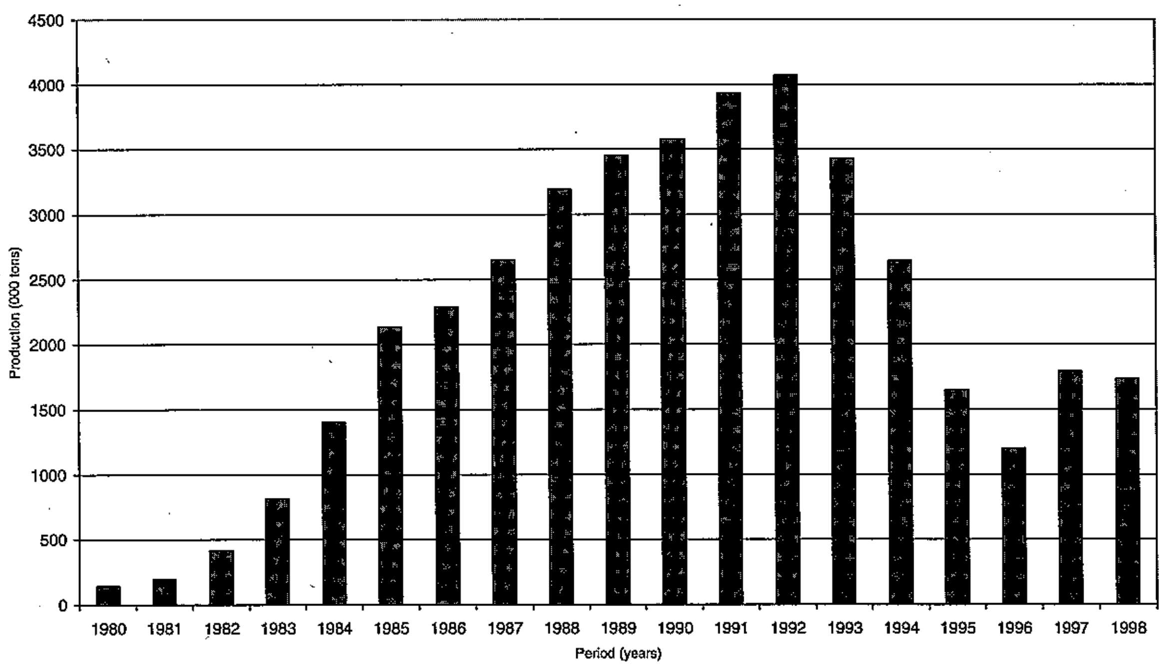

Fig. 2 Wheat production in Saudi Arabia.

Agriculture Organization of the United Nations (FAO) awarded a certificate of appreciation to the Kingdom for this achievement.

Management practices for optimal crop production

It is important to highlight some of the major management practices required for optimal crop production in an arid environment which are summarized below.

1. Sub-soiling and rotavation of land

Deep tillage or sub-soiling plays a significant role in increasing the productivity of sandy desert soils especially when the hard layer/hard pan is very close to the soil surface, because the presence of the hard pan limits plant root growth, water penetration, and creates a temporary sub-surface water table which is harmful to land productivity. This operation is not very popular due to its economic implications and should be adopted only if other management practices were not effective. In addition, rotavation and simple plowing of land are also necessary to eliminate weeds along with plowing crop residues into the soil. This will also act as an alternate source of organic material for improving the water-holding capacity, decrease the infiltration rate of soil and enhancing the exchange sites on the soil particles for better retention of applied fertilizers.

2. Pre-irrigation and leaching requirements

Accumulation of salts in soils is a universal phenomenon in irrigated agriculture and in an arid environment. Leaching of salts from the surface soil before planting is a prerequisite for sustainable agriculture in a desert environment. The objective of applying pre-planting irrigation/leaching requirement could be manifold in terms of storage of soil moisture in the soil profile, which might be utilized later on by the crop during the growth period. Also, the leaching will provide salt-free soil for germination and emergence of crop seeds.

3. Seedbed preparation

The seedbed should be prepared in considering all the necessary requirements for establishing a good crop stand, normal plant growth and removal of weeds and other undesirable elements harmful to plant growth. The important considerations are pre-irrigation, application of a basal dose of NPK fertilizer, herbicides and proper compaction of soil for efficient running of farm implements such as planters, fertilizer distributors, etc. which are used for planting and other agricultural practices.

4. Planting practices

Planting process is very complex and involves a number of practices such as sowing methods, date of sowing, seeding rate, selection of suitable crop varieties, optimal fertilizer application and control of insect pests in a given soil, water and crop growth conditions, because an appropriate combination of all these practices will ensure a good crop stand. For example: wheat production was optimum when wheat was grown between November 10 and January 20 and covers all types of climatic conditions in the Kingdom of Saudi Arabia. Presently, wheat varieties, namely Yokora Roja and Probred are cultivated and account for more than 95% of total wheat production in the country. Moreover, these varieties are accepted by the Grain Silos and Flour Mill Organization. Taking into consideration the planting practices, a seeding rate of 160 kg ha^{-1} is recommended for good crop stand. Seeding should be performed with an automatic planter to keep the depth of seed placement suitable for proper germination and emergence of crop.

5. Fertilizer application

Application of fertilizer depends on the soil type and location, initial fertility status of soil, quality of irrigation water, soil salinity, etc. Generally, fertilizer is applied at different crop growth stages and the application varies with the crop types (Hamadallah and Bashour, 1987; FAO, 1987). For example in the case of wheat crop, fertilizer is applied in split doses, i.e. sowing, tillering, flowering and booting stage to obtain maximum yield and for higher water and fertilizer use efficiency. In Saudi Arabia, the fertilizer is applied at three different times. 1) Preplanting: Diaminonium phosphate (DAP) = 18 - 46 - 0 : Broadcasted on the soil surface and mixed with the top soil at a rate of 200 kg DAP ha^{-1} =92 kg P_2O_5

ha^{-1} +36 kg N ha^{-1}.* Potassium sulfate (K_2SO_4 = 50% K_2O) : Broadcasted and mixed with the top soil at a rate of 100 kg K_2SO_4 ha^{-1} = all the potassium fertilizers. 2) During sowing time: the DAP at a rate of 200 kg is placed in rows between the seed rows at a distance of 6 cm from seed end at a level 3 cm lower than the seeds using special seeders. 3) After germination: 150 kg DAP ha^{-1} is broadcasted on the soil. Later on, urea (46% N) at a rate of 475 kg ha^{-1} is injected through the irrigation system. This amount of urea is added in about ten doses at approximately 7-10 day intervals. The first dose of urea is applied at about three weeks after germination. Generally the majority of the nitrogen fertilizers should be added before the plant reaches the booting stage, whereas, in case of potato and alfalfa, the fertilizer is applied differently for increased crop production. The following fertilization recommendation was found to be suitable for sandy calcareous soils in semi-arid and arid regions that are irrigated with water having a TDS between 800-1000 mg L^{-1}. The maximum yield obtained was 7.2 tons ha^{-1} (wheat), 20-25 tons ha^{-1} (alfalfa hay) and 40-45 tons ha^{-1} (potato). Alfalfa is a legume crop, which also fixes some of the nitrogen from the free air, only in the presence of specific bacteria of the genus *Rhizobium*. The most economical and practical way to introduce the bacteria is through mixing the bacterial inoculum with the seed before planting. The recommended NPK fertilizers for wheat, alfalfa and potato are summarized below.

Fertilizer application to different crops (kg ha^{-1})

Crop	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)
Wheat	220-250	185	50
Alfalfa	100-300	200	—
Potato	200-220	150	40-60

One of the main objectives of fertilizer application is to achieve higher crop production and higher fertilizer use efficiency. An example of nitrogen use efficiency for wheat crop is presented below where the crop received both inorganic fertilizer and supplemental N-fertilizer from effluent water. The irrigation water was derived from well water and the aquaculture effluent containing 40 mgN L^{-1}.

Nitrogen use efficiency for wheat crop

Yield and nitrogen use efficiency (NUE) of wheat was investigated under field conditions using two types of irrigation water with and without nitrogen on a sandy-loam to loamy-sand soil during 1992-93 and 1993-94 (Hussain and AL-Jaloud, 1996). Depending upon the nitrogen treatments, the mean crop yield ranges in 1992-93 were: grain yields 6.19 - 6.87 Mg ha^{-1} and biomass 15.41 -16.34 Mg ha^{-1} (treated effluent). The NUE for grain yield in 1992-93 ranged between 16.70 - 50.23 kg kg^{-1} N (well water) and 20.65 - 91.56 kg kg^{-1} N (treated effluent), whereas the NUE in 1993-94, varied between 10.49 - 32.73 kg grain kg^{-1} N (well water) and 21.30 - 72.93 kg grain kg^{-1} N (treated effluent). The NUE for total biomass in 1992-93 varied between 46.54 - 130.32 kg kg^{-1} N (well water) and 53.66 - 158.77 kg kg^{-1} N (treated effluent). Similarly, the NUE in 1993-94 varied between 35.99 - 102.1 kg biomass kg^{-1} N (well water) and 59.27 - 161.89 kg biomass kg^{-1} N (treated effluent). A significant decrease in NUE was observed with increasing nitrogen application both for grain and biomass production. In conclusion, a higher grain yield and NUE of wheat crop can be achieved with low application rates of nitrogen if the crop is irrigated with treated effluent containing nitrogen in the range of 20 mg L^{-1} and above.

Irrigation application

Water requirement of a crop depends on many factors such as crop variety, climate, date of planting, quality and quantity of irrigation water, soil type, irrigation system, etc. As an example, the irrigation schedule is presented for those farms where wheat and alfalfa production was 7.2 tons ha^{-1} and 20-25 tons ha^{-1} (dry hay), respectively in the central region of Saudi Arabia. The main purpose of application of the calculated amount of irrigation water to a given crop is to obtain optimum yield with a minimum amount of water especially in an arid environment where water availability is scarce. Water requirement of wheat and alfalfa crops as recommended by the Ministry of Agriculture and Water, Kingdom of Saudi Arabia for the central region of Saudi Arabia is presented in the following pages (Al-Zeid *et al.*, 1985).

1. Wheat

Period	Irrigation water (cm)
Pre-irrigation	12 - 14
November	10 - 12
December	8 - 10
January	10 - 12
February	12 - 20
March	15 - 20

2. Alfalfa

Month	Irrigation water (cm)
January	13 - 15
February	15 - 18
March	18 - 20
April	20 - 22
May	22 - 24
June	24 - 28
July	28 - 30
August	28 - 30
September	24 - 28
October	22 - 24
November	18 - 20
December	14 - 18

Water Use Efficiency (WUE) of some cereal crops

Wheat crop

Water use efficiency and yield of wheat were determined in a field experiment using different types of irrigation waters with and without nitrogen fertilizer on a sandy to loamy sand soil during 1991-92 and 1992-

93 (Hussain and Al-Jaloud, 1995). Depending upon the fertilizer treatments, the mean crop yield ranges in 1992-93 were: biomass from 4,290 to 13,960 kg ha^{-1} (well water) and 6,460 to 14,870 kg ha^{-1} (aquaculture effluent) and grain yield from 770 to 5,010 kg ha^{-1} (well water) and 2,140 to 5,790 Mg ha^{-1} (aquaculture effluent). The WUE for grain yield in 1991-92 was 2.67 to 12.24 kg ha^{-1} mm^{-1} (well water) and 4.29 to 12.67 kg ha^{-1} mm^{-1} (aquaculture effluent). The WUE for grain yield in 1992-93 ranged from 1.22 to 7.97 kg ha^{-1} mm^{-1} (well water) and 3.40 to 9.21 kg ha^{-1} mm^{-1} (aquaculture effluent). The WUE for biomass in 1991-92 ranged from 8.74 to 29.16 kg^{-1} ha^{-1} mm^{-1} (well water) and 11.34 to 30.02 kg ha^{-1} mm^{-1} (aquaculture effluent), whereas in 1992-93, the WUE for biomass ranged from 6.82 to 22.19 kg ha^{-1} mm^{-1} (well water) and 8.68 to 23.64 kg ha^{-1} mm^{-1} (aquaculture effluent). In conclusion, the application of 150 to 225 kg N ha^{-1} for well water irrigation and 75 to 150 kg N ha^{-1} for aquaculture effluent irrigation containing 40 mg N L^{-1} would be sufficient to obtain optimum grain yield and higher WUE of wheat in Saudi Arabia.

Barley crop

Water use efficiency and yield of barley were determined in a field experiment using various types of irrigation water with and without nitrogen fertilizer on a sandy to loamy sand soil during 1994-95 (Hussain *et al.*, 1998). Depending upon the fertilizer treatments, the mean crop yield ranges were: green-matter from 20.0 to 55.0 Mg ha^{-1} (well water) and 23.0 to 66.5 Mg ha^{-1} (aquaculture effluent); dry-matter from 7.04 to 20.69 Mg ha^{-1} (well water) and 8.45 to 20.90 Mg ha^{-1} (aquaculture effluent); biomass from 4.37 to 21.31 Mg ha^{-1} (well water) and 8.53 to 19.94 Mg ha^{-1} (aquaculture effluent) and grain yield from 2.19 to 5.50 Mg ha^{-1} (well water) and 3.63 to 7.25 Mg ha^{-1} (aquaculture effluent). The WUE for grain yield was 3.48 to 8.74 kg ha^{-1} mm^{-1} (well water) and 5.76 to 11.53 kg ha^{-1} mm^{-1} (aquaculture effluent). The WUE for biomass ranged from 6.95 to 33.88 kg^{-1} ha^{-1} mm^{-1} (well water) and 13.55 to 31.70 kg ha^{-1} mm^{-1} (aquaculture effluent). The WUE for dry-matter ranged from 11.20 to 32.90 kg ha^{-1} mm^{-1} (well water) and 13.44 to 33.22 kg ha^{-1} mm^{-1} (aquaculture effluent). In conclusion, application of 100 to 150 kg N ha^{-1} for well water and upto 50 kg N ha^{-1} for aquaculture effluent irrigation containing 40 mg N L^{-1} would be sufficient to obtain optimum grain yield and higher WUE of barley in Saudi Arabia.

Alfalfa production

Alfalfa is the principal forage crop in the Kingdom. It has become an important component of the sustainable agriculture-based industry in oases with date palm as major fruit tree and other cereal crops of minor importance. The total area under alfalfa cultivation is presented in Fig. 3 between 1984-1998. Alfalfa is a leguminous crop and has the ability to fix part of the atmospheric nitrogen to meet its requirements if inoculated properly at the time of plantation. However, in view of the prevailing extremely hot climatic conditions, the inoculation and subsequent nitrogen fixation may not be sufficient for optimum production (Bokhari *et al.*, 1989). Therefore, the basal dose of NPK fertilizer must be applied to meet crop fertilizer requirements.

Vegetable production

Total production of vegetables reached 2.66 million tons in 1998 compared to around 0.500 million tons in 1978, increasing by 2.16 million tons with an increase of 432 %.

Potato production

In general, the Government of the Kingdom of Saudi Arabia pays considerable attention to the production of all kinds of vegetables but special emphasis was placed on potato crop due to its significant importance as a source of food to the inhabitants. To achieve this objective, a very special potato production program was developed in cooperation with potato-producing countries like Holland (Zaag, 1991). In order to encourage farmers, the government provides improved seed varieties to the farmers at nominal prices. As a result, the potato output reached 347 thousand tons in 1998, showing an increase of 344.4 thousand tons or more than 7,487% over the base year output level of 4.1 thousand tons in 1978 (Fig. 4).

Fruit production

Fruit production reached 1,196 thousand tons in 1998 compared to 470 thousand tons in 1980 with a net increase of 726 thousand tons (254% increase) over the output of the base year (Fig. 5). This pronounced increase in fruit production is attributed to the dynamic policies of the Saudi Government for encouraging the farming community to develop and improve fruit production. Such support includes the provision of subsidies to date palm growers and other fruits of significance for expansion by planting improved varieties, supplying free seedlings of different kinds of fruit trees such as grapes, citrus, peach, apricot, figs, melons, sweet melons, etc., free extension and plant protection services. Date is the main fruit of the country and its total production reached 648 thousand MT in 1998.

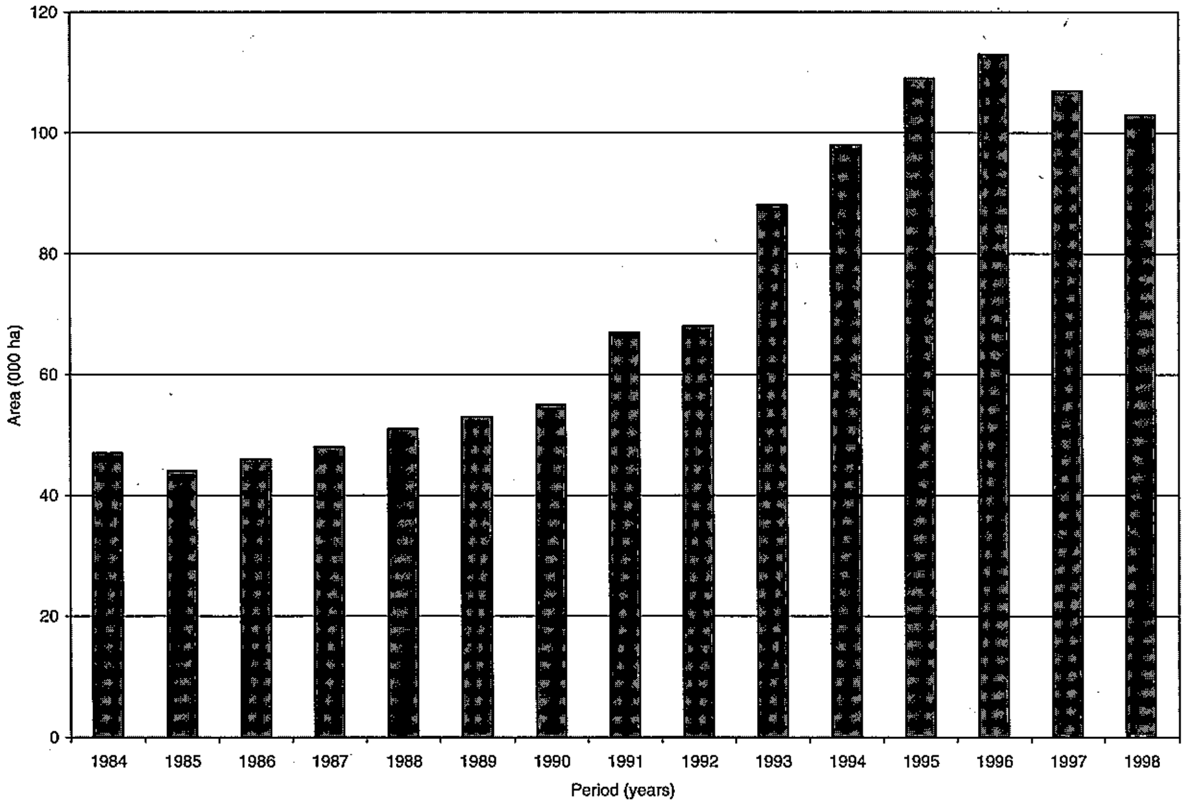

Fig. 3 Total cultivated area for alfalfa production in Saudi Arabia.

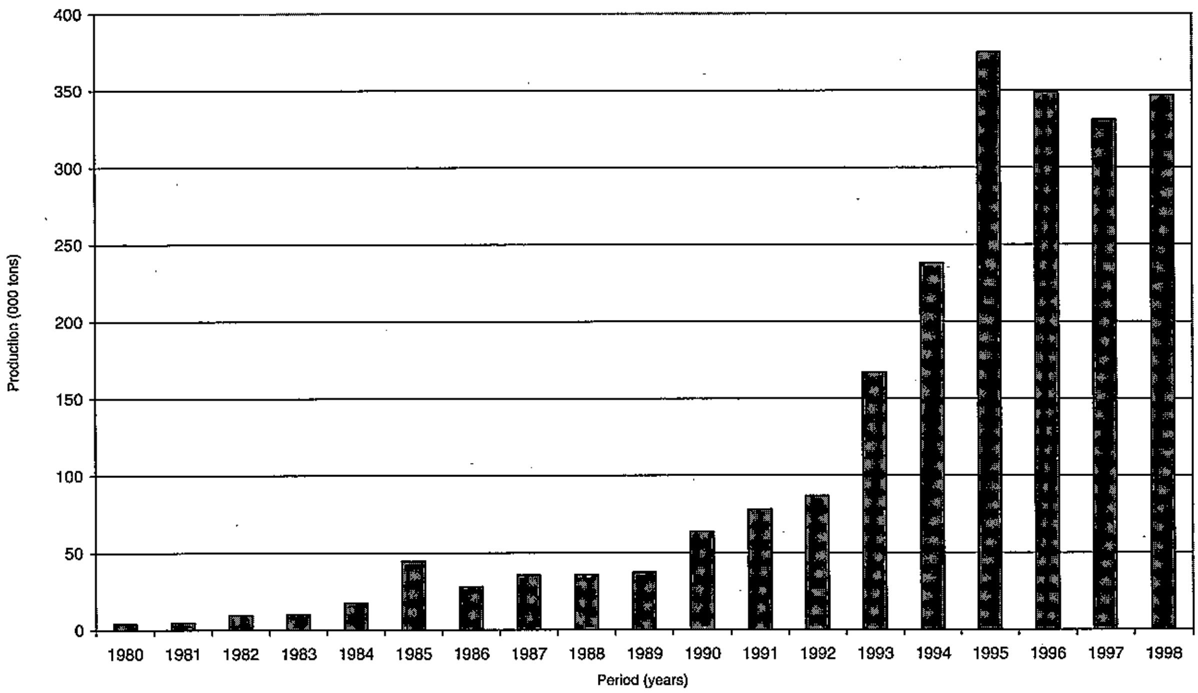

Fig. 4 Potato production in Saudi Arabia.

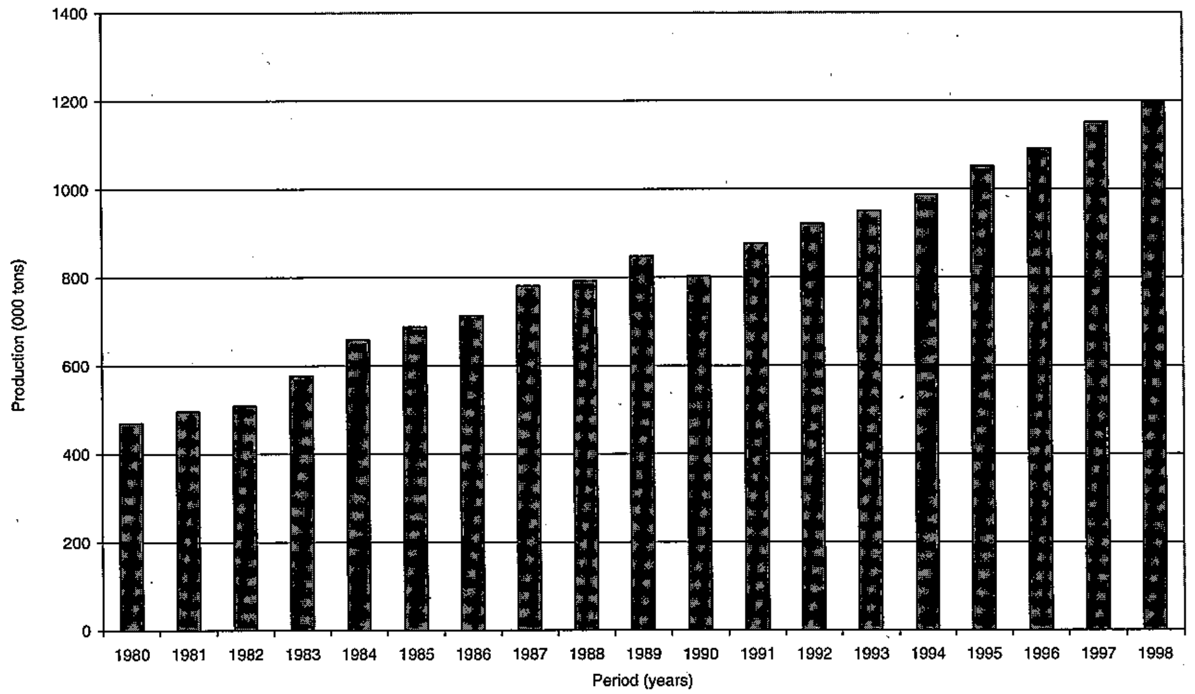

Fig. 5 Fruit production in Saudi Arabia.

Conclusions

The paper has highlighted the potential to grow some of the promising cereal and forage crops in an arid environment for sustainable agricultural production. To achieve higher crop production under such agroclimatic conditions, certain soil, water and crop management practices such as land preparation, water requirement, suitable crop selection, improved planting methods, appropriate fertilizer application, leaching requirements, quality and quantity of irrigation and optimum insect-pest control should be adopted. Additionally, the Agricultural Extension Service, Ministry of Agriculture and Water should play a pivotal role in educating the farming community on farming techniques.

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