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In cooperation with the **National Center for Agricultural Research & Technology Transfer, Amman, Jordan**

Potassium and water management in West Asia and North Africa

Edited by A.E. Johnston

International Potash Institute
Basel, Switzerland
2003

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Proceedings of the Regional Workshop of the International Potash Institute

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Session 1

Introduction to potassium fertilization

Balanced fertilization in the WANA region

A. Krauss

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Food security in the WANA region, a burning issue

West Asia North Africa, the WANA region, is characterised by a steadily growing population. It is expected that the population will increase by a further 60% by 2030 (Fig. 1). It is also assumed that, by the year 2030, more than 2/3rd of the population will live in urban centres with no possibility of producing their own food.

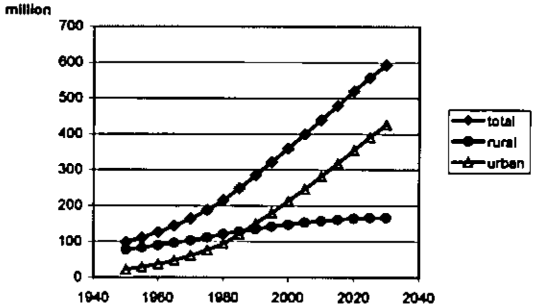
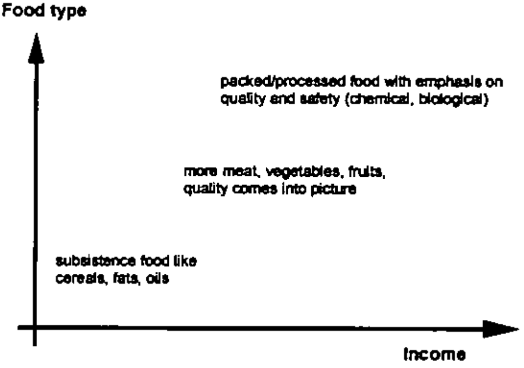


Fig. 1. Evolution of the population in the WANA region (data source: FAO, 2002).

Even if the diet does not change, an increasing population requires an increase in food production. But with increasing urbanisation and increasing income, people demand more animal protein, fruits and vegetables. Also the quality and safety of food becomes an important determinant when selecting food from the market (Fig. 2).



after KERN, 2000

Fig. 2. Relationship between income and food type.

Rosegrant *et al.* (1995) suggest that by 2020 the demand for meat and eggs in WANA will increase by 47%, whereas the demand for wheat and rice will increase by 24% only. To supply the population adequately with food, the countries of the WANA region will have to increase imports of wheat from 28.2 million tons (Mt) currently to 41.6 Mt within the next 20 years. Meat imports are expected to increase even more drastically from 1.05 Mt currently to 3.6 Mt in 2020, adding substantially to the budget requirement of these countries.

As a consequence of the increasing demand for food and feed, crop production in WANA has to be increased substantially, if the cost of food imports is not to increase excessively.

However in WANA, the availability of land and water is limited. The area of arable land and permanent crops has increased only slightly in the last two decades (by about 13%) to 94 million ha (Mha) currently. At the same time, the population has increased by 64% to currently 352 million. These changes have reduced land availability per capita from 0.38 ha in 1980 to 0.26 ha currently. In other words, to feed the growing population, the productivity of the existing cropped land has to be increased because horizontal expansion of crop production is hardly possible. But in recent years, there has been little or no upward trend in cereal yields in WANA, and the annual variation in yield has become more variable. Consequently, the per capita cereal production is declining (Fig. 3), widening the gap between cereal production and demand.

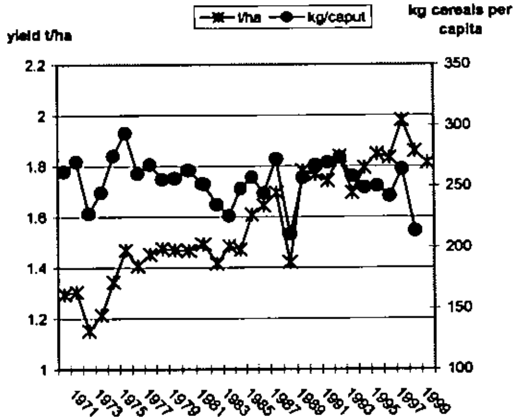


Fig. 3. Cereal yield and per capita production in the WANA region (data source: FAO, 2002).

Mineral fertilizers play a dominant role in increasing the productivity of cultivated land

In the past in WANA, the increase in fertilizer use and cereal yields were fairly parallel (Fig. 4). The use of mineral fertilizers increased rapidly in the last three decades from 1 to currently 6 Mt N+P_2O_5+K_2O. During the same period, cereal production rose from some 40 to about 70-90 Mt but with signs of stagnation in recent years. There is also a rather serious decline in apparent fertilizer use efficiency (FUE) which has decreased from some 35 kg cereals per kg NPK to currently 15 kg.

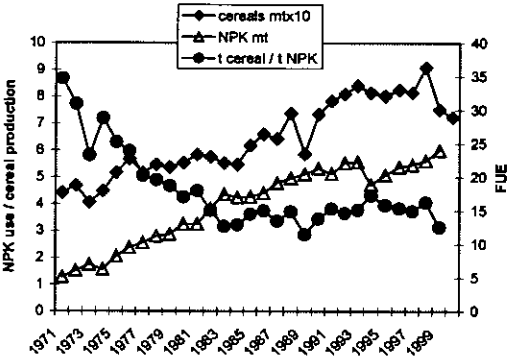


Fig. 4. Fertilizer use, cereal production and fertilizer use efficiency (FUE) in WANA (data source: FAO, 2002).

One of the factors responsible for stagnating yields and decreasing FUE is the current imbalance in fertilizer use (Fig. 5). This refers in particular to the ratio of N to K. Using data for 1997-99, of the applied nutrients, about 66% was N, 25-30% was P_2O_5 and a meagre 5-7% was K_2O. On average, the countries of WANA applied 39 kg/ha N, 17 kg/ha P_2O_5 and 4 kg/ha K_2O. The highest N use was in Egypt with 289 kg/ha, applied together with 41 and 10 kg/ha P_2O_5 and K_2O, respectively ($N:P_2O_5:K_2O$ = 1:0.14:0.03). Lebanon applied the highest rate of P with 104 kg/ha with an $N:P_2O_5:K_2O$ = 1:1.44:0.29, and Israel the highest rate of K with 55 kg/ha K_2O with an $N:P_2O_5:K_2O$ = 1:0.36:0.59.

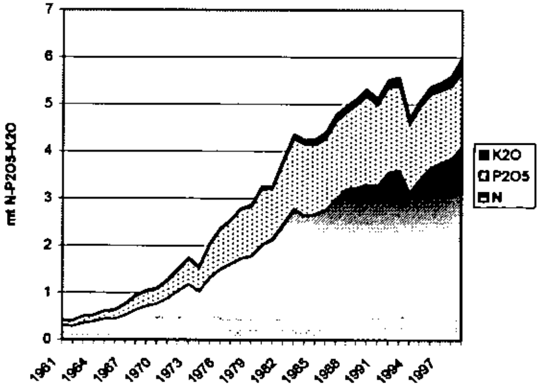


Fig. 5. Development of fertilizer use in WANA (data source: FAO, 2002).

The current N:K ratio in the fertilizers used in WANA is 1:0.08 i.e. 12 times more N than K_2O. This contrasts sharply with the ratio at which plants require these two nutrients. The N:K ratio is 1:1 in cereals and up to 1:1.5 in crops such as potatoes, vegetables and sugar beet. This N:K ratio in the WANA region is much wider than the average ratio of all developing countries (N:K = 1:0.21) or the developed countries (N:K = 1:0.39).

Within the WANA region, the N:K ratio differs substantially between countries (Fig. 6). Turkey and Egypt, the biggest fertilizer consumers, apply N and K at a ratio of about 1:0.03. Iran has considerably increased fertilizer use within the last few years and changed the N:K ratio from 1:0.04 in 1997 to a current ratio of 1:0.23 in 1999. Morocco (1:0.32) and Israel (1:0.59) have a fairly balanced N:K ratio, and Algeria an even closer ratio of 1:0.77.

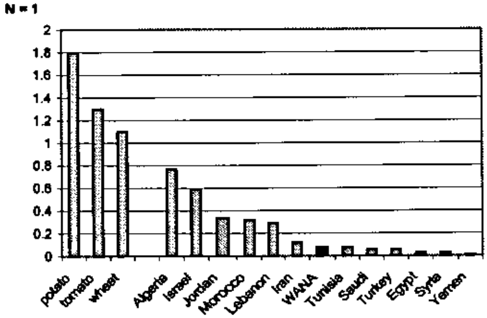


Fig. 6. N:K ratio in fertilizer use in selected countries of the WANA region in relation to nutrient uptake by crops (fertilizer use, mean 1997-99).

Unbalanced fertilization results in soil nutrient mining

In the WANA region, the N Balance was negative in the 1970s (Fig. 7) and then changed rapidly during the last two decades with N applied and removed now being almost the same.

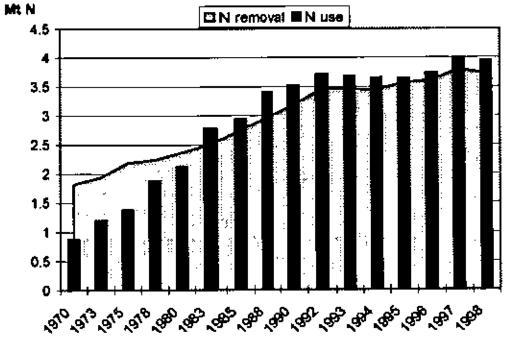


Fig. 7. N removal by crops in relation to N use in WANA.

The situation for P is comparable (not shown). After an early period with a negative balance, the amount of P applied and removed now appears to be in equilibrium. There is a completely different picture for the K balance (Fig. 8). Potassium inputs with potash fertilizers represent less than 10% of the K that is taken up by plants and removed with the harvested crops. The apparent K deficit is estimated at almost 4 Mt K_2O annually or the equivalent of 37 kg/ha K_2O. It is doubtful whether this large negative balance would be lessened appreciably by including the K in organic manures, which are used locally only for horticultural crops.

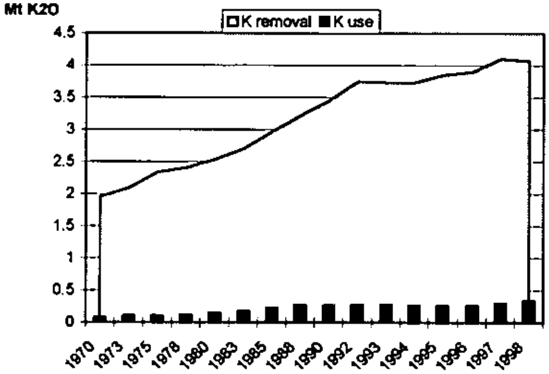


Fig. 8. K removal by crops in relation to K use in WANA.

The K balance is worst in Egypt with a deficit of 195 kg/ha K_2O. Farmers there apply as potash fertilizers only a fraction (5%) of the K that is removed by the harvested crops. The K balance in other countries of WANA, although negative, is less serious than in Egypt. Farmers in Turkey and Lebanon apply about 50 kg/ha K_2O less than that which is removed by crops, the K deficit in the other countries ranges between 15 and 30 kg/ha K_2O. The exception is Israel, where added K balances K removal by crops.
Negative nutrient balances indicate soil nutrient mining and thus loss of soil fertility.

What is the effect of soil K mining?

- *Sustainability of soil fertility*: Potassium in soils can be divided into several fractions according to the availability of the K to plants. The soil K fractions are interrelated by dynamic exchange processes. Potassium in the soil solution is immediately available for uptake by plant roots. After removing solution K either by uptake or leaching, it is replenished by K from the exchangeable fraction, which is a readily available pool. With exhaustion of this fraction, namely with negative K balances, the plant has to rely on K released from the less readily available pool of the non-exchangeable or fixed fraction. However, too little is known of the rate of release of fixed K although it is often assumed to be slower than that of the exchangeable fraction to the soil solution.

A high yielding crop absorbs K at a rate of up to 10 kg K_2O/ha/day. When the release of K to the soil solution fails to meet this demand then crop growth and yield are restricted. The more the plant has to rely on K release from the non-exchangeable fraction, the greater is the risk of small yields.

When water soluble K fertilizer is added to K exhausted soils, two things can happen simultaneously. Besides K uptake by plant roots, K can be transferred to the fixed pool and become less readily available to the plant (Fig. 9). Plants grown on K fixing soils require a much higher potash supply than on non-fixing soils and thus, have greater production costs.

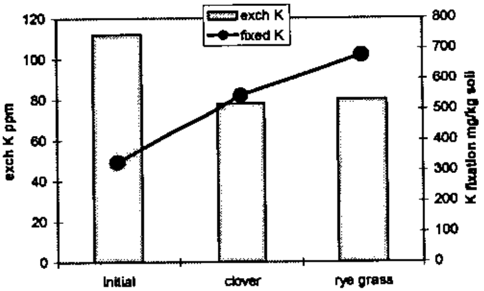


Fig. 9. Effect of exhaustive cropping on K fixation (after Tributh *et al.*, 1987).

- *Yield*: Numerous field trials with a wide range of crops and soil types could demonstrate that, with soil K mining, yields decrease because of deteriorating soil fertility. The results in Figure 10 also show that the response of crops to soil K mining differs with the genotype. Cereals, with their extensive root systems, are obviously more efficient at extracting soil K than are dicots, such as potato and many vegetable crops, that have a smaller root system. Such differences in K requirement highlight the need for different critical soil K limits according to the crop and/or crop rotation.

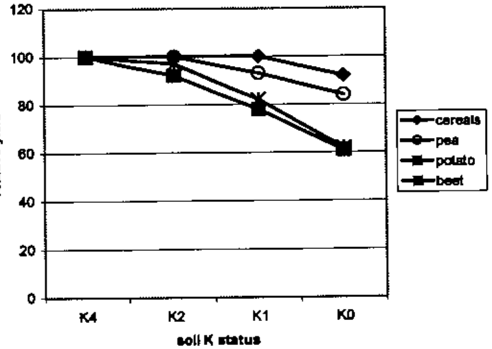


Fig. 10. Genotypical yield responses to soil K mining (after Merbach *et al.*, 1999).

Significant yield responses to K have been shown in the WANA region. El Hadi and Etourneaud (1995), working in the Nile delta of Egypt, demonstrated in the early 1990s that applying 60 kg/feddan K_2O increased the yields of berseem, cotton, beans and several cereals by 4 to almost 10% although the soils contained up to 500 ppm exchangeable K. Similar results were obtained in Upper Egypt. Badraoui *et al.* (1997) showed for sugar beet that investing one dollar in potash returned up to eight dollars through larger yields.

- *Quality*: The quality of agricultural products becomes a dominant factor when those buying food are not restricted by price. Quality can be expressed according to the nutritive value, hygienic and organoleptic properties, the functional properties, and the compatibility of the production methods with environmental issues. Due to its multi-functional role in the plant, K is considered to be the nutrient most involved in aspects of food quality. Higher protein content in wheat, oil content in soybean and groundnut, fibre content in cotton, better shelf-life of fruits and vegetables are some of the findings from field trials with potash. For example, applying K and Mg not only increases the yield but also the quality of sugar beet in Hungary (Fig. 11). Agbani *et al.* (1999) reported from Morocco that applying 150 kg/ha N and 300 kg/ha K_2O has proved to be the most effective combination for the highest extractable sugar content from sugar beet.

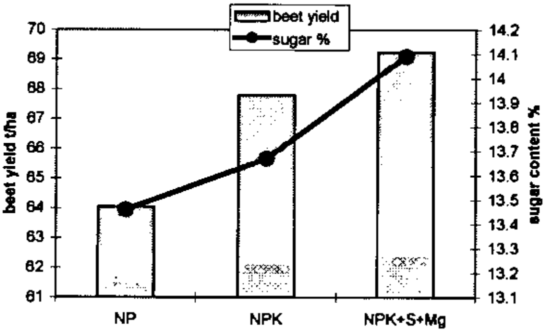


Fig. 11. Effect of balanced fertilization with K and Mg on yield and quality of sugar beet (IPI trials Hungary, 2000).

- *Stress tolerance*: The nutrition of plants has a substantial impact on their predisposition to attack and/or tolerance to pests and diseases by affecting the growth pattern, the anatomy, morphology and particularly the chemical composition. The ratio between N and K in the plant tissue is particularly important in controlling the host/pathogen relationship. Perrenoud (1990) reviewed almost 2450 references on this subject. He concluded that the use of K decreased the incidence of fungal diseases by 70%, the incidence of attacks bacteria was decreased by 69%, by insects and mites by 63% and by viruses by 41%. Minimizing the attack by pests and diseases increased the yield of plants, in the case of fungal diseases by 42%, with bacteria by 57%, with insects and mites by 36%, and with viruses by 78% (Fig. 12).

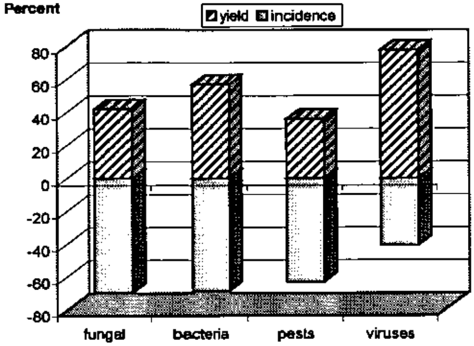


Fig. 12. Effect of potassium on yield increase and pest incidences (Perrenoud, 1990).

The function of K in plants as an osmotically active cation and its involvement in controlling the water relationships in plants gives balanced fertilization with K the unique opportunity to improve the tolerance of plants to drought, frost and to salinity. Wyrwa *et al.* (1998) demonstrated that drought reduced the grain yield of triticale by 54% on soils low in K but with an adequate K supply by only 16%. This benefit was due to the role of K in controlling stomatal movement and thus, the loss of water under drought stress.

Bogdevitch (2000) showed that oats grown on soils with 234 ppm K could survive late frost without obvious damage whereas much of the crop grown on K deficient soil (132 ppm K) was killed. Potassium in the cell solution lowers the freezing point and thus protects the plant from frost damage provided there is an adequate supply of K.

Shoot weight of salt affected barley was increased when additional K was applied (Helal and Mengel, 1979). The plants treated with extra K had also a higher K and lower Na content in the shoot and showed a much better conversion of N into protein than the salt affected plants without the "meliorative" extra K.

- *Compatibility with the environment*: Lower yields in field trials with inadequate potash (i.e. an imbalance in N, P, K supply) show that the use efficiency of other nutrients is decreased. Dobermann (1999) showed that for rice the recovery efficiency of N increased from 26% at low K (20 kg/ha K_2O) to 36% at adequate K (80 kg/ha K_2O). Thus less N at risk to loss was left in the rooting zone when the K supply was adequate. Loss of nitrate by leaching could pollute surface and groundwater or contribute to global warming if converted to nitrous oxide and lost to the air. With lower yields, the use efficiency of other inputs such as land, water and energy decreases as well. Therefore, an insufficient supply of K leads to waste of natural resources, it is a threat to the environment and reduces the profit of the farmer.

What are the benefits of balanced fertilization for society?

- *Yield and income*: Lower yields with insufficient K are synonymous to losing opportunity yield and income (Fig. 10). With a higher income from using adequate K, the farmer is inclined to spend more money on non-agricultural products. This attracts other business, creates jobs and contributes to the development of the rural area. He also may stay on his farm and will not migrate into an urban area because, with higher income, he gains in social security.

- *Quality and competitiveness*: Increasingly, the price at which agricultural products are sold is based on quality criteria, such as protein or oil content in cereal and oil seeds, sugar content in beets and cane, or simply by the freshness and appearance of fruits and vegetables. As quality criteria become more important, farmers producing crops with inferior quality will loose their competitiveness and therefore income and profit. Apart from these direct impacts on the farmer, there is an indirect benefit of quality-oriented production to society. For example in sugar production, for each one percent less sugar in the root about 6% more beets have to be transported and extracted to yield the same amount of white sugar. The higher energy consumption and lower profitability in extracting low quality beets are obvious. Furthermore, the higher content of noxious N in sugar beets with too much N and inadequate K, lowers the amount of sugar which can be extracted.

- *Stress tolerance*: Less pest and disease incidence with balanced fertilization reduces the need for agrochemicals, reduces storage losses, especially in fruits and vegetables, and the marketable crops have a better appearance. This lowers production costs and increases competitiveness at the market when offering healthy and safe products. Also, it should not be forgotten that, in an age of globalization and the liberalization of international trade, freedom from pests and diseases is all important, if the hygienic standards set by the importing country are not met, the market is quickly lost.
  Variable yields when plants are vulnerable to climatic and soil-borne stress are not only a financial risk for the producer but also impair the planning of the food supply of the nation.

- *Compatibility with the environment*: Increasingly, consumers, especially in developed countries, will ask whether food is produced in environmentally friendly ways. This refers, in particular, to agricultural products. The rapidly increasing market of so-called 'bio'-products is evidence of this development. A higher N fertilizer use efficiency and less pest and disease incidence with balanced fertilization with an adequate K comply with the requirement of safeguarding the environment.

Conclusion

Extended soil K mining as practised in WANA is a time bomb. It prevents the full exploitation of the yield potential of modern varieties of many crop plants and thus deprives the farmer from achieving maximum profit from his cultivated fields. This in turn might force him to abandon his land and with his family migrate to towns where they add to the growing number of poor people.

When imbalances in nutrient supply prevent the full exploitation of the genetic potential of crops, the opportunity to improve food production and lower the bill for costly imports is missed. The money saved on imports, when there is higher domestic production, could be spent on other socially desirable objectives.

Improving crop quality by balanced fertilization increases the competitiveness of the producer in both local and international markets. The export of fruits and vegetables from the Near East increased in the last 20 years from 3.11 Mt, worth $1.46 billion to 6.5 Mt currently worth $4.26 billion (mean 1997-99, FAO-web, 2002). It would be interesting to estimate the gain in both quantity and value of exported agricultural produce if balanced fertilization was applied to all crops.

Good governance in respect of nutrient management proves the reliability of farmers and gives them advantages at the market because they are perceived to produce healthy and safe food. Balanced fertilization improves the use efficiency of fertilizers, N in particular, and this not only contributes to protect the environment but also to safeguard a natural resource. To achieve all the benefits noted above, the fertilizer industry strongly supports the concept of balanced fertilization to optimize food production with minimum adverse effect on the environment.

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Fertilizer consumption in the Near East: Low potassium rates?

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Abstract

Potassium (K) is absorbed by plants in larger amounts than any other nutrient except nitrogen (N). The total K content of soils may range from only a few hundred kg ha^{-1} in coarse textured soils formed from sandstone or quartizite to 50,000 kg ha^{-1} or more in fine textured soils formed from rocks rich in K-bearing minerals. Unlike N and phosphorus (P) which are deficient in most soils in the Near East, the need for K frequently arises only after a few years of cropping of virgin soils. A steady increase in N fertilizer consumption in the Near Eastern region was observed during the past two decades. The use of P fertilizers also increased but at a slower rate than N fertilizers. The consumption of K fertilizers, however, did not increase in parallel to that of N or P. This observation deserves evaluation to ensure that unbalanced fertilization programmes do not prevail in the region at large, especially for vegetable and fruit tree production. With today's intensive agriculture, considerable quantities of K fertilizers are required to satisfy the needs of these crops and sustain soil fertility. It is recommended that long-term field experiments be conducted in Near Eastern countries on K fertilization of different crops and the data obtained should be exchanged among the countries to maximize the benefits. Planning and supervising this program could be the responsibility of a committee with representatives from IPI and the various countries in the Near East.

Introduction

The Near East region has about 590 million people and has among the highest population growth rate (about 2.5%) and more than 70% of its land area is arid and semi-arid. The Near East is a major producer of fertilizers in the world and has become the largest food importing region in the developing world. With limited arable land resources and serious water scarcity, proper management of plant nutrients is essential.

In the Near East, the loss of soil fertility from continued nutrient mining by crop removal without adequate replenishment, combined with unbalanced plant nutrient practices, poses a serious threat to agricultural production. The recycling of nutrients from crop residues and animal manure cannot make up for the removal of nutrients by harvested products. Therefore, the use of mineral fertilizers is essential to meet crop requirements and to increase crop production.

Considering the importance of agricultural production, it is imperative to establish the relationship between yield, use of plant nutrients, economic viability and environmental quality. Farmers should know how much fertilizers to apply, which plant nutrients are needed for their soil and crops to provide the optimum economic return without damaging the environment.

The FAO estimates that about two-thirds of the required increase in crop production in developing countries will have to come from yield increases on land already under cultivation. Plant nutrients are the most important inputs for increasing yields. Over the past 35 years, additional nutrients applied as fertilizers have been responsible for 55% of the yield increases in developing countries. The development of plant nutrition management to increase the quantity of plant nutrients in farming systems, and thus crop productivity, is a major challenge for food security in the Near Eastern countries.

Balanced plant nutrition

In the Near Eastern countries, the quantity of nutrients available for recycling via plant and animal residues is not sufficient to compensate for the amounts removed in agricultural products, even in low-productivity situations. Consequently mineral fertilizers have to play a key role in areas where increased yields are required.

The insufficiency of one plant nutrient limits the efficiency with which other nutrients are taken up, reducing crop yield as indicated in Figure 1. Unbalanced availability of nutrients can lead to mining of soil reserves for nutrients in short supply and to losses of plant nutrients supplied in excess. Unbalanced fertilization is an uneconomic waste of valuable resources and it should be avoided in successful agricultural activities.

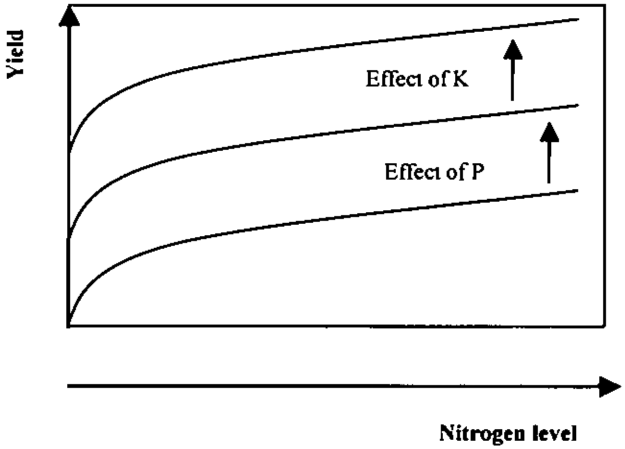

Fig. 1. Yield response to balanced plant nutrition: insufficiency of one plant nutrient limits the efficiency with which other plant nutrients are taken up, reducing crop yield.

Fertilizer consumption in the Near East

The overall fertilizer production in the Near East in 1997 was about 11 million tonnes (Mt) of which 8.6 Mt were used in the Near East and about 2.4 Mt were exported to other countries (Table 1).

There are large differences in fertilizer use per unit area in the region: from 50 kg ha^{-1} in Sudan to 347 kg ha^{-1} in Egypt and more than 7000 kg ha^{-1} in protected vegetable production in the United Arab Emirates and other Near Eastern countries.

Table 1. Total consumption and production of fertilizers in Near Eastern countries in 1998 (Source: FAO Regional Office, Cairo).

Country	Consumption (tons)	Production (tons)
Afghanistan	5,000	5,000
Algeria	97,000	28,400
Bahrain	600	233,000
Cyprus	20,339	-
Egypt	1,010,500	1,090,155
Iran	1,152,413	977,200
Iraq	339,800	325,000
Jordan	112,000	1,626,100
Kuwait	1,200	348,500
Kirgizstan	31,000	-
Lebanon	60,205	134,500
Libya	61,800	408,200
Malta	1,000	-
Mauritania	3,800	-
Morocco	303,900	1,182,800
Oman	7,100	-
Pakistan	2,659,334	1,727,977
Qatar	1,165	55,000
Saudi Arabia	326,800	1,093,000
Sudan	77,400	-
Syria	318,000	177,141
Tunisia	95,500	863,580
Turkey	1,825,700	1,121,100
Turkmenistan	144,000	110,000
United Arab Emirates	30,900	299,600
Yemen	1,200	-
Total	**8,687,656**	**11,805,753**

Nitrogen is by far the mostly used nutrient in the Near East; a steady increase in consumption has been observed during the past two decades. The use of P fertilizers also increased but at a slower rate than N fertilizers. The consumption of K fertilizers, however, did not increase in parallel to that of N or P fertilizers. This observation deserves evaluation to be sure that unbalanced fertilization programmes do not prevail in the region at large, especially for vegetable and fruit tree production.

Potassium is absorbed by plants in larger amounts than any other nutrient except N. The total K content of soils may range from only a few hundred kg ha^{-1} in coarse textured soils formed from sandstone or quartzite to 50,000 kg ha^{-1} or more in fine-textured soils formed from rocks rich in K-bearing minerals.

Unlike N and P which are deficient in most soils in the Near East, the need for K frequently arises only after a few years of cropping virgin soils. This phenomena was observed by the author in Saudi Arabia where K application was not required until five years after converting virgin aridisols into irrigated wheat and until two years after starting vegetable and alfalfa production. There are similar observations in the United Arab Emirates, Jordan, Lebanon and Syria.

When rates of N and P are adequate and as yields increase, the demand for K increases. With today's intensive agriculture which demands the production of high yielding crops, considerable quantities of K are required to meet the needs of these crops. Under such conditions, K fertilizers are needed in considerable quantities because the K release from slowly available forms in the soil is often not sufficient.

The data in Table 2 show that the fertilizer consumption in the Near East is extremely biased in favour of N (65%) with P_2O_5 32%, and K_2O 7%; a ratio of 10:5:1. Average application ratios of $4N:2P_2O_5:1K_2O$ would be the minimum for balanced standard application rates to obtain yield of good quality and, at the same time, sustain soil fertility.

In several field trials in the Near East, there was only a small response to K fertilization probably because the experiments lasted only for a few years under conditions of low productivity. Long-term field trials on irrigated wheat showed a good response to K fertilization. With crop intensification, micronutrient application and sometimes sulphur, calcium and magnesium may be needed to ensure balanced nutrient levels and optimum yields. This situation is common in protected vegetable production in many Near Eastern countries.

Recommendations

It is recommended that governments in the Near East should:

- Support research programmes studying best fertilization rates, methods and management practices.
- Conduct long-term field experiments in different countries on K and micronutrient fertilization on various crops and exchange data. IPI should undertake responsibility for supervising this programme in cooperation with individual countries.

- Educate farmers about proper fertilizer use to improve current lack of knowledge about the integrated use of nutrients; the importance of soil testing and the need to apply balanced fertilizers to avoid soil pollution and poor productivity.
- Ensure availability of good quality fertilizer in the market place.
- Improve the performance of the agricultural extension programmes in their countries and develop suitable guidelines for fertilizer recommendations for various field crops, vegetables and fruit trees.

Table 2. Fertilizer consumption in some Near Eastern countries in 1000 t nutrients (values in parentheses = % of the total fertilizer use; IFA, 1994).

Country	N		P_2O_5		K_2O	
Afghanistan	38.9	(82)	6.9	(14)	1.5	(3)
Algeria	73.8	(56)	34.8	(26)	22.3	(17)
Cyprus	14.5	(55)	9.7	(37)	2	(7)
Egypt	869	(79)	195	(17)	27.8	(2)
Iran	555	(61)	321	(35)	25	(2)
Iraq	410	(90)	35	(7)	11	(2)
Jordan	6.3	(38)	8	(49)	2	(12)
Lebanon	18	(49)	14	(38)	4.2	(11)
Libya	34.6	(31)	71.3	(64)	4.1	(3)
Morocco	171.7	(51)	103.6	(31)	59.1	(17)
Pakistan	914.6	(75)	261.4	(21)	28.6	(2)
Saudi Arabia	113.3	(52)	87.7	(40)	14.2	(6)
Sudan	41.7	(98)	5.7	(10)	2	(4)
Syria	119	(63)	63.7	(33)	5.8	(3)
Tunisia	50.2	(52)	42.7	()	2.5	(2)
Turkey	985.8	(60)	620	(38)	24.6	(1)
Mean % usage		(65)		(32)		(7)
Developed counties	29950	(53)	13250	(23)	12582	(22)
Developing countries	42719	(65)	15797	(24)	6772	(10)
World	72669	(60)	29048	(24)	19354	(16)

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Potassium efficiency of crop species grown in the field on a low potassium supplying soil

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Abstract

This study investigated the efficiency of potassium (K) use by wheat and sugar beet under field conditions. Data were obtained from a long-term fertilizer experiment on a sandy clay loam in which K application rates varied from 0 to 1000 kg K ha^{-1} $year^{-1}$ with the last application in 1986. In 1997, sugar beet and spring wheat were sown and, during the growing season, there were four harvests of wheat and five of sugar beet. At each harvest, the following parameters were determined: dry matter yield and K concentration of sugar beet leaves and beet, wheat straw and ears, root length, (RL), shoot growth rate, (GR_s), shoot growth rate/root length, (GR_s/RL), K uptake, K influx and soil solution concentrations.

Sugar beet and wheat both used K efficiently, the crops on the plot with least K producing nearly 80% of the beet and grain yield, respectively, that was produced on the plot with more K. Compared to wheat, sugar beet had a larger internal K requirement; the shoot growth rate, GR_s, was twice that of wheat but root length, RL, was only 34 to 48 % that of the wheat. In consequence, sugar beet had a larger GR_s/RL, with a greater demand for K uptake by the roots. However, beet showed an exceptionally high K uptake efficiency, being five times greater than wheat on the soil with least K. The K efficiency of wheat was attributed to a higher utilization efficiency or lower internal requirement, slower growing shoots, and a large root system.

In an attempt to understand the underlying mechanisms of K uptake by these plants, a mechanistic model was used. However, the model calculated only 10 and 40% of the measured K uptake by sugar beet and wheat, respectively. Sensitivity analysis to assess the significance of single parameters, showed that in the soil with least K, the soil solution K concentration, (C_{Li}), was the most important factor controlling K uptake, especially for sugar beet. This indicates that roots may have increased the K concentration in soil solution by chemical mobilization.

Introduction

The severity of food shortage is especially serious in the so-called developing countries in Africa, Latin America and Asia (Chapin, 1987), where agriculture is faced with major problems of low soil fertility. To meet food demand, crop cultivation expanded into marginal areas for crop production with regard to nutrient and water supply which further threatened soil fertility (Sauerbeck and Helal, 1990). Soil fertility could be improved by adding fertilizers, a choice which is restricted both by lack of enough capital, and fertilizer availability. Moreover, unlimited chemical fertilizer use and decreased fertilizer efficiency present serious risks to the environment through water and air pollution. A promising alternative could be the use of nutrient efficient cultivars. Such cultivars could mean more efficient soil nutrient and fertilizer use as well as improved environmental protection, through minimizing the use of chemicals, that is a strategy of "tailoring the plant to fit the soil" (Rengel, 1999).

There are usually large amounts of total K in the soil, but its concentration in the soil solution and the plant available fraction is not always sufficient to meet plant needs. Therefore plant species which are able to use the less readily available K could have a significant agronomic importance.

A K efficient species or cultivar is one that is able to produce a large yield when grown on a soil with limited K supply for a standard species or cultivar. Several authors reported differing K efficiency by different crop species and cultivars (Trehan and Claassen, 1998; El Dessougi and Claassen, 2001). Plants differ in their K efficiency due to differences in efficiency in utilization or uptake by the roots or both. Efficiency in utilization is defined as dry matter produced per unit K in the dry matter. Efficiency in acquisition is defined in terms of total uptake per plant or specific uptake per unit root length (Marschner, 1995). The uptake is a function of the root morphological characteristics such as the size of the root system, root hairs, root radius and/or physiological activity of the roots, such as different uptake kinetics which result in different uptake rates per unit root and time, that is the influx (Steingrobe and Claassen, 2000), and/or ability to chemically change the rhizosphere to improve the availability of nutrients (Sattelmacher *et al.*, 1994).

This study investigated the K efficiency of wheat (*Triticum aestivum* L.) and sugar beet (*Beta vulgaris* L.) in the field on a low K supplying soil. It also aimed to understand the mechanisms responsible for differences in K uptake efficiency of wheat and sugar beet by simulating K uptake with a mechanistic model and assessing the significance of single soil and plant parameters by sensitivity analysis.

Materials and methods

The study was carried out on the site of a long-term field experiment on a sandy clay loam with a low K supplying capacity. The soil had 33% clay, 31% silt, 3.8% C_{org}, pH ($CaCl_2$ 0.01M) 7.2 and the experiment had started in 1976 and had ended in 1986, thereafter all plots received no K fertilizer. Plants were sampled from the plot which had received no K (K0) (NH_4-OAc exchangeable K, (K_{exch}) 782 μmol K kg^{-1} soil, soil solution concentration, (C_{Li}) 4.2 μM) and from the plot which had received 1000 kg K ha^{-1} a^{-1} (K1) (K_{exch} 1047 μmol K kg^{-1} soil, C_{Li} 7.5 μM). In 1997, spring wheat cv. Star, and sugar beet cv. Kawetina were sown on 50 m^2 plots on March 13th and April 4th, respectively. Before sowing, 43 kg P as superphosphate and 80 kg N ha^{-1} as ammonium sulphate and ammonium nitrate were applied. Samples of both crops were harvested on 27th May, 24th June, 8th July, 5th August and on 7th October for sugar beet. At each harvest date 3 sub-samples of plants, roots and soil were taken from random areas of each plot. Data necessary for modelling were obtained from the field experiment and the plant and soil parameters are as given by Claassen and Steingrobe (1999).

Shoots

Wheat samples were from an area of 0.5 m^2, final harvest 1 m^2 per treatment. The plants were separated into stems and ears after flowering. Sugar beet samples were from an area of 1.5 m^2 and plant analysis was carried out on the leaves and beets separately. Sample dry weight was recorded and K content was determined (after wet digestion) by flame photometry.

Root sampling and sample preparation

Roots were sampled from the same plots as the shoot samples, using a hand auger with 8 cm diameter (Böhm, 1979). The cores were divided into the 0-15, 15-30, 30-60 cm soil layers. The 60-90 cm layer was sampled only at the final harvest, since it generally contains few roots and the soil solution K concentration was very low. Each soil sample consisted of 2 soil cores, one in and one between the rows of wheat, and 4 soil cores two in and two between the rows for sugar beet. The roots were washed out carefully and the root length was measured using the line intersection method of Tennant (1975).

Shoot growth rate in relation to root length (GR_s/RL)

This ratio is related to the K acquisition load on roots imposed by the shoot growth. It is calculated by dividing the shoot growth rate by the average root length: $\frac{GRs}{RL} = \frac{SW_2 - SW_1}{t_2 - t_1} \times \frac{2}{RL_1 + RL_2}$, where: SW= shoot dry weight, RL= root length (cm) t= time and the indices 1 and 2 represent the first and second harvest.

Potassium influx

For calculating the influx, at least two harvests are necessary (Claassen and Jungk, 1984). Assuming linear root growth by plants growing in the field, the influx was calculated as: $In = \frac{U_2 - U_1}{t_2 - t_1} \times \frac{2}{RL_1 + RL_2}$, where: In= influx, U= nutrient element content in the shoot (mol), t_1 and t_2 are the date of first and second sampling and RL_1 and RL_2 are root lengths at t_1 and t_2.

Exchangeable potassium, soil solution K, pH and water content

One gram field moist soil was weighed into a filter paper placed in a funnel. The soil was extracted five times with 10 mL 1 M NH_4OAc, pH 7 at 15 minutes intervals. The K concentration in the filtrate was determined by flame photometry.

The soil K content was calculated on dry weight basis. The soil solution was obtained by a modified displacement technique of Adams (1974). The pH was measured in 0.01 M $CaCl_2$ in a 1:2.5 soil:solution ratio. Soil samples were dried at 105°C to constant weight to determine the gravimetric water content.

Statistical analysis

The data were statistically analyzed using simple analysis of variance (ANOVA), where significant differences were found, mean separation was conducted using the Tukey test.

The model

The model is based on three steps: a) desorption of nutrients from the soil solid phase b) transport of nutrients to roots by mass flow and diffusion (Barber, 1962), c) nutrient uptake into the root following Michaelis-Menten kinetics. The data used for simulating K uptake were obtained from the field experiment. For plant and soil parameters used in the model sec Steingrobe and Claassen (2000). Parameters of the uptake kinetics are the maximum influx theoretically achieved at infinite concentration, I_{max}, minimum solution concentration at which influx equals efflux, that is net influx equals zero, C_{Lmin} and the Michaelis constant which is the concentration that allows uptake at half I_{max} minus C_{Lmin}, K_m. A direct measurement of these parameters in soil is not possible and the K_m and C_{Lmin} were taken from Meyer (1993). The I_{max} was derived from measured influx and a multiplication factor (1.2 to 12) according to Meyer (1993).

Results and discussion

Extra soil potassium increased beet dry matter yield significantly ($p \leq 0.05$) but had no significant effect on wheat grain yield (Fig. 1).

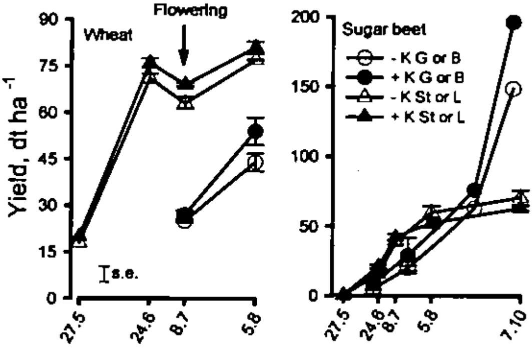

Fig. 1. Dry matter yield of spring wheat grain (G) and straw (St) and sugar beet roots (B) and leaves (L) grown on a sandy clay loam in the field with two levels of soil K: -K open symbols, +K closed symbols.

Our findings for wheat agree with those of Kuhlmann (1983) who did not detect any statistically significant increase in wheat grain yield regardless of the K content in soil or plant. Clearly efficient K species produce a large proportion of maximum dry matter even at low soil K concentrations. Considering the relative yield, sugar beet and wheat produced nearly 80% of the beet and grain yield on the low K soil (K0) relative to the soil which had received K fertilizer (K1). This means that both species had a similar K efficiency. These findings contrast with those of Claassen (1994) who concluded from a field experiment, that sugar beet was less K efficient than wheat, because it produced a lower relative yield compared to wheat.

Efficient plant species employ specific physiological mechanisms to increase the effectiveness of nutrient utilization, (Sattelmacher *et al.*, 1994), e.g. they possess lower internal nutrient requirements or require a smaller concentration of the nutrient in question in the plant tissues for dry matter production. To assess the nutritional status of the plants, the K concentration in dry matter was measured and was found to increase significantly ($p \leq 0.05$) in both species when grown on the soil with more K (Fig. 2). The K concentration in dry matter of sugar beet leaves declined from 6.55 to 3.46% in K sufficient plants and from 5.28 to 2.05% where there was less soil K. The values for wheat shoots declined from 3.79 to 2.07% with adequate K and from 2.96 to 1.42% where there was less K. The internal K requirement to produce 80% of maximum yield was between 3.5-5% for sugar beet and 2-3% for wheat (Fig. 2). These values are lower than those of Kuhlmann (1983) who reported about 4.2% K in wheat dry matter at the stage of shoot elongation, and between 4.5-6% in sugar beet dry matter at full expanded leaf stage.

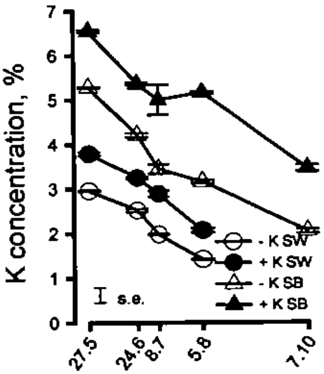

Fig. 2. K concentration in spring wheat shoot (SW) and sugar beet (SB) leaves grown on a sandy clay loam in the field with two levels of soil K: -K open symbols, +K closed symbols.

Our results agree with the values given by Bergmann (1993) for K concentration in dry matter required for optimum dry matter yield which are 3.5-6.0% for sugar beet and 2.9-3.9% for wheat at comparable growth stages. However, our data show that the K concentrations in dry matter, although within the range of that needed were at the lower end of the range indicating that the availability of K was low. Our results and those cited from the literature show that wheat is more efficient in utilizing K for dry matter production as compared to sugar beet.

Nutrient amount and mobility in the soil as well as acquisition characters of the plant such as root size, uptake kinetics and mobilizing ability of the root system, influence nutrient supply to the plants (Jungk and Claassen, 1997; Claassen and Steingrobe, 1999; Sattelmacher *et al.*, 1994). A large root system as well as alteration of root geometry could be considered as one of the strategies developed by plants for a high uptake efficiency (Rengel, 1999). Wheat had produced a total root length of 21 and 19 km m^{-2} in July on soils K_0 and K_1, respectively (Fig. 3). This could be the reason for its efficiency, especially because, that for both treatments, around 80% of the root system was produced before flowering in June. At this time, intensive vegetative growth took place and the largest amount of K was needed. Claassen (1994) showed that not only the root size is important for wheat K efficiency, but also that the rapid shoot growth in June and July occurred with an already fully developed root system capable of acquiring the necessary K by exploiting a larger soil volume. At all harvests, sugar beet had a much smaller root system producing a maximum of 13 and 10 km m^{-2} in August on soils K_0 and K_1, respectively, (Fig. 3). Hence the efficiency of sugar beet cannot be attributed to a large root system because it had only 34 to 48% of the root length of wheat over the whole growth period.

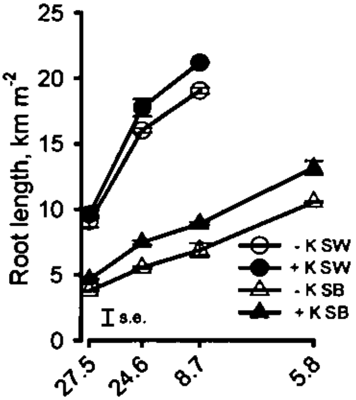

Fig. 3. Root length of spring wheat (SW) and sugar beet (SB) in a soil depth 0-90 cm grown on a sandy clay loam in the field with more (+K) and less (-K) exchangeable K.

Sauerbeck and Helal (1990) suggested that root development and physiological activity is controlled by the shoot since nutrient uptake by the root, translocation to the shoot and subsequent redistribution in the different plant organs is controlled by complex communications between shoot and root. The shoot growth rate /root length ratio, GR_s/RL is a measure for the demand for nutrients the growing shoot is putting on the roots. The greater this ratio the higher is the demand on the roots. Figure 4 shows the GR_s/RL ratio of wheat and sugar beet, where K had been applied in the past and the plants were growing optimally and K uptake was not restricted. The plants could take up enough K to meet their requirement, which represents the K demand to be met by the shoots. A direct comparison between the crops for nutrient demand is difficult, since at the same sampling dates the plants were at different growth stages. However, the largest value for sugar beet was more than twice that of wheat (Fig. 4). This is to be expected because of its faster growing shoots (1.2 to 2 times higher shoot growth rates as compared to wheat, data not shown) and smaller root system (Fig. 3). This means sugar beet had a much greater demand for nutrient acquisition, i.e. each single root had to absorb much more K to meet the shoot demand. Nevertheless, sugar beet proved to be as K efficient as wheat.

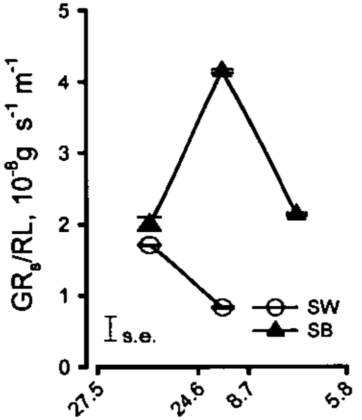

Fig. 4. Shoot growth rate (GR_s) in relation to root length (RL) of spring wheat (SW) and sugar beet (SB) grown on a sandy clay loam at optimum soil K levels.

Total K uptake in the dry matter is a measure for the ability of plants to acquire K from the soil and accumulate it in the shoots. It is the product of dry matter yield and K concentration in dry matter. The higher dry matter produced by sugar beet, 150 and 70 dt ha^{-1} beet and leaves, respectively, as compared to wheat, 45 and 77 dt ha^{-1} grain and straw, respectively (Fig. 1), and its higher K concentration in dry matter (Fig. 2), resulted in twice as much K taken up by sugar beet in comparison to wheat (Fig. 6). Hence it is obvious that sugar beet had a higher uptake efficiency than wheat. This high uptake efficiency of sugar beet can only be explained by the high uptake efficiency of the single roots or influx, which is a measure for the physiological capability of the roots to extract K from soil at limiting K supply.

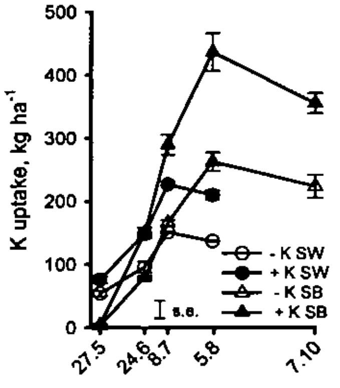

Fig. 5. K uptake of spring wheat (SW) and sugar beet (SB) grown on sandy clay loam in the field with more (+K) and less (-K) exchangeable K.

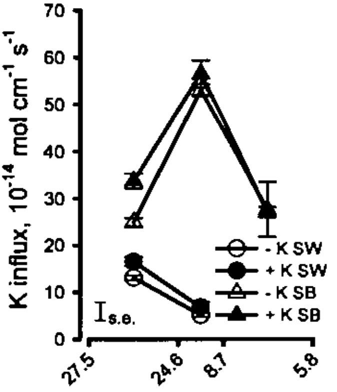

Fig. 6. K influx of spring wheat (SW) and sugar beet (SB) grown on sandy clay loam in the field with more (+K) and less (-K) exchangeable K.

As is seen in Figure 7, the influx increased with plant age from 25 x 10^{-14} and 34 x 10^{-14} mol cm^{-1} s^{-1} in the growth period 27.5-24.6 to a maximum of 53 x 10^{-14} and 56 x 10^{-14} mol cm^{-1} s^{-1} in 24.6-8.7 for sugar beet fertilized and unfertilized treatments, respectively, then decreased for both treatments. These values corresponded to twice the influx compared to wheat on both treatments between 27.5 and 24.6, and 10 and 8 times higher influx on two treatments between 24.6 and 8.7 (Fig. 7). The results of this study also showed that to meet the demand for K acquisition imposed by the fast growing shoots, sugar beet increased its uptake rates per unit root and time considerably. Especially at the growth period 24.6 to 8.7 with the highest demand for K acquisition on the roots (Fig. 4), sugar beet had nearly twice the influx rate compared to the growth periods 27.5 to 24.6 and 8.7 to 5.8 (Fig. 7). Sadana and Claassen (1999) reported a similar high K influx of sugar beet.

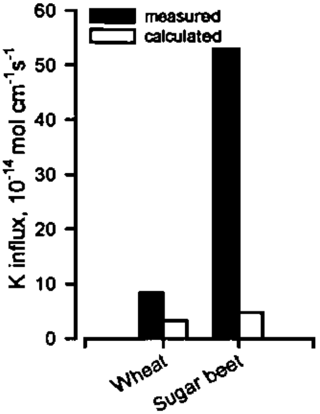

Fig. 7. Comparison between measured and calculated K influx of spring wheat and sugar beet grown on sandy clay loam in the field with least exchangeable K.

The influx realized by sugar beet was relatively high for the very low measured soil solution concentrations and transport to the roots would probably limit K uptake. (Jungk and Claassen; 1997; Claassen and Steingrobe, 1999). Hence in an attempt to understand the underlying mechanisms of K uptake by these crops the K uptake was simulated with the objective of comparing measured and calculated K uptake. Since it is more important to study the plant performance under deficient K conditions only the data from deficient K treatments will be discussed here. At the time of highest uptake, the model calculated only 10% and 40% of the measured K influx of sugar beet and wheat, respectively, (Fig. 8).

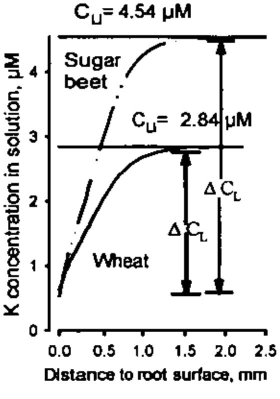

Fig. 8. Calculated concentration profiles of K in soil solution around the roots of sugar beet and spring wheat grown on a sandy clay loam soil in the field during the period 24.6-8.7.

Both species reduced the K concentration at the root surface, C_{L0} to around 0.5 µM, which corresponded to 12 and 22% of the C_{Li} of sugar beet and wheat, respectively, (Fig. 9).

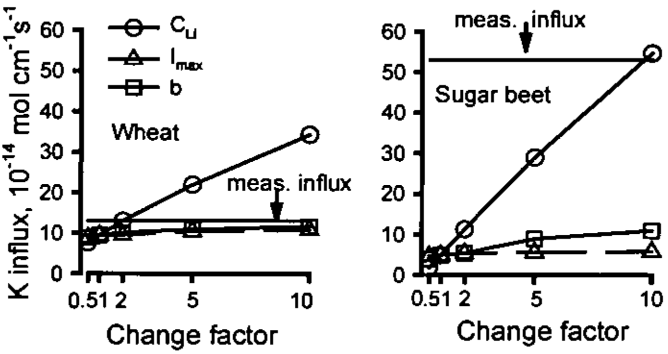

Fig. 9. Sensitivity analysis for sugar beet and spring wheat grown on a sandy clay loam in the field without K fertilization at the growth period 24.6-8.7.

The diffusive flux to the roots is a function of the concentration gradient between C_{L0} and C_{Li}, ΔC_L. The respective ΔC_L were 4 and 2 µM for sugar beet and wheat. No inter-root competition existed since the concentration at average half distance between neighbouring roots, r_1 was maintained at the value of C_{Li}. A higher ΔC_L would increase the diffusive flux to the roots (Claassen and Steingrobe, 1999), but both species already created the highest possible ΔC_L, because C_{L0} was close to the minimum concentration, C_{Lmin} and thereby maximized diffusive flux to the roots. Accordingly, changes in root uptake kinetics, for example a higher I_{max}, or lower K_m would not influence calculated uptake (Steingrobe and Claassen, 2000). To quantify the significance of plant and soil uptake parameters a sensitivity analysis was conducted. Here only one parameter at a time is changed and its effect on uptake assessed. The investigated parameters were: I_{max}, the buffer power, b, and the soil solution K concentration, C_{Li}. The results of the sensitivity analysis conducted for sugar beet and wheat at the time of greatest discrepancy between measured and calculated uptake showed that an increased I_{max} or b would not improve the prediction. Even by increasing both parameters by a factor of 10, the calculated influx was not equal to measured, because as explained, the transport capacity of the soil was exhausted (Steingrobe and Claassen, 2000). It is obvious that under K deficiency conditions only a higher C_{Li} value would be effective in closing the gap between the calculated and measured influx (Fig. 2b). This indicates that some processes which increase C_{Li} occur in the rhizosphere, for example, possible solubilization of K by root exudates. These processes are not included in the model and their nature is not known.

Conclusions

1. Sugar beet was similarly K efficient as wheat, that is both produced about 80% of the plot with the lower amount of K.
2. Wheat efficiency could be attributed to a large root system and a high utilisation efficiency or low internal K requirement.
3. Sugar beet, even though it had a small root system, a higher shoot growth rate and a high internal requirement had a similar K efficiency to wheat, because of a high efficiency of the individual root or influx.
4. A simulation model could not explain the K uptake under K deficiency conditions. This leads to the conclusion that some processes which increase the availability of K occurs in the rhizosphere. This higher K availability can be obtained by the model only by an increased concentration of K in soil solution.

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Session 2

Crop response to potassium in semi-arid conditions

Response of sugar beet to potassium fertilization under the desert conditions of Egypt

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Summary

Current research has studied the role of potassium (K) fertilizer in association with nitrogen (N) and phosphorus (P) fertilizers for the production of sugar beet grown under the desert conditions of Egypt.

Five field experiments were carried out at Nubaria, N.W. Delta and at Ras Seder, South Sinai. These experiments tested two levels of N: 90 and 180 kg N ha^{-1} and 4 or 6 levels of K from 0 to 360 kg K_2O ha^{-1} and a basal application of P, 35 or 70 kg P_2O_5 ha^{-1} depending on the site at which the experiment was done.

The results showed that the yields of fresh roots and sugar were increased at least two-fold with the highest rates of K compared to the yields on the control soil.

The percentage sugar was slightly increased with increasing K levels. However, some significant differences were obtained between treatments. The effect of K on yield was associated with the higher level of N application in most experiments.

The effect of K was greatest at Ras Seder where the experiment was carried out under the stress conditions induced by using highly saline irrigation water.

The results showed the vital role of K for sugar beet production especially on soils that are impoverished in available K and where the irrigation water is saline.

Introduction

Balanced fertilization is a major cause of increasing crop yields, while unbalanced fertilization leads to a considerable reduction of fertilizer use efficiency. A negative K balance will ultimately lead to a considerable loss in soil fertility.

The nutrient supplying power of the newly reclaimed soils in Egypt, especially those under desert conditions, is very small for most of the nutritive elements. Applying K gave significant responses for most crops grown on such soils (Abdel Salam *et al.*, 1980; Serry, 1980; El-Kadi, 1999).

The economic importance of sugar beet has increased in the last two decades in Egypt and will partially substitute for sugar cane, yet little research has been done on this crop. A large portion of the newly reclaimed soils will be devoted to the production of sugar beet and the present work was carried out to establish the balanced nutrient requirements.

Materials and methods

There were five field experiments, four at Nubaria, Northwest delta, and one at Ras Seder, South Sinai during two successive winter seasons of 1998-1999 and 1999-

2000. The experiments tested N, P and K and each treatment was replicated eight times. The treatments are shown in Table 1.

Table 1. Experimental treatments.

Location	Fertilizer, kg ha^{-1}*									Season
	N		K (K_2O)						P_2O_5	
	N_1	N_2	K_O	K_1	K_2	K_3	K_4	K_5		
Nubaria 1	90	180	0	100	200	300			35	1998-1999
Nubaria 2	90	180	0	100	200	300			35	1998-1999
Nubaria 3	80		0	120	180	240	300	360	70	1999-2000
Nubaria 4	200		0	120	180	240	300	360	70	1999-2000
Ras Seder 5	90	180	0	100	200	300			35	1998-1999

* N as ammonium sulphate, P as superphosphate and K as potassium sulphate.

Phosphorus was added prior to soil cultivation, K and N fertilizers were added together with the amount divided into three equal portions and applied at 30, 75 and 110 days from emergence.

Nile water (400 mg L^{-1} TSS) was the irrigation source at Nubaria, while saline well water (3500 mg L^{-1} TSS) was used at Ras Seder.

Some characteristics of the soils of Nubaria and Ras Seder are shown in Table 2.

Table 2. Characteristics of the soils used.

Character	Nubaria	Ras Seder
Clay %	16	9
Silt %	20	12
Sand %	64	79
Texture class	sandy loam	loamy sand
TSS dS m^{-1}	3.8	11.2
$CaCO_3$ %	8.2	37.0
Organic matter %	0.42	0.61
Available N mg kg^{-1}	115	70.0
Available K mg kg^{-1}	46	32.0
Available P mg kg^{-1}	4.8	5.40

At harvest, the yield of fresh roots and leaves and sugar % were determined (Henry, 1950) and total sugar yield calculated.

Results and discussion

Nitrogen and K fertilization significantly increased the yield of sugar beet and sugar content in Experiment 1 at Nubaria (Table 3 and Fig. 1), especially with 200 and 300 kg K_2O ha^{-1}. The largest yields were given by treatment N_2K_3, the lowest with N_1K_0. These increases were about 62% and 82% for root and sugar yields, respectively. The increase in yield was slightly affected by increasing N level. Although the increase of sugar content was only slightly affected by treatment, yet most of these increases were significant statistically. The sugar yield followed the same trend as the yield of roots and sugar percentage.

Table 3. Effect of nitrogen and potassium on beet and % sugar yield in Experiment 1 at Nubaria.

Treatment	Yield (t ha^{-1}) Fresh leaves	Yield (t ha^{-1}) Fresh roots	Sugar (t ha^{-1})	Sugar %
N_1K_0	26.10	72.90	14.6	20.3
N_1K_1	22.33	72.55	15.3	21.1
N_1K_2	25.92	90.33	19.7	21.8
N_1K_3	27.23	115.98	26.1	22.5
N_2K_0	28.30	73.50	13.7	18.7
N_2K_1	27.10	74.90	15.3	20.4
N_2K_2	29.80	94.20	20.2	21.4
N_2K_3	30.20	117.10	26.5	22.6
$LSD_{0.05}$	1.55	2.65	0.98	0.56

The yield trends were also observed for Experiment 2 at Nubaria (Table 4 and Fig. 2) except that the increase in % sugar was not significant. Both N and K increased yields, especially N when combined with K. The largest yield of both leaves and tops was with N_2K_3 and these were about twice those with N_1K_0.

Table 4. Effect of nitrogen and potassium on beet and sugar yield and % sugar in Experiment 2 at Nubaria.

Treatment	Yield (t ha^{-1}) Fresh leaves	Yield (t ha^{-1}) Fresh roots	Sugar (t ha^{-1})	Sugar %
N_1K_0	10.71	42.84	9.90	21.7
N_1K_1	11.42	48.80	10.50	21.5
N_1K_2	15.23	57.59	12.70	22.0
N_1K_3	15.97	70.82	15.80	22.3
N_2K_0	18.20	45.76	9.06	19.8
N_2K_1	17.60	55.87	11.5	20.8
N_2K_2	17.95	64.83	13.9	21.5
N_2K_3	18.65	84.65	18.6	22.0
$LSD_{0.05}$	1.34	2.33	0.76	N.S.

Effect of nitrogen and potassium fertilization on sugar beet yield and sugar content

Figure 1

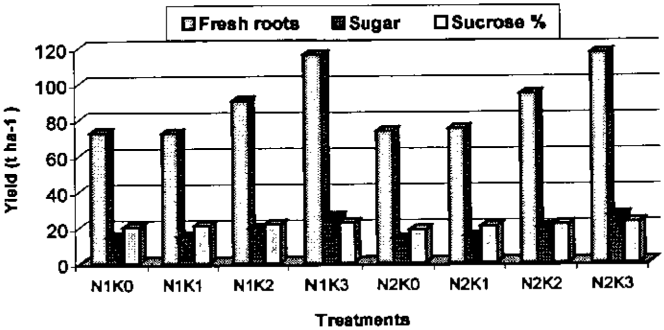


Figure 2

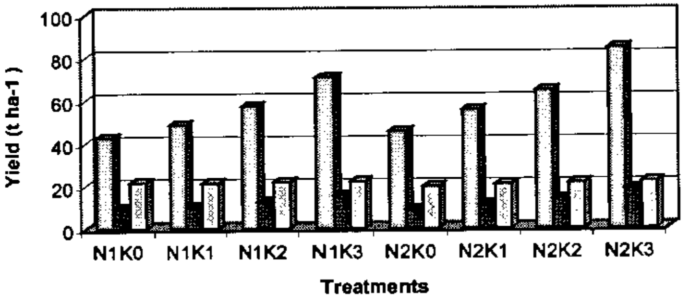
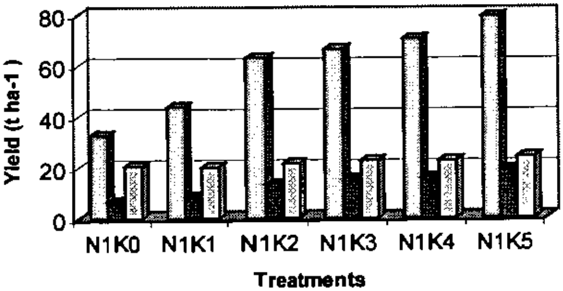


Figure 3



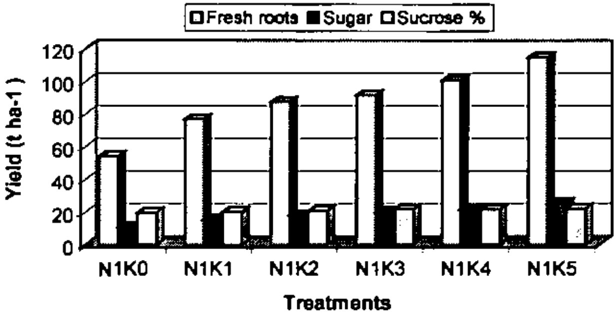


Figure 4

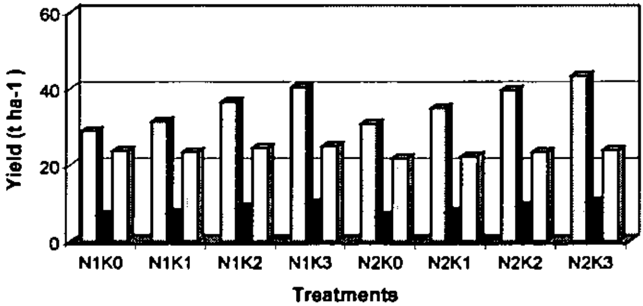


Figure 5

The data in Table 5 and Fig. 3 show a large response of beet to K up to 360 kg K_2O ha^{-1}. The yield of roots was increased by 142% compared to that with K_0. The yield of sugar at the highest K level was about 3 times that on the control treatment (K_0). The % sugar was also affected positively by increasing the K level and the differences between treatments were significant at the largest levels of K application.

Table 5. Effect of nitrogen and potassium on beet and sugar yields and % sugar in Experiment 3 at Nubaria.

Treatment	Yield (t ha^{-1})		Sugar (t ha^{-1})	Sugar %
	Fresh leaves	Fresh roots		
N_1K_0	26.1	32.7	6.73	20.6
N_1K_1	24.7	43.9	8.86	20.2
N_1K_2	21.8	63.1	13.62	21.6
N_1K_3	20.0	66.5	15.60	22.8
N_1K_4	16.0	70.6	16.03	22.7
N_1K_5	26.7	79.5	19.26	24.2
$LSD_{0.05}$	2.12	2.20	1.18	0.93

The same yield trends and significance were also observed in Experiment 4 at Nubaria (Table 6 and Fig. 4). At Ras Seder at Sinai, yields were not increased by N at the two largest amounts of K that were tested (Table 7 and Fig. 5). The percent of sugar did not show significant differences between treatments.

Table 6. Effect of nitrogen and potassium on beet and sugar yields and % sugar in Experiment 4 at Nubaria.

Treatment	Yield (t ha^{-1})		Sugar (t ha^{-1})	Sugar %
	Fresh leaves	Fresh roots		
N_1K_0	24.2	54.3	10.75	19.8
N_1K_1	20.2	76.9	15.53	20.2
N_1K_2	19.1	87.6	18.13	20.7
N_1K_3	19.1	91.7	20.08	21.9
N_1K_4	19.0	100.7	21.75	21.6
N_1K_5	20.6	114.9	25.51	22.2
$LSD_{0.05}$	1.82	3.24	1.86	1.03

Table 7. Effect of nitrogen and potassium on beet and sugar yields and % sugar at Ras Seder.

Treatment	Yield (t ha^{-1})		Sugar (t ha^{-1})	Sugar %
	Fresh leaves	Fresh roots		
N_1K_0	10.44	28.90	6.9	23.7
N_1K_1	11.55	31.40	7.4	23.4
N_1K_2	14.26	36.49	8.9	24.5
N_1K_3	15.10	40.40	10.1	24.9
N_2K_0	12.30	30.80	6.7	21.8
N_2K_1	13.50	34.90	7.8	22.3
N_2K_2	13.90	39.60	9.3	23.4
N_2K_3	13.80	43.40	10.4	23.9
$LSD_{0.05}$	0.953	1.340	0.743	N.S.

The N and K content of the shoots and roots in experiments 1 and 2 at Nubaria and at Ras Seder are in Table 8. The % K in shoots was increased significantly with increasing fertilizer K. There were slight variations in % K with increasing N level. Percentage K in roots was small compared to that in shoots and followed the same trend as in the shoots. The % N in the shoots did not show any significant variation between treatments, in the roots while there were some significant differences between treatments, there was no specific trend.

Table 8. Effect of nitrogen and potassium on the percentage nitrogen and potassium in the shoots and roots.

Treatments	K%						N%					
	Nubaria 1		Nubaria 2		Ras Seder		Nubaria 1		Nubaria 2		Ras Seder	
	Shoots	Roots	Shoots	Roots	Shoots	Roots	Shoots	Roots	Shoots	Roots	Shoots	Roots
N_1K_0	3.90	0.173	2.80	0.167	2.80	0.159	1.02	0.043	1.22	0.043	1.35	0.040
N_1K_1	4.50	0.186	4.50	0.171	3.30	0.172	1.10	0.038	1.15	0.048	1.15	0.039
N_1K_2	4.80	0.192	4.60	0.189	4.30	0.192	0.98	0.030	1.20	0.032	1.23	0.034
N_1K_3	3.80	0.206	4.90	0.198	4.50	0.199	0.96	0.028	1.09	0.027	1.05	0.029
N_2K_0	3.50	0.169	2.20	0.164	2.60	0.154	1.51	0.041	1.45	0.040	1.43	0.038
N_2K_1	4.30	0.181	3.30	0.180	3.80	0.168	1.25	0.031	1.20	0.036	1.25	0.031
N_2K_2	4.50	0.192	4.00	0.186	3.80	0.186	1.28	0.029	1.22	0.028	1.28	0.025
N_2K_3	4.80	0.198	4.50	0.192	4.20	0.195	1.35	0.028	1.15	0.026	1.05	0.021
$LSD_{0.05}$	0.20	0.005	0.22	0.004	0.31	0.007	NS	0.003	NS	0.002	NS	0.003

Discussion

The large effect of K on the yield of sugar beet grown on these sandy loam calcareous soils of Egypt was because they are very impoverished in available K due to the intensive and continuous cropping without replenishing the K and other nutrients removed by the crops. Large yields usually remove large amounts of nutrients especially if the shoots are removed from the field.

There was a progressive increase in yields with increased applications of K up to 300 and 360 kg K_2O ha^{-1}. Balanced fertilization should include the use of K when growing sugar beet which is becoming a very important crop in Egypt.

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Response to K fertilizers by crops grown in calcareous soils in Jordan

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Abstract

Potassium (K) is an essential nutrient for enzyme activation affecting most of the biochemical and physiological processes that influence plant growth and crop productivity and performs several functions that affect the quality of agricultural products. Plants require quite large amounts of K and therefore, providing crops with sufficient K is essential to obtain larger yields and better quality. Moreover, K is needed for normal growth under biotic and abiotic stress. Calcareous soils are usually developed in dry regions, as in Jordan, and are relatively rich in K. In dry regions, improving water use efficiency (WUE) is crucial for successful agriculture. Under drought stress conditions, K may play a major role in enhancing plant growth and WUS. In addition, agricultural intensification with continuous application of nitrogen (N) and phosphate (P) fertilizers has led to soil K depletion. Therefore, under such conditions a response to K is expected. Field and greenhouse experiments were conducted to measure the crop response to K of apple trees and lettuce. The fertilizers were added through irrigation water (fertigation), while in the greenhouse experiment they were added directly to the soil before planting. Overall, K had a positive effect on plant growth, yield, water use efficiency and quality parameters.

Introduction

A plant's requirement for K is quite high, the concentration in vegetative tissue usually ranges from 1 to 4% on a dry matter basis. Therefore, providing agricultural crops with sufficient K is essential to obtain larger yields and better quality. Potassium has been shown to stimulate the growth, yield and quality of various vegetable crops (Singh and Verma, 1991; Saimbhi and Randhawa, 1983). Potassium is an essential element which performs several functions that affect the quantity and quality of agricultural products. It is involved in enzyme activation that affects most of the biochemical and physiological processes that influence plant growth and crop productivity. In addition, K is essential for normal growth of plants under water and salt stress conditions and for increasing plant resistance to diseases and other stress conditions (Gardner *et al*., 1985).

Although, K is present in relatively large quantities in most soils (averaging about 2%), the plant available K is usually much less particular in coarse textured soils and in neutral and acid soils. Under the pressure of agricultural intensification and depletion of most soil nutrients, K was found to be needed for crops growing even in basic and fine textured soils.

Zeolites, naturally occurring aluminosilicate minerals, have a high cation-exchange capacity (Kithome *et al.*, 1998) and their use in agriculture has potential due to their unique chemical and physical properties such as ion exchange principally for K, adsorption, and hydration (Williams and Nelson, 1997). Because of their unique cation exchange properties, zeolites are being investigated for use as fertilizer enhancers and other agricultural amendments (Jacob and Allen, 1990). A large proportion of the exchange site of zeolites can be precharged with ammonium-nitrogen (NH_4^+-N), K^+, or iron (Fe^{+2}) and thus, act as slow release fertilizers.

Little research on K has been conducted in Jordan because the soils are mostly calcareous and believed to be rich in K. On the other hand, response to K has been reported in irrigated intensive agriculture. In addition, environmental stresses are common in Jordanian agriculture and positive K effects under stress conditions are well documented.

These studies evaluated the response of apple trees (in a field experiment) and lettuce (in a glasshouse experiment) to different rates of K applied through irrigation water.

Methodology

A glasshouse pot experiment tested four rates of K (0, 150, 300 and 450 mg K/kg soil) and two rates of zeolite (equivalent to 0 and 2 t/ha). Before planting, the pots were first filled with soil or mixtures of soil and zeolite. The pots were randomized inside the glasshouse in a randomized complete block design (RCBD).

Tensiometers were installed in the pots of each treatment to identify the soil moisture level and to determine the amount of irrigation water to be applied and water consumption by the crops. Soil moisture was kept at field capacity by adding water whenever the water content fell to 0.3 bar.

Seedlings of lettuce (~5 cm high) were planted in the pots and grown from 7 February to 17 April 2001. Plants were irrigated after planting to reach field capacity then irrigation was performed as needed. At the end of the experiment plants were harvested, weighed fresh and then dried (at 68°C).

Soil samples were analyzed (Page *et al.*, 1982) before starting and after the experiment for various soil properties (Table 1).

Table 1. General characteristics of the soil and soil-zeolite mixture before planting lettuce.

	pH	EC dS/m	K ppm	P ppm	CEC Meq/100 g	O.M. %	Na Meq/l	Cl Meq/l
Soil	8.0	0.88	431	29	36.3	1.28	1.68	5.00
Zeo	8.1	2.49	7073	327	59.1	0.08	24.91	7.00

Table 2. General characteristics of the soil of apple experiment.

Soil depth	pH	EC dS/m	K ppm	P ppm	N %	Soil texture
0-30 cm	7.6	1.28	365	44.1	0.07	Clay loam
30-60 cm	7.6	1.89	272	-	0.08	Clay loam

A field experiment evaluated the response of apple trees to different rates of N, P and K fertilizers. Phosphorus was applied directly to the soil, while N and K were added through irrigation water at different concentrations. All treatments were tested in a split-split block design with three replicates. The general characteristics of the soil are in Table 2 and treatments in Table 3.

Table 3. Treatments applied in the apple experiment.

Element	1998		1999	
	ppm	kg/ha	ppm	kg/ha
P1	-	6	-	6
P2	-	12	-	12
P3	-	18	-	18
K1	25	65	25	100
K2	50	130	50	200
K3	75	195	75	300
N1	25	65	25	100
N2	50	130	50	200
N3	75	195	75	300
IW+Fertilizer M3/ha	2600		4000	

The P was applied to the soil as TSP in January, while N and K were added with the irrigation water (IW) as urea and K_2SO_4. Irrigation was performed at 100% E. pan reading from June to September.

A split-split plot design was used with 3 replications where the main, subplot and sub-subplot treatments were P, K and N, respectively. The apple cultivar was Golden delicious and rootstock MM106. The plantation was 5 years old and the trees were planted at 5 × 3 m. Soil sampling was made from the 0-30 cm, 30-60 cm soil depth.

Results

Lettuce experiment

The soil was calcareous, with a high soil pH, low in organic matter and N, but higher in K and P. The cation exchange capacity was typically high for such a soil.

Mixing the soil with zeolite markedly increased most parameters especially K and CEC.

The addition of K had no significant effect on neither shoot dry weight nor plant height of the lettuce (Fig. 1). The results were similar with the two levels of zeolite. However, zeolite increased growth through increasing both the dry weight and the height of the plants. The positive effect of zeolite on soil physical properties (aeration, water holding capacity, etc) was probably the factor enhancing growth of the lettuce. The soil fertility status seemed not to be a limiting factor for growth under the conditions of the experiment. It should be mentioned that irrigation was performed whenever the soil moisture reached the 50% of the field capacity.

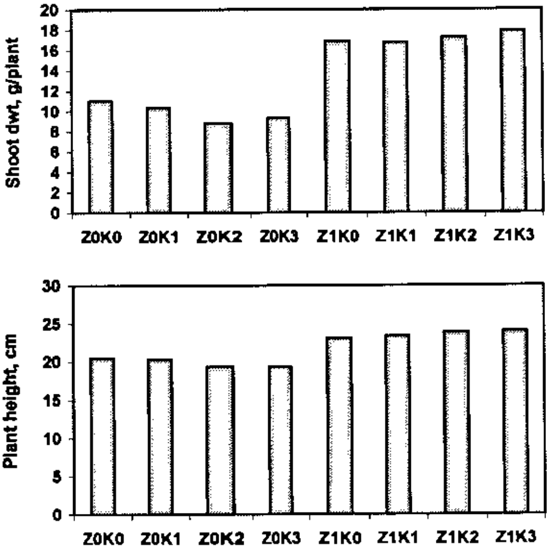

Fig. 1. Shoot dry weight and plant height of lettuce as affected by zeolite and K application.

The K content increased at the highest two rates of K application to the soil not amended with zeolite (Fig. 2). However, with zeolite application, the % K even in the K0 treatment was as high as in any of the K treatments alone. The high K content in zeolite obviously provided the plant with sufficient K. On the other hand, the % N was not affected by the amount of K applied except when zeolite was added. The % P was also not affected at the two levels of zeolite. However, sodium (Na) decreased at the highest rate of K possibly indicating competition between K and Na for the absorption sites of the roots. K is known to compete with Na and inhibit Na uptake, a salt negative impact (Mitchell and Shannan, 1991). Such phenomenon led to a higher K/Na ratio, which used to be considered an indication of salt tolerance, the K/Na ratio increased with increasing K rates.

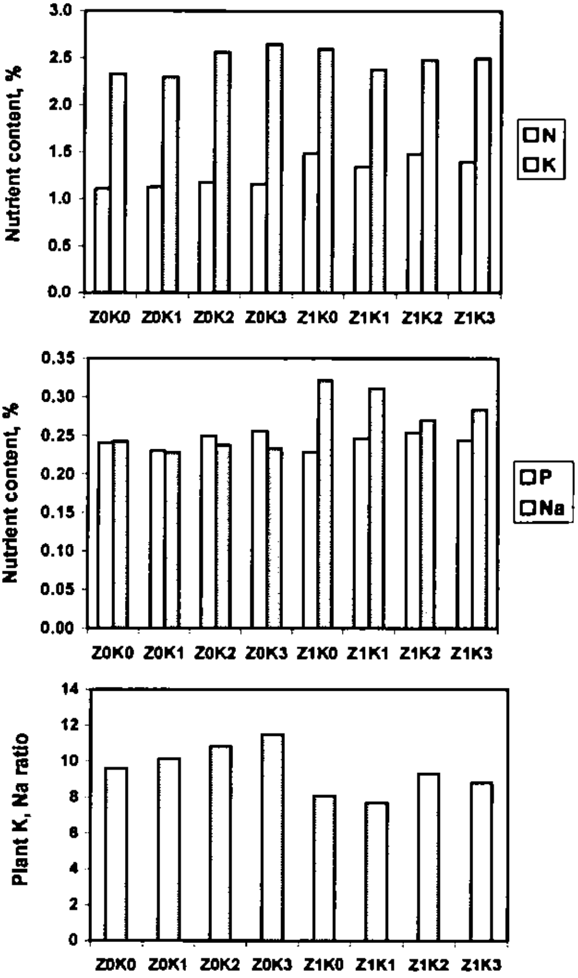

Fig. 2. Nutrient content of lettuce as affected by zeolite and K application.

The soil content of K and P are shown in Fig. 3. Soil K increased with increasing K application rates at both levels of zeolite. With zeolite application, soil K was higher at all rates because of the K provided by the zeolite. As the K rates increased, the increase in soil K became less and less following a quadratic relationship and Michaelis Menten relationship. So the exchange sites for K absorption became less until all were saturated with K. With zeolite there were more absorption sites but the same phenomenon was observed (Fig. 3). Soil P status was not affected by K rates but was higher with zeolite addition.

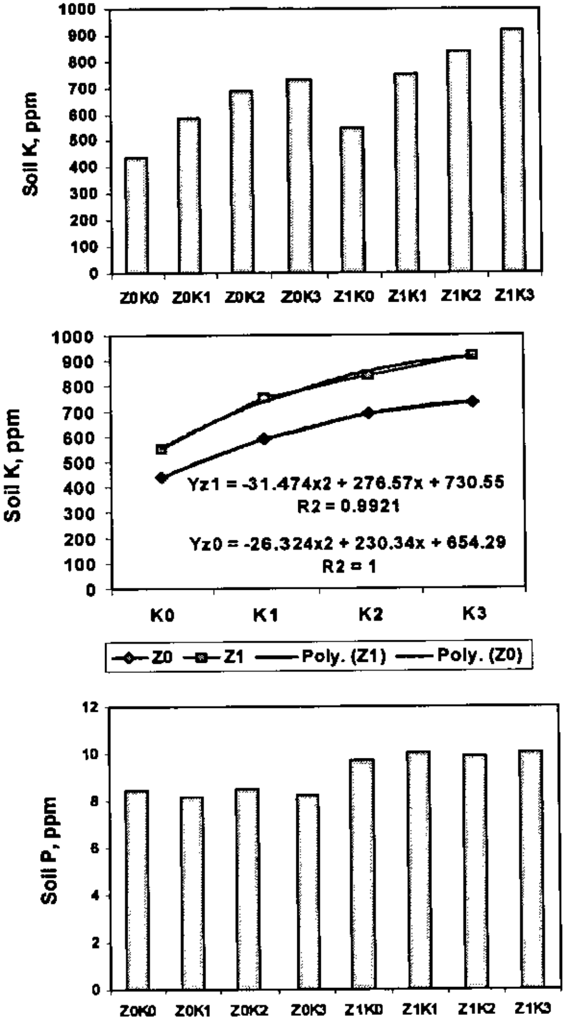

Fig. 3. Soil P and K at the end of the growing period of lettuce as affected by zeolite and K application.

The water use efficiency (WUE) was affected by the application of both K and zeolite (Fig. 4). The WUE increased with increasing K rates only when zeolite was added. It should be mentioned that the soil amended with zeolite had a high water holding capacity, lower losses by evaporation and leaching (Williams and Nelson, 1997). Under these conditions, K helped the lettuce plants to use the available moisture conserved by zeolite more efficiently.

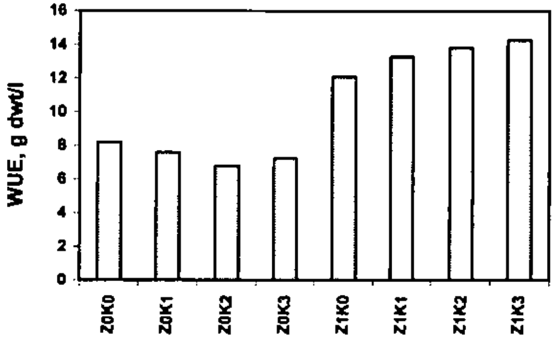

Fig. 4. Water use efficiency by lettuce as affected by zeolite and K application.

Apple experiment

The apple fruit yield for the two season are shown in Fig. 5. The results indicate that the yield was increased with increasing K rates in 1998 and increased similarly by the highest 2 rates in 1999 season. In general, the yield in 1999 was higher than in 1998, perhaps due to the more favorable environmental conditions or to the residual K from that applied in 1998, especially for the second K rate (K2). With a higher level of N and P, a greater response to K was observed in 1998 but not in 1999 except with the K2. This could indicate the synergistic interaction among these nutrients (Mohammad *et al.*, 1997) and the higher N and P the higher the K would be to enhance the balanced fertilization.

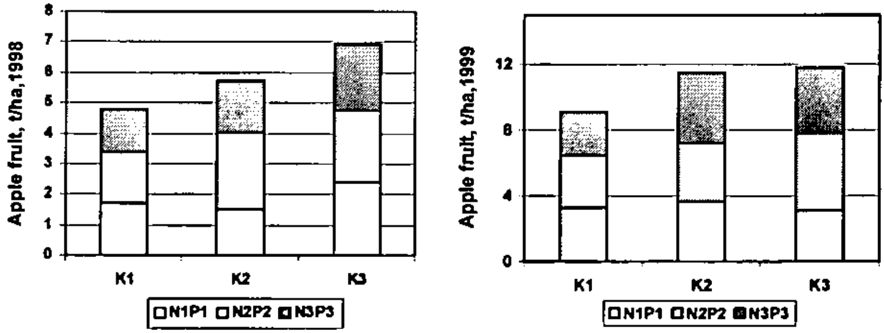

Fig. 5. Apple fruit yield as affected by the interaction effect of applied N, P and K fertilizers.

Partitioning the interaction effect it can be observed that the K2 increased the yield the most at the second rate of N (N2) in 1998 (Fig. 6). The addition of K enhanced the yield at each level of N application. In addition, there was a tendency to increase the yield as the K rates increases at each level of P application (Fig. 7).

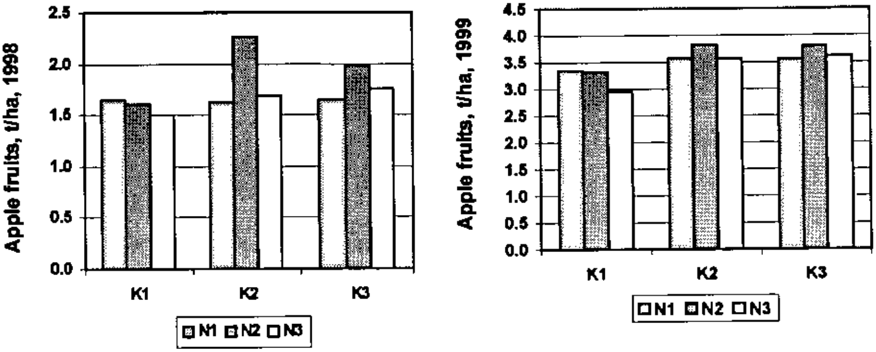

Fig. 6. Apple fruit yield as affected by the interaction effect of applied N and K fertilizers.

In 1998, as the P rates increased at the first rate of K (K1), the yield decreased probably due to inadequate K supply at higher fertility level created by P application. As K application increased (K2 and K3), the yield increased also.

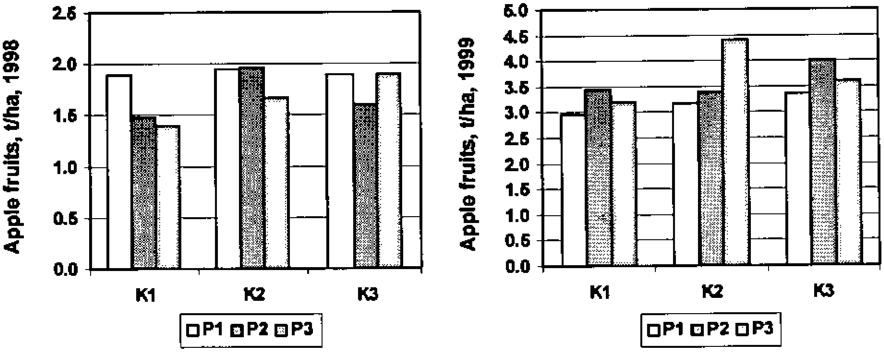

Fig. 7. Apple fruit yield as affected by the interaction effect of applied P and K fertilizers.

The average fruit size or weight was also affected by the application of K (Fig. 8). The average fruit weight correlated significantly with K rates and followed a quadratic polynomial relationship in 1998 and a linear relationship in 1999. This indicates that the K affected the fruit size more than the number of fruits in this experiment. The nutrient uptake by the apple fruits as affected by the NPK application is illustrated in Fig 9. It can be seen that nutrient uptake increased with increasing K rates, indication the synergistic effect of K on other nutrients such as N and P.

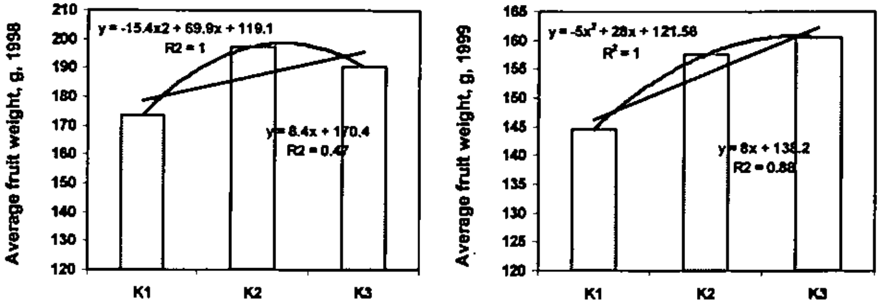

Fig. 8. Effect of K rates on apple fruit weight.

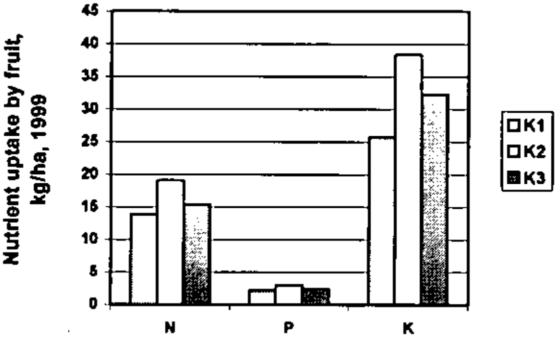

Fig. 9. Effect of K rates on nutrient uptake by apple fruit.

In conclusion, the response by crops to K grown in calcareous soil can be obtained. Other positive influence of K was obtained by enhancing water use efficiency and enhancing uptake of other nutrients. These observation will be of more importance when intensive agriculture is practiced and the addition of K would be necessary to balance the fertilization.

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Potassium fertilization for cotton on soils with large amounts of gypsum

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Introduction

The soils on 20% of the total arable area in Syria contain large amounts of gypsum. These soils are located in the middle and southern part of the Al-Jezzira area that includes the river beds of the Al-Fourate, Khabour and Balikh rivers.

Research has shown that decreased yields are associated with soils with large amounts of gypsum, in part, because they contain very small amounts of plant available nutrients. The objective of the study reported here was to determine the optimum application of potash (K) fertilizer for cotton grown on soils with different levels of gypsum.

Materials and methods

The study in 1996 and 1997 was at the Ghornata farm, Al Rekka Mohafazat.

The soils were divided into two groups: i) those with <24% gypsum, ii) those with 24-44% gypsum. Individual plots were 6 × 5 m and every plot had seven rows of planted cotton. There were three K treatments, 50, 100, 150 kg K_2O/ha (K1, K2 and K3, respectively) and a control (K0) without K.

There were three replicates of each of the four treatments arranged in a randomized block design.

Nitrogen (N) as urea, was applied to all plots at the recommended rate and divided into four applications: 20% at planting, 40% 30 days after panting, 20% 60 days after planting and 20% 75 days after planting. Phosphate fertilizer at the recommended rate was applied at soil preparation.

The soil at both sites was sampled before planting (Table 1).

Table 1. Some characteristics of the soil used for the experiment on cotton at Ghornata, Syria.

Year	% gypsum	pH	EC dS/m	Organic matter %	Available P mg/kg	Available K mg/kg
1996	<24	7.8	3.8	0.78	27	135
	24-44	7.7	5.7	0.46	37	150
1997	<24	7.5	5.9	0.67	11	165
	24-44	7.6	4.4	0.85	19	145

Yields

Yields of cotton were recorded in both years (Table 2).

Table 2. Yields of cotton at Ghornata, Syria in 1996 and 1997.

Treatment kg K_2O/ha	Year and % gypsum 1996 <24%	 24-44%	 1997 <24%	 24-44%
	Cotton kg/ha			
0	761	858	723	862
50	925	1039	924	1002
100	1202	1110	1190	1110
150	1399	1119	1355	1212

Average yields across all treatments and soils were very similar in 1996 and 1997 and were always largest with the largest amount of K fertilizer. On the control treatment and with only 50 kg K_2O/ha, yields were larger on the soils with more gypsum in both years. However, when the cotton was given 100 or 150 kg K_2O/ha, yields were larger on the soils with less than 24% gypsum.

In 1996, the increase in yield given by the K2 and K3 treatments, compared to K0, was statistically significant at the 5% level on soils with <24% gypsum but the increases on soils with 24-44% gypsum were not significant.

In 1997, the increase in yield given by the K2 and K3 treatments, compared to K0, was statistically significant at the 1% level on soils with both amounts of gypsum.

Conclusions

These preliminary studies suggest that there is a need to further test the application of K on soils with large amounts of gypsum on which cotton is grown. It will also be necessary to study the need for N and P on these soils and their interaction with K. The response of cotton to K fertilizer on soils with large amounts of gypsum must be related to the availability of soil K assessed by soil analysis.

Potassium fertilization for sugar beet in Syria

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Introduction

In 1996, a series of experiments were started in Syria to determine the requirements of sugar beet for potassium (K) and relate the results to available K in soil as determined by analysis.

Nitrogen (N), phosphorus (P) and K recommendations for sugar beet are based on soil analysis data for the top 30 cm of soil.

For N, mineral N is extracted and the soil assigned to one of five classes and N fertilizer recommendations are adjusted according to the soil N class (Table1).

Table 1. Fertilizer nitrogen recommendations for spring sown sugar beet based on soil analysis for mineral nitrogen.

Nitrogen class	1	2	3	4	5
Mineral N, mg/kg	<5	5.1-9	9.1-15	15.1-19	>20
Fertilizer recommendation, kg N/ha	220	210	200	150	100

For P, readily available phosphorus is determined and the soil assigned to one of six classes and the phosphate fertilizer recommendation depends on the soil P class (Table 2).

Table 2. Phosphate fertilizer recommendations for spring and autumn sown sugar beet based on soil analysis.

Phosphorus class	1	2	3	4	5	6
Available P, mg/kg	<3	3.1-5	5.1-7	7.1-9	9.1-12	>12
Phosphate recommendation, kg P_2O_5/ha						
spring sown	160	140	120	90	50	-
autumn sown	150	130	110	80	40	-

For K, readily available potassium is determined and the soil assigned to one of eight classes. The K recommendations for both autumn and spring sown sugar beet depends on the soil K class (Table 3).

Table 3. Potash fertilizer recommendations for spring and autumn sown sugar beet based on soil analysis.

Potassium class	1	2	3	4	5	6	7	8
Available K, mg/kg	<60	61-120	121-180	181-240	241-300	301-360	361-420	>420
Potash recommendation, kg K_2O/ha								
spring sown	180	140	120	100	80	60	40	-
autumn sown	160	140	120	100	80	60	3	-

This paper presents average data for three years for sugar beet grown at Deil el Zor in the Mohafazat administrative district.

Materials and methods

Some characteristics of the soil at Deit el Zor are given in Table 4.

Table 4. Analytical data for the soil at Deit el Zor prior to planting.

EC dS/m	pH	$CaCO_3$ %	mg/kg available		Sand	Silt	Clay
			P	K		%	
4.41	6.4	27.2	1.8	139	40	33	27

The soil had 139 mg/kg available K and was in class 3 for K (Table 3) with a recommendation of 120 kg K_2O/ha.

Besides a control (K0), four amounts of K (K1, K2, K3, K4) were tested supplying 90, 120, 180 and 240 kg K_2O/ha applied as potassium sulphate. There were four replicates of each treatment giving 20 plots in a randomized block design. Each plot was 10 × 5 m with rows 50 cm apart.

Basal N was applied each year according to the concentration of mineral N in the soil (Table 1). It was applied in two equal applications, half at planting, half at seedling emergence. All plots received P each year, the amount depended on soil analysis (Table 2).

Yields

Yields of sugar beet roots and sugar percentage are in Table 5.

Table 5. Average annual yield of sugar beet roots and percentage sugar, Deir el Zor.

Treatment kg K_2O/ha	Root yield t/ha	% sugar
0	36.9	13.7
90	39.0	12.5
120	42.2	13.2
180	44.0	13.9
240	45.0	14.2

Yield and % sugar increased up to the largest amount of K tested, but the yield increase was only statistically significant up to a K application of 120 kg K_2O/ha. However, depending on the cost of a kg of K_2O as sulphate of potash, and the value of the extra yield achieved by applying 180 and 240 kg K_2O/ha, it may have been economically advantageous to apply more K than 120 kg K_2O/ha.

Chairman: *A.N. Fardous*
NCARTT
Amman, Jordan

Session 3

Potassium and water

Effect of potassium amount and time of application on maize yields under water deficit

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Introduction

Maize is an important crop for animal feeding as well as human nutrition. It is well adapted to a wide range of climatic conditions and can be grown successfully between latitudes 58°N and 35-40°S (Arnon, 1975). It is grown on a wide variety of soils and will give good yields if it is well managed and its large water requirement (near to 500 mm) can be met. In the Ege region of Turkey, Ul (1990) recommended 400 mm of irrigation for maize grown as a second crop and suggested that it should be applied at the vegetative, flowering, seed-set and grain maturation phases. However, one of the shortcomings of this region in summer is lack of water, which is often the limiting factor for productivity. In fact, drought is generally the most important stress that plants suffer. On the other hand, when plants are not well supplied with nutrients, water is less efficiently used by the plant. Potassium is stated to be involved in the water economy of plants (Krauss and Kemmler, 1989) and is required to combat drought stress.

The objective of this project was to study the effect of rate and timing of K fertilization on the yield and yield components of maize under full and deficit irrigation conditions in a wheat-maize crop rotation.

Materials and methods

A three-year ongoing field experiment was started in 1999 with maize, cv. Luce, grown as a second crop after winter wheat. Treatments were applied cumulatively on each plot. Nitrogen (N) and phosphorus (P) were applied as recommended and K was tested at different rates and times (0; 150+150; 300; 300+300; 600 kg ha^{-1} K_2O), either once as a basal dressing at preplanting or as split application, first half at preplanting and the second half at the 5-6 leaf stage. Furrow irrigation was practiced at three different levels, 1.0 (full irrigation); 0.75 (medium irrigation) and 0.50 (least irrigation) based on data from Class A pan evaporimeter. The experiment was in split blocks with 5 replicates. Some physical and chemical properties of the soil are given in Table 1. Yield, yield components like plant height, ear length, leaf area index, and some physiological parameters like leaf succulence index, relative turgidity and stomatal densities were measured according to standard methods (Hepaksoy *et al.*, 1997; Romero-Aranda and Syvertson, 1996).

Table 1. Physical and chemical properties of the experimental soil.

	%			Available (mg kg^{-1})			
pH	$CaCO_3$	O.M.	Tot. N	P	K	Ca	Mg
7.60	3.8	0.46	0.070	1.89	150	2550	360

Results and discussion

Maize yield

Yields in 1999, 2000 and 2001 clearly showed the importance of water (Fig. 1). The effect of K was significant when the crop was exposed to dry conditions (Fig. 2). The results showed that with full irrigation, yield responses in the first and second years were positive and significant at the 1% and 5% levels, respectively. The relationship between yield and applied K was curvilinear above 300 kg K_2O ha^1.

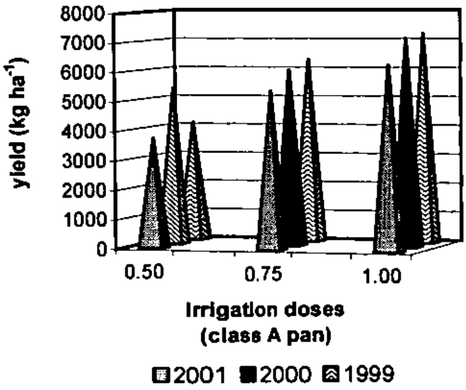

Fig. 1. Maize yield (kg ha^{-1}) as a function of the amount of irrigation.

On the other hand, in the third year, there was a linear increase (significant at the 1% level) when split K application was not included. We have concluded that 300 kg K_2O ha^{-1} is the economic K application with full irrigation conditions based on yields for three years. With less than full irrigation, the yields of the control plots were lowest in the three years. However, even though 300 kg K_2O ha^{-1} increased yields in the three years, we do not recommend more K than this particularly with least irrigation because the economic K rate may be less than this. Therefore, 300 kg K_2O ha^{-1} at preplanting as a basal dressing or, perhaps less than this, can be considered as appropriate for balanced fertilization and maintaining a sufficient soil reserve.

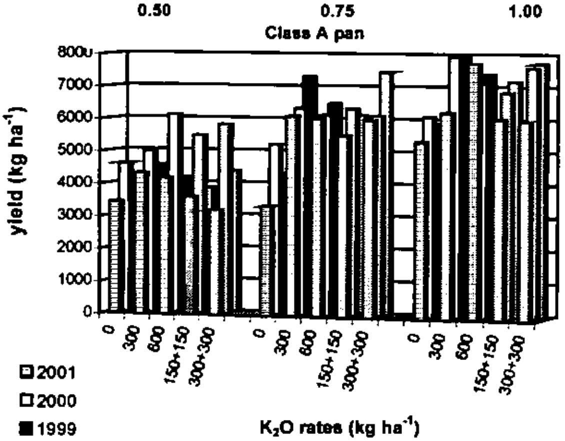

Fig. 2. Maize yield (kg ha^{-1}) as a function of the amount of irrigation.

Plant height

Plant height and leaf area are significant components of vegetative growth. In this study, the effect of water on plant height was significant at the 1% level. On the other hand, the effect of extra K was not significant in the first two years but was at the 5% level in the 3rd year. The highest plants were on the control (K_0) plots which received only N and P. However, if these plants are excluded, the height of those that received K as 300 as 600 kg K_2O ha^{-1}, together with the recommended amounts of N and P fertilizers, increased as K increased (there was a positive correlation, 0.654**) indicating the benefit of balanced fertilization (Fig. 3).

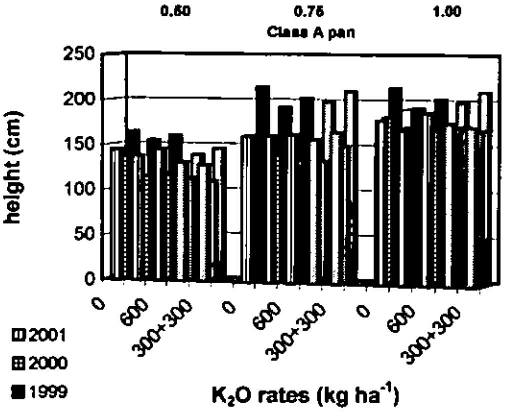

Fig. 3. Plant height (cm) as a function of irrigation and amount of potassium.

Ear length

Ear length is directly related to yield and the effect of irrigation on ear was significant at the 1-5% level in all three years. On the other hand, there was no significant effect of K on ear length, but in the first year with full and medium irrigation, ear length slightly increased with increasing in K. With least irrigation in the first year, ear length decreased with increased K application. In the second year, the ears on all the control K_0 plots at every level of irrigation were the shortest but there was no distinct response to K. In the last year of the study, with least irrigation, the responses to K were negative, as in the first year, and with medium irrigation there was a positive response to 300 kg K_2O ha^{-1} and a smaller response to 600 kg K_2O ha^{-1}. The fact that ear length with this particular treatment was close to that with the same amount of K but full irrigation deserves attention. The longest ear lengths were measured with full irrigation and K_2O applications over 300 kg ha^{-1} (Fig. 4).

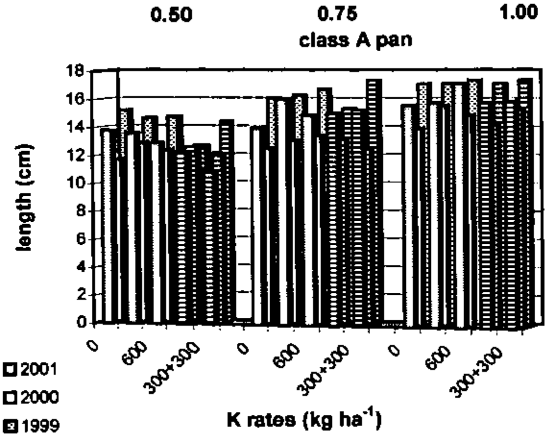

Fig. 4. Ear length (cm) as a function of irrigation and amount of potassium.

Leaf area index

As a component of plant vigor, leaf area is an important criteria since it is the key determinant for the interception and utilization of solar energy. For maize, Mengel (1987) suggests the optimum leaf area index (LAI) as 5 (5 $m^2/1$ m^2). In the present study, leaf area index were determined in the last two years of the study and the results showed the unique effect of water. When K was supplied, and with full irrigation, leaf area index increased with the increasing amounts of K but the increases were not statistically significant. Split application had no positive effect. Similar effects of K were also found in the plants that received either least or only a moderate water supply. Even though K improved total leaf area under these deficit water conditions, the leaf area index figures were always lower compared to that with full irrigation highlighting once more the effect of water. If leaf areas are evaluated together with the plant heights, results show that tallest plants, which were on the control plots without K fertilizer, did not necessarily have the largest total leaf area. Thus, an opposing situation existed in this context (Figs. 5 and 6).

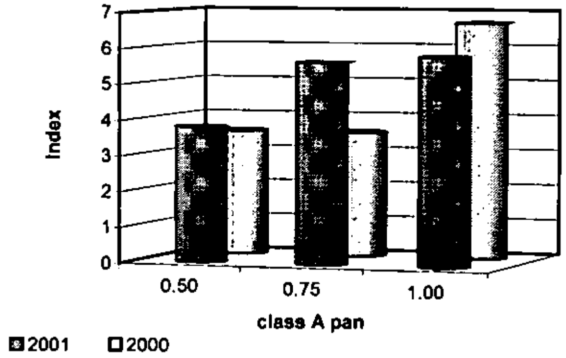

Fig. 5. Leaf area index as a function of irrigation (2001-2000).

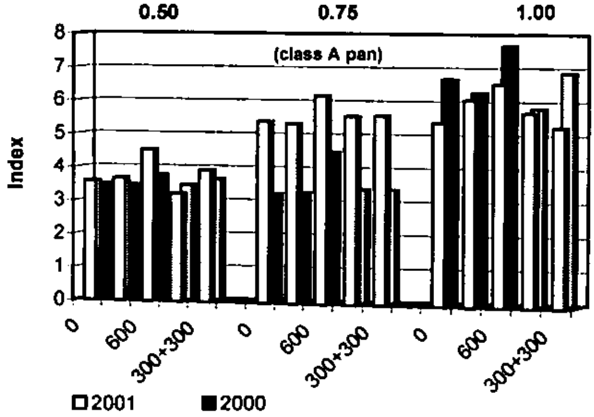

Fig. 6. Leaf area index as a function of irrigation and amount of potassium.

Succulence index

Succulence index is a significant parameter of leaf water relations and as the succulence of cells increases, intercellular spaces decrease and the diffusion of CO_2 to the site of carboxylation in the chloroplasts is affected (Anaç *et al.*, 1999). With regard to succulent plant, Marschner (1998) noted the thickness of leaf cuticle and their low surface area per unit of fresh weight. In the present study, there was no clear cut response in succulence index to irrigation. However, with full irrigation, increasing amounts of K generally decreased succulence index. A possible reason is that under optimum conditions, K might stimulate stomatal opening as well as the transportation of photosynthates and this might lower the water content per unit leaf area. Similarly, with least and moderate irrigation, plants without K had the highest succulence index. If the succulence index and the total leaf area are considered together, the effects go in opposite directions, the low total leaf area of the plants without K might be the reasons for the high water retention per unit area, the succulence index. The plants without K generally might have a lower water content and K supply increases it (Fig. 7).

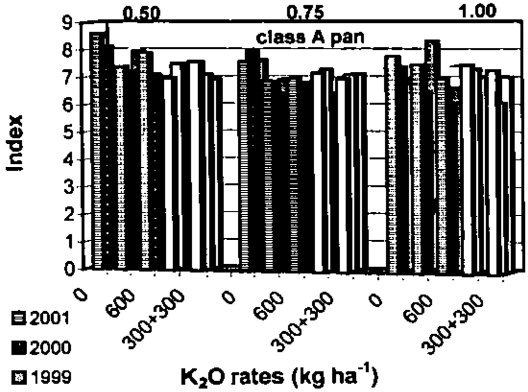

Fig. 7. Succulence index as a function of irrigation and amount of potassium.

Relative turgidity

Relative turgidity (RT) or relative water content (RWC) is defined as the water content relative to the water content of the same tissue at full turgor. Relative water content is related to the water potential (Ψ) of the same tissue (Hsiao, 1973). Sen Gupta *et al.* (1990) reported that K effects on the relationship between the relative water content and water potentials in stressed plants was primarily responsible for the K protective effect on photosynthesis. The same authors also state that an altered RWC/Ψ relationship can be facilitated by osmotic adjustments during drought periods. Results from this study showed significant (1%) effect of irrigation treatments on the relative turgidity of the leaves. In the case of K effects, once again split application was not effective. On the other hand, enhanced K rates generally significantly (1%) decreased the relative turgidity values with full irrigation in all of the study years. With only moderate water deficiency, generally there were increments in relative turgidity compared to that of the control treatment. Thus, this result might imply a protective effect of K on lowering the transpiration losses by regulating the stomatal opening. However, the decline in relative turgidity with increasing K and full irrigation might be due to the effects of K on stomatal opening to increase photosynthetic activity but this might affect water loss through these apertures. However, under severe water stress, there was no definite response to K (Fig. 8).

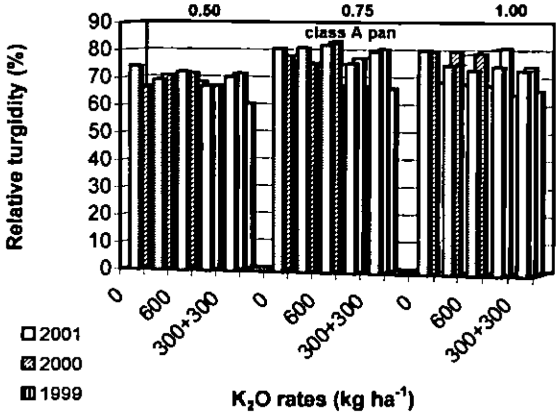

Fig. 8. Relative turgidity (%) as a function of irrigation and amount of potassium.

Stomatal density

There is conflicting data in the literature on stomatal density. Generally under stress conditions and particularly under salt and water constraints, reduced stomatal density is considered as a tool for adaptation to prevent water loss. On the other hand, under optimum growing conditions, Trolldenier (1971) reported that K supply is an efficient agricultural practice to increase photosynthesis via stomatal density. It has also been noted that the radius of the stomatal aperture and the distribution of stomata is very effective in the diffusion of water vapour. The 3rd year results of this study showed that, under full irrigation conditions, the number of stomata increased with increasing K irrespective of whether the application was split or not. On the other hand, under both of the deficit irrigation conditions, an opposite trend was found. As the K rates increased, stomatal number declined, 16% under severe water deficit and 7% under moderate deficit. The results also showed that stomata were always less dense in the most stressed condition (Fig. 9).

Wheat yield

Yields of the rainfed wheat in the crop sequence were affected by the amount of irrigation applied of the previous maize crop. Generally, full irrigation to maize resulted in lower yields of wheat. This can be explained by the differences in K availability (Table 2). With most irrigation, more K and other nutrients were taken up by maize and this subsequently decreased wheat yield. The residual K effect, irrespective of the level of irrigation, positively affected the wheat.

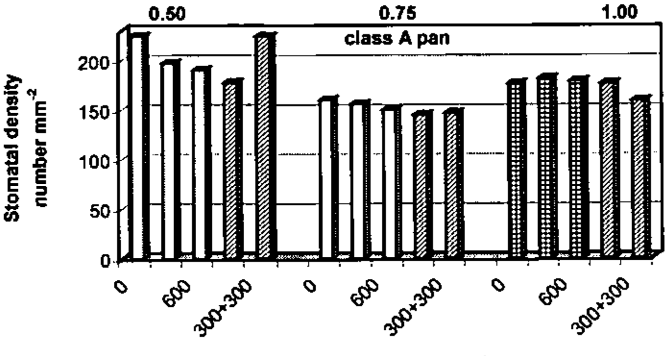

Fig. 9. Stomatal density (number mm^{-2}) as a function of irrigation and amount of potassium.

Table 2. Wheat yield (kg ha^{-1}) as a function of residual soil K.

Treatments (kg ha^{-1} K$_2$O)	Exchangeable K (mg kg^{-1})			Wheat yield (kg ha^{-1})		
	Irrigation to maize					
	0.50	0.75	1.00	0.50	0.75	1.00
0	160	160	170	4009	3540	3035
150+150	190	198	190	4238	3239	3408
300	218	246	232	3459	3670	3736
300+300	242	240	222	4197	3540	3616
600	320	254	246	4199	4502	3354

Conclusions

- The unique effect of water cannot be denied.
- 300 kg K$_2$O ha^{-1} can be an economic amount with full irrigation. With less irrigation, lower rates of K should be tested in further experiments.
- Preplanting K as a basal dressing is recommended.
- Plant height, leaf area index, ear length and relative turgidity were significantly correlated with yield.
- An efficient K fertilization can affect the soil reserves and have an impact on the yield of wheat, subsequent crop.

Acknowledgement

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Crop yield and water use efficiency as affected by potassium fertilization

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Abstract

Potassium (K) is vital for many plant processes. It improves crop yield and water use efficiency and is required to activate at least 60 different enzymes involved in plant growth. In eight different experiments all over Iran in the past seven years (1993-2000), with wheat and corn each in two locations, potato, tomato, cotton, and citrus orchard, the application of K fertilizers with the same amount of water in both control and treated plots, increased crop yield and hence the water use efficiency.

In Karaj region of Iran, wheat grain yield without K was 4830 kg/ha and this was increased to 5780 and 5660 kg/ha with K application. Because the same amount of water 3120 m^3/ha was applied to all crops, the water use efficiency (WUE) increased from 1.55 to 1.85 kg grain/m^3 of water. In Darab, by using 3900 m^3/ha irrigation water, the grain yield was increased from 4267 to 4667 and 5300 kg/ha by using K fertilizers, and hence the WUE increased from 1.09 to 1.20 and 1.36 kg grain/m^3. WUE increased also in most other crops especially with potato and tomato. In the Karaj region, with maize given 7500 m^3/ha irrigation water, the yield on the control plots was 5042 kg/ha, and with K it increased to 11517 kg/ha. WUE increased from 0.67 to 1.54 kg grain/m^3. In Darab, with maize given 8000 m^3/ha irrigation water, the yield was 6170 kg/ha without K and this increased to 12730 kg/ha with K; WUE increased from 0.77 to 1.59 kg/m^3. It is evident that for both wheat and maize although the soil had more available K in Darab, WUE was lower than in Karaj mainly due to the use of more irrigation water. In another study on potato in Zanjan, with 7000 m^3/ha water, two rates of potassium sulphate (SOP) were tested. While the yield of potatoes was 18300 kg/ha in the control plots (NP), it increased to 34600 and 37900 kg/ha by applying 100 and 200 kg/ha K_2O (K_1 & K_2), respectively. Hence, water use efficiency increased from 2.61 in the control plot to 5.00, and 5.41 kg tubers/m^3 of water with K_1 and K_2 respectively. In a tomato plantation in Marand region, an application of MOP at 100 and 150 K_2O/ha with 8000 m^3 water/ha increased the yield from 48000 to 59000 and 64000 kg/ha, respectively. Hence, WUE increased from 6.00 to 7.40 and 8.00 kg fruit/m^3.

In Kashmar, three levels of K and three of irrigation water were tested on cotton. The results Showed that by using 150 kg/ha SOP, the water requirement was reduced by 20%. In another 4-year study in a citrus orchard, three levels of water and four rates of K were tested. The results showed that K fertilizer increased the yield and saved 3000 m^3 of water/ha. While WUE in the control plot was 2.75 kg fruit/m^3, it increased to 3.25 kg/m^3 in SOP treated plots.

Introduction

Potassium (K) is vital for many plant processes and it is required to activate at least 60 enzymes involved in plant growth. Potassium improves crop yield and quality. It relieves water, salt and drought stresses, hence K reduces crop water requirement. Because K has a dominant role in the opening and closing of the stomata, through which water is transpired from the leaves and CO_2 enters the leaves. When water supply is short, K is pumped out of the guard cells and the pores close tightly to prevent loss of water. If K is inadequate, the stomatal activity becomes slow and water losses are high. The accumulation of potassium in plant roots produces an osmotic pressure gradient that draws water into the roots. Plants deficient in K do not absorb sufficient quantities of water and, in consequence, they exhibit a temporary drought stress.

With the absence of K-fertilization in the past or the continuation of unbalanced fertilization at present, especially on K depleted soils growing crops intensively, Iran is faced with lower yields and poor quality of some agricultural products compared to systems practicing balanced fertilization in the past 6 years. Adequate K supplies to plants increase plant uptake of water as well as improving water use efficiency (WUE). Considering such roles, it was therefore, our aim to investigate the effect of K-fertilizers in order to improve the yield and increase WUE with different crops in various locations during the past seven years on the calcareous soils of Iran.

Materials and methods

On farms growing wheat in the Karaj and Darab regions, different rates and sources of K were tested. In Karaj 3120 and in Darab 3900 m^3 water/ha were used during the growing period. In the maize fields in Karaj and Darab, 7500 and 8000 m^3/ha of irrigation water were applied with different rates and types of K fertilizer. In another study on potatoes in Zanjan, 7000 m^3/ha of irrigation water and two rates of potassium sulphate (SOP) were tested. In a tomato plantation in Marand region, application of MOP at two rates (100 and 150 K_2O/ha) with 8000 m^3/ha of irrigation water was tested. In 1996, in Kashmar region, three levels of K (0, 50 and 150 kg/ha SOP) and three levels of irrigation water (421, 628 and 785 mm) with three replicates in a split-plot design were tested. In another 4-year study during 1993-97 in a citrus orchard, which was under drip irrigation, a split-plot design was used with three levels of water (40, 55 and 70% of evaporation from a class A pan) as the main plots, and four rates of K (0, 500, 1000 and 1500 g/tree SOP) as the sub-plots. There were three replicates of each treatment and there were two trees in each sub-plot. It was our aim to investigate the effects of K with balanced fertilization in order to improve the yield and quality of the different crops, and also to increase the WUE. The experimental data were analyzed and Duncan test and LSD calculations made.

Results and discussion

All the soils used for these experiments were calcareous with pH 7.7-8.1, organic carbon less than 1.0% and textures ranging from loam to clay. The percentage clay ranged from 14 to 38% and available K from 150 to 240 mg/kg (Table 1).

Table 1. Some important chemical characteristics of the studied soils.

Location	pH of paste	$CaCO_3$ %	OC %	Clay %	Available K (mg/kg)
Karaj	8.0	8.0	0.52	18	180
Darab	8.1	40	0.50	25	212
Zanjan	7.7	11	0.90	38	240
Marand	7.9	10	0.62	35	180
Kashmar	7.8	22	0.40	15	150
Jahrom	7.8	59	0.59	14	230

Effect of K fertilizers on wheat yield and its water use efficiency in Karaj and Darab

Karaj: The experiment in 1999 was a complete randomized block design and compared the effects of MOP and SOP on the yield of the cultivar Mahdavi grown in a soil with 0.52% organic matter and 180 mg/ha available K. The treatments were: T_1, NP (control); T_2, NPK_{100} (MOP); T_3, NPK_{100} (SOP); T_4, NPK_{150} (MOP); T_5, NPK_{150} (SOP); T_6, NPK_{200} (MOP); and T_7, NPK_{200} (SOP). The amount of irrigation water used was 3120 m^3/ha, and the water contained HCO^-_3 and Cl^- at a level between 1 and 1.5 me/l and was classified as suitable for crop irrigation and there were no salinity limitations. Table 2 shows the wheat yield and WUE obtained from the different rates and sources of K.

Table 2. Effect of potassium on wheat yield and WUE in Karaj and Darab.

Treatments	Karaj		Darab	
	Yield (t/ha)	WUE (kg grain/m^3)	Yield (t/ha)	WUE (kg grain/m^3)
Control (NP)	4830 B	1.55	4267 B	1.09
NPK_{100} (MOP)	5780 A	1.85	4667 B	1.20
NPK_{100} (SOP)	5660 A	1.81	5300 A	1.36

Yields followed by the same letter are not significantly different.

Darab: The effect of different rates and sources of K were tested similarly on wheat yields in Darab. The amount of irrigation water used was 3900 m^3/ha and the results are given in Table 2.

Effect of different levels of potassium on the yield of maize

Karaj: A complete randomized block experiment with three treatments and three replicates was carried out during 2000 on a calcareous soil containing 296 mg K/kg. The treatments included: T_1, NP (control); T_2, NPK_{100} (SOP); and T_3, NPK_{100} (MOP). The amount of irrigation water used was 7500 m^3/ha and the results are given in Table 3.

Table 3. Effect of K fertilizers on corn grain yield and WUE in Karaj.

Treatments	Yield (kg/ha)	WUE (kg/m^3)
Control NP	5042 C	0.67
NPK_{100} (MOP)	7933 AB	1.13
NPK_{100} (SOP)	11517 A	1.54

Darab: A complete randomized block experiment with 6 treatments and 3 replicates was used for this test. The soil at Darab Research Station used for this experiment had 40% $CaCO_3$, 0.50% OC and 244 mg/kg available K. The irrigation water contained Cl^- and HCO_3^- at 4 and 5 me/l, respectively, and was applied at 8000 m^3/ha. The treatments included: T_1, NP (control); T_2, NPK_{150} (MOP); T_3, NPK_{150} (SOP); T_4, NPK_{300} (MOP); T_5, NPK_{300} (SOP); and T_6, NPK_{450} (SOP+MOP). The average yields are given in Table 4.

Table 4. Effect of K fertilizers on corn yield and WUE in Darab.

Treatments	Yield (kg/ha)	WUE (kg/m^3)
Control NP	6170 F	0.77
NPK_{150} (MOP)	8800 CD	1.10
NPK_{150} (SOP)	10230 A	1.27
NPK_{300} (MOP)	11570 B	1.45
NPK_{300} (SOP)	10870 D	1.36

Effect of K fertilizers on potato yields and water use efficiency in Zanjan

An experiment in 2000 at Zanjan province's Agricultural Research Station tested the effect of K fertilizers on potato yields and quality and WUE. A complete randomized block design was used with 12 treatments and 3 replicates. The treatments included: T_1, the farmers conventional fertilizers (NP); T_2, NPK+a complete formula of micronutrients (based on the soil test); T_3, T_2+200 kg SOP/ha; T_4, T_2+400 kg SOP/ha; T_5, T_2+200 kg MOP/ha; T_6, T_2+400 kg MOP/ha; T_7, T_2+200 kg SOP/ha before planting; and 200 kg MOP/ha as a sidedress; T_8, T_2+400 kg SOP/ha before planting and 400 kg MOP/ha as a sidedress; T_9=T_4+50 kg $ZnSO_4$/ha; T_{10}=T_4+100 kg $ZnSO_4$/ha; T_{11}=T_{10}+100 kg $MgSO_4$/ha, T_{12}=T_8+100 kg $ZnSO_4$/ha. The amount of irrigation water used was 7000 m^3. Yields and WUE are in Table 5.

Table 5. Effect of K fertilizer on potato yield and WUE in Zanjan.

Treatments	Yield kg/ha	WUE (kg tubers/m^3)
T_1 (NP)	18300 E	2.61
T_2 (NPK+Micro)	20800 E	2.97
T_3 (T_2+SOP_1)	34600 BC	4.94
T_4 (T_2+MOP_2)	37900 AB	5.41
T_5 (T_2+MOP_1)	29600 D	4.23
T_6 (T_2+MOP_2)	27600 D	3.94
T_7 (T_2+SOP_1+MOP_1)	34400 C	4.91
T_8 (T_2+SOP_2+MOP_2)	30400 D	4.34
T_9 (T_4+Zn_1)	37100 BC	5.30
T_{10} (T_4+Zn_2)	40700 A	5.81
T_{11} (T_{10}+Mg)	38100 AB	5.44
T_{12} (T_8+Zn_2)	28500 D	4.07

Effect of K fertilizers on tomato yields and water use efficiency in Marand

A complete randomized block experiment with five treatments and three replicates in 1999 at Marand tested the effect of K rates and sources on tomato yields and WUE. The fertilizer treatments included: T_1, NP (control); T_2, NP+K_{200} (MOP); T_3, NP+K_{200} (SOP); T_4, NP+K_{300} (MOP); T_5, NP+K_{300} (SOP). The soil had 15% clay, 10% $CaCO_3$, 0.62% OC, and available P and K of 10 and 180 mg/kg, respectively. The amount of irrigation water used was 8000 m^3/ha and it contained HCO_3^- and Cl^- at levels of 1.8 and 2.6 me/l, respectively. There were no salinity limitations. Tomatoes were planted in rows and the N, P, and micronutrients were applied at rates based on soil tests. SOP and one third of the MOP were applied at planting and the rest of the MOP was applied as a sidedress along with the N fertilizer. The results are in Table 6.

Table 6. Effect of K fertilizers on tomato yields and WUE in Marand.

Treatments	Tomato yield (kg/ha)	WUE (kg fruit/m^3)
Control	48000 C	6.00
MOP_{200}	59000 C	7.38
SOP_{200}	51000 B	6.38
MOP_{300}	64000 A	8.00
SOP_{300}	59000 B	7.38

The analysis of variance showed that most of the treatments were significant at the 1% level. The largest yield was obtained by using 300 kg/ha MOP with a WUE of 8 kg fruit/m^3 water.

Effect of K fertilizers on cotton yield and water use efficiency in Kashmar

In the Kashmar region in 1996, three levels of K (0, 50 and 150 kg/ha SOP) and three levels of irrigation water (421, 628, and 785 mm) were tested in an experiment with three replicates in a split-plot design. The results showed that the effects of SOP and the interaction with irrigation water levels were significant at the 5% level. By using 150 kg/ha SOP, the water requirement was reduced by 20% and 1570 m^3/ha of irrigation water were saved without significant reduction in the yield of cotton. With most irrigation (785 mm) and 150 kg/ha SOP, water use efficiency increased up to 4.87 kg/m^3. With the least irrigation (471 mm) and 50 kg/ha SOP, water use efficiency increased to 6.71 kg/m^3.

Effect of K fertilizers on citrus yield and water use efficiency in Jahrom

In another 4-year study during 1993-97 in a 17 year-old citrus orchard that was drip irrigated, a split-plot design was used to test three levels of water (40, 55 and 70% of evaporation from a class A pan) on main plots, and four rates of K (0, 500, 1000 and 1500 g/tree SOP) as the sub-plots. There were three replicates and two trees per sub-plot. The experimental site was located at Jahrom Experiment Station with a medium textured soil, 60% $CaCO_3$ and without salinity problems. Yield was decreased significantly by the driest treatment; water applied to replace only 40% of evaporation. SOP increased yields significantly compared with the control plot. Furthermore, water and K had a significant interaction. The optimum treatment was water applied to replace 55% of the evaporation with 500 g K/tree as SOP. This treatment saved 3000 m^3/ha of irrigation water without a significant decrease in the yield of citrus. While water use efficiency in the control plot was 2.72 kg fruit/m^3, it increased to 3.25 kg/m^3 with the best treatment.

Conclusions

The average values show that the improved crop yields and their WUE were caused by the application of either MOP or SOP. Where the two K sources were compared, the yields with MOP were larger with wheat, corn and tomato, but SOP was better with potatoes. Potato yields in Zanjan with 200-400 kg/ha of SOP were increased up to 110%, and K had a very significant influence on increasing WUE. The statistical analyses showed that both K treatments did not differ significantly. The larger amount of MOP significantly (at the 1% level) increased yields compared with the control plot. The results were in agreement with those from Pakistan Research Institute (Anon., 1995), and those of many other investigators including Krauss (1992 and 1999), Malakouti and Nafici (1997), and Malakouti (1999).

The interaction of K and irrigation water was significant. The results showed that, in Kashmar, by using 150 kg/ha SOP, the water requirement of cotton was reduced by 20%. In Jahrom, K increased the yield of citrus and 3000 m^3/kg of irrigation water was saved; WUE in the control plot was 2.75 kg/m^3, it increased to 3.25 kg/m^3 in SOP treated plots. According to recent investigations, the involvement of K in "osmoregulation" i.e. the adjustment of the plant cell to environmental condition seems to be one of the most important biophysical roles of K. Thus it is possible that K, in addition to its many biochemical functions, improves the tolerance of the plant to various stress situations such as drought. The same research showed increasing K levels minimized water use. Combining the results for the seven consecutive years showed that the maximum yield with MOP was not significantly different to that with SOP. As negligible amounts of chloride ion accumulated in the surface horizons of soil that which received 150 kg KCl/ha, and because MOP is less expensive and more available than K_2SO_4, it can be recommended for the areas with non-saline soils and for crops which are not sensitive to chloride.

For both wheat and maize despite the higher available soil K in Darab, WUE was lower than Karaj mainly due to more irrigation water being used. There are relationships between irrigation, evapotranspiration (ET), crop growth and water use efficiency. Soil evaporation is a significant proportion of total ET especially when leaf area index is low in a semi-arid region such as Darab. The application of MOP to tomatoes increased both yield and WUE. The ability of plants to accumulate K improves tissue hydration and this is an important effect of K, especially for potato and tomato. Potassium chloride was more suitable than potassium sulphate as a K source for tomato in Marand.

In summary, it can be said that:

1. Balanced fertilization is the best tool to increase crop yield as well as quality.
2. By applying excess K to K-depleted soils, crop yield has been increased and hence the water use efficiency.
3. By increasing the amount of K applied, especially SOP, the water requirement of cotton has been decreased by 20%, an important effect in dryland situation of the WANA Region.

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Session 4

Potassium and salinity

Efficiency of potassium fertilization under saline and drought conditions in Egyptian soils

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Abstract

Series of long-term field trials at Nubaria Research Station on newly reclaimed calcareous soils studied the effect of four levels of potassium (K, K120, K240 and K360 kg K_2O ha^{-1}) on crop production under water stress conditions. Surface irrigation with normal and half-normal amounts of irrigation water was used. Soil samples were taken from the experimental site for chemical analyses. The crops grown were maize, wheat and Faba bean. On the sandy soils at Ismailia Research Station, two long-term field trials studied the effect of sulphate of potash (SOP) and muriate of potash (MOP) applied at 70 and 140 kg K_2O ha^{-1}. Sprinkler irrigation was used in one trial and drip irrigation in the other. The crop rotation with sprinkler irrigation was wheat, peanut; wheat, peanut; berseem, sesame; berseem, peanut as winter and summer crops respectively. With the drip system, the rotation was sesame; Faba bean, sesame; onion, peanut; Faba bean, fodder maize as winter and summer crops respectively. Soil samples were collected from every plot of both trials before cultivation and yearly after the summer crops to determine total soluble salts (TSS), chloride and available K.

On the calcareous soils, maize responded significantly to K up to 240 kg K_2O ha^{-1} with normal irrigation and up to 360 kg K_2O ha^{-1} with half-normal irrigation. At both levels of irrigation, Faba bean responded up to 240 kg K_2O ha^{-1} while wheat only responded up to 120 kg K_2O ha^{-1}. The maximum percentage yield increase over the control treatment ranged between 5 to 8% for maize, 15% to 21% for wheat and 4 to 11% for Faba bean under normal irrigation and were larger, 8-22% for maize, 22-29% for wheat and 10-16% for Faba bean, with half-normal irrigation.

On the sandy soils, after 4 years cropping, the amounts of total soluble salts and chloride in the surface layer of the soil had increased slightly with sprinkler irrigation irrespective of whether K was added as SOP or MOP.

On the sandy soils with drip irrigation, addition of MOP at 140 kg K_2O ha^{-1} increased the total soluble salts under the dripper area by 18 times and chloride by 35 times compared to the concentration at the beginning of the experiment.

On the sandy soils with sprinkler irrigation, the winter crops were wheat and berseem, the summer crops were peanut and sesame. Yields were significantly increased by SOP applied at 140 kg K_2O ha^{-1}, the increases were about 14% for wheat, 40-43% for peanut, 17-18% for berseem and 23% for sesame. With 70 kg K_2O ha^{-1} applied as MOP, yield increases were 5-14% for wheat, 11-22% for peanut and 4-12% for berseem.

With drip irrigation, the application of SOP to sesame, Faba bean, onion, peanut and fodder maize gave significant increases in yield at both rates of addition; on the other hand, addition of MOP decreased yields of all crops, especially Faba bean and peanut).

Introduction

The irrigated soils in Egypt, which represent 3.5% of the total area, are cultivated two or three times a year and this intensive cultivation depletes the soil of some plant nutrients. Hamdi *et al.* (1971) found that after five successive crops, the potassium (K) supplying power of unfertilized alluvial soils of the Nile-Valley decreased. Because of the influence of K on crop tolerance to water stress, plants well supplied with K need less water to produce a given yield than plants under supplied K (Mengel and Forster, 1973). Abd El Hadi *et al.* (1990) found that addition of SOP to Egyptian soils increased the production of some important field crops. Soil salinisation is a major concern in Egypt especially since the construction of the High Dam in the early 1970s because previously annual floods from the Nile leached out salts. Also inefficient management of irrigation water under semi-arid or arid conditions, combined with a highly intensified agriculture, leads to a build-up of salts in the upper layers of the soil. For these reasons, SOP (50% K_2O and 18% S) has been the only source of K used in Egypt. On the other hand, although MOP (KCl, 60% K_2O) is a cheaper source of K, it contains 48% (Cl) which contributes to soil salinisation. However, the question is asked to which crops, on which kind of soils, and under which water management system can MOP be used in Egypt.

To answer, a part of this question, two long-term trials were set up on sandy soil to evaluate the comparative effects of SOP and MOP on different annual crops, as well as on soil salinisation and the soil content of chloride and available K. In addition, an experiment on a calcareous soil evaluated the effect of K on drought tolerance with surface irrigation using normal and half-normal amounts of irrigation water.

Experimental work

The soils in the western part of the Nile Delta are mainly calcareous soils. During 1992-1995 the effect of K (0, 120, 240 and 360 kg K_2O ha^{-1}) on the production of some major field crops was studied under surface irrigation with the recommended (normal) and half the recommended (half rate) amount of irrigation water. The crops grown were maize, wheat and Faba bean. The K-treatments were arranged in a randomized block design with 4 replicates.

The soils in the eastern part of the Nile Delta are mainly sandy soils. Two long-term field trials during 1995-1999 studied the effect of 0, 70 and 140 kg K_2O ha^{-1} applied either as SOP or MOP on the production of some major field crops under sprinkler and drip irrigation. With sprinkler irrigation, the crop rotation was wheat-peanut; wheat-peanut; berseem-sesame and berseem-peanut. With drip irrigation, the crop rotation was sesame; Faba bean-sesame; onion-peanut and Faba bean-fodder maize. The K-treatments were arranged in Latin square design with five replicates.

Recommended rates and time of application were used for nitrogen (N) and phosphorus (P) but K was applied in two equal amounts, one at planting, the other a month later in each cropping season. Soil samples were collected from the calcareous soils before starting the experiment. They were analyzed for total soluble salts, pH, calcium carbonate and cation exchange capacity (CEC) (Jackson, 1973), mineral nitrogen was extracted by 1% K_2SO_4 and determined by the Kjeldahl method. Phosphorous was extracted by 0.5% M $NaHCO_3$ and determined photometrically (Olsen, 1954). Potassium and sodium were extracted by normal ammonium acetate and determined flamephotometrically. For the sprinkler and drip irrigation experiments, representative soil surface (0-30 cm) samples were collected from each plot after harvesting the summer crop every year to follow changes in the concentration of TSS in soil water extract (1:5), soluble chloride was also determined by titration with silver nitrate according to Jackson (1973).

Results and discussion

Results of the field trial under surface irrigation on the calcareous soils

In the soil, the concentration of total soluble salts (TSS) was moderate, with a small amount of sodium. The concentration of N and P was small while that of extractable K was moderate but $CaCO_3$ was large, the CEC was 12.5 meq/100 g soil, and the pH was in the slightly alkaline range.

Table 1. Soil analysis of the calcareous soil at Nubaria.

Layer	pH	TSS	N	P	K	Na	CEC	K/CEC	$CaCO_3$
		%	mg/kg				meq/100 g soil	%	%
S*	7.2	0.18	20	8.1	530	225	12.8	10.6	24.3
SS**	7.7	0.16	20	4.6	410	190	12.2	8.4	20.7

* S = Surface layer **SS = Sub-surface layer

Yield of the crops grown with surface irrigation

There were two levels of surface irrigation, normal and half-normal, and four levels of K with 4 replicates for maize, wheat and Faba bean.

Maize: In 1992, 1994 and 1995, K significantly increased maize yield and the effect of irrigation was also significant (Table 2). Compared to the control, with normal irrigation the maximum yield, on average was obtained with 240 kg K_2O ha^{-1}, the yield was increased by 0.73 t ha^{-1} (8.0%). With half rate of irrigation, 360 kg K_2O ha^{-1} increased yield by 1.55 t ha^{-1} (22%). The statistical analysis showed that there were significant effects at the 5% level of K in three of the four seasons, normal irrigation increased yield significantly in all the 4 seasons but only in one season was there a significant K × irrigation effect.

Table 2. Effect of different levels of potassium and irrigation on maize grain yield grown on calcareous soils.

kg K_2O ha^{-1}	Normal irrigation rate						Low irrigation rate					
	1992	1993	1994	1995	Av.	%	1992	1993	1994	1995	Av.	%
0	9.05	10.79	8.04	8.27	9.03	100	6.17	9.36	6.08	6.45	7.02	100
120	9.94	11.15	8.19	8.10	9.35	105	6.85	10.58	6.46	6.45	7.59	108
240	10.53	11.11	8.95	8.45	9.76	108	6.56	9.70	6.70	8.29	7.81	111
360	8.94	11.37	8.79	9.37	9.62	107	8.01	10.75	6.65	8.86	8.57	122

LSD 5%	1992	1993	1994	1995
K-levels	0.55	n.s.	0.55	1.07
Irrigation	0.39	1.03	0.39	0.75
K × irrigation	0.78	n.s.	n.s.	n.s.
C.V. %	8.00	13.42	7.26	13.00

Kock and Estes (1975) concluded that K deficient plants of *Zea mays* L. had greater diffuse resistance than those with higher K rates. Abd El Hadi *et al.* (1987) found that the addition of 48 kg K_2O /feddan increased maize grain yield by 6.4%.

Wheat: There was a significant effect (at 5% level) of K on grain yield (Table 3) in both seasons but there was no significant interaction between K and irrigation. Irrigation showed a significant effect only in 1992/93. Maximum grain yield was obtained with 360 kg K_2O ha^{-1} in both seasons with normal irrigation, the increases were 20% and 23% respectively, compared with the control, with half rate irrigation, maximum grain yield was obtained with 120 kg K_2O ha^{-1} in 1992/93, but with 360 kg K_2O ha^{-1} in 1994/95, yield increases of 17% and 42% respectively.

Table 3. Effect of different levels of potassium and irrigation on wheat and Faba bean grain yield grown on calcareous soils.

kg K_2O ha^{-1}	Wheat 1992/93 Irrigation rate Normal	 Half	Faba bean 1993/94 Irrigation rate Normal	 Half	Wheat 1994/95 Irrigation rate Normal	 Half
	t ha^{-1}					
0	4.61 (100)	3.76 (100)	2.82 (100)	2.07 (100)	4.25 (100)	3.67 (100)
120	5.39 (117)	4.56 (121)	2.94 (104)	2.28 (110)	4.80 (113)	4.49 (122)
240	5.16 (112)	4.38 (116)	3.13 (111)	2.41 (116)	5.17 (121)	5.06 (138)
360	5.51 (120)	4.40 (117)	3.03 (107)	2.27 (110)	5.22 (123)	5.22 (142)
LSD at 5%						
K-level	0.64		0.95		0.65	
Irrigation	0.05		0.10		n.s	
K × irrigation	n.s.		n.s.		n.s.	
C.V. %	16.34		6.57		12.89	

These results agree with those of Forster (1976) who found an effect of K on flag leaf area, as well as on chlorophyll content, during grain filling. Forster and Mengel (1974) found that improved K supply increased grain yield and grain/straw ratio of wheat. On a sandy soil, Forster (1976) showed that the increase in grain yield due to K was mainly in individual grain mass. In the Nile Delta, Abd El Hadi *et al.* (1990) and in the Middle and Upper Egypt soils, Mohamed *et al.* (1992) found that wheat responded to K. Also Bakhsh *et al.* (1986) reported that in Pakistan both SOP and MOP were almost equally effective in increasing wheat yields on calcareous soils.

Faba bean: Grain yield of Faba bean was increased by K up to 240 kg K_2O ha^{-1} under both normal and half rate of irrigation. The increase was 0.31 t ha^{-1} (+11%) for normal irrigation and 0.34 t ha^{-1} (+16%) for half rate irrigation compared to the control (Table 3). Statistical analysis showed that K level and irrigation had significant effects but there was no N×K interaction. Kamh *et al.* (1986) also found that K slightly increased the yield of Faba bean by, on average, 8% in calcareous soil.

Results of field trials under drip and sprinkler irrigation on sandy soils

Three factors were studied, three levels of K, two sources of K and two methods of irrigation.

Soil analysis under drip irrigation: The content of TSS, Cl and available K all tended to increase over time with K treatment although there was some variability between years (Table 4). On average, during the five years, TSS % increased from 0.08% for K0 to 0.16 and 0.20%, respectively, for the low and the high rates as SOP, but were larger, 0.46 and 0.58% respectively, for the corresponding rates as MOP. The Cl content (meq/100g soil) increased little from 0.43 with SOP but with MOP it increased to 4.72 and 5.99 for low and high K rate. There was only a small build-up of available K with both SOP and MOP.

Soil analysis under sprinkler irrigation: Under sprinkler irrigation, there were only small changes in TSS, Cl and available K (Table 5). On average, TSS% was not changed by either SOP or MOP and the Cl content (meq/100 g soil) was only slightly increased from 0.22 with K0 to 0.28 and 0.31 for the low and the high MOP rates, respectively. The chloride and total soluble salts were leached by the irrigation water with sprinkler irrigation. As with drip irrigation, there was only a small build-up of available K with either SOP or MOP.

Crop yields with drip irrigation: The yields of all crops were increased, but not always significantly, by K applied as SOP (Table 6). SOP at 70 kg K_2O ha^{-1} gave significant increases in the yields of sesame in 1996 and 1997, onion bulbs (1997/98) and fodder maize (1999) by about 11%, 22%, 12% and 26%, respectively; increases in Faba bean grain and peanut seed yield were small. At the higher rate of SOP, 140 kg K_2O ha^{-1}, the yields of all crops were increased significantly by about 25% and 36% for sesame, 20% for onion, 25 % for peanut, 15% and 41% for Faba bean, and 27% for fodder maize.

Table 4. Soil content of TSS, available K and chloride after harvesting the summer crop each year at Ismailia Research Station under drip irrigation.

Potassium treatments															
	Control (Zero-K)			Potassium sulphate (SOP)						Potassium chloride (MOP)					
				(70 kg K_2O ha^{-1})			(140 kg K_2O ha^{-1})			(70 kg K_2O ha^{-1})			(140 kg K_2O ha^{-1})		
Year	TSS* (%)	Avail. K, mg/kg	Cl, meq/ 100 g soil	TSS* (%)	Avail. K, mg/kg	Cl, meq/ 100 g soil	TSS* (%)	Avail. K, mg/kg	Cl, meq/ 100 g soil	TSS* (%)	Avail. K, mg/kg	Cl, meq/ 100 g soil	TSS* (%)	Avail. K, ppm	Cl, meq/ 100 g soil
1995**	0.04	43	0.23	0.04	43	0.23	0.04	43	0.23	0.04	43	0.23	0.04	43	0.23
1996	0.09	44	0.28	0.17	55	0.38	0.21	55	0.36	0.33	69	2.61	0.57	68	3.55
1997	0.10	55	0.41	0.23	63	0.39	0.29	61	0.27	0.69	83	6.35	0.85	77	9.10
1998	0.09	53	0.74	0.19	68	0.96	0.26	75	1.04	0.66	70	8.04	0.70	80	9.05
1999	0.06	49	0.48	0.16	55	0.61	0.21	63	0.60	0.59	75	6.33	0.72	83	8.00
Mean	0.08	49	0.43	0.16	57	0.51	0.20	59	0.50	0.46	67	4.72	0.58	70	5.99

* TSS = Total soluble salts

** 0-Time

Table 5. Soil content of TSS, available K and chloride after harvesting the summer crop each year at Ismailia Research Station under sprinkler irrigation.

	Potassium treatments														
	Control (Zero-K)			Potassium sulphate (SOP)						Potassium chloride (MOP)					
				(70 kg K_2O ha^{-1})			(140 kg K_2O ha^{-1})			(70 kg K_2O ha^{-1})			(140 kg K_2O ha^{-1})		
Year	TSS* (%)	Avail. K, mg/kg	Cl, meq/ 100 g soil	TSS* (%)	Avail. K, mg/kg	Cl, meq/ 100 g soil	TSS* (%)	Avail. K, mg/kg	Cl, meq/ 100 g soil	TSS* (%)	Avail. K, mg/kg	Cl, meq/ 100 g soil	TSS* (%)	Avail. K, mg/kg	Cl, meq/ 100 g soil
1995**	0.03	38	0.21	0.03	38	0.21	0.03	38	0.21	0.03	38	0.21	0.03	38	0.21
1996	0.04	46	0.18	0.04	63	0.18	0.04	70	0.17	0.07	59	0.23	0.07	55	0.21
1997	0.04	45	0.21	0.04	60	0.29	0.03	63	0.25	0.04	51	0.31	0.05	57	0.33
1998	0.04	49	0.29	0.05	50	0.34	0.04	55	0.31	0.05	60	0.35	0.05	65	0.44
1999	0.03	41	0.23	0.04	45	0.26	0.05	43	0.32	0.04	49	0.32	0.05	52	0.39
Mean	0.04	44	0.22	0.04	51	0.26	0.04	54	0.25	0.05	51	0.28	0.05	53	0.31

* TSS = Total soluble salts

** 0-Time

Table 6. Effect of different sources and levels of potassium on crop production (t ha^{-1}) during four years crop rotation (1995-1999) at Ismailia Research Station, with drip irrigation.

K level (kg ha^{-1})	K source	1995/96 Winter crop	1996 Summer crop	1996/97 Winter crop		1997 Summer crop	1997/98 Winter crop	1998 Summer crop	1998/99 Winter crop		1999 Summer crop
			Sesame Grain	Faba bean Seed	Faba bean Straw	Sesame Grain	Onion Bulb	Peanut Seed	Faba bean Seed	Faba bean Straw	Maize Fodder
0	K_2SO_4 (SOP)	-	0.222	1.45	5.70	0.212	3.24	1.70	1.11	4.90	2.02
70		-	0.246*	1.55	5.98	0.259*	3.62*	1.82	1.23	5.14	2.55*
140		-	0.278*	1.67*	6.26*	0.289*	3.89*	2.11*	1.57*	5.66*	2.56*
Mean		-	0.262	1.61	6.12	0.274	3.76	1.97	1.40	5.40	2.55
70	KCl (MOP)	-	0.243*	1.41	5.34*	0.230	3.26	1.59	1.18	4.64	2.22
140		-	0.215	1.29	4.96*	0.195	3.01	1.47	1.06	4.45	2.18
Mean		-	0.229	1.35	5.15	0.213	3.14	1.53	1.12	4.54	2.20
LSD	5%	-	0.020	0.18	0.35	0.030	0.32	0.27	0.14	0.33	0.21
C.V.	%	-	5.69	8.63	4.44	7.99	6.80	11.73	8.21	4.89	6.74

* Significant compared to K0

Table 7. Effect of different sources and levels of potassium on crop production (t ha^{-1}) during four years crop rotation (1995-1999) at Ismailia Research Station, with sprinkler irrigation.

K-level (kg ha^{-1})	K-source	1995/96 Winter crop		1996 Summer crop	1996/97 Winter crop		1997 Summer crop	1997/98 Winter crop	1998 Summer crop	1998/99 Winter crop	1999 Summer crop
		Wheat		Peanut	Wheat		Peanut	Berseem	Sesame	Berseem	Peanut
		Grain	Straw	Seed	Grain	Straw	Seed	DY	Grain	DY	Seed
0	K_2SO_4 (SOP)	1.54	4.12	4.26	1.65	4.28	3.64	6.87	0.271	5.80	3.37
70		1.64	4.10	4.93	1.92	4.57	4.29*	7.55	0.289	5.68	3.90
140		1.76*	4.12	6.11*	1.88	4.83	5.09*	8.12*	0.334*	6.79*	4.77
Mean		1.70	4.1	5.52	1.90	4.70	4.69	7.83	0.312	6.24	4.34
70	KCl (MOP)	1.62	4.17	4.84	1.88	4.26	4.44*	7.67*	0.277	6.31*	3.75
140		1.45	4.19	4.78	1.71	3.93	4.30*	7.93*	0.314*	6.31*	3.99
Mean		1.54	4.18	4.81	1.80	4.10	4.37	7.80	0.296	6.31	3.87

LSD	5%	0.12	N.S.	0.84	N.S.	0.46	0.36	0.71	0.04	0.47	0.656
C.V.	%	5.35	10.08	12.17	8.38	7.63	5.93	6.72	9.19	5.51	12.00

* Significant compared to K0

These positive responses could be due to the initially low soil K content (43 mg/kg). On the other hand, K applied as MOP often had only small effects and often decreased yields particularly at the higher rate when applied to the legume crops (Faba bean and peanut) and Faba bean straw was more adversely affected than the grain yield (Table 6). The increase in TSS% and soluble chloride were the reasons of the harmful effects on crop growth with MOP under drip irrigation. Accumulation of chloride in the vacuoles of root cells, lowers their osmotic water potential and enables the plant to absorb water under salt stress (Krauss, 1992). Excessive Cl in the rooting media appears to reduce growth by restricting nitrate uptake and thus inducing N deficiency because the leaf NO_3 content correlates positively with grain yield (Torres and Bingham, 1973). Also, under saline conditions, P uptake is more adversely affected by chloride than by sulphate (El-Nennah and Abdou, 1977). Krauss (1993) noted that it should not be forgetten that the influence of the accompanying anion modifies the efficiency of K in its role in nutrient efficiency.

Crop yield under sprinkler irrigation: In the experiment with sprinkler irrigation, the winter crops were wheat and berseem, and the summer crops were peanut and sesame. The yields of all crops were increased by K applied as SOP and at the higher rate, 140 kg K_2O ha^{-1}, the increase was frequently statistically significant (Table 7). On this low K soil (38 mg/kg), the increases were about 14% for wheat, 40-43% for peanut and 17-18% for berseem. On the other hand, MOP application had very few negative effects with sprinkler irrigation because of the lack of salt accumulation (Table 5) due to the larger amount of water applied with sprinkler rather than drip irrigation. Berseem and peanut yields were significantly increased by both MOP rates, but the increases were less than those with the higher SOP rate.

Conclusion: In Egypt, alluvial soils were considered in the past to be rich in K but currently, they show a rapid decline in their content of exchangeable K. In consequence, significant yield increases due to applying K are observed in all major crops (Abd El Hadi *et al.*, 1990; Abd El Hadi, 1993). The continuous removal of K in crops is likely to cause considerable damage to soil fertility under the intensive cropping systems used in Egyptian agriculture. The importance of K fertilization in Egyptian agriculture has seen a rise in SOP use from 3000 t in 1970 to 65000 t in 1995. In part, this is because the completion of the High Dam has resulted in the deposition of the suspended Nile silt in the lake upstream of the dam rather than being deposited on the flood plain of the Nile.

The results of these experiments show that:

1. In calcareous soil, there is a positive and significant effect of K, even on soils rich in K. The explanation might be related to the large calcium content and the competition between Ca and K for absorption at the root surface. The acidifying effect of SOP in the rhizosphere possibly contributes to enhance the ion uptake. Yields were always larger with normal rather than half-normal irrigation suggesting

that K did not contribute to limit the effect of water stress, induced by the much smaller amount of water applied.

2. In sandy soils with drip and sprinkler irrigation, salinity build-up due to MOP addition was less with sprinkler irrigation than with drip irrigation because more water was applied with sprinklers.

3. There were considerable advantages from using SOP with drip irrigation because smaller amounts of salts accumulated in soil.

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Role of potassium on crop yield under saline conditions in three regions of Iran

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Abstract

A factorial experiment tested three levels of water (EC 6.0, 7.5 and 12.0 dS/m), six levels of nitrogen (N) (0, 90, 135, 180, 225 and 270 kg N/ha as urea), five levels of phosphorus (P) (0, 45, 90, 135, and 180 kg P_2O_5/ha as TSP), and four levels of potassium (K) namely (0, 60, 120, and 180 kg K_2O/ha as potassium sulphate, SOP) on the yield and nutrient content of the stamens in three regions of Iran (Qom, Varamin, Neishaboor).

Higher salinity conditions caused yellowing of the leaves and browning of the leaf tips and margins symptomatic of K deficiency. However, the leaves contained above normal levels of K but may require more K due to the accumulation of chloride in the leaves.

Maximum grain yields with saline water with EC, 6.0 or 7.5 dS/m, were obtained with 180 kg N/ha, with water with EC, 12 dS/m, 225 kg N/ha were needed. The highest yield with water of any quality was obtained with 120 kg K_2O/ha. With low salinity water (EC, 6 dS/m), the interactive effects of N and K on the grain yield were positive and significant. With increasing water salinity, the concentration of N and K in the wheat stamen increased with increasing grain yield and K levels, however, under increasing salinity conditions and urea levels, the Cl concentrations in the stamens decreased.

If water salinity goes beyond a certain limit (EC, 6 dS/m), then fertilization will be less effective in increasing wheat grain yield because the adverse effects of salinity are larger than the benefits of added nutrients.

Nitrogen and K requirements of wheat increased with increasing irrigation water salinity and it is suggested that for each 4 dS/m increase in salinity, an increase of 20 kg N/ha and 15 kg K/ha are recommended for winter wheat.

Introduction

Soil and water, two important and necessary resources for agricultural production, produce the best results when used under optimum conditions. Water shortage and salinity are two of the limitations on water resources which combined with the limitations caused by soil salinity (44.5 Mha in Iran (Moameni *et al.*, 2001) and 7% of world land (Munns, 2001)) indicate the need for care in the management of these resources.

The effect of salinity on wheat appears as non-homogeneous sprouting of the seeds, and dark blue-green leaves in addition to burning of the leaf margins, chlorosis and dropping of leaves (Saadat, 2001). Fertilizers may relieve these conditions, adversely affect them or have no effect whatever, depending on the extent of the salinity problem (Bernstein *et al.*, 1974; Feigin, 1985); Hu and Schmidhalter, 1997; 2001; Kafkafi *et al.*, 1982). Fertilizers have a positive effect if applied at early growth stages (Hu and Schmidhalter, 1997). If K/Na ratio in plant tissues is lowered it may cause a disturbance in N metabolism which could then be remedied by K application (Malakouti and Nafisi, 1994). Gunes (1996) reported that the hazard from salinity for wheat was caused by increases in the concentration of sodium (Na), chloride (Cl) and the Na/K ratio and a decrease in K concentration. Potassium uptake by wheat increased with the application of potassium sulphate (SOP) and decreased with an increase in the degree of irrigation water salinity (Doroudi and Siadat, 1999). Potassium applied at 120 kg K_2O/ha where irrigation water had an EC of 6 dS/m increased wheat yield (Saadat, 2001). Leaf growth due to salinity was decreased, and the concentration of elements in these conditions may have been decreased, increased or remained the same because it depends on the element and its place in leaf (Hu and Schmidhalter, 2001). In general, it seems that salinity hazard cannot be completely corrected and that it had a larger effect than nutrient deficiency in wheat (Doroudi and Siadat, 1999). This paper describes research on the role of K on wheat yields under saline conditions.

Materials and methods

A factorial experiment with a completely randomized split block design using 3 qualities of water (6.0, 7.5 and 12.0 dS/m), six levels of N (0, 90, 135, 180, 225 and 270 kg N/ha as urea), five levels of P (0, 45, 90, 135 and 180 kg P_2O_5/ha as TSP) and four levels of K (0, 60, 120 and 180 kg K_2O/ha as K_2SO_4) with three replications per treatment, was carried out in the Qom, Varamin and Neishaboor regions of Iran for two consecutive years. All of the P and K and 1/3 of urea were applied before planting. The remaining N was applied during tillering and at ear formation. Seven, 1 cm flood irrigations were applied and the irrigation water was sampled. A composite soil sample from 0-30 cm depth was collected before the experiment. Stamens were collected during ear formation. After harvest, grain and straw yields as well as the levels of N, K and chloride (Cl) in the stamens were determined.

Results and discussion

Table 1 shows that the water had high levels of Na and Cl and that K increased with the increase in salinity.

Table 1. The chemical analysis of the irrigation water used in each experiment.

Parameter	EC=6			EC=7.5			EC=12		
	Qom	Varamin	Neishaboor	Qom	Varamin	Neishaboor	Qom	Varamin	Neishaboor
EC	6.0	6.1	6.15	7.5	7.4	7.4	12.0	11.8	12.2
pH	8.1	7.4	8	8	7.3	7.5	7.5	7.5	7.5
Cl^-	29	16.4	40.5	63	37.6	57	95.6	46	90
HCO_3^-	1	4.8	2.4	1.7	5.5	3	1.7	7	2.7
SO_4^{2-}	11.7	15	17	14.2	36.7	19	30.1	51.9	41.5
Ca^{++}	11.4	10.8	8.2	17.3	19.2	10.8	23.5	18	23.5
Mg^{++}	5.4	14	10.3	10.5	24.2	12.8	17.7	30.2	25.7
Na^+	44	12.5	42	49	37.5	48	83	62	85
K^+	0.12	0.17	0.24	0.65	0.45	0.48	1.25	0.84	0.73

Table 2 shows the effect of salinity on grain yield. In each region, grain yield was decreased with increasing salinity.

Table 2. The effect of potassium and salinity of the irrigation water on grain yield at various locations.

Region	K treatment	EC=6 dS/m	EC=7.5 dS/m	EC=12 dS/m
		Grain yield (kg/ha)	Grain yield (kg/ha)	Grain yield (kg/ha)
Qom	K_0	3958	3558	3275
	K_{60}	4508	4125	3591
	K_{120}	5550	4300	3850
	K_{180}	5162	3825	3750
Varamin	K_0	2410	2621	2120
	K_{60}	3376	3130	2660
	K_{120}	3742	3491	3172
	K_{180}	3617	3320	3084
Neishaboor	K_0	2784	2550	2266
	K_{60}	2855	3344	2760
	K_{120}	2870	3467	2633
	K_{180}	2810	3420	2301

Potassium up to 120 kg K_2O/ha increased the yield at each level of salinity at Qom and Varamin, but the increases were only consistent up to 60 kg K_2O/ha at Neishaboor, with more K, the grain yield decreased (Table 2).

The effect of K was only statistically significant with irrigation water with EC = 6 dS/m at Qom and Varamin but not Neishaboor, where the soil contained 480 mg/kg available K. By using irrigation water with higher salinity (7.5 and 12 dS/m), grain yield increased with increasing K applications, but the increases were not significant because of the K in the irrigation water. The irrigation water with EC = 7.5 dS/m at Qom, Varamin and Neishaboor contained 0.65, 0.45 and 0.48 meq K/L, respectively. Thus the 6800 m^3/ha water used for irrigation applied 172, 119 and 127 kg K/ha, respectively. When the EC was 12 dS/m, the amount of K added was 332, 223 and 194 kg at the three sites, respectively, based on the amount of irrigation water applied. This would, to a large extent, have met the K requirement of the wheat crops.

With increasing salinity of the irrigation water, the N concentration in the stamen decreased, but it increased with K rates up to 120 kg K_2O/ha (Table 3).

Table 3. The effect of K treatment on the stamen nitrogen, potassium and chloride content.

	EC= 6 dS/m				EC=7.5 dS/m				EC=12 dS/m			
	K_0	K_{60}	K_{120}	K_{180}	K_0	K_{60}	K_{120}	K_{180}	K_0	K_{60}	K_{120}	K_{180}
N (%)	2.3	2.8	2.9	2.7	2.1	2.2	2.4	2.2	1.8	1.9	2	2
K (%)	3.2	3.4	3.8	4	2.9	3.2	3.5	3.8	2.8	3	3.2	3.7
Cl (%)	1.1	1.4	1.4	1.2	1.4	1.5	1.6	1.5	1.7	1.8	1.7	1.8

It seems that this is due to increasing N uptake and by regulating the Na/K ratio by using K fertilizer. Table 3 shows that % K in the stamen increased with K application but decreased with poor water quality due to the effects of salinity on root growth and decreased K uptake.

Table 3 shows that, up to 60 kg K_2O/ha, the Cl level in the stamen increased but beyond that it decreased probably because K increased N uptake as NO^-_3 and this decreased Cl uptake. The Cl level in the stamen did, however, increase with increasing salinity.

The results showed that despite high K levels in the leaves, yellowing and leaf tip burning, both signs of K deficiency appeared in some treatments, because some K accumulated in the vacuoles to counter the accumulation of Cl. Thus extra amounts of K fertilizer may need to be applied in conditions of high salinity. By application of SOP in this condition, K concentration in leaf and grain yield will be increased.

Increased urea rates decreased leaf Cl and increased N and K concentrations, reducing the effects of salinity (results not shown). By using urea, root growth and N and K uptake rates were increased, increasing the K concentration in the leaves. Nitrogen application (180 kg/ha for EC of 6 and 7.5 dS/m; and 225 kg/ha for EC of 12) increased the wheat grain yield.

Concluding remarks

- With increasing water salinity, wheat grain yield and K and N levels in the stamen all decreased but Cl increased.
- K at 120 kg K_2O/ha increased the yield at each level of water quality.
- Nitrogen at 180 kg N/ha for EC of 6 and 7.5 dS/m and at 225 kg/ha for EC of 12 dS/m increased the grain yields.
- Increasing the amount of urea increased the K and decreased the Cl concentration in the leaves.
- Extra K could counter the adverse effects of saline conditions, by making more K available as a counter ion to Cl.
- Under saline conditions, above 6 dS/m, fertilization will be less effective in increasing yield due to the adverse effects of salinity.

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A review on potassium and stress relations in plants

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Introduction

As an essential element, potassium (K) has an effective role in the physiological and biochemical mechanisms of all living organisms including plants. Some of the functions of K in plants include:

- Water relations and osmotic potential. By creating an osmotic potential, cells take up water. For example, to open stomata K is accumulated in the guard cell, to close stomata K is moved out of the guard cells (Mengel and Kirkby, 1982). Reversible turgor changes in specialized tissues result in responses to light and mechanical stimulus as photonastic and seismonastic movement, for example in insectivorous plants and mimosa (Marschner, 1998).
- Activates a large number of enzymes.
- Required for protein synthesis.
- Affects photosynthesis.
- Compensates charges in the cytoplasm, chloroplasts, vacuoles, xylem and phloem by cation-anion balance.

Under optimum physiological and biochemical conditions, yields and quality are better. However, plants do not live under ideal conditions and usually several growth factors are far from optimum. Plants can survive under stress by modifying biochemical and physiological processes. Stress factors can be biotic or physiochemical. Biotic factors include infection by microorganisms and pests as well as competition by other organisms. Physiochemical factors result from deviations in climatic and environmental conditions.

This paper reviews some crop responses to stress in the presence and absence of K fertilization. Special emphasis is given to K in relation to disease, cold, salt and drought stress effects on yield, quality parameters and morphological and physiological aspects.

Potassium and disease resistance

Potassium is important in enhancing the disease resistance of crops. Koseoglu *et al.* (1996) presented results from a pear (*Pyrus comminis* L) orchard, cv. Santa Maria, with no chemical disease control in the Antalya- Korkuteli region of Turkey. Leaf and shoot samples, from trees with different levels of fire blight, *Erwinia amylovora*, were analyzed for nutrient elements. The incidence of disease (number of strikes) decreased with increasing leaf K concentrations (r^2=78.4) (Fig. 1), especially up to 1.70 g K per 100 g leaf. With increasing leaf K concentrations from 1.27 to 1.70 g K 100 g^{-1}, the incidence of disease decreased by 75%.

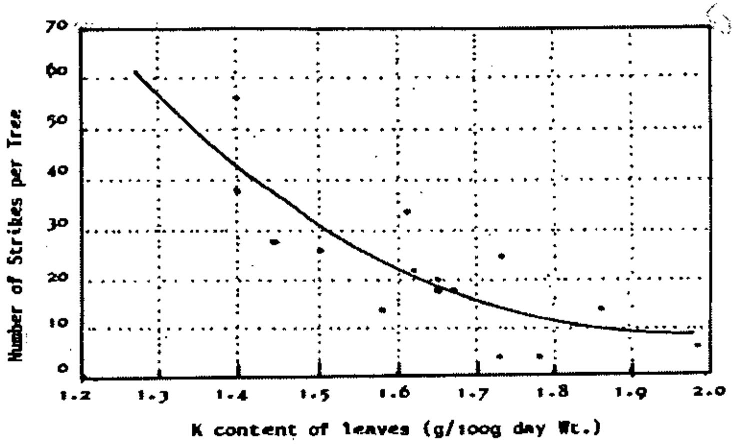

Fig. 1. Relationship between number of strikes and K content of leaves (after Koseoglu, 1996).

The incidence of fire blight also decreased (r^2=45.9) as the K content of shoots increased (Fig. 2). Thus increasing leaf and shoot K concentrations increased the fire blight resistance of the pear trees.

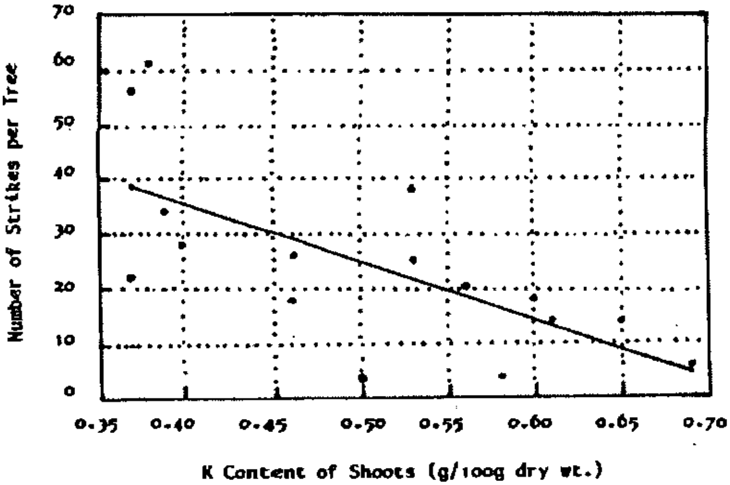

Fig. 2. Relationship between number of strikes and K content of shoots (after Koseoglu, 1996).

Potassium and chilling relations

In another related study, the effect of K fertilizer on the chilling tolerance of some vegetable seedlings was measured (Hakerlerler *et al.*, 1997). Tomato, pepper and eggplant seedlings were kept for two weeks indoors and grown in hotbeds with 500 mg kg^{-1} K_2O in four different forms with a control treatment. The seedlings were then transferred outdoors for five weeks under a plastic cover where the average minimum and maximum temperatures in March and April 1997 ranged from 4.0° to 16.1°C, lower than the long-term average. With tomatoes, K, except KNO_3, statistically (1%) increased the total plant root weights but on pepper and eggplants neither the amount nor form of K had any effect on root weight except KH_2PO_4 which increased it. All three of the test plants showed a statistically significant (1%) increase in plant weight, and further maximum chilling resistance, only with the application of KH_2PO_4 (Table 1). The authors speculate that with KH_2PO_4 the increased K uptake accompanied by $H_2PO_4^-$ increased membrane permeability by inducing and increasing phospholipids.

Table 1. Influence of potassium levels and forms on chilling tolerance as measured by total plant and root weight (after Hakerlerler *et al.*, 1997).

	Plants	K_0	K_1			
			KCl	KNO_3	KH_2PO_4	K_2SO_4
Total plant weight (mg)	Tomato	820	1360	670	4740	1050
	Pepper	269	276	250	1297	267
	Eggplant	820	770	610	3900	450
Root weight (mg)	Tomato	140	230	120	650	180
	Pepper	79	66	70	317	77
	Eggplant	120	110	90	570	90

The analytical data showed that the N content of the three plants was not affected by the application of K nor was the P concentration except with KH_2PO_4. Even the K concentrations were not increased consistently and there was no effect on Na, Ca or Mg. There were some variable effects on Fe and Cl (Hakerlerler *et al.*, 1997).

Potassium and salinity relations

Soil salinity is a severe problem for food production in many regions of the world. The ability of the plants to replace K by sodium (Na) is important to avoid the accumulation of excess Na. Hepaksoy *et al.* (1999) studied alternative production systems for satsuma mandarines in the Ege region of Turkey, an area threatened by seawater intrusion and with typical Mediterranean climatic conditions, dry and hot summers and mild rainy winters. The effect of K supply, rootstock and leaf age on leaf Na content was measured under saline conditions. In the experiment two rootstocks, five levels of saline water and three levels of K were tested. The results showed that the rootstock affected the Na content of leaves and that additional K fertilizer significantly lowered the leaf Na concentrations in the old leaves of *Troyer citrange* rootstock, particularly in the plots with a high salt concentration (Fig. 3). Eleizalde and Larsen (1983) obtained similar results for the effect of K on salt tolerance of tomato and pepper plants grown in pots under greenhouse conditions. Three K rates were tested and K improved the growth of both plants irrigated with saline water either from the sea or from wells. In general, the best result was with the highest, 400 ppm K rate.

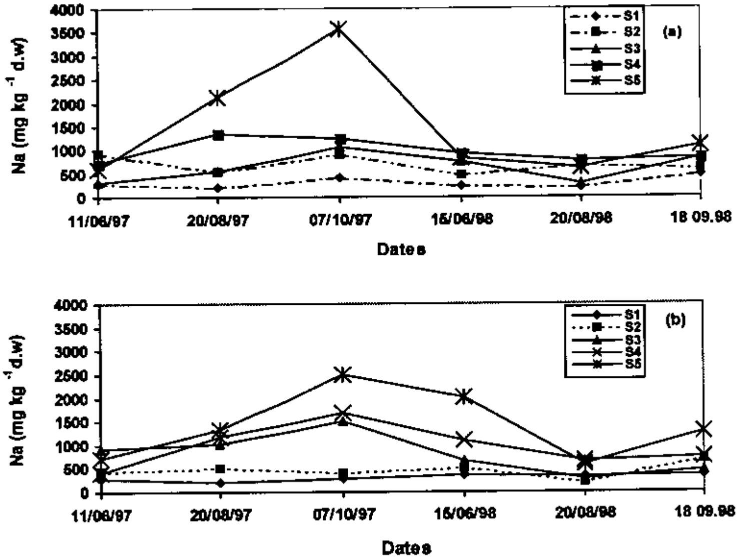

Fig. 3. Sodium content of the old leaves on *Troyer citrange* at K_0 (a) and K_2 (b) levels of K under different salinity conditions (S_1, S_2, S_3, S_4, S_5: 0.65, 2.00, 3.50, 5.00, 6.50 dS m^{-1} respectively) (after Hepaksoy *et al.*, 1999).

Potassium and drought relations

Plants with different K contents show effects on stomatal opening. During the day, stomata of well nourished plants open early in the morning and close only with drought stress, so gaseous exchange takes place readily. Trolldenier (1971) reported that in K deficient plants stomata remain open during midday heat and they therefore wilt more rapidly. Saxena (1985), reporting other work, noted that progressive water stress, due to hot and dry winds, caused barley leaves with adequate K contents to close their stomata within a few minutes with a drastic reduction in the transpiration rate. In severely K deficient plants, transpiration rate increased initially and did not decline below the normal level for more than 40 minutes (Fig. 4).

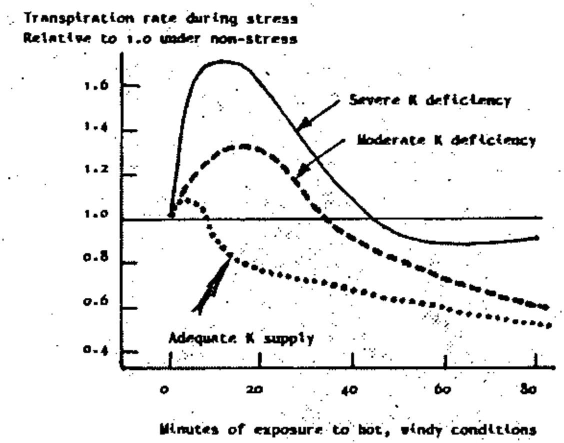

Fig. 4. Potassium deficiency in barley results in a high and prolonged transpiration loss under hot, windy conditions (Saxena, 1985).

Bo Larsen (1981) reported that drought tolerance and resistance in needle plants were positively affected by the K content which dramatically reduced the transpiration rate. However, increasing N caused a slight increase in transpiration rate (Fig. 5).

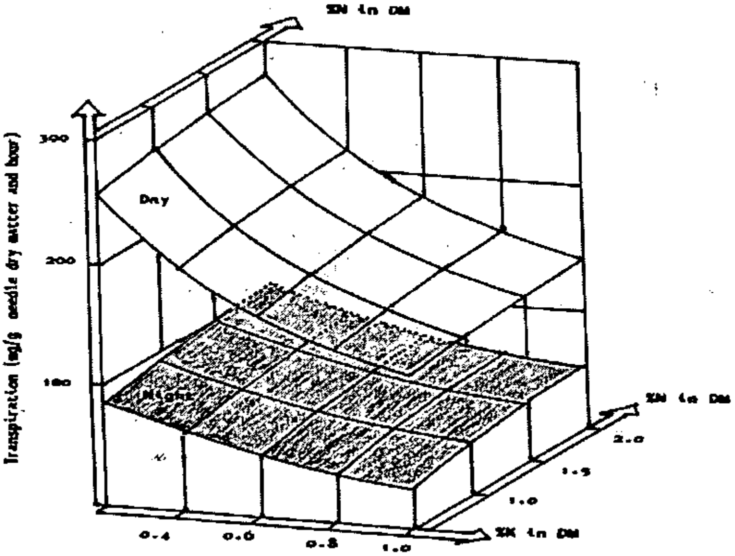

Fig. 5. The rate of transpiration of needle plants in relation to the N and K level under drought condition (after Bo Larsen, 1981).

The transpiration loss per unit needle dry matter and per hour was less during the night than during the day (Fig. 5). Bo Larsen also studied the effect of drought on plant mortality of needle species, recording the number of days to reach 50% normality. Results again confirm the impact of K on the resistance of drought (Fig. 6). The plants with a lower K content (0.3%) died just over three days while plants with 1% K and 2% N lived up to the seventh day.

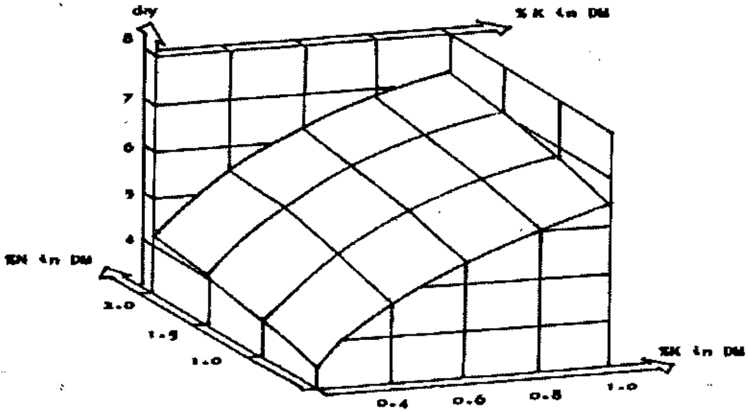

Fig. 6. The effect of N and K contents of needle plants to drought resistance (after Bo Larsen, 1981).

Jensen and Tophoj (1985) studied on the interaction of K status and water stress on barley yield and water relations in a pot experiment. With four K rates, four water stress levels were compared with the full irrigation (W_0), W_1, W_2, W_3, W_4 denoting increased soil water stress treatments. The results showed that with the higher K applications, tissue water content rose significantly. Potassium improved the plant water status during periods of soil water stress and the final yield was strongly positively correlated with the leaf water content at the end of the stress periods. The larger yield with most K and water was associated with prolongation of the grain filling period (Table 2) and an increase in grain mass.

Table 2. The duration (days) of the grain filling period for barley subject to four potassium levels (K1-K4) and five water treatments (W0-W4) (after Jensen and Tophoj, 1985).

	K_1	K_2	K_3	K_4
W_0	29	35	36	35
W_1	27	33	34	33
W_2	25	31	32	31
W_3	23	27	27	27
W_4	22	25	25	25

Kemmler and Krauss (1987) also reporting the work of others, noted the effect of K fertilization on yield with both deficient and excess rainfall (Table 3). Compared the optimum rainfall conditions, maize yields were increased by both insufficient and excess rainfall in the absence of K.

Table 3. The effect of potassium application to maize as influenced by rainfall during the growing period (after Kemmler and Krauss, 1987).

Rainfall (mm)	Yield, t ha^{-1}		% increase in yield
	NP	NPK	
202 (insufficient)	5.65	8.10	43.36
448 (optimum)	9.30	9.80	5.37
655 (excess)	5.71	8.73	52.88

Conclusion

Under optimum growing conditions, potassium has an important place in balanced fertilization and nutrition because of its effects on the biochemical and biophysical functions in plants. Adequate K is important in stress conditions by protecting plants in threatening conditions.

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Session 5

Crop response to potassium

New recommendations for the fertilization of wheat, sugar beet and sunflower in the Doukkala and Gharb irrigated regions of Morocco

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Abstract

In arid and semi-arid Mediterranean regions like Morocco, irrigation is essential to ensure good yields. However, water use efficiency needs to be improved by adopting well-tried agricultural techniques such as fertilization. Balanced fertilization of the major crops should be based on soil testing. The interpretation of soil tests needs regional crop and soil specific critical levels obtained from field experiments. In addition, data on the capacity of soil to supply nutrients and crop nutrient requirements are needed to estimate the amount of fertilizers to be used by farmers.

Within a large program dealing with improving the performance of the large-scale irrigation scheme PAGI, a sub-program was set-up to support the agricultural development in the irrigated areas of Morocco (PSDA). Soil fertility management for the major crops under irrigation was one of the adaptative research components of the PSDA. Seventy field experiments tested the response of sugar beet, wheat, and sunflower to nitrogen (N), phosphorus (P) and potassium (K) additions in the Doukkala and Gharb regions between 1995 and 2001. Relative yield and crop response coefficients were used to assess the response of the crops to fertilizers and crop response curves were used to estimate the optimal rate of each fertilizer. The content of N, P and K at crop maturity was considered to be the minimum soil supplying capacity of these three nutrients. Nitrogen, P and K use efficiencies were calculated for each treatment. The apparent fertilizer use coefficient by the crops was also calculated.

It was clearly demonstrated that the soil fertility status does not depend on soil type but was related to the agricultural history of the plots. However, critical levels depend on soil type and crop yield. For example, in Doukkala wheat responded to K only when the yield was larger than 5 t/ha and only on Hamri, Rmel and Faid soil types. It was also confirmed that the response to nitrogen was not related to soil mineral N or soil organic matter content before planting.

For farmers who can afford to have their soil analyzed before planting, the amount of fertilizer to be added to each of the crops can be estimated using the results from this study. For those who are not able to analyze their soils, adapted regional

quantities of fertilizer are proposed for each crop considering the likely overall fertility of the soils for the majority of farmers.

Some of the proposed fertilizer additions are used by farmers in the Doukkala and Gharb regions. This research program is being extended to cover more soil types, crops and irrigated regions of Morocco.

Introduction

Soil fertility management for intensive cropping systems under irrigation is a major component of sustainable agricultural development in Mediterranean countries. Although, in arid and semi-arid Mediterranean regions like Morocco, irrigation ensures good yields, water use efficiency needs to be improved by adopting well-tried agricultural techniques such as fertilization. Balanced fertilization of the major crops should be based on soil testing. The interpretation of soil tests needs regional crop and soil specific critical levels obtained from field experiments. In addition, data on the capacity of soil to supply nutrients and crop nutrient requirements are needed to estimate the amount of fertilizers to be used by farmers.

Within a large program dealing with improving the performance of the large-scale irrigation scheme PAGI, a sub-program was set-up to support the agricultural development in the irrigated areas of Morocco (PSDA). Soil fertility management for the major crops under irrigation was one of the adaptative research components of the PSDA. Diversity of crops, soil types and climatic conditions make fertilizers recommendations very difficult. Non-adapted general fertilizer formulas have been used for a long time with no monitoring of soil fertility changes. With the development of laboratory facilities to perform soil tests for farmers, it is becoming necessary to have critical levels to interpret the results at a local level for the major crops grown and soil types in the region. This paper presents a synthesis of the major results obtained from field trials in the Doukkala and Gharb agricultural regions of northwestern Morocco.

The specific objectives of the trials were: i) to determine critical levels for the interpretation of soil tests specific to each region, soils type and crop; ii) to evaluate the capacity of the soil to supply N, P and K; iii) to evaluate the crop requirements of N, P_2O_5 and K_2O for the potential yields in each region; iv) to calculate the amount of fertilizer, based on soil tests, for farmers who can afford to have soils analyzed before planting; and v) to suggest new regional fertilizer formulas to be used by those farmers who cannot afford to have their soil analyzed before planting.

Materials and methods

Doukkala and Gharb regions are two of the nine large-scale irrigation systems in Morocco. The potential irrigable land is estimated to be 380,000 ha, of which 190,000 ha (50%) are effectively irrigated. Sugar beet, wheat and sunflower are the major crops cultivated in these regions. Chromoxerets (Tirs), calcixerolls (Tirs and Hamri), xerochrepts (Faid), and xeralfs (Hamri and Rmel) are the major soil types occurring in the Doukkala semi-arid region. In the Gharb region, which is located in a sub-humid Mediterranean-type climate, the major soil types are pelloxererts (Tirs), haploxerolls (clayey Dehs), xerochrepts (loamy Dehs), and calcixerolls (Hamri).

Seventy field experiments tested the response of sugar beet, wheat and sunflower to N, P and K additions in the Doukkala and Gharb regions between 1995 and 2001. The experiments had a completely randomized block design testing N×P, N×K and P×K with 4 replicates of each treatment. Relative yield and crop response coefficients were used to assess the response of the crops to nutrients added and crop response curves were used to estimate the optimal rate of each fertilizer. The uptake of N, P and K at crop maturity was considered to be the minimum soil supplying capacity of these three nutrients. The nitrogen, P and K use efficiencies and the apparent fertilizer use coefficient by the crops were calculated.

Results and discussion

Response to fertilizers

Because of the high spatial and temporal variability of mineral N in the soils before planting, no correlation was found between the response of wheat, sugar beet and sunflower to N fertilizer. Response to N occurred even on soils with a high soil mineral N status. So, no critical levels were determined to interpret soil N fertility (Tables 1 to 4) in these irrigated areas.

Table 1. Critical levels, nutrient use efficiency, and apparent fertilizer use for wheat under irrigation in Doukkala region.

Nutrient	Critical level	Nutrient use efficiency (kg/100 kg grains)	Apparent fertilizer use coefficient	Observations
Nitrogen	No critical level	3.50	0.65	Soil nitrogen supplying capacity can be estimated using the max. yield without N addition and soil organic matter content
Phosphorus	<17.5 mg P_2O_5/kg soil	0.60	-	-
Potassium	<260 mg K_2O/kg soil for Hamri, Rmel and Faid soil series. No response on Tirs soil series	1.54	-	No addition of K_2O if the yield <5 t/ha

Wheat responded to the addition of P in the Gharb and Doukkala regions with a small difference in the critical level for the two regions. Wheat responded to P in the Doukkala region when grown on soils with less than 17.5 mg P_2O_5 /kg of soil using the Olsen method of analysis (Table 1). In the Gharb region, the response limit was 16.0 mg P_2O_5/kg of soil (Table 2). Presently, it is very exceptional to find soils having less than these values in the two regions because of the overuse of P fertilizer by farmers for more than 20 years.

Table 2. Critical levels, nutrient use efficiency, and apparent fertilizer use for wheat under irrigation in Gharb region.

Nutrient	Critical level	Nutrient use efficiency (kg/100 kg grains)	Apparent fertilizer use coefficient	Observations
Nitrogen	No critical level	3.95	0.60	Soil nitrogen supplying capacity can be estimated using the max. yield without N addition. No correlation between N soil test and crop response to N fertilizer
Phosphorus	<16 mg P_2O_5/kg soil	0.74	0.165	Critical level for Dehs soil series only. Needs to be determined for Tirs soil series
Potassium	No response to K_2O	3.00	-	Soils have a very high K supplying capacity. No K fertilizer required

Sugar beet and sunflower responded also to P fertilizer when the Olsen soil P was less than 12.2 and 21.6 mg P_2O_5/kg of soil, respectively (Tables 3 and 4).

This is the first time in Morocco that wheat responded to K fertilizer. The response occurred in the Doukkala region when the yield was larger than 5 t/ha and only on non-clayey soils (Hamri, Rmel, and Faid types). The critical level, below which the response to K occurred was 260 mg K_2O/kg of soil (Table 1). In the Gharb region having younger soils, rich in K bearing minerals like illite and intestratified illite/smectite, wheat did not respond to K.

Sunflower crops, which need more K than wheat, responded to K fertilization in the Gharb region and the critical level was 149 mg K_2O/kg. However, very few soils have less than this concentration in this region. Sugar beet, which has a high demand for K, responded to K addition in the Doukkala region on all soil types, including the Tirs soils which are clayey. An exchangeable potassium interpretation scheme was established for sugar beet taking into consideration the clay content (Fig. 1).

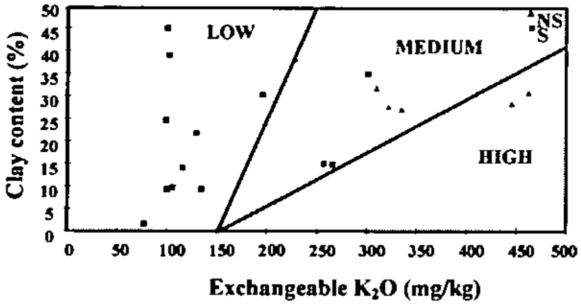

Fig. 1. Soil exchangeable potassium interpretation scheme for sugar beet in the irrigated region of Doukkala, Morocco.

Crop nutrient requirements

The amounts of N, P_2O_5, and K_2O required to produce 1 quintal (100 kg) or 1 t of the harvested crop are presented in Tables 1 to 4. These quantities, referred to as nutrient use efficiency, are needed to calculate the amount of fertilizer to add to get a given yield.

Table 3. Critical levels, nutrient use efficiency, and apparent fertilizer use for sugar beet under irrigation in Doukkala region.

Nutrient	Critical level	Nutrient use efficiency (kg/1000 kg)	Apparent fertilizer use coefficient	Observations
Nitrogen	No critical level	3.14	0.56	Soil nitrogen supplying capacity can be estimated using the max. yield without N addition. No correlation between N soil test and crop response to N fertilizer
Phosphorus	<12.2 mg P_2O_5/ kg soil	1.40	-	Very few plots have less than 12 mg P_2O_5/kg
Potassium	See soil test K interpretation scheme in relation to clay content	6.00	-	Low: soil K crop requirement × 1.2. Medium: add crop requirement High: no K_2O addition

Wheat needs to take up 3.5 kg N to produce 1 quintal of grain in the Doukkala region and 3.95 kg N/quintal in the Gharb region. For sugar beet, the mean N use efficiency in the Doukkala region is 3.14 kg/t of fresh beets (roots). To produce one quintal of sunflower seed in the Gharb region, the crop requires 3.47 kg N.
Wheat needs 0.6 kg P_2O_5/quintal in the Doukkala region and 0.74 kg P_2O_5/quintal in the Gharb region. Sugar beet required 1.4 kg P_2O_5/t of beets. Sunflower needs only 0.67 kg P_2O_5/quintal seeds.
Sugar beet and sunflower require large quantities of K; 6 kg K_2O/t of beets and 7.23 kg K_2O/quintal of seeds, respectively. Only 1.54 kg K_2O/quintal of grain is required by wheat in the Doukkala region. The K use efficiency by wheat in the Gharb region is exceptionally large because of luxury consumption from soils with a very high K status.

Fertilizer use coefficients

The recovery of fertilizers by the crops is expressed by the apparent fertilizer use coefficient (Tables 1 to 4). The results show that between 50 and 65% of fertilizer N was taken up by the crops. The apparent fertilizer use coefficient for P and K fertilizers was very low. However, the unused P and K fertilizers remaining in the soil can be used by the following crops. It was found that fixation and release processes complicate the understanding of the apparent recovery of fertilizers. The use of ^{15}N labelled techniques is necessary in order to better understand the recovery of N fertilizer by the crops.

Table 4. Critical levels, nutrient use efficiency and apparent fertilizer use for sunflower under irrigation in Gharb region.

Nutrient	Critical level	Nutrient use efficiency (kg/100 kg)	Apparent fertilizer use coefficient	Observations
Nitrogen	No critical level	3.47	0.53	Soil nitrogen supplying capacity can be estimated using the max. yield without N addition. No correlation between N soil test and crop response to N fertilizer
Phosphorus	21.6 mg P_2O_5/ kg soil	0.67	0.21	Critical level for Dehs soil series only. Needs to be determined for Tirs soil series
Potassium	149 mg K_2O/ kg soil	7.23	0.44	Low: soil K crop requirement × 1.2 Medium: add crop requirement High: no K_2O addition

Recommendations of fertilizer applications

A survey of soil fertility status was performed in the Doukkala and Gharb regions. Taking into account the results obtained in this study, it was possible to suggest general amounts of fertilizer that can be used by the majority of the farmers.

Table 5 presents the quantities of nutrients needed to make better use of water in the Gharb and Doukkala irrigated regions. Farmers who can afford to make a soil analysis before planting can use the data presented in Tables 1 to 4 to compute the amount of fertilizers to be added to each field. For those who are not yet able to have a soil analysis done, the quantities to be added depend on the region, the crop, the soil type and the target yield.

The Doukkala and Gharb agricultural development services are presently promoting the use of these quantities. They are also increasing their laboratory capacities to make soil tests for more farmers. Similar experiments are being done for other crops, especially orchards and sugar cane in the Gharb region and sunflower in the Doukkala region.

Table 5. Recommended fertilizers formulas for wheat, sugar beet and sunflower in the Gharb and Doukkala irrigated regions in Morocco.

Crop	Region	Soil type	Yield (t/ha)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
Wheat	Doukkala	Tirs	5	153	23	0
		Hamri, Faid, Rmel	5	153	23	75
		Hamri, Faid, Rmel	<5	153	23	0
	Gharb	Dehs, high in P_2O_5	5	120	0	0
		Dehs low in P_2O_5	5	120	80	0
Sugar beet	Doukkala	All types high in P_2O_5	80	220	0	360
		All types low in P_2O_5	80	220	53	360
Sunflower	Gharb	Dehs high in P_2O_5	4	120	0	0
		Dehs low in P_2O_5	4	120	70	0

Effect of potassium fertilization on development and yield of potatoes under central Saudi Arabia conditions

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Abstract

This study was conducted during autumn 1997/1998 at the Experimental Farm of the College of Agriculture and Veterinary Medicine, King Saud University in Al-Qassim. The study evaluated the vegetative and reproductive performance of potato plants under five different fertilization treatments, rates per ha, 1- Control, 2- nitrogen (N) at 202.4 kg N, 3- N and phosphorus (P) at 202.4 kg N and 158.4 kg P_2O_5, 4- N, P and potassium (K) at 202.4 kg N, 158.4 kg P_2O_5 and 50 kg K_2O, and 5- N, P and K at 202.4 kg N, 158.4 kg P_2O_5 and 150 kg K_2O.

Increased fertilization significantly increased plant vegetative growth, plant leaf cover and total tuber yield. Increasing K application from 50 to 150 kg K_2O ha^{-1} significantly increased tuber yield, and the other treatments gave a larger yield than the control. Potassium fertilization is essential for potato production under central Saudi Arabia conditions.

Introduction

Potato (*Solanum tuberosum* L.) is an important crop among the popular vegetables in the world, being a cheap source energy, due to its large content of carbohydrate, and containing significant amounts of vitamins B and C and minerals. Moreover, potato is used also in many industries, such as starch and alcohol production (Abdel-Aal *et al.*, 1977). In Saudi Arabia, potato is an important vegetable crop and the Qassim region produces about half of the potatoes produced in Saudi Arabia (Zaag, 1991).

Potato plants require much more K than may other vegetable crops. Although most soils in Saudi Arabia are rich in K, more should be applied as a fertilizer for potatoes because they need a lot within a short time (Zaag, 1991). An adequate supply of K increases yield and improves quality because it strengthens stems, thus preventing lodging and it increases the size of tubers and yields (Archer, 1985; Beringer, 1987, Ibrahim *et al.*, 1987; Omran *et al.*, 1991). Potassium is also important in helping crops adapt to environmental stress. It promotes plant tolerance to insect attacks and resistance to fungal disease.

This investigation tested the application of N and P and the importance of K on the growth and yield of potatoes under the arid conditions prevailing in the central region of Saudi Arabia.

Materials and methods

Plant material and experimental design

This study was conducted at the Experimental Farm of the College of Agriculture and Veterinary Medicine, King Saud University, Al-Qassium branch, during the autumn of 1997-1998. The farm is situated at 26° 18 N latitude and 43° 58 E longitude and an altitude of 725 m above sea level, in central Saudi Arabia. The soil is sandy with 96.3% sand, 1.8% silt and 1.9% clay; the pH ranged from 8.2 to 8.6, and available N, P and K from 13-17, 15-18 and 31-43 mg kg^{-1}, respectively. The irrigation water had a pH of 7.11 and total soluble salts of 945 mg l^{-1}, the SAR value was 2.66. The maximum and minimum means of monthly temperatures are 29° and 16°C, respectively. The maximum mean monthly % relative humidity is 43.3, while the minimum value is 18.3. The annual rainfall is 123.7 mm.

The treatments, per ha, were:

1. Control (no fertilization).
2. N at 202.4 kg N.
3. N and P at 202.4 kg N and 158.4 kg P_2O_5, respectively.
4. N, P and K at 202.4 kg N, 158.4 kg P_2O_5 and 50 kg K_2O, respectively.
5. Application of N, P and K at 202.4 kg N, 158.4 kg P_2O_5 and 150 kg K_2O, respectively.

Each treatment was replicated three times in a complete randomized block design. Each plot was 3 × 4 m and contained 4 rows 75 cm apart with 30 cm between plants within the row. Presprouted tubers, cv Agaksy, were used. The required agricultural practices were done as necessary during the growing season.

The growth and yield parameters measured were:

1. Vegetative growth: the fresh weight of the above ground parts was determined.
2. Percentage of foliage coverage: the % of foliage coverage per square meter was measured.
3. Yield: total yield per plot on 10th January 1998 was converted to t ha^{-1}.

The data were statistically analyzed by analysis of variance using a SAS package. Comparison of treatment means was done using LSD test at the $P=0.05$ level of significance. Correlation coefficients were computed between vegetative growth, & cover and yield.

Results and discussion

Vegetative growth

All three nutrients, N, P and K, had a significant effect on the yield of fresh shoots (Table 1), and the extra K with N and P gave the largest yields of fresh shoots, 11.33 t ha^{-1}, and increase of 198% compared to the control.

Table 1. Effect of fertilizer treatments on potato growth and yield.

Treatments	1	2	3	4	5	LSD
Foliage t ha^{-1}	5.73 c	7.53 b	8.88 b	8.01 b	11.33 a	1.51
% foliage coverage	38.70 d	45.50 cd	48.13bc	55.33 b	65.80 a	8.21
Final yield t ha^{-1}	23.71 d	27.70 c	30.10 b	32.02 b	37.96 a	2.29

Increasing K fertilization from 50 to 150 kg K_2O ha^{-1}, increased the weight of shoots by 141% probably because large amounts of K were taken up during the early vegetative growth stage. These results agree with those obtained by Beringer (1987); Ibrahim *et al.* (1987) and Omran *et al.* (1991) who found that K fertilization had a significant effect on the growth of potato plants.

There was no significant difference between the yields of fresh shoots given by N, N and P, and N, P and K at 50 kg K_2O ha^{-1}. The smallest yields of fresh shoots were observed from control plots.

The percentage of foliage coverage

The highest % of foliage coverage (65.8%) was given by 150 kg K_2O ha^{-1}, plus N and P, while the least was on the control treatment and N alone (38.7 and 45.5%, respectively). Potassium deficiency manifests itself as a dark green colour and a bronze discoloration of the leaves, which, in the later stages, may become necrotic. Moreover, visual symptoms of extreme deficiency are invariably seen first on the older leaves. Most species initially show a marginal chlorosis, spreading towards the main vein as the deficiency becomes worse (Archer, 1985).

Yields

Yields were increased by N, P and K (Table 1), the largest yield (37.96 t ha^{-1}) was given by N and P with 150 kg K_2O ha^{-1}. Applying only N (at 202.4 kg ha^{-1}) increased yield least to 27.7 t ha^{-1} compared to other fertilization treatments, but increased yield by 116.8% compared to the control treatment. Therefore, an adequate supply of K increases yield. These data agree with those of Forster and Beringer (1983) and El-Fakhrani (1998). At Michigan State University, Vitosh (1990) reported that K is very similar to N in that it can greatly affect potato tuber quality, by lowering specific gravity (percent solids). Also, he noted that because most potatoes are grown on sandy soils in Michigan and sandy soils do not hold large amounts of K, growers must pay particular attention to K fertilization. Soil testing is the key to determining the amount of K fertilizer to apply.

Correlation among the growth parameters

Vegetative growth and % of leaf cover were significantly correlated with tuber yield, r = 0.96 and 0.99, respectively (Table 2). Thus tuber yield reflected the %

foliage cover. Plants require K for photosynthesis, osmotic regulation and the activation of enzyme systems and, in this study, gave a larger yield with more K. This, together with the fact that yield and leaf cover were strongly correlated suggests that both leaf area and K uptake and utilization mainly controlled yields in this study.

Table 2. Correlation coefficients between potato yield, vegetative growth and % of leaf coverage.

	Yield	Vegetative growth	% leaf cover
Yield	1.00	0.96*	0.99**
Vegetative growth		1.00	0.92*
% leaf cover			1.00

*, ** Significant at P 0.05 and P 0.01, respectively.

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Session 6

Country Reports

Analyzing the trend of K fertilizer use in Iran in the past decade

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The total amount of mineral fertilizers used in the world in 1998/99 was around 136 Mt nutrients. The figure consisted of 81.2 Mt nitrogen (N), 32.8 Mt phosphorus (P), and 22.0 Mt potassium (K), giving the $N:P_2O_5:K_2O$ ratio of 100:40:27. In the same year, the primary nutrient ratios of the fertilizers used in Iran improved to 100:41:21. The situation in 1998/99 had been completely different at the beginning of the 1990s, in fact, compared to the world's primary nutrient consumption ratios of 100:47:32 in 1990/91, the relevant figures in Iran were around 100:111:3, reflecting abnormally large amounts of P fertilizer used and with almost no attention given to the use of K fertilizers. Insufficient extension activities had contributed to greater attention being focussed on N and P fertilizers, with disregard of the principle of balanced fertilization and little attention to the use of K fertilizers, micronutrients or organic amendments.

A review of the changing patterns of fertilizer use in Iran in the past five years is indicative of the changes taking place in both the type and quantity of fertilizers required. These changes are coming mainly from efforts directed towards balanced fertilization. While the kinds of fertilizers used prior to the beginning of the 1990s were limited mainly to urea and diammonium phosphate, currently 15 types of fertilizers, representing all the three primary nutrients, are applied to different crops and soils. Also, the average total annual consumption of 2.2 Mt of the four years prior to 1998 increased to 2.8 Mt in 1999-2000, and it is expected to reach 3 Mt in 2000-2001. Towards our objective of balanced fertilization, we have noted with satisfaction that the application of muriate of potash (MOP) in the paddies of the north is on the increase, significantly contributing to yield increases and reduction of physiological stress symptoms in our rice crop. The chemical analysis of soil samples from different parts of the country clearly indicate a gradual depletion of available K in the root zone amounting, on average, to about 10-20 mg/kg of soil/year. Also recent data about the soils in the rice fields in the north, which contain high amounts of clay, indicate that the available K content of most soils is now below 300 mg/kg even though the soil contains large amounts of clay. Also in the rice paddies, as well as in fields of cash crops, there is a negative K balance. With the declining trends in available soil K, positive responses of different crops to K fertilizers are becoming more common.

It is of interest to note that due to persistent droughts of recent years in Iran, K fertilizer use has gained added significance as K is an important factor in combating moisture stress under drought conditions. It is a scientific fact that K, in addition to its effect in increasing yield and improving quality, also reduces environmental stress in plants. It is also important to note that, in certain cases, an insignificant yield response to added K may be due to low rates of application rather than a sufficiency of K in the soil. When the interlayer K of some minerals is depleted, adding an inadequate amount of K, especially in the form of sulphate of potash (SOP), will result in some K being transferred to the interlayer spaces and, in consequence, there will be no significant yield response to this rate of application. For example, in a recent study, sugarcane did not significantly responded to SOP applied at 200-300 kg K_2O ha, but sugar yield was increased by 20% when 800 kg K_2O ha was applied. In Iran, we recommend that in areas where soil tests show low levels of available K, or where the crops have a large demand for K, and where double cropping is becoming a common practice, then either small amounts of potassium nitrate or MOP should be applied as a top dressing, or adequate amounts of SOP should be added to the soil before planting. Many results indicate that the total available K in soil is often not enough to meet the plant's daily uptake requirement for K and hence regular K fertilization is required.

While there is still a long way to go before we reach our final goal of balanced fertilization, we believe that the steps taken so far have been in the right direction. In the past five years, scientific and extension endeavours by the staff of the Soil and Water Research Institute have reshaped fertilizer consumption in Iran such that in the past year, the ratio of primary nutrients use was about 100:50:20. Our immediate goal is to improve this ratio to 100:45:35+5% micronutrients in the country's current five-year development plan that started in March 2000.

Potassium status in Iraqi soils

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Abstract

Potassium (K) has been forgotten in fertilizer recommendations for long time in Iraq due to the widespread belief that Iraqi soils are in general well supplied with native K. The results of recent laboratory investigations and field experiments have shown that this assumption is not always correct.

This paper reviews the results from basic research works and field experiments on soil K during the last 25 years.

The first survey on the content of soluble, exchangeable and non-exchangeable K indicated considerable variations. The ranges were 0.01-0.60, 0.49-3.01 and 1.47-5.67 $cmol_c\ kg^{-1}$ of soluble, exchangeable and non-exchangeable K, respectively. The content of soluble and exchangeable K increased with increasing soil salinity and other salinity related factors. Based on the soil K test values, it was concluded that a response to K was unlikely in most Iraqi soils.

Further investigations on K fixation in Iraqi soils showed that the soils have a high fixation capacity, about 28-76% of the added K was fixed. X-ray diffraction showed that the high K-fixation capacity was mostly due to the presence of beidillite in the fine soil fractions and vermiculite in coarser fractions.

Using thermodynamic parameters, potassium activity, activity ratio, capacity - intensity relationship, free energy and buffering capacity of K, to evaluate the K-supplying power of Iraqi soils indicated differences in thermodynamic parameters between soils with similar soil K test values. It was concluded that the thermodynamic parameters better indicate the K-supplying power when compared to exchangeable K, which did not adequately measure soil K availability in the soils studied. Therefore, it is recommended to use the thermodynamic parameters to describe the status and behavior of K in agricultural soils.

The kinetic parameters were also used to evaluate the release of K in Iraqi soils. It was shown that the power function equation was the best among those tested namely kinetic equations – zero order, first order, second order, diffusion and Elovich equations – for describing mathematically the release of K. The K rate coefficient values estimated by the power equation ranged 0.18-0.52 mg K kg^{-1} min^{-1} for unfertilized soils to 0.32-0.94 mg K kg^{-1} min^{-1} for K fertilized soils. The statistical analysis showed a strong significant positive correlation between plant dry matter yield and K uptake and K release rate coefficients. Based on the rate coefficient values, the Iraqi soils studied had a low rate of K release despite their high soil K test values. This conclusion has a practical importance.

A series of field experiments evaluatd the response of different crops to K fertilizer under intensive cropping. The results showed that applying K fertilizer to most Iraqi soils such as alluvial, newly reclaimed soils, gypsiferrous, light textured soils and saline soils significantly increased dry matter yield and K uptake by the plants.

There was no significant difference between potassium chloride (MOP) and potassium sulphate (SOP). The yield and K uptake results agree with those obtained from the thermodynamic and kinetic investigations.

Introduction

Potassium has been forgotten in fertilizer recommendations in Iraq for a long time due to the widespread belief that Iraqi soils are well supplied with native K. The results of recent laboratory investigations and field experiments have shown that this assumption is not always correct.

This paper reviews the results from basic research on the status and behavior of K in Iraqi soils during the last 25 years.

Physiographic formation and soils in Iraq

There are five types of physiographic formation in Iraq: mountain ranges, foothills, desert, the Gezera and the Mesopotamian plain and three different regions: Uplands and Mountains, Lower Mesopotamian and the desert (Buringh, 1960).

The first region which is considered as a rainfed zone includes several different soil groups which are: Lithosols, shallow and medium chestnut and brown soils. The lower Mesopotamian plain, the oldest agricultural plain in the world, covers central and southern parts of Iraq and includes different physiographic units. The parent material of the soils consists mainly of the river sediments and nearly all the soils are classified as alluvial. Salinization and the accumulation of salts in the soils occur due to the arid climate and the hydrological conditions. Deserts cover more than half of the land of Iraq and have an extremely low agricultural potential because there are no developed soils.

Fertility status

The natural fertility of most soils is very low and there is a shortage of organic matter, nitrogen (N) and phosphorus (P), but, based on the exchangeable potassium test, Iraqi soils are considered rich in potassium (K) (Al-Zubaidi, 1977).

Mineralogy of Iraqi soils

The state and behaviour of soil K depend on soil mineralogy, therefore it is necessary to give a short summary of the mineralogical composition of Iraqi soils. Clay mineralogy is dominated by montmorillonite, mica and chlorite with some vermiculite and polygorskite (Hanna and Rihany, 1964; Al-Rawi *et al.*, 1949). Quartz is the dominant mineral (22-50%) in the sand and silt fractions and the quartz feldspars ratio is 1:2 in these fractions (Al-Rawi *et al.*, 1969). Al-Temimi (1984) and Edan and Al-Zubaidi (1987) identified beidillite derived from montmorillonite in the clay fraction of some soils. Recently Al-Zubaidi *et al.* (2001) investigated the mineralogy of Iraqi soils and found chlorite, mica and kaolinite in the sand and silt fractions in addition to quartz plagioclase and K-feldspars. Coarse clay consisted of chlorite, illite, kaolinite and beidillite with trace amounts of interstratified layers of mica-smectite. Fine clay had the same mineralogy as coarse clay except that beidillite was the dominant mineral and there were trace amounts of polygorskite.

Potassium content in Iraqi soils

Al -Zubaidi and Pagel (1979) determined the content of different forms of K in soil samples collected from different regions of Iraq (Table 1). Soluble K was determined in a soil - water extract, exchangeable K by N-ammonium acetate and non-exchangeable K by extraction with HNO_3. The content of soluble, exchangeable and non-exchangeable K varied considerably, soluble K varied from 0.010 to 0.601, average 0.111 cmol$_c$ kg^{-1}, while exchangeable K varied from 0.49 to 301, average 1.08 cmol$_c$ kg^{-1}. The non-exchangeable K varied from 1.47 to 5.67, average 3.8 cmol$_c$ kg^{-1}. The K saturation percentage ranged from 2.21 to 9.96 with an average value 4.51.

Table 1. Content of soluble, exchangeable, non-exchangeable K and K saturation percentage of soil samples collected from different regions of Iraq.

Profile No.	Short description and location	Depth, cm	Content of K, cmol$_c$ kg^{-1}			K-saturation
			Soluble	Exch.	Non-exch.	percentage
59	Northern Iraq	0-25	0.051	1.99	4.25	4.37
	dark brown soil	25-55	0.031	1.05	3.73	2.44
	Rainfall 700-800 mm	55-100	0.010	0.93	3.53	2.21
	"Sulaimania"	100-120	0.020	0.94	3.77	2.64
		120-140	0.015	0.61	3.68	2.96
5	Northern Iraq	0-14	0.061	1.61	5.17	8.00
	light brown soil	14-22	0.026	1.15	5.05	5.00
	Rainfall 300-400 mm	34-61	0.010	0.64	3.00	3.00
	"Tel Affer"					
2	Middle Iraq	0-30	0.601	1.47	4.71	7.31
	alluvial soil	30-60	0.371	1.15	4.19	5.52
	Rainfall 100-200 mm	60-100	0.016	3.01	3.69	3.01
	"Abu-Ghraib"	100-200	0.102	0.64	3.66	2.60
26B	Middle Iraq	0-5	0.315	2.24	5.31	8.45
	alluvial soil	5-20	0.156	1.84	4.76	6.69
	Rainfall 100-200 mm	20-40	0.133	1.66	4.99	5.96
	"Abu-Ghraib"	40-70	0.156	1.61	4.74	6.02
		70-120	0.243	1.46	3.97	6.00

Table 1. Continued.

Profile No.	Short description and location	Depth, cm	Content of K, $cmol_c\ kg^{-1}$			K-saturation
			Soluble	Exch.	Non-exch.	percentage
19	Middle Iraq	0-30	0.092	1.34	4.22	5.30
	alluvial soil	30-60	0.056	0.92	3.23	4.00
	Rainfall 100-200 mm	60-90	0.061	0.90	2.33	4.04
	"Salman Pak"	90-120	0.056	0.70	3.44	3.18
		120-160	0.036	0.56	3.22	2.77
10	Middle Iraq	0-12	0.435	0.91	4.04	5.22
	Alluvial soil	12-53	0.128	0.59	4.69	2.84
	Rainfall 100-200 mm	53-90	0.072	0.56	3.83	2.64
	"Al-Dalmag"	102-130	0.062	2.37	1.47	2.47
21	Middle Iraq	0-20	0.100	1.10	3.88	5.54
	Alluvial soil	20-40	1.013	1.14	3.92	4.16
	Rainfall 100-200 mm	40-70	0.066	0.64	2.88	4.46
	"Yosfia"	70-120	0.015	0.88	3.27	3.71
41	Southern Iraq	0-25	0.136	1.37	2.27	9.96
	Alluvial soil	25-55	0.043	0.93	4.32	4.24
	Rainfall 100 mm	55-80	0.049	0.81	3.55	3.10
	"Effag"	80-150	0.056	0.75	3.29	4.70
		110-190	0.074	0.49	2.65	4.36
44	Southern Iraq	0-20	0.140	1.17	4.24	7.60
	Alluvial soil	20-50	0.087	1.07	5.67	3.98
	Rainfall 100 mm	50-80	0.079	0.64	3.40	2.69
	"Aldiwania"	80-150	0.087	0.70	3.13	2.72
	Range		0.010-0.601	0.49-3.01	1.47-5.67	2.21-9.96
	Mean		0.111	1.08	3.8	4.51

The different K forms were significantly correlated (Table 2).

Table 2. Correlation coefficients (r) between different potassium forms.

K-value	Soluble K	Exch. K	Non-exch. K	K-saturation percentage
Soluble K	-	0.555^{***}	0.471^{***}	0.898^{***}
Exch. K	-	-	0.507^{***}	0.756^{**}
Non-exch. K	-	-	-	0.451^{**}

Table 3 shows the correlation coefficients between the different K forms and some chemical and physical properties of the soils. There was a strong positive correlation between the different K forms and electrical conductivity (EC) and other EC-related values such as soluble sodium (Na) and soluble chloride (Cl) and SAR.

Table 3. Correlation coefficients (r) between different potassium forms and some chemical and physical properties of the soils.

Soil properties	Soluble K	Exch. K	Non-exch. K	K-saturation percentage
Clay, %	-0.496***	0.228	0.107	-0.526***
OM, %	0.11	0.296	0.223	0.168
$CaCO_3$	0.330*	0.085	0.159	0.412**
CEC	-0.457***	0.071	-0.075	-0.527***
EC	0.890***	0.444***	0.396**	0.776***
ESP	0. 563***	0.392**	-0.575***	0.150
Soluble Na	0.972***	0.150	0.429**	0.869***
Soluble CL	0.930***	0.499**	0.406**	0.812***
SAR	0.859***	0.560***	0.434**	0.801***

Evaluation of the soil potassium content

Al-Zubaidi and Pagel (1979) proposed that the critical values for K efficiency for plant nutrition were exchangeable K 140 mg kg^{-1}, non-exchangeable K 400 mg kg^{-1} and K saturation percentage 2.3, then the following conclusions can be made from the data of Table 1.

The lowest value for exchangeable K was 0.49 $cmol_c$ kg^{-1} (192 mg kg^{-1}) in the 110-190 cm depth in sample 41 indicating that all the soils contain a sufficient quantity of exchangeable K. Moreover more than 90% of all the soils contained twice critical level of exchangeable K and the non-exchangeable K was very high and about 90% of all soil samples contained 2.5 times more than the proposed critical value. All the soil samples, except one, are characterized by a high degree of K saturation.

Assuming 3 M kg of soil per 1 ha in the top 25 cm layer, then the average content of each K form per hectare is: soluble K 130 kg ha^{-1}, exchangeable K 1266 kg ha^{-1} and non-exchangeable K 4457 kg ha^{-1}. The total easily available K (soluble + exchangeable) equals 1396 kg ha^{-1} and the sum of the content of the three forms of K is 5853 kg ha^{-1}. Such a quantity of K is enough for at least 10-15 years of cropping but this needs verification.

Potassium fixation

The K fixation capacity of five surface soils from different locations in Iraq was determined in wetting and drying experiments in the laboratory (Jackson, 1967). The soils were from Hammam Al Alil and Baji (in the northern region), Sammara

and Al-Dour (from the middle region), and Missan (from the southern region). Potassium, as potassium sulphate, was added at four rates: 0.25, 0.50, 0.75 and 1.00 cmol$_c$ kg^{-1}. Between 28-76% of the added K was fixed in non-exchangeable forms (Table 4) and the fixation capacity of the soils was in the order:
Missan > Hamam Al Alil Beji > Sammara > Al-Dor. The extent of K fixation was mostly due to the presence of beidillite in the fine clay and vermiculite in the coarse clay (Edan *et al.*, 1987). The removal of calcium carbonate from the soils caused a significant increase in the amount of fixed K (Edan and Al-Zubaidi, 1992).

Table 4. The amount of fixed potassium in the studied soil samples.

Soil sample No. and location	Added potassium, cmol$_c$ kg^{-1}			
	0.25	0.50	0.75	1.00
	Fixed potassium, cmol$_c$ kg^{-1}			
1. Hamam Al-Alil	0.106	0.321	0.412	0.566
2. Beji	0.134	0.291	0.421	0.567
3. Al-Dor	0.122	0.254	0.264	0.284
4. Samara	0.125	0.250	0.306	0.409
5. Mussan	0.175	0.354	0.573	0.736

Crop response to potassium fertilizer

To test the conclusion that Iraqi soils are rich in K and no response to K fertilizer would be expected, a series of lysimeter and pot experiments were conducted on barley, corn, alfalfa and rice. Different amounts of K fertilizer were added and different soil types were used. In experiment 1, besides the control, K was tested at 140 and 280 kg ha^{-1} to a newly reclaimed soil containing 0.31 cmol$_c$ kg^{-1} exchangeable K which was intensively cropped with barley (*Hordium vulgar*) followed by corn (*Zea mays* L.) in special lysimeters. Adding K dramatically increased the dry matter yield and K uptake by barley and corn (Al-Zubaidi *et al.*, 1994).

In experiment 2, lysimeters were filled with either a sandy loam or a silt clay loam having exchangeable K 0.16 and 0.37 cmol$_c$ kg^{-1} respectively, and K was tested at 0 (control) and 200 kg K ha^{-1}. Alfalfa (*medicago sativa* L.) was grown for 240 days and five harvests (cuts) were taken.

There were significant differences between the control and K fertilized soils in dry matter yield and total K uptake at every cut on both soils (Table 5) (Al-Rabai, 1995). This experiment was continued for a further 720 days with 15 cuts and the results indicated a good response of alfalfa to K over this extended period (Table 5). The contribution of exchangeable and non-exchangeable K to the K taken up by alfalfa are shown in Table 6 (Al-Zubaidi and Obaidi, 2001). Continuous cropping for a long period of time resulted in the uptake of non-exchangeable K and the contribution of non-exchangeable K was larger in the unfertilized treatment, 67.8% and 82.5% for the silty clay loam and sandy loam, respectively, compared to 52 6%

and 75.0% for the heavier and lighter soil, respectively. The uptake of non-exchangeable K by intensively managed crops was also observed by Sinclair (1997), Momen *et al.* (1988) and Al-Zubaidi and El-Semak (1995).

Table 5. Cumulative dry matter weight and cumulative potassium uptake of alfalfa.

A- after 5 cuts

Soil	Treatment	Dry matter weight, kg ha^{-1}	K uptake, kg ha^{-1}
Silt clay loam soil	K_0 K_1	15760 19080	407.5 614.2
Sandy loam soil	K_0 K_1	13650 16950	317.6 454.5

B- after 15 cuts

Silt clay loam soil	K_0 K_1	38400 41100	755 1020
Sandy loam soil	K_0 K_1	29800 36600	560 855

Table 6. Contributions of exchangeable and non-exchangeable potassium in supplying potassium to alfalfa after 15 cuts.

Soil	Treatment	Cumulative K uptake, kg ha^{-1}	Contribution(%)	
			Exch. K	Non-exch. K
Silt clay loam soil	K_0 K_1	755 1020	32.2 48.0	67.8 52.0
Sandy loam soil	K_0 K_1	564 855	17.5 25.0	82.5 75.0

In another experiment with a gypsiferous soil with about 36% $CaSO_4$ $2H_2O$ and exchangeable K 0.15 $cmol_c$ kg^{-1}, was cropped with alfalfa (*Medicago sativa* L.) for 4 months and 4 cuts were obtained. There were three treatments: 0 (control) and 150 and 200 kg K ha^{-1}. There was a significant response to K (Tables 7 and 8) (Al-Samari, 1996).

A pot experiment was conducted with soils collected from the Ap horizon of different rice soils (P_2, P_4 and P_6) that varied in the length of cropping. The initial exchangeable K in the three soils was 0.585, 0.598 and 0.338 $cmol_c$ kg^{-1}, respectively. The soils were cropped continuously with four crops of rice and there were three treatments 0 (control) and 150 and 300 kg K ha^{-1}. Rice responded to both levels of K (Table 9) and 46.5% of the total K uptake where no K was applied came from the non-exchangeable K.

Table 7. The effect of potassium application on the dry matter weight of alfalfa and potassium uptake in gypsiferous soil.

A- dry matter

K treatment	Cut number				Cumulative dry matter weight, g pot^{-1}
	1	2	3	4	
0	2.50	2.82	2.45	2.43	10.20
150 kg ha^{-1}	3.68	3.55	3.03	3.02	13.30
200 kg ha^{-1}	4.10	4.02	3.88	2.56	15.56

B- potassium uptake

K treatment	Cut number				Cumulative K uptake, g pot^{-1}
	1	2	3	4	
0	96.0	65.0	43.0	40.0	244
150 kg ha^{-1}	147.4	116.4	99.3	97.1	460
200 kg ha^{-1}	180.0	150.0	120.0	105.0	555

Table 8. The relative yield of alfalfa and the response percentage.

Cut number	Relative yield, %			Response, %
	K_1	K_2	K_1	K_2
1	67.7	60.9	47.0	64.0
2	79.4	70.4	25.4	42.0
3	80.9	63.1	23.4	58.0
4	80.4	68.2	24.2	46.0

Table 9. The response of rice to K-fertilizer.

Soil number	Cropping number	Response, %	
		K150	K300
P2	1	26.83	43.90
	2	32.88	42.47
	3	37.50	51.56
	4	43.86	52.63
Average		35.27	47.64
P4	1	35.39	42.35
	2	48.61	59.72
	3	50.77	67.69
	4	37.29	57.63
Average		43.02	56.85
P6	1	20.00	41.54
	2	27.59	50.00
	3	44.90	69.30
	4	57.14	85.71
Average		51.42	73.84

The significant responses to K fertilizer in these experiments with soils rich in exchangeable K suggested that exchangeable K was not a very good indicator of the amount of K removed during cropping, a conclusion reached by others. Therefore, such a parameter cannot always be used for K fertilizer recommendations and it becomes necessary to consider thermodynamic and kinetics parameters. Recently such parameters have been used successfully for assessing and evaluating the K status in several soils (Woodruff, 1955; Beckett, 1964; Bandyopadhyay and Goswami, 1985; Beegle and Baker, 1987; Mazumdar and Saxena, 1989; Martin and Sparks, 1983; Sparks, 1989; Al-Zubaidi and Al-Rabai, 2001).

Thermodynamics of potassium in Iraqi soils

In order to characterize the status and behaviour of K in Iraqi soils thermodynamically, eight soil surface samples were collected from different locations, representing the most dominant soil groups in Iraq. The soil samples were similar in their content of extractable K (0.80-0.82 $\text{cmol}_c\ \text{kg}^{-1}$) (Table 10). The thermodynamic parameters determined were ionic strength, activity coefficient of K, activity ratio (K: Ca + Mg) and the free energy of replacement (- F) of K- Ca + Mg were determined. The quantity intensity Q/I curves were determined and the buffering capacity and labile pool K values were calculated from these curves (Al-Zubaidi and Al-Rabai, 2001).

Table 10. Comparison between NH_4-extractable potassium and thermodynamic parameters.

Soil No.	NH_4-extr. K $\text{cmol}_c\ \text{kg}^{-1}$	ΔF cal. mol.^{-1}	K-buffering capacity, $\text{cmol}_c\ \text{kg}^{-1}\text{mol.}^{-1}\ \text{L}^{-1}$	Labile K, $\text{cmol}_c\ \text{kg}^{-1}$
1	0.81	-2825	153	1.358
5	0.82	-3075	87	1.037
6	0.81	-2504	278	3.408
11	0.81	-3687	150	1.928
12	0.80	-2750	78	0.874
14	0.80	-3062	237	2.917
19	0.80	-1245	225	3.539
28	0.82	-2541	556	2.711

The results showed that the thermodynamic parameters were different despite the similarity in exchangeable K (Table 10). The thermodynamic parameters better expressed the K supplying power of these soils with varying texture and mineralogy than did exchangeable K. Based on the values of free energy (Woodruff, 1955) and buffering capacity (Beegle and Baker, 1987), these Iraqi soils have been classified in different categories and it was concluded that the thermodynamic parameters can be successfully used to describe the status and behaviour of the K.

The test of the thermodynamic parameters for evaluating the response of alfalfa to K in the experiment above showed that the values of thermodynamic parameters were significantly changed reflecting the effects of cropping and fertilization on the dynamic of K during growing (Al-Zubaidi and El-Bassam, 1992), the changes are shown in Table 11.

Table 11. Some thermodynamic parameters and exchangeable extractable potassium before and after cropping of alfalfa.

Soil and treatment		NH_4-extr. potassium, $cmol_c\ kg^{-1}$		K-buffering capacity, $cmol_c\ kg^{-1}\ (mol/L)^{1/2}$		Labile-K $cmol_c\ kg^{-1}$	
		Before	After	Before	After	Before	After
Sandy loam	K0	0.14	0.12	94	207	1.086	0.405
	K1	0.17	0.14	94	164	1.458	0.456
Silty clay loam	K0	0.35	0.33	176	148	1.667	2.212
	K1	0.38	0.31	221	176	2.116	2.212

Highly significant correlations between some thermodynamic parameters values and the dry matter yield of alfalfa and K uptake were obtained (Table 12).

Table 12. Correlation coefficient values (r) between some thermodynamic parameters values and dry matter yield of alfalfa and potassium uptake.

Parameter	Dry matter weight, kg/ha				Potassium uptake, kg/ha			
	SL		SiCL		SL		SiCL	
	K0	K1	K0	K1	K0	K1	K0	K1
ak	0.844^{*}	0.901^{***}	0.655^{*}	0.721^{*}	0.933^{**}	0.925^{**}	0.896^{**}	0.952^{**}
Δ-F	0.922^{**}	0.973^{**}	0.945^{**}	0.864^{*}	0.732^{*}	0.759^{*}	0.701^{*}	0.731^{*}
Labile-K	0.782^{*}	0.788*	0.782^{*}	0.799^{*}	0.752^{*}	0.822^{**}	0.821^{**}	0.890^{**}
K-buffering eapacity, $P.B.C^k$	0.713^{*}	0.752^{*}	0.801^{*}	0.824^{*}	0.862^{*}	0.891^{**}	0.862^{*}	0.882^{**}

The thermodynamic parameters were also tested for the gypsiferous and rice soils and the obtained results confirmed those above.

Kinetics of potassium in Iraqi soils

The evaluation of soil fertility has recently switched from measurements of the amount of nutrient, in particular K, to the rate at which a nutrient (K) can be supplied (Cooke, 1979). Therefore any procedure for assessment of soil K can hardly provide meaningful information unless the rate of release is included.

A series of laboratory, pot and lysimeter experiments were carried out to investigate the kinetics of K release in Iraqi soils and to develop a scoring system for K release kinetics, implying a potential supply index in relation to the response of several crops to applied K fertilizer.

Eight surface soil samples collected from eight dominant soil groups in Iraq were used and some chemical and physical properties of the soils are shown in Table 13. Potassium was extracted by the method of Singh *et al.* (1983). Soil samples were leached for ten successive 15 min. periods with hot, 6.25 M HCL in 1:10 soil : acid ratio under reflux. Cumulative extracted K was plotted against the square root of the reaction time to give release curves. The data was fitted to five kinetic models: Zero, first order, parabolic diffusion, Elovich, Power function equation. The kinetic equations were evaluated by comparing coefficients of determination $(r)^2$ and the values of the standard error of the estimate (SE) which were determined by least square regression analysis (Martin and Sparks, 1983).

Table 13. Some properties and potassium content of soil samples used for kinetics experiment.

Soil sample No. and soil group	Texture	EC dSm^{-1}	pH	CEC, $cmol_c\ kg^{-1}$	Potassium content $cmol_c\ kg^{-1}$			
					Exch.	Non-exch.	Min.	Total
2 Torrifluvent	SL	2.70	7.9	8.2	0.22	0.54	31.5	32.2
9 Chromexert	SL	0.60	8.1	8.2	0.56	0.66	26.0	26.8
11 Chromexert	L	1.30	7.4	18.8	0.30	0.80	30.6	31.6
15 Calciorthid	CL	0.15	8.0	23.0	0.76	1.83	22.5	24.6
16 Gyppsiorthid	SCL	0.30	8.2	12.3	0.83	1.82	18.4	25.4
18 Xerochrept	SICL	0.90	7.2	24.8	0.44	0.52	31.4	32.4
20 Calcixeroll	SIL	0.95	7.9	32.0	0.50	0.68	33.1	34.0
23 Lithicrendol	C	1.05	7.8	34.0	0.60	0.81	26.9	28.3

The results showed that K release proceeds through two stages (Al-Obaidi and Al-Zubaidi, 2000). The first one involved a rapid release of exchangeable K, while the second one involved the release of K with a very slow release rate. According to the classification proposed by Goulding and Loveland (1984), the capacity of K release was classified as low-high, while the rate of K release from mica was classified as very low (Table 14). The very low rate of K release may explain the response of most Iraqi soils to K fertilizer in spite of their high content of K.

Table 14. Capacity and the rate of potassium release of the studied soil samples.

Kinetic parameter	Phase	Range	Average	Classification
K release capacity, mg kg^{-1}	Exch.	23-3511	1169	
	Non-exch.	172-2115	879	
	Soil mica	196-4236		Low-high
K release rate, mg kg^{-1} min^{-1}	Exch.	102- 422	298	
	Non-exch.	33- 321	140	
	Soil mica	79- 328	220	Very low

The applicability of different kinetic equations to describe the release of K showed that the power function equation appeared to fit the experimental data and it was the best among the equations tested as judged by the high (r) value (0.98**) and the lowest standard error of estimate (SE) 0.06.

The regression analysis technique showed that the release rate constant values (K) estimated by power function equations were highly and positively correlated with clay, CEC, OM, ECe and exchangeable K, and negatively correlated with the sand fraction and lime content.

In order to find out the relationship between the rate constants, estimated by the power function equation and the plant growth parameters, the data from the lysimeter experiment with alfalfa given above was used.

The results showed that soil K release constants, estimated by the power function equation, were in the range 0.18-0.52 mg kg^{-1} min^{-1} for the unfertilized treatment, while they were 0.32-0.94 mg kg^{-1} min^{-1} for the K fertilized treatment. The results also showed a highly positive correlation between K release rate constant values and dry matter yield of alfalfa (r=0.92**) and K uptake (r=0.93**) (Table 15) (Al-Zubaidi and Al-Obaidi, 2001). This indicates that the rate constant of power function equation could be used to predict the K supplying power of soil.

Table 15. Potassium rate constant values, dry matter weight and potassium uptake under different K-application treatment

Soil	Treatment	Cumulative dry matter, mg ha^{-1}	K uptake, kg ha^{-1}	Rate constant*, mg kg^{-1} min^{-1}
SICL	K0	34.8	755	0.52
	K200	41.1	1020	0.94
SL	K0	29.8	564	0.18
	K200	36.6	855	0.32

* Correlation coefficient (r) between rate constant and cumulative dry matter weight = 0.92**, and cumulative potassium uptake = 0.93**.

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Potassium status in Jordanian agriculture

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Introduction

The area of Jordan is 8.93 × 10^6 ha, but a small proportion (<10%) can be used for agriculture (Table 1). Land use depends on many factors including climate, soil type, availability of water and topography, but the main factor is moisture availability. Therefore, the land can be divided into four broad groups:

1. Desert zone

The average annual rainfall in this region is usually less than 100 mm. Temperatures vary widely with a mean maximum between 36 and 44°C, a mean minimum between 1, and 8°C, and a mean annual about 18°C. This zone is important for grazing. The plains carry only a very sparse vegetation, but the valleys support a significant range of palatable species for animals.

Table 1. Geographical areas according to rainfall in Jordan.

Region	Area (ha × 10^3)	% of total area	Average annual rainfall (mm)	Min. temp. °C	Max. temp. °C
Desert	8080	90.5	<200	1-8	36-44
Arid	510	5.7	200-350	3-7	34-40
Semi-arid	190	2.1	350-500	3-7	27-33
Semi-humid	100	1.1	>500	3	27-33
Water area	50	0.6	-		
Total	8930	100			

Source: Annual Report of the Ministry of Agriculture, Jordan (1999).

2. Low rainfall zone

This includes lands that receive 100-200 mm rainfall. It has an arid climate with a mean annual daily temperature of 16 to 18°C. The vegetation is mainly steppe grassland and brush species important for grazing. The valley bottoms can be used for the production of barley and wheat.

3. Rainfed agriculture zone

This includes lands that receive more than 250 mm rainfall but mostly during the months of November, December, January, February and March. Mean annual temperature ranges from 18 to 24°C, with an average maximum of 30°C in August, and an average minimum of 0.5°C in January. Within this zone, there are two main subdivisions:

A. Hilly and steeply sloping lands growing mainly tree crops

B. Undulating lands of the major plains with wheat as the main crop and smaller areas of tobacco, sorghum and summer crops.

4. Irrigated agriculture area (IAA)

The total irrigated agriculture area (TIAA) is about 163.2 $\times 10^3$ ha (Table 2), although the actual IAA in 1999 was only about 92.6 $\times 10^3$ ha (Table 3), i.e. about 58% of the TIAA. The IAA increased by about 20% compared to 1994. The major area of IAA is in the Jordan Valley (with 70% of the TIAA). The major irrigated crops are trees (including citrus and bananas grown only in the Jordan Valley), vegetables and cereals. In 1999, tree crops occupied 54.4%, vegetables 40.3% and cereals 5.3% of the IAA.

Table 2. The total agriculture area in Jordan.

Area	(ha $\times 10^3$)	% of total agricultural area
Irrigated agriculture area	163.2	32
Non-irrigated agriculture area	346.8	68
Total	510.0	100

Source: Annual Report of the Ministry of Agriculture, Jordan (1999).

Table 3. The actual cropping in irrigated and non-irrigated areas in Jordan during 1994 and 1999 (area $\times 10^3$ ha).

	Trees	Vegetables	Tobacco	Cereals	Total
Non-irrigated areas					
1994	83.2	3.5	2.7	137.0	226.5
1999	100.1	2.2	1.2	124.0	227.5
99 vs 94	16.9	-1.4	-1.5	-13.0	1.0 +
Irrigated areas					
1994	33.73	36.99	0	6.75	77.47
1999	50.39	37.39	0	4.84	92.62
99 vs 94	16.70	0.4	0.0	-1.9	15.2 +
Total areas					
1994	116.92	40.53	2.68	143.79	303.92
1999	150.48	39.56	1.17	128.88	320.09
99 vs 94	33.60	-1.0	-1.5	-14.9	16.2 +

Source: Annual Report of the Ministry of Agriculture, Jordan (1999).

The actual agriculture area under different crops in Jordan in 1999 is shown in Table 4.

Table 4. The actual agriculture area under different cropping in Jordan during 1999.

Agriculture area use	(ha × 10^3)	% of total agricultural area
Trees + cereals + tobacco + vegetables	320.09	67.9
Forest	77.16	16.4
Fallow	74.17	15.7
Total	471.42	100

Source: Annual Report of the Ministry of Agriculture, Jordan (1999).

Water resources

Table 1 shows that over 90% of the country' s area receives less than 200 mm annual rainfall and only 3.2% more than 350 mm. The total volume of annual rainfall is 6 × 10^9 m^3, much of which evaporates back to atmosphere while about 8% is lost by surface runoff. Total annual consumption is 876 x 10^6 m^3 of which about 604 × 10^6 m^3 (68.9%) are used for irrigation, 234 × 10^6 m^3 for domestic supply and the remainder, 37 × 10^6 m^3, are used by industry (Table 5). In the near future the currently available volume of water will not be able to meet the total water need for domestic, industry and agriculture (Table 6). The Ministry of Water and Irrigation (MOWI) predicts that the expected water deficit for the country could reach 325 × 10^6 m^3 in 2005.

Table 5. Total water use and the % of water use in agriculture during 1994-1997.

Year	Agriculture × 10^6 m^3	Industry × 10^6 m^3	Domestic × 10^6 m^3	Total × 10^6 m^3	% of water use in agriculture
1994	640	23	189	852	75.1
1995	656	25	228	909	72.1
1996	653	26	216	895	72.9
1997	604	37	234	876	68.9

Source: Annual Report of the Ministry of Water and Irrigation, Jordan (1998).

Table 6. Water requirement in 1995 and expected available resources during 2000-2010.

Volume of water 10^6 m^3	1995	2000	2005	2010
Available resources	800	850	1125	1175
Demand	1000	1150	1450	1550
Deficit	200	300	325	375

Source: Annual Report of the Ministry of Water and Irrigation, Jordan (1999).

Soils in Jordan

The soils of Jordan can be classified by four major zones which consist of different soils depending on differences in soil forming factors.

Rift Valley

Jordan Valley Soils

This area includes young soils, many of which cannot be called true soil. Soils located in the northern part are the oldest and become younger to the south. In the North-South direction, time and climate have played a major role in determining soil properties. In the North, the soils become deeper, with more $CaCO_3$ at depth and finer in texture, higher in organic matter and less saline mainly due to higher precipitation, lower temperature and a long time for weathering. In the East-West direction, the slope plays a major role in determining soil properties.
The soils range from deep, very coarse texture to shallow. Generally, the soil in the valleys has developed from the rock formation surrounding the valley. Alluvial soils occupy a very narrow strip along the Jordan River. According to the FAO soil map, the soils are classified in this area as Calcic Luvisols and Calcic Xerosol.

Wadi Araba

This area is located south of the Dead Sea and extends to the Red Sea. Soils in the true meaning do not exist in this area and those are Yermosol, very coarse textured and low in organic matter.

Highland soils

These soils occur west of the Jordan Valley. They are high in clay (>60%) (mainly montmorillonite). The depth of the soil depends on many factors such as slope, geographic location, aspect... etc. Four main soil orders can be identified: Entisol, Inceptisol, Vertisol and Alfisol. The color of the soils in this area varies and depends on clay, carbonate content and free iron oxide. It ranges from yellow brown to reddish brown.

Desert soils

This zone occupies about 80-85% of the total area. Grey desert soils predominate; they are characterized by their shallowness, high salinity or alkaline and low organic matter. They have unstable an surface structure and are often of low productivity.

Steppe

This zone is transitional between the semiarid and sub-humid area of the plateau and desert. Variation in topography is a good criterion that can be used to indicate the soil depth and intensity of weathering. Slope in this area greatly modifies moisture distribution. Consequently, soil depth increases towards the bottom of the slope.

Table 7. Chemical and physical properties of selected soils from different regions in Jordan.

Region	Local	Depth (cm)	pH (H_2O)	$CaCO_3$	O.M %	EC_e dS/m	N %	P mg/kg	K mg/kg	Texture
Jordan Valley	N-JV	0-25	8.2	18	1.6	2.5	0.127	7	275	Clay
		25-50	8.1	35	0.4	2.9	-	5	300	Clay
	M-JV	0-25	7.9	33	0.6	4.6	0.015	13	410	Clay loam
		25-50	7.9	38	0.2	5.3	-	10	450	Clay loam
	S-JV	0-25	8.4	48	0.12	12	0.002	10	542	Clay loam
		25-50	8.6	55	0.02	15	-	5	450	Sandy clay loam
Ghor Al-Safi	S-JV	0-25	8.0	22	0.98	14.7	0.05	11	652	Sandy loam
		25-50	8.3	28	0.29	12.8	-	3	732	Sandy loam
Irbid	N-JOR	0-25	8.2	8.1	1.13	0.89	0.087	5.5	712	Clay
		25-50	8.3	9.9	0.69	0.52	0.054	4.3	427	Clay
Al-Mafraq	N-JOR	0-25	7.9	25.1	0.52	8.3	0.027	4.3	455	Clay loam
		25-50	8.1	28.3	0.12	6.7	0.014	3.9	521	Clay loam
Al-Khaldia	N-JOR	0-25	8.0	22.3	0.68	18.1	0.049	5.4	335	Silty clay
		25-50	8.1	25.4	0.42	20.9	0.024	3.4	310	Silty clay
Al-Baqa	N-JOR	0-25	8.1	15.3	0.98	2.1	0.069	12.3	435	Clay
		25-50	8.1	18.6	0.62	2.9	0.054	5.9	399	Clay
AL-Rabbe	M-JOR	0-25	8.4	12.3	0.98	1.8	0.077	4.9	612	Clay
		25-50	8.1	15.7	0.59	2.5	0.044	3.1	527	Clay
AL-Shoubak	S-JOR	0-25	7.9	24.6	0.88	1.4	0.067	10	312	Clay loam
		25-50	7.6	27.3	0.49	2.5	0.035	6	421	Clay loam

Source: NCARTT.

Texture also becomes finer in the same direction. Soils orders that occur in this area belong to Inceptisol, Entisol, Aridisol and Vertisol.

These soils were classified as yellow and yellow Mediterranean soils. The yellow soils are extremely calcareous, weakly developed, low in organic matter, crusty, with a weak C_{ca} horizon. The yellow Mediterranean soils have a more developed B-horizon than the yellow soils.

Generally, the soils of Jordan are characterized by their poor fertility due to the fact that they have been under cultivation for centuries. The low organic matter content, high pH and carbonates mean small amounts of indigenous nutrients in soil that have restricted availability. Table 7 shows the chemical and physical properties of selected soils from different regions in Jordan. Table 8 shows the content of some nutrients in plant tissue of crops grown on these soils in the Jordan Valley. The values confirm the need to add K fertilizers.

Table 8. Content of some nutrients in plant leaves of crops grown in the Jordan Valley.

Crop	N %	P_2O_5 %	K_2O %	Fe mg/kg	Cu mg/kg	Zn mg/kg	Mn mg/kg
Tomato	2.74	1.00	5.22	250	22	144	125
Cucumber	2.57	0.90	4.11	187	25	166	118
Sweet pepper	2.66	0.65	5.21	220	30	170	125
Eggplant	2.63	0.67	4.28	198	18	198	132
Onion	2.03	0.55	3.28	230	26	165	144
Lemon	1.77	0.24	0.87	72	15	102	35
Orange	2.20	0.26	0.98	65	12	45	25
Mandarin	2.05	0.33	0.75	69	19	39	21

Source: Qawasmi *et al.* Reports NCARTT (1994, 1996, 1998, 2000).

Use of fertilizer in Jordan

The use of chemical fertilizers started in the irrigated agriculture area in the 1960s. In rainfed agriculture, farmers only apply organic manure.

Farmers in irrigated areas of the Jordan Valley usually use more fertilizer and manure than is needed by crops (Table 9) and there is no scientific basis for determining the amount of fertilizer to apply. More than 50% of farmers in the Jordan Valley use more than 60 m^3 ha^{-1} of organic manure for crops grown in plastic houses, and 40% of farmers apply more than 600 kg N ha^{-1}, and about 37% apply more than 120 kg P ha^{-1}. In the open fields, the animal manure is applied with small quantities of fertilizers.

Table 9. Mean fertilizers rates applied on vegetables in Jordan.

Crop	Method	TSP	Urea	AS	COMP	SOP	DAP	Fe
Potato	Conv.	300	300	-	-	25	-	-
kg ha^{-1}	Fert.	430	230	140	90	21	-	-
Tomato	Conv.	500	400	-	-	200	-	-
kg ha^{-1}	Fert.	640	450	230	180	-	-	-
Cucumber	Conv.	300	300	-	-	100	-	-
kg ha^{-1}	Fert.	750	410	290	500	-	-	1.4
Squash	Conv.	300	300	-	-	100	-	-
kg ha^{-1}	Fert.	500	260	250	100	-	-	-
Onion	Conv.	100	100	-	-	-	-	-
kg ha^{-1}	Fert.	560	190	190	30	-	-	-

Legend: Conv. = Conventional fertilization; Fert. = Fertigation; TSP = Triple superphosphate; AS = Ammonium sulphate; SOP = Potassium sulphate; DAP = Diammonium phosphate; Fe = Iron.

In general, the recommended rates of fertilizers for the major crops in Jordan are based on a combination of data from the literature, local experience (Tables 9, 10) and recommendations by the private sector. The Ministry of Agriculture, through its Extension Service and National Center for Agricultural Research and Technology Transfer (NCARTT) provides advice for farmers on the use, form, mode and quantities of fertilizers to be applied on different crops. Regional centers belonging to NCARTT provide soil and plant analyses for farmers at a minimum charge to encourage the proper use of fertilizers.

Table 10. Nutrients removed (kg/ha) by the main crops grown under plastic houses in the Jordan valley.

Crop	Yield	N	P_2O_5	K_2O
Tomato	150 t/ha	420	150	820
	kg / ton	2.80	1.00	5.46
Cucumber	120 t/ha	297	108	552
	kg / ton	2.47	0.90	4.60
Sweet pepper	100 t/ha	284	47	524
	kg / ton	2.84	0.47	5.24
Eggplant	100 t/ha	263	67.0	408
	kg / ton	2.63	0.67	4.08
Onion	55 t/ha	222	117	314
	kg / ton	4.03	2.12	5.70

Source: Reports NCARTT (1994, 1996, 1998, 2000).

The amount of fertilizers imported into Jordan each year between 1990 and 2000 is in Table 11. Jordan imports various NPK compound fertilizers, urea, ammonium sulphate, triple superphosphate and various micronutrient fertilizers. The quantities imported are not based on real agriculture need and are much less than those required. Recently (1989) diammonium phosphate (DAP) production has been started locally and the quantities produced about 7 × 10^5 t $year^{-1}$ domestic need. The production of single superphosphate (SSP) is nearly 10 × 10^3 t $year^{-1}$.

Table 11. Amounts of imported fertilizers in the period 1990-2000.

Year	Nitrogen fertilizers	Phosphorus fertilizers	Potassium fertilizers	Mixed fertilizers		Micro fert.	
	(t)	(t)	(t)	Solid (t)	Liquid (Litre)	Solid (t)	Liquid (Litre)
1990	29367	2488	300	2670	0	-	-
1991	42180	947	590	2946	2960	121	-
1992	75229	208	1307	4265	8984	228	18640
1993	44404	315	1037	2818	16100	-	-
1994	26717	195	1179	3928	6992	177	15520
1995	32988	2962	1398	18463	-	218	9030
1996	30877	3088	3110	3523	-	203	-
1997	41388	-	792	2658	-	219	-
1998	32501	-	1563	4653	22265	265	-
1999	24040	-	1696	5236	23010	303	54584
2000	16330	-	2792	7087	21976	253	46221

Source: Annual Report of the Department of Soils and Irrigation, MOA (2000).

Phosphoric acid has been produced in Jordan since 1997, with annual production of 224 × 10^3 t. Potassium chloride is produced in large quantities, more than 2 × 10^6 t $year^{-1}$ from the Dead Sea, all the production is for export. About 4 x 10^3 t of SOP is produced per year. Small amounts of monoammonium phosphate (MAP) and urea phosphate are produced locally nowadays. In the near future, 150 × 10^3 of KNO_3 and 5 × 10^3 of MgO will be produced in Jordan per year (Table 12).

Table 12. Local production of fertilizers in Jordan during 1999.

		Nitrogen fertilizers	Phosphorus fertilizers	Potassium fertilizers	Mixed fert.	Micro fert.
Liquid	(Litre × 10^3)	50	224 H_2PO_4	-	6	5
Solid	(t × 10^3)	6	700 DAP 10 SSP	2000 KCl 4 K_2SO_4	200	0.1

Source: Annual Report of the Department of Soils and Irrigation, MOA (2000).

Production of liquid fertilizers has started and they are used extensively in Jordan. Farmers can now order their own formula of solid and liquid fertilizers to suit their soil conditions and the crop to be grown.

Conclusions

More research is needed in the major agricultural areas in a form of integrated programs on fertilization for different crops. This is essential to improve K recommendation to increase both the yields and quality of agricultural crops.

Impact of soil nature and mineral composition on the management and availability of potassium in Lebanese soils.

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Abstract

Lebanon is an eastern Mediterranean country with 3-month mild winter season from December to March. There is a complex geomorphology with mountain and hill dominance and limestone with alternating marl abundance. The soils are in general saturated with exchangeable calcium (Ca) with the exception of Andosols and Andic Cambisols in the North and Arenosols in the Central Mountains. The mineralogy of the calcareous soil groups is dominated by montmorillonite, with a smaller calcite and illite content, while an intermediate amount of kaolinite and/or illite characterizes the unsaturated soil groups.

Soil analysis showed that with increasing kaolinite and illite, the potassium (K) activity ratio increased from 0.03 in the soils with calcite dominance up to 0.136 in the calcareous soils with montmorillonite prevalence and 0.205-0.326 in the soils with high kaolinite and illite. In the last soil group, both exchangeable and non-exchangeable K increased steadily with increasing presence of the respective minerals.

Research in the country focuses on optimal K threshold values in calcareous soils, especially for K-demanding crops. The K fertilization policy should not only address the amounts in the soil, as currently practiced in Lebanon, but also the K activity ratio, and include the potential ability of the soil to supply K as well as the availability of K to different plant species. This essential element should be made available in the context of the soil mineralogy, base saturation and crop needs. An appropriate management of K in Lebanese soils, notably under intensive cropping systems, would reduce the period between application of K and commencement of plant growth to minimize interactions of K in the soil, and allowing minimal water depletion in the root zone. This could be achieved by using modern irrigation techniques and fertigation, which could significantly increase K use efficiency.

Introduction

Due to a weak extension service, the fertilization of Lebanese land is mainly based on farmers' skills and inherited know-how. Usually, the fertilizer application is not related to soil reserves, crop demand and expected yield (Darwish, 1995). The farmer's concept of fertilization is based on the assumption that crops rely on the amount of fertilizers added yearly. But the amounts are not related to the specific soil and crop demands. As a result, K build-up is considerable in glasshouse soils (Atallah *et al.*, 1997). Crop rotations are either absent i.e. monoculture or they are very simple with no legume. For this reason, Lebanese farmers usually over-fertilize their land. Instead of improving soil fertility, this results in disturbing the balance between nutrients in the soil. For this reason, there has been an increase in the nitrate content in the inland groundwater (Darwish *et al.*, 2000).

In addition, salinization of the groundwater in some areas of the coast has resulted from excess pumping and seawater intrusion (Khawlie, 1999; El Moujabber and Bou Samra, 2001). Besides the competition between monovalent and divalent cations in Ca saturated soils, the input of monovalent cations, including Na with salts can further restrict the availability of K to K-demanding crops as protected tomato and cucumber, citrus, bananas and potato on the southern and northern coastal plains. Studies on the use of K in Lebanon showed a positive response of citrus on sandy soils at the Abde experimental station, North Lebanon (Dourmanov and Khouzami, 1974), while increasing K input to soils growing potatoes increased crop water use efficiency (Karam *et al.*, 2001).

In general, farmers apply equal amounts of low solubility complex fertilizers to major field crops, including potatoes. The ratio of $N:P_2O_5:K_2O$ is not always related to crop demand and offtake and often different nutrient inputs are summed to give a total addition (Johnston, 1997). The ratio of $N: P_2O_5:K_2O$ varies between 1:0.25-2.0:0.02-0.64 for the WANA countries, while it is 1:0.38:0.44 in the United States (Johnston, 1997). This implies the necessity of appropriate and integrated plant nutrient management. This paper summarizes the K status of Lebanese soils in relation to their mineralogy and K input in different cropping systems. It stresses the viability of a complex approach to K fertilizer application starting from K activity and forms of fertilizers, crop specific demands and response, and the ability of the soils to provide plants with sufficient K, notably during periods of maximum demand.

Current status of K in the Lebanese agriculture

Geomorphology, climate and soils of Lebanon

A complex geomorphology and diverse climatic conditions distinguish Lebanon. The country can be subdivided into three major pedoclimatic zones: 1. Dry coastal Mediterranean area with a mild winter and quaternary plains; 2. Sub-humid and humid mountain Mediterranean area with a short snow cover over steep mountains and limestone rocks; 3. The high inland Bekaa valley mainly with alluvial and colluvial soils. Central and western Bekaa has a dry subtropic climate while its northern and northeastern parts are semi-arid. These natural factors have resulted in diverse soil formations varying from Petric Calcisols in the northeastern Bekaa plain to Eutric Luvisols, Vertic and Calcaric Cambisols, Eutric Vertisols, Calcaric Arenosols and Eutric Fluvisols in the Central Bekaa, Lebanese Mountains and western Mediterranean coast respectively.

Land cover in the Lebanese mountains

This consists of pine and oak forests and coppices, shrubs and grasslands alternating with rock outcrops with severe water erosion and land degradation due to urban encroachment. Agriculture consists of cash field crops, vegetable and fruit production in the plains, apple and grape production in the mountains and citrus and banana cultivation on the coast. Glasshouses are dominant at some littoral locations with an intensive water and nutrient input for tomatoes and cucumber.

Soil and K interactions

The analysis of Lebanese arable soils (Sayegh *et al.*, 1990) showed that the soils of the Central Bekaa contained an optimum level of exchangeable K (200 mg/kg), while the soils of the coastal and mountain areas are generally deficient (100-175 mg/kg). However, it is rather difficult to divide the soils into such categories given the impact of land use and fertilizer policies on the residual K in the soil, its interaction with other elements and eventual accessibility. Indications of Ca deficiencies, due to excess K input, are seen in protected tomatoes and cucumber (Atallah *et al.*, 2000) and possibly in mountain apple orchards cultivated on neutral and slightly acidic soils. This is mainly due to disbalanced fertilizer input not related to the specific site and crop.

A study of the K supplying power of the soils (Masri and Darwish, 1984) showed that the slightly calcareous Cambisols and calcareous Arenosols under citrus in South Lebanon had, relatively, the largest potential supplying power (PBC) values (4.11 and 5.70 respectively). Meanwhile, the Calcisols contained the lowest potential (1.34). The analysis of the forms of K in these soils units showed that they contained 760-980 mg/kg total K and the exchangeable K varied from 51 and 52% of the total K.

The Calcisols contained the most water soluble K (38%) compared to 9 and 12% of the total K for the remaining soil units. It seems that the low level of water soluble K in Cambisols and Arenosols could be related to the eventual accessibility of K to the roots, while Calcisols saturated with exchangeable Ca, the antagonistic effect of bivalent cations may have resulted in retarding K diffusion from the soil solution. Meanwhile, given their low CEC and PBC, Calcisols are not able to maintain the K supply to crops.

Potassium activity versus soil mineralogy

The Lebanese soils are in general saturated with exchangeable Ca with the exception of Andosols of the North and Arenosols of the Central Mountains. The mineralogy of the calcareous soil groups is dominated by montmorillonite, with a smaller calcite and illite content while an intermediate amount of kaolinite and/or illite characterizes the unsaturated soil groups (Sayegh *et al.*, 1990).

Analysis of the available soil information on Lebanon (Lamouroux, 1971; Darwish and Gradoussov, 1979) showed some increase of kaolinite and illite from calcareous to non-calcareous soils.

Table 1. Impact of soil origin and mineralogy on the K status of major Lebanese soils (adapted from Sayegh *et al.*, 1990).

Mineralogy	Other minerals*	Nature	% saturation	Potassium, cmol$_c$ kg^{-1}		Activity
				Exchangeable	Fixed	
High kaolinite	Q, I, m, v	Non-calcareous	80-90	1.0	1.6	0.205
Medium kaolinite	Q, M, I	Slightly calcareous	80-94	0.6	1.0	0.105
Weak kaolinite	M, I, v, c, k	Slightly to medium calcareous	100	2.0	2.4	0.326
Weak kaolinite	M, i, v, c, k	Slightly to non-calcareous	97	0.9	1.2	0.130
	Q, C, M, k	Highly calcareous	99	0.7	1.1	0.136
Very weak kaolinite	M, q, v	Non-calcareous	96	0.4	0.5	0.052
	C, q, m, I, v	Calcareous	93	0.4	0.5	0.030
	D, Q	Calcareous	99	1.7	1.2	0.517

* Q: Quartz; I: Illite; M: Montmorillonite; V: Vermiculite; C: Calcite; D: Dolomite. Capital letters: major; Small letters: minor.

The K activity ratio increased from 0.03 in the soils with calcite dominance up to 0.136 in the calcareous soils with montmorillonite prevalence and 0.205-0.326 in the soils with a high kaolinite and illite content (Table 1).

In the last soil group, both exchangeable and non-exchangeable K increased steadily with the increasing presence of the respective minerals. However, K activity did not show clear correlation with % saturation.

Crop and element interactions

It is well known that K affects seed and fruit size and quality, for example citrus. Experiments in north Lebanon on citrus cv. Washington Navel showed a positive response to K on sandy soils (Dourmanov and Khouzami, 1974). However, similar experiments are lacking on other, clay montmorillonitic and vertic soils that dominate the area of citrus production in Lebanon. A survey of farmer practice for fertilizer application on citrus showed that the ratio of N:P_2O_5:K_2O was 1:1:1 (Table 2) in 46% of orchards in South Lebanon (Masri and Darwish, 1984).

The leaf analysis showed no correlation between leaf K and K in the upper 40 cm of the soil. One reason for this is that farmers' fertilizer application varies with soil type and history of fertilization. In fact, Lebanese farmers mostly apply complex fertilizers to citrus orchards (Figure 1). Around 5% of them apply a single form of K either as patent Kali or potassium sulphate. Consequently, there is an opportunity to improve farmers' practice by modifying the ratio between nutrients according to crop demand.

Table 2. Ratio of the major nutrients in the fertilizers applied to citrus in South Lebanon.

N:P_2O_5:K_2O ratio	Number of orchards	% of total
1 : 0 : 0	8	14
1 : 1 : 1	27	46
2 : 1 : 1	12	21
3 : 1 : 1	4	7
5 : 1 : 1	6	10
0 : 1 : 2	1	2
Total	58	100

On the other hand, the main problem for marketing grapes is the color and shelf-life and the level of available K affects these quality indicators (Vidaud *et al.*, 1993). The general fertilization recommendations for table grape are 50-150 kg N, 60-100 kg P_2O_5 and 0-240 kg K_2O/ha respectively (Tarchitzky and Magen, 1997).

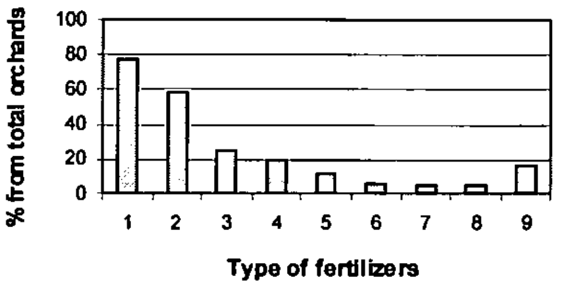

Fig. 1. Fertilizer application to citrus orchards in South Lebanon.
1. Complex; 2. Organic; 3. Ammonium nitrate; 4. Ammonium sulphate;
5. Chillan nitrates; 6. Superphosphates; 7. Patent Kali; 8. Potassium sulphates; 9. Microelements.

The area planted with grapes in Lebanon is 12.000 ha with an average yield of 7.6 t/ha (Ministry of Agriculture, 1999). In Lebanon, general farmer practice consists of applying yearly 2 kg ammonium sulphate and 1 kg superphosphate/plant. In many cases, potassium is neglected or added once in three years in a complex fertilizer with $N:P_2O_5:K_2O$ ratio of 17%:17%:17%, but even this is only under the better conditions. The amount of complex fertilizer added is usually 314.5 kg/ha but the components usually have low solubility and are applied to the soil.

Wheat is another strategic crop in Lebanon occupying 75% of the 52000 ha cultivated with cereals (Ministry of Agriculture, 1999). The area changes continuously according to government policy on subsidy. Total wheat grain production until 1996 was less than 20000 t but increased to 67000 t in 2000. The two main wheat varieties, Starck and Waha, are cultivated in the Bekaa plain which is the major wheat growing area of the country, producing 92% of the total production. The average yield varies from 7.5 t/ha in the fertile southern part of the plain to about 2 t/ha in the northern, dry part.

The main crop rotation is sugar beet-wheat-legume-potato and 2000 kg/ha of 17% NPK complex fertilizer is broadcasted before seedbed preparation for sugar beet, followed by 400 kg/ha of ammonium nitrate during growth. The residual P and K is considered sufficient for the next crop of wheat which gets only 200 kg/ha of urea (60% N) applied in two doses, during April-May. Starting from 2000-2001, government subsidies are oriented solely toward wheat production and sugar beet cultivation is totally neglected. Thus in the crop rotation, sugar beet has been replaced by wheat and consequently, there is a need for a new fertilization policy.

For potatoes, applying up to 288 kg K/ha in Central Bekaa resulted in a decline in both the transpiration and photosynthesis curves at midday (Karam *et al.*, 2001). Increasing amounts of K significantly increased yield up to 47 t/ha, which was associated with an increase in tuber size, by 25% with treatment K1 and 50% with K2 and K3, mainly in the larger tuber size (>50 mm) in comparison with the control K0. Similarly, water use efficiency was higher with more K.

Nitrogen and potassium interactions in fertigated potato

The form of a K fertilizer as well as the rate of N and K affects nutrient interaction and availability. The soil application of potassium sulphate for potatoes irrigated with macro sprinklers resulted in the accumulation of K in the shoots and late translocation to tubers (Table 3). By the stage of physiological maturity, the ratio of K-shoot to K-tubers was in favour of the fertigated treatment for an equivalent input of K and this was associated with a similar distribution of the shoot/tuber dry matter.

Table 3. Ratio of shoot/tuber potassium (K) and dry matter (DM) for potato var. Spunta at two phenological stages, receiving the same level of N and K applied in the soil and irrigated by macro sprinklers (Ncs), or by fertigation (N2) in Central Bekaa, Lebanon.

Treatments	Ratio of shoots to tuber			
	at maximum shoot growth 72 days after sowing		at physiological maturity 103 days after sowing	
	K	DM	K	DM
Ncs	2.54	2.03	1.0	0.50
N2	2.08	1.45	0.73	0.83

Trends and recommendations

Research in Lebanon should focus on optimal K threshold values in calcareous soils, notably for K demanding crops like potatoes and seed field crops and fruit trees. With the change in the government policy towards subsidized crops, the cultural practice has been changed and the need arises for a new fertilization policy consisting of on-farm advice for the application of K fertilizer to the wheat-potato-wheat-legume rotation. Additionally, experiments need to address the improvement of the quality for apples, grapes, citrus and bananas.

Moreover, the potassium fertilization policy should not only address amounts in the soil, as currently practiced in Lebanon, but it must also use the activity ratio. K fertilizer recommendations should include the potential ability of the soil to supply K as well as the current availability of soil K in its interaction with other elements. The amounts of K applied should relate to soil mineralogy and base saturation and timed to meet maximum plant needs. An appropriate K management for Lebanese soils could be provided through appropriate and integrated plant nutrient management. This implies improving the application technique, reducing interactions of K in the soil, applying a soluble form of K fertilizer, and allowing minimal water depletion in the root zone. This could be achieved by using modern irrigation techniques and fertigation, which could significantly increase K use efficiency.

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Potassium status in soils and crops: Fertilizer recommendations and present use in Morocco

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Abstract

Climatically, Morocco is essentially an arid and semi-arid country. To meet the food requirements of its growing population, a large effort has been devoted to water resources and its use for irrigation. At present, the irrigated sector, which represents only 13% of the total agricultural land, contributes about 50% of the production. However, water use efficiency in terms of product per cubic meter, needs to be improved. Balanced fertilization is one way to increase productivity. Soil fertility surveys and experimental research have been done in the different agro-ecological zones of Morocco.

Soils which are potassium (K) deficient with respect to high K demanding crops, such as sugar beet, sugar cane, sunflower, fruit trees and vegetables are located along the Atlantic coastal plains and plateaus. Soil K critical levels depend on soil type and the crop grown, and its potential yield. The last parameter proved to be important in assessing the response of a crop on a given soil type. Potassium greatly increased the quality of the production.

In the last ten years, pressurized irrigation systems have been developed in many arid and semi-arid regions of Morocco. Fertigation, using drip systems, has proved to be effective in water economy and water use efficiency.

Introduction

Morocco is an arid country with limited soil and water resources. Only 7% of the total area is located in the sub-humid mountainous regions of the North. Rainfed agriculture, which covers about 6 Mha, is dominated by an erratic cereal production. Water mobilization and its use for irrigation have been the basis for the economic and social development of Morocco since 1967. Presently, the irrigated agricultural sector covers 1 Mha (13%) of the total agricultural land which itself is only 12.7% of the total area of the country. Irrigated agriculture contributes up to 50% of the agricultural production.

However, water use efficiency (WUE) in terms of product/m^3 is still low compared to the potential. Balanced fertilization is one way to increase productivity and thus WUE.Many soil fertility surveys and research experiments have been done in Morocco including work on K. This paper summarizes some of the available information about fertilizer use in Morocco, the K status of Moroccan soils and the results of some fertility experiments.

Fertilizer consumption in Morocco

Moroccan farmers have used about 750,000 t of fertilizer per year during the last 10 years. This quantity represents only 28% of the need, which is estimated to be 2.5 Mt/year (Hammoutou, 2001). Compared to other Mediterranean countries, Morocco uses only a small quantity of fertilizers (Table 1). Large differences exist between the irrigated and rainfed agricultural production systems and also depending on the crop. Of the fertilizers applied, 58% are used in the irrigated areas, which represent only 13% of agricultural land. Vegetable, sugar and citrus crops cultivated under irrigation use 32%. However, cereals, which cover 76% of the agricultural land, receive only 42% of total fertilizer use.

Potassium fertilizers represent only 15% of the total consumption (50,000 tons of K_2O/year) mostly as potassium sulphate (SOP) and potassium chloride (MOP). Most of the potassium (75%) is used in the irrigated areas, especially for sugar beet in Doukkala region, and for vegetables.

Table 1. Fertilizer consumption in the Mediterranean region.

Region	Quantity of fertilizers used [kg($N+P_2O_5+K_2O$)/ha] 1981-85	1991-95	Reference
All Mediterranean region	109	107	MEDAGRI (2001)
North Medit. countries	134	130	MEDAGRI (2001)
South Medit. countries	51	62	MEDAGRI (2001)
Morocco	31	32	MEDAGRI (2001)
Morocco	-	45	Hammoutou (2001)
France	-	300	Hammoutou (2001)
Italy	-	161	Hammoutou (2001)
Spain	-	82	Hammoutou (2001)
Syria	-	60	Hammoutou (2001)
Tunisia	-	55	Hammoutou (2001)

Potassium status of the soils

Many studies on the K status of Moroccan soils have been made during the last 15 years. The results are summarized in Table 2. Although high spatial variability is a common feature, four different agricultural zones can be distinguished with respect to soil K fertility:

Zones with high soil K status: this group includes the soils of the Rif Mountains, the pre-Rif hills, which are formed on tertiary marls and secondary shale containing mica, illite and feldspars minerals; and the young alluvial soils of the Gharb plain, the Sais plateau, and the Moulouya plain. Although the mean exchangeable K is high, it is possible to find K deficient soils.

Zones with low soil K status: the red Mediterranean soils of the Atlantic Coast developed on calcareous sandstones and the terra Rosa developed on dolomitic limestone of the Atlas Mountains are low in K. The soils of Doukkala and Chaouia regions are generally low in exchangeable K, but the spatial variability is high.

Zones with medium soil K status: soils of the inland plains (Tadla, Haouz, Tessaout) have medium K status. They are developed on sediments coming from the erosion of the Middle and High Atlas mountains.

Zones with variable soil K status: soils of the Sahara and south of the Atlas Mountains have a very high variability in exchangeable K.

Table 2. Potassium status of soils in Morocco (mg K_2O/kg soil).

Region	Min	Max	Mean	Var. coeff. (%)
Rif, Gharb, Sais, Moulouya	133	1165	548	30
Middle Atlas, Atlantic Coast, Doukkala, Chaouia	40	500	180	53
Tadla, Haouz, Tessaout	112	728	380	34
South of the Atlas, Sahara	68	1528	397	64

There is no correlation between soil K fertility and soil type. The K fertility depends mostly on the parent material and the agricultural history of the land. However, soil K critical levels depend on the soil type and the crop, and its potential yield. Other K fertility criteria, such as K fixation and release capacity in relation to soil clay mineralogy were extensively studied and presented in earlier reports (Badraoui *et al.*, 1992; Badraoui *et al.*, 1997a; 1997b).

The extension services in Morocco promote soil analysis as a basis for adequate fertilizer recommendations. However, unless soil tests are calibrated with critical soil K levels for the major soil types and the most common crops, soil testing may not be sufficient to achieve a better use of fertilizers by farmers. In the last 20 years, soil fertility research in Morocco has been very active in establishing critical soil K levels in order to interpret soil analysis data. Some results were presented by Badraoui *et al.* (2002) for sugar beet, wheat and sunflower under irrigation. Here we give some additional data on the effect of K on crop productivity in Morocco.

The effect of potassium fertilization on the productivity and fruit quality of cucumber in the Agadir region (Abahmane, 1992)

A glasshouse experiment with cucumber grown on a sandy-loam soil containing 190 mg K_2O/kg exchangeable K tested rates of K ranging from 150 to 1500 kg K_2O/ha. Nitrogen (N) was applied at 450 kg/ha and phosphorus (P) at 300 kg P_2O_5/ha.

The total yield varied from 140 to 181 t/ha and K had a positive effect on fruit weight, fruit volume and export yields. The maximum yield was obtained with 500 kg K_2O/ha. Thus, when the soil K test is lower than 190 mg K_2O/kg of soil, cucumber responds to K under intensive cropping. The small increase in yield between 500 and 1000 kg K_2O/ha was not economic.

At maturity, K uptake ranged from 382 to 590 kg K_2O/ha depending on the amount of K applied (Table 3), maximum uptake was when 1000 kg K_2O/ha were applied.

Table 3. Nutrient uptake by cucumber grown in the glasshouse in the Agadir region of Morocco.

K treatment kg K_2O/ha	Nutrient uptake, kg/ha			$N-P_2O_5-K_2O$ ratio
	N	P_2O_5	K_2O	
150	200	118	382	1-0.59-1.91
500	270	154	539	1-0.57-1.99
1000	250	149	590	1-0.60-2.36
1500	230	133	530	1-0.58-2.30

The mean nutrient uptake balance of 1-0.58-2.14 shows that the cucumber crop needs two times more K than N and almost four times more K than P. At the maximum yield, the cucumber crop contained 1.5 kg N, 0.86 kg P_2O_5, and 2.99 kg K_2O/t of fruit.

Under glasshouse conditions, the soil nutrient supplying capacity (SNSC) is large (Table 4). At the optimum yield, the apparent SNSC to meet the cucumber requirement needs are 115 kg N/ha and 109 kg P_2O_5/ha.

Table 4. Soil nitrogen and phosphorus supplying capacities for cucumber as influenced by potassium application in the Agadir region.

K treatments	SNSC for nitrogen (kg N/ha)	SNSC for phosphorus (kg P_2O_5/ha)
150	42	73
500	115	109
1000	92	104
1500	72	88

Foliar application of potassium to citrus in Agadir region

The Agadir region is a major citrus producing area in Morocco and the classical way of using fertilizers is progressively changing to using fertigation. The yield of Clementine oranges is largely related to the fruit caliber and K and P have a major role in the development, maturation and quality of the fruit.

An experiment tested the effects of potassium phosphate (0-28-26) as a foliar application on Clementine trees (El Otmani *et al.*, 2001). The treatments were:

- Fertigation + foliar application of potassium phosphate (0.6 ml/m^3) applied at 10 L/ha twice:
  - at beginning of flowering stage
  - at beginning of flowering stage and at beginning of maturation stage
- Control: fertigation supply of 167 kg N-90 kg P_2O_5-230 kg K_2O/year

A substantial increase of yield, fruit number and weight per fruit was obtained when the foliar application of potassium phosphate was at both flowering and maturation stages (Table 5).

Table 5. Effects of foliar application of potassium phosphate on yield and yield components of Clementine oranges in the Agadir region.

Treatments	Total yield, kg/tree	Number of fruit per tree	Weight/fruit, g
Control	28.3 b	296 b	96.6 b
Flowering stage	31.8 b	340 ab	93.9 b
Flowering and maturation stages	40.3 a	394 a	103 a

Besides total yield, the exportable yield was increased by the foliar application of potassium phosphate but more important was the earlier maturation induced by this treatment. Foliar application of K and P proved to be effective on citrus trees in the Agadir region.

Long-term potassium fertility experiment

In 1984, a long-term K fertility experiment was started in the Gharb region using sugar cane as a soil K-depleting crop. The mean annual uptake of K by sugar cane is 500 kg K_2O/ha. The experiment was on an alluvial soil high in exchangeable K (>400 mg K_2O/kg) and with a very high K release rate (1.5 mg K_2O/kg daily). The irrigation water adds about 50 kg K_2O/ha per year.

The main results after 15 years of cropping without K fertilization are:

- A very slight decrease in exchangeable K;
- No apparent changes in clay mineralogy as assessed by x-ray diffraction;
- An increase of cation exchange capacity (CEC) of the soil; and,
- An important micro-structural transformation in the clay fraction as assessed by high transmission electron microscopy. The principal micro-structural transformations are: i) lower clay particle size, ii) weathering of sand and silt fractions, and iii) more interstratified illite/smectite clays not identified by x-ray diffraction.

The alluvial soils of the Gharb region, which are developed on erosion products of shale coming from the Rif mountains, have a large content of K bearing minerals. The K release rate is sufficient to cover the need of the most K demanding crops. The case of the alluvial soils in the Gharb region cannot be applied to other soils in Morocco. The soils of other regions, such as Doukkala and the Atlantic coastal plains, have low K release rates and K fertilizers are needed (Agbani *et al.*, 1997).

Potassium fertilization in rainfed agriculture in Morocco

Cereals are the major crops in the rainfed agricultural zone of Morocco. They cover about 6 Mha. Except for rainy years, yields are generally low (less than 2 t/ha) compared to the potential. Cereals do not respond to K fertilizers in the arid and semi-arid regions. Most sub-humid areas, which can produce high yields, have soils with high K fertility. Tree plantations and vegetable crops receive some K, but experiments are needed to assess the effect of K fertilization on orchards and vegetable crops in favourable semi-arid regions where annual rainfall is higher than 400 mm.

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The potassium status and its effect on the agricultural development in the kingdom of Saudi Arabia

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Introduction

The agricultural policy in the kingdom of Saudi Arabia has been very successful leading to a very noticeable increase, about 70%, in production. In addition, any surplus was exported to the international markets due to its high quality. Production from the agricultural sector was worth about 5200 M $ and, at the same time, agricultural imports were reduced by 3200 M $ and exports increased to 530 M $. All this has been achieved by the guidance of God and then the good policies of the Government represented by the Ministry of Agriculture and Water.

The country mostly lies in the arid region with the rate of evaporation greatly exceeding that of precipitation in general. Thus all the major farming areas have irrigation, and on the large farms water is supplied through central pivots covering an area of 35-75 ha.

Many factors have played a great role in agricultural development. One important factor is fertilization. Applying an adequate quantity of the right quality is the key for improved plant growth and production. Potassium (K) is a major element for plant nutrition. Sandy soils, which form the majority of the kingdom's soils, do not hold large amount of K and K has to be applied.

Agriculture in the kingdom

The kingdom of Saudi Arabia, which is part of the desert belt that includes some areas of north Africa and south west Asia, falls between the longitudes 34 40 and 56 E, and latitude, 16 30 and 32 N. The total area is approximately 2.25 M km^2 which is about 80% of Arabian peninsula (Ministry of Agriculture and Water, 1998).

Saudi Arabia is characterized by hot dry weather and is classified as an arid region occupying about 5% of the world's arid zone (Bashour, 1987). Relative humidity is low except along the eastern and western coastal zones where it sometimes reaches 90%.

Before the discovery of oil in 1935 and the emergence of oil-based industry, the main source of income was agriculture, practiced mainly in oases. The revenue generated by oil and oil by-products have brought about radical changes in the life-style of all sectors of society including those engaged in agriculture.

Many regions of the kingdom have adequate water resources and good soil for crop production. The major agricultural production areas are in Al-Qassim, Al-Jouf, Tabouk, Hail, Al-Hofouf, Al-Kharj, Wadi-Aldawasir and Nejran and Jizan. In 1980, specialized agricultural companies were established there and lands and loans were given to these companies to help their agricultural production and support the national economy. During the third national development plan (1980-1985), greater emphasis was given to the development of indigenous resources, especially water and agriculture. The objective was to achieve self-sufficiency in food production using locally available resources. It was expected that by 1990 Saudi Arabia would import very little produce for local consumption. Significant self-sufficient was achieved in production of some major agricultural commodities, including wheat, and certain commodities were produced in surplus and were exported to other countries.

Soil types in the kingdom

Soil can be defined as a suitable medium for plant growth and development. Plants are fixed in the soil by their roots and get water and dissolved nutrients from the soil via the roots. Fertile soil contains plant nutrients in a readily available form and plant growth and production are mainly dependent on soil fertility. The soil water holding capacity mainly depends on the soil texture. According to a report released by the Land Management Department of the Ministry of Agriculture and Water in 1985, there are 3 extensive areas of sand dunes covering about 40% of the kingdom's land. This report classified the land suitable for agriculture into the following classes:

Land suitability class	Area (ha)
I	157,000
II	718,200
III	629,500
IV	15,191,000
Total	26,695,700

The soil in these four classes are mainly alluvial soil developed by the weathering of silt-stone, shale and sandstone and thoroughly mixed by the action of wind and water or deposited in layers of varying texture. Soils suitable for cultivation are loamy sands or sandy loams in texture. The soil is usually calcareous and in some areas contains gypsum. Different soil types have developed due to the differences in soil forming processes such as temperature, aridity and wind erosion.

Chemical weathering of the soil occurs at a slow rate due to the low rainfall and in some areas soils contain high levels of soluble salts. Generally, the soil has little soil organic matter (less than 1%) and low available phosphorus (P) and nitrogen (N). The K level in most soils is adequate and varies with the soil texture, sandy soils usually have low levels of K. The dominant soil types include Entisols, Inceptisols and Artidisols. Special fertility management skill is required due to high content of $CaCO_3$ and the coarse texture of the soil.

Table 1. Summary of chemical characteristics of soil from some major agricultural areas in the kingdom.

Location	EC dSm^{-1}	pH	CaCO$_3$ %	P	K	Fe	Zn	Cu	Mn	Soil texture
				ppm						
Hail	3.3	7.7	8.5	8.6	156	1.8	0.5	0.3	1.5	SL
Tabuk	2.0	8.0	9.6	13.5	313	1.3	0.9	0.2	3.1	SL
Harad	1.8	8.9	13.6	1.3	20	1.6	0.3	0.1	0.7	SL
Al-Jouf	5.2	8.7	7.0	0.9	565	1.0	0.2	0.2	0.6	SL
Al-Kharj	2.7	7.7	21.2	5.8	241	4.0	0.7	0.5	4.8	SL
Al-Qassim	10.8	7.5	14.0	3.5	240	7.5	0.5	1.1	2.0	SL

Table 2. Summary of chemical characteristics of irrigation water from some major agricultural areas in the kingdom.

Location	EC dSm^{-1}	pH	TDS	Ca	Mg	K	B	Cl	Na
			ppm						
Hail	2.04	7.97	1436	169	29	8	0.35	375	280
Tabuk	0.74	6.95	418	53	ND	4	0.25	98	60
Harad	1.92	7.39	1330	143	57	8	ND	450	230
Al-Jouf	2.43	7.74	1536	139	49	16	0.55	505	300
Al-Kharj	4.52	7.06	5440	450	281	23	ND	710	2485
Al-Qassim	0.74	7.35	456	44	14	12	0.25	80	135

Fertilizers use in the kingdom

The use of fertilizers in the kingdom was unusual and was practiced randomly. Traditional agriculture was mainly around valleys oases where water was available from springs and shallow wells. Manuring was the main practice for applying nutrients to palm trees, orchards and vegetables. The rapid development of a new agriculture in the country necessitated the use of chemical fertilizers, especially N, P and K. The amount of P (P_2O_5) and K (K_2O) used in the country in 1987 was 206,140 t and 33,970 t, respectively (FAO, 1987). A summary of the most commonly used fertilizers in the kingdom since 1987 is given below together with their composition, with respect to the major elements, and to their degree of importance (%) (Mamdallah and Bashour, 1987).

Fertilizer type	%
Nitrogen fertilizer - urea (46% N)	29.6
Phosphorus fertilizers	
- Triple superphosphate (46% P_2O_5)	11.6
- Single superphosphate (20-25% P_2O_5)	N.S.
Potash fertilizers	
- Potassium sulphate (48-52% K_2O)	7.3
Compound fertilizers (two or more major nutrients)	
- Nitrophos (23-23-0)	20.7
- Nitrophoska (18-18-5-1)	12.0
- DAP (18-46-0)	7.5
- MAP (11-52-0)	5.3
- Nitrophoska (12-36-8)	5.4
- Nitrophoska	0.3

The importance of potassium fertilization

The use of fertilizers in the country has witnessed increased demand as a result of the horizontal expansion in agricultural cropping, accompanied by the farmers' awareness of the importance of maintaining good quality of the produce and achieving a sizeable economic return. For example, the N fertilizer industry is now meeting the needs of the local market, and achieving a surplus for export to other countries. Potassium and P fertilizers are imported and are needed in large amounts. Potassium chloride, also known as muriate of potash (0-0-60), is the cheapest and most common source of K fertilizer. It is used in most bulk blend starter fertilizers and for direct application. Some research has shown that potassium sulphate (SOP) and potassium nitrate (NOP) will have less effect on tuber specific gravity than potassium chloride, although all these three fertilizers will reduce specific gravity at high rates of application. Under good irrigation management and at moderate rates, very little difference in tuber quality has been observed in the field. Because of the higher cost of SOP and NOP and the lack of consistent improvement in tuber solids, these sources of K are not recommended over potassium chloride.

The amount of K taken up by many crops is greater than most other nutrients and may equal or exceed the uptake of N. On organic dairy farms in Denmark, K deficiency has been observed only occasionally. As a consequence of any increase in organic plant production, K might become a significant yield-limiting factor.
Soil type, mineralogy and K status are important factors in the K-supply of crops during the growing season. In Denmark, soil K-status is traditionally measured by means of the ammonium acetate method. This method estimates the amount of exchangeable K in soils. Crops growing in situations with a limited K supply are able to use K from the slowly exchangeable K fraction in soils and K from the subsoil. To obtain an improved assessment of the plant available K fraction, it would be necessary to examine other soil testing methods for K to include slowly exchangeable K and the contribution of K from the subsoil.

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Present situation of potassium use in agriculture in Syria

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Although potassium (K) is one of the major plant nutrients required in large amounts by most crops, K consumption in Syria is much less than it should be. The amount sold annually from 1990 to 1999 in relation to the amount held in stock is in Table 1.

Table 1. Quantity of potassium sold in Syria in the 10 years 1990-1999.

Season	Planned quantity t K_2O	Quantity in stock t K_2O	Quantity sold t K_2O	Sold as a % of quantity in stock	Sold as a % of planned quantity
1990/1991	22500	17200	9000	52%	40%
1991/1992	22500	13000	5900	45%	26%
1992/1993	22500	12000	5900	49%	26%
1993/1994	23500	14500	6400	44%	27%
1994/1995	23500	16000	6500	41%	27.6%
1995/1996	23500	16000	5800	36%	24.6%
1996/1997	20000	13500	7000	52%	35%
1997/1998	20000	10000	7300	73%	36.5%
1998/1999	20000	14000	8200	59%	41%
1999/2000	20000	13500	7400	55%	37%

The quantity sold each season has varied from 5900 to 9000 t K_2O. The planned quantity, i.e. the amount that should be available for sale, represents only about 30% of the quantity 65,000 t K_2O that estimates suggest should be applied annually.

Three examples illustrate the situation with regard to soil K status and K use in Syria:

Citrus: Of the soils planted with citrus, 59% are considered to be low in K, 9.5% have only medium amounts, 18.5% have adequate and 13% good levels of K.

Olive: Of the soils planted with olives, 12% are very poor in potash, 23% poor, 38% medium and 17% good.

Sugarbeet: 17% of farmers growing sugarbeet apply K fertilizer at rates less than the rate recommended by the Ministry of Agriculture for the amount of available K in their soil. 26% apply the recommended rate and only 3% more than the recommended rate.

Fertilizer and potassium status in soils and crops in Tunisia

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Introduction

In recent years, agricultural production has been intensified in Tunisia. However, even when water is not a limiting factor, yields and water use efficiency are still low mainly because of other limiting factors including agricultural techniques such as fertilization.

In rainfed areas, the main crops are cereals and olive trees while in the irrigated areas, the main crops are fruits and vegetables. This paper discusses Tunisian agriculture and the current situation regarding fertilization and K fertilization in Tunisia.

1. Background

1.1. General physical description

Tunisia is in the Mediterranean basin with a true Mediterranean environment with hot summers, winter rainfall and mild winters (Kassam, 1981) although there are variations related to the landscape. Soil characteristics, their nutrient status and their agricultural use are related to both the landscape and the climate.

Septentrionale Tunisia, the northern third of Tunisia, is divided into two main regions, the Tell and the Steppes, separated by the Dorsale, mountains oriented south-west to north-east and ending in the Cap Bon peninsula.

The Tell is a region with great variability in the landscape, with plains surrounded by mountains. The Steppes are plateaux which go from an altitude of 1000 m to sea level. The Dorsale is composed of the south-east ridges of the Tell. Part of the Tell and all the Steppes have a semi-arid climate. Agricultural production is in both the Tell and the Steppes.

1.2. The soil

Tunisia is almost entirely underlain by sedimentary rocks. From the Saharian shield to the Atlas, marnes, calcareous and sandstone rocks or sediments, were deposited until the middle of the Tertiary period and were affected by the Atlas orogeny. The soils are mainly from continental or coastal formations.

Soil types are related to the topography, the rock material, and the bioclimate, i.e. North and South of the Dorsale. The jebels (hills: Kroumirie-Mogods, Dorsale) were constituted by the Oligomicean and Pliovillafranchian orogenies acting on sedimentary rocks. Generally, soils are calcareous because they were directly formed from the rocks without any Quaternary silt. Very shallow and eroded soils are on the upper slopes while deeper and more weathered soils are at the slope foot, at the edge of the glacis. The slope is variable, constituting a major erosion risk unless cultivated with great care. These soils are classified as Lithosols, Regosols and Rendzinas depending on the parent material. Organic matter content decreases with the increase in aridity (2 to less than 1%).

Plateaux and glacis are observed throughout the country. They were developed during the quaternary era and are located on the lower slope of the mountains. Calcareous accumulation constitutes their main characteristic in the semi-arid and arid area and variation results in the differences in soil types.

Calcareous accumulation can be as crust and soil types are then shallow Rendzinas in the north and Lithosols in the steppes (South of the Dorsale). Organic matter is concentrated in the upper layer, ranging from 2 to 3% in the Rendzinas to less than 1% in the Lithosols of the steppes.

Soft calcareous accumulation (crusting) is associated with calcareous Cambisols (brown calcareous soils). These soils are deep with a high organic matter content (2%) and large water storage capacity. In semi-arid areas, these soils are suitable for cereal production.

Calcareous accumulation can be throughout the whole profile, being more concentrated in the deeper layers. These soils are classified as isohumic (Calcic Xerosols); they have high water storage capacity, organic matter content ranging from 2 to less than 1% at the south of the Dorsale.

Plains are of alluvial formation, water being directed to the lower part of the plain called garaa or sebkha. Variations in soil classification are related to the vertic character, to hydromorphy and to salinity.

A major characteristic of Vertisols is the presence of wide cracks observed in the profile from the upper layer to a depth of more than 50 cm. The cracking is related to their clay content, the clay being mainly montmorillonite. Vertisols have a large water storage capacity; when dried, reduction in water content affects the whole profile. The organic content is homogeneous in all the layers of the profile and varies between 2 to 4% while it can be as low as 1% in soils with a vertic tendency in the arid areas. They are considered the best soils for cereal production.

Hydromorphy and salinity increase from the peripheral area (coarse texture, better drainage) to the inner part of the plains where soils are fine-textured and generally deep; water accumulates in the inner part in winter and salinity increases from the upper part to the lower part of the plain; it also increases from the North to the South of the country. Soils with hydromorphic aspects are little evolved and classified as Gleysols, they are used for barley production. Salt affected soils with a high degree of gleying are at the edge of the sebkha and classified as Solonchachs and Solonetz soils.

Sand accumulation and beaches are coastal formations (e.g. Cap Bon peninsula, plain of Sfax). They consist of red Mediterranean soils, red lessivé soils, calcimorph soils or isohumic soils. Soils located on recent dunes are not evolved. They are classified as Lithosols and Regosols with a low organic content (<1%). They are mainly used for orchards and are irrigated when water is available.

1.3. The climate

The main climatic characteristics of the different bioclimates have been summarised and are mapped at a scale of 1/500000 (Bortoli *et al.*, 1969). The authors also describe the main bioclimatic zones in Septentrionale Tunisia.

The main regional climatic variations are between the Tell and the Steppes, which highlights the limit of the Dorsale. From the North to the South, and mainly in the South of the Dorsale, the aridity increases as well as the year to year variability.

The rainfall is erratic and irregular. It decreases from humid to arid areas while its irregularity increases. For an average rainfall between 600 (sub-humid) and 300 mm (semi-arid), the standard deviation is between 200 and 100 mm, respectively.

Average temperature from December to May varies from 8.5°C (January at Siliana) to 21.1 (May at Kairouan). Temperatures are not high enough during the cereal growing season to stop vegetative growth. The average value of maximum day temperature from April to June is between 19.4°C and 33.2°C, however maximum recorded day temperature may be very large in April (35.7°C at Jendouba, 37.8°C at Kairouan) and particularly in June (from 35.9°C to 46.9°C). These very hot conditions are frequent and could affect crop growth; the major risk being from the sirocco.

Sirocco is a hot dry wind blowing from the Sahara in the south to the south-west (Bortoli *et al.*, 1969). Its duration is generally between 1 and 2 days but it results in a temperature rise of up to 10°C within a day, a decreased air humidity and an increased evaporation. It can occur all year round but mainly from April to September.

1.4. Consequences for agricultural production

Jebels are used mainly for forests and grazing areas. At the edge of the jebel are orchards and the start of the cereal areas which stretch from the glacis to the edges of the sebkha.

Nutrient status of soils is related to the climatic area. In the north of the Dorsale, soil humification allows a better nutrient status and nitrification is important in spring. With increased aridity, organic matter content is lower and nitrogen (N) is provided by fertilizer application.

Calcium carbonate is almost always present in Tunisian soils with a content of active calcium carbonate between 5 and 20%, which increases soil pH and reduces P availability with consequences for orchards and cereals.

Considering the different soil and climatic constraints, two factors will determine the potential of a soil for agricultural use: the organic matter content and the water storage capacity. In soils with low organic matter content, nutrients can be provided by applying fertilizers but water for irrigation is a scarce resource and cannot be applied whenever drought occurs. Hence, water availability becomes the main limiting factor for increasing agricultural production and this factor is related to the climatic area, the rainfall and its timing and the water storage capacity of the soil.

2. Tunisian agricultural production

2.1. Farming systems

Farms are under both private and public ownership. Along with a developed public sector, there is an important private sector with great variability in the size of the farms and in the farming systems. There are about 471,000 farm holdings with an average area of 11.2 ha. In the private sector, the main agricultural areas (24% of the cultivated land) are cultivated by 1% of the farmers having farms of at least 100 ha while 38% of the cultivated area is cultivated by 85% of the farmers whose farms are less than 20 ha (Ministère de l'Agriculture, 1996). This fragmented production results in very variable agronomic practices.

2.2. Main crops

Tunisia has a total area of 163,610 km² of which 9 Mha are agricultural area with 2.8 Mha of annual crops, 2.3 Mha permanent crops and 3.9 M ha permanent pastures. The irrigated land occupies 0.380 Mha, 30000 ha being drip irrigated (Table 1).

Table 1. Land use in Tunisia.

	Area (Mha)
Area	16
Agricultural area	9
Annual crops	2.8
Permanent crops	2.3
Permanent pastures	3.9
Irrigated land	0.380

2.2.1. Annual crops

Annual crops (Table 2) are mainly cereals, and among them the most important crop is durum wheat which occupies about 0.8 Mha. Production and yields are highly variable and related to the rainfall. When rainfall is high and well distributed during the growing season, yields can reach 1.4 t/ha with a production of 2.8 Mt while in a dry year, national production can be as little as 0.3 Mt.

Irrigated cereals are grown on about 7,000 ha and the objective is to reach 10,000 ha. Even in this case, cereal yields are still low and do not reach yields obtained on experimental stations.

2.2.2. Permanent crops and fruit trees

Olive trees, almonds and vineyards are the main non-irrigated fruit trees in Tunisia. Olive trees occupy more then 1.5 Mha while the vineyard area has decreased during the last years from 46000 ha in 1961 to 27000 ha in 2000.

During recent years, grape production has been developed in irrigated areas as well as other fruit trees (Table 2). With the use of irrigation, yield increased and agronomic practices have been intensified for some species while others still have very low yields and low intensification. For irrigated orchards, yields increased while in rainfed conditions, yields are still highly variable (Figure 1). Among fruits, the production of citrus and dates is oriented towards export.

2.2.3. Vegetables

Area and yield of the main vegetables is summarized in Table 2 and Figure 1. During the last few decades, an effort has been deployed to develop the irrigated sector in Tunisia. Although it represents only 7% of the cultivated areas, it contributes 30% to the total agricultural production and yields of most crops are increased significantly in recent years. The use of irrigation has allowed an increase in both the vegetable area and yield with the increased use of inputs.

Table 2. The areas of annual crops, trees and vegetables in Tunisia.

Annual crops	Mha	Vegetables	ha	Fruit trees	ha
Cereals	1.53	Tomato	27 000	Olives	1 500 000
Fodder crops	0.22	Pepper	15 000	Almond	170 000
Food legumes	0.10	Potatoes	27 000	Grapes	27 000
Vegetables	0.15	Melon	27 000	Pistachio	22 000
		Others	30 000	Peaches	20 000
				Apricot	12 000
				Apples	26 000
				Pears	12 500
				Citrus	18 000
				Date palms	30 000

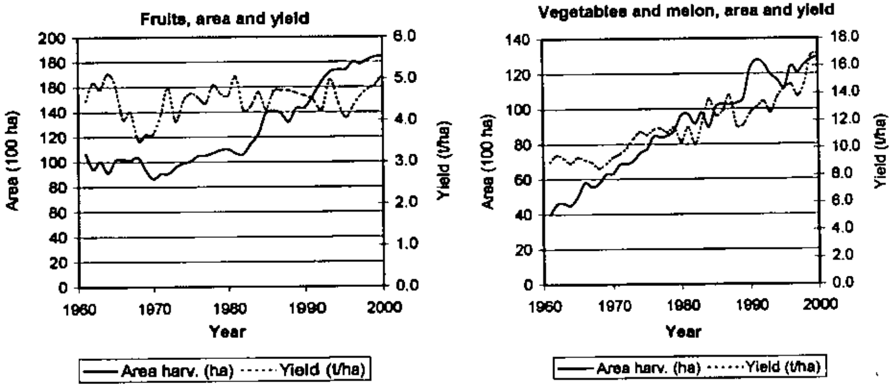

Fig. 1. Fruits and vegetables: Area and yield (FAO Database).

2.3. Use of fertilizer in Tunisia

The amount of N, P and K used in Tunisia increased during recent years; it has been reported as 3000, 10000 and 2300 t in 1961 and 65000, 43000 and 4200 t in 1999, respectively. Hence, fertilizer use is unbalanced, although the increased use has occurred in recent years. In the early sixties, the N:P_2O_5:K_2O ratio was about 1.00:3.50:0.08 and at the end of the century, it was 1.00:0.70:0.06. Consumption of P has been reduced while N increased as well as K but to a smaller extent (Figure 2).

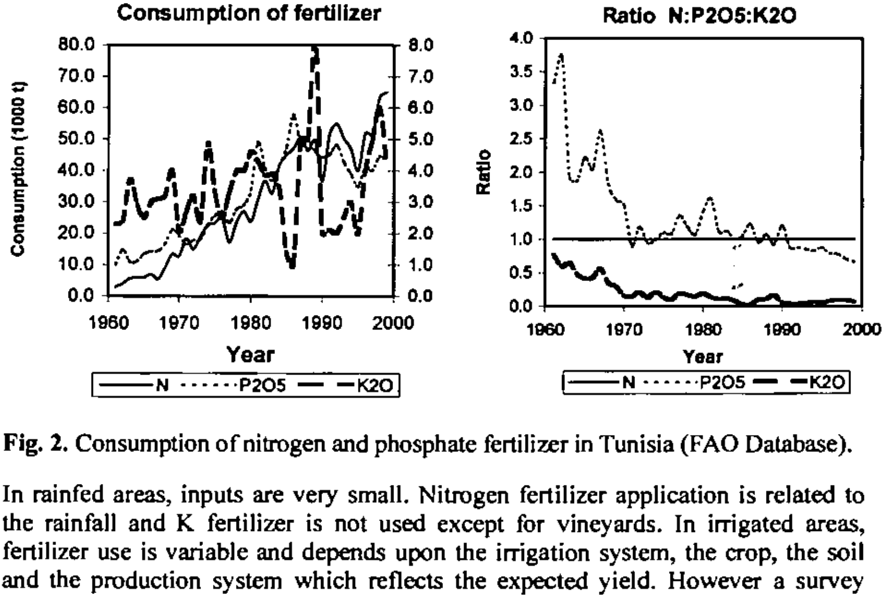

Fig. 2. Consumption of nitrogen and phosphate fertilizer in Tunisia (FAO Database).

In rainfed areas, inputs are very small. Nitrogen fertilizer application is related to the rainfall and K fertilizer is not used except for vineyards. In irrigated areas, fertilizer use is variable and depends upon the irrigation system, the crop, the soil and the production system which reflects the expected yield. However a survey made by the Ministry of Agriculture gives an estimate of the use of N and P fertilizer for different crops (Table 3).

Table 3. Use of fertilizer in Tunisia (Ministère de l'Agriculture).

	N, P_2O_5 (kg/ha)	N, P_2O_5 (1000 t)
Cereals	22, 18	33, 27
Fodder crops	19, 17	4, 4
Fruits	24, 10	4, 2
Vegetables	51, 31	6, 4

2.4. Use of potassium fertilizer

In Tunisia, field experiments in rainfed conditions showed that K fertilizer did not increase yield. It was shown that fine textured soils had enough K to satisfy crop needs, rainfed conditions being associated with lower yields.

This result was also observed in irrigated conditions for cereals but other results showed a positive effect of K fertilizer on wheat in irrigated conditions (Mhiri, 1997). With olive trees, it was observed that K increased yield in irrigated conditions and also could have a small effect on sandy soils in rainfed conditions.
Research results had contradictory results and it could be related to soil texture.
Alluvial soils are clayey to clayey loam with montmorillonite, kaolinite and illite. On the other hand, sandy soils have a low level of available K and a major proportion of fruit trees are grown on sandy soils.
The use of K fertilizer will depend mainly on the crop and the level of intensification. For fruits, K is applied as K_2SO_4 or KNO_3. It can be either broadcasted or used with fertigation or as a foliar spray. For vegetables, K is applied with drip irrigation. For cereals, no K is applied. However, it can be applied to irrigated cereals but results on its effect are contradictory. In some experiments, we observed that K had an effect on limiting the spread of wheat leaf diseases.

3. Conclusion

Nutrient availability to the crop is related to several factors and nutrient application should meet the requirements of the plant. Integrated nutrient management should take into account soil, weather and target yield for the different elements. Fertilizer recommendations are still needed for integrated plant nutrient management and efficient crop production in an environmentally benign way.

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Potassium content of arable lands and irrigation waters in Turkey

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Turkey is a peninsula with a surface area of 78 Mha. Agricultural lands cover about 36% of this total and about 35% of the total population (63 million) work in agriculture. About 26 Mha could be irrigated, but only 8.5 Mha can be irrigated economically.

Annual rainfall varies from 220 to 2500 mm, the average is 624.6 mm equal to 501 km^3 per year. About 186 km^3 is lost by surface runoff. According to the research of the State Water Works (DSI), river flow can be regulated and maximum benefit gained by means of a total of 805 dams and 485 hydroelectricity stations (Table 1).

Table 1. Land resources (DSI).

The projected area of Turkey	77.95 Mha
Arable lands	28.05 Mha
Irrigable lands	25.85 Mha
Economically irrigable lands	8.50 Mha
Existing irrigation area (beginning of 1999)	4.70 Mha (brut)
Irrigation schemes constructed by DSI (beginning of 1999)	2.164 Mha
Water resources	
Mean annual precipitation in Turkey	642.6 mm
Volume of the mean annual precipitation in Turkey	501.0 km^3
Surface water	
Annual flow	186.05 km^3
Annual runoff coefficient	0.37
Annual amount of water to be used for consumptive purposes	95.0 km^3
Present annual consumption	27.5 km^3
Groundwater	
Annual safe yield	12.2 km^3
Allocated amount	7.6 km^3
Present annual consumption	6.0 km^3

Generally, our agricultural soils are low in organic matter, slightly alkaline in reaction, except in the East Black Sea region, and generally with a large clay fraction. From 1970, the area growing vegetables and fruit orchards has increased while the area of vineyards and olive plantations has decreased (Table 2).

Table 2. The distribution of agricultural lands (1000 ha).

Year	Arable area	Fallow land	Field crops	Horticult. crops	Viticult.	Fruits	Olive	Total
1970	15591	8705	24296	447	845	1019	731	27338
1975	16241	8177	24418	490	790	1163	801	27662
1980	16372	8188	24560	596	820	1386	813	28175
1985	17908	6025	23933	662	652	1470	816	27506
1990	18868	5324	24192	635	580	1583	866	27856
1991	18776	5203	23979	652	586	1560	877	27654
1992	18811	5089	23900	663	576	1565	871	27575
1993	18940	4887	23827	654	567	1615	872	27535
1994	18641	5255	23896	709	567	1618	881	27671
1995	18464	5124	23588	785	565	1340	556	26834
1996	18635	5094	23729	790	560	1344	568	26991
1997	18605	4917	23522	775	545	1364	658	26864
1998	18751	4905	23656	783	541	1389	600	26969
1999	18436	4905	23341	790	530	1404	600	26665

Table 3. Production of agricultural crops grown in Turkey (Ministry of Agriculture and Rural Affairs, 2001).

Crops	Production 1999 (t)	Production 2000 (t)
Field crops	**59,526,576**	**63,578,357**
Cereals	28,885,720	32,248,694
Pulses	1,355,550	1,311,300
Industrial plants	19,426,312	21,268,981
Oil plants	1,150,994	958,382
Bulbous plants	8,708,000	7,791,000
Vegetables	**22,083,352**	**22,357,612**
Vegetables edible leaves	1,633,680	1,670,650
Vegetables edible fruits	19,122,500	19,283,500
Leguminous vegetables	622,000	660,000
Bulbous and root vegetables	628,660	653,450
Other vegetables	76,512	90,012
Fruits	**13,069,237**	**14,179,138**
Pome fruits	2,968,700	2,901,100
Stone fruits	1,966,200	3,357,300
Citrus	2,263,400	2,222,200
Hard shell-fruits	786,000	758,000
Grape and berries	3,989,405	4,182,500
Tea	1,095,532	758,038

According to the statistics given by Ministry of Agriculture and Rural Affairs, the three major crops grown in Turkey in 2000 were:

Wheat, 21 Mt; sugarbeet, 18.8 Mt; and tomatoes, 8.9 Mt.

Fertilizer statistics show that less potassium (K) is used than nitrogen (N) and phosphorus (P) (Table 4). Compared to 1998, total K use decreased by 9% in 1999, total use was 80675 t K_2O.

Table 4. The fertilizer consumption in Turkey between 1995 and 1999 (Anonymous, 2000).

Fertilizer type	Fertilizer consumption (t) 1995	1996	1997	1998	1999	Change (%) 96/95	97/96	98/97	99/98
AN %26	1252951	1294681	1187884	1272858	1226696	3	-8	7	-4
AN %33	144559	191933	249551	367972	614824	33	30	47	67
AS	292718	244297	303278	354830	322102	-17	24	17	-9
Urea	580804	728356	725448	897153	1000001	25	0	24	11
TSP	90415	60261	82389	66873	48039	-33	37	-19	-28
DAP	560335	573600	607417	725456	631626	2	6	19	-13
20:20: 0	945621	975174	1043235	1198981	1212561	3	7	15	1
15:15:15	271698	306556	306894	333848	313480	13	0	9	-6
25: 5:10	2459	1669	24074	49929	71936	-32	1342	107	44
8:24: 8	218560	195816	84000	1678	83	-10	-57	-98	-95
12:30:12			3772	138673	94251			3576	-32
10:25:20				17905	20666				15
25: 5: 0	7655			9868		-100			-100
26:13: 0			1010	1340	977			33	-27
11:52: 0	272	343	476			26	39	-100	
Total compound	1446265	1479558	1463461	1752222	1713954	2	-1	20	-2
K_2SO_4	11615	17307	16465	19980	14076	49	-5	21	-30
KNO_3	6081	6622	5494	6723	8634	9	-17	22	28
$Ca(NO_3)_2$	323	684	1068	841	1117	112	56	-21	33
TOTAL	*4386066*	*4597299*	*4642455*	*5464908*	*5581069*	*5*	*1*	*18*	*2*
N	1053737	1147658	1167003	1394906	1485624	9	2	20	7
P_2O_5	579613	578044	592397	701983	637924	0	2	18	-9
K_2O	67090	73515	66374	88509	80675	10	-10	33	-9
TOTAL	*1700440*	*1799217*	*1825771*	*2185398*	*2204223*	*6*	*1*	*20*	*1*

Potassium contents of the agricultural soils in Turkey

The most used method for determining the available K in the soils of Turkey is extraction with 1 N ammonium acetate. The soils in the seven different agro-ecological regions in Turkey have different properties and different crops are grown on them. In addition, to different soil properties, the variation in rainfall in these regions creates variations in the K content of the soils.

For example, the East Black Sea region generally is covered by podsols and the main crops are tea, hazelnut and maize. Average annual rainfall is 1000-1200 mm and for this reason, 70-80% of the soils need K fertilization. Because of the high rainfall and little fertilizer use, the K content of soils was less than in soils from the other regions. For 381 soil samples from this region, the average exchangeable K was 253.44 mg kg^{-1}, range 27.44 to 1227.48 mg kg^{-1}.

The Tea Research Institute in this region reports that more than 70% of the soils need K fertilization. There is no detailed data related to the soil analyses for hazelnut. However, Turkey is the primary producer of hazelnuts worldwide and meets 80% of the world's requirement. In samples taken from different places in this region, 15-55% were reported to have low levels of K (Sarimehmet, 1987). Another researcher (Genc, 1987) states that the region's soils were deficient in K and P. In 120 samples, the K content varied and, in general, was between 200 to 300 mg kg^{-1} (Aktas, 1978 and 1979; Kacar *et al.*, 1978; Karaçal, 1973).

In the Thrace region, the part near to Marmara Sea, the non-calcic brown, Grumusol and Rendzinas are the dominant soil groups. The crops grown are sunflower, maize, processing tomatoes, sugar beet, tobacco and wheat. Data for 250 soil samples taken from soils growing processing tomatoes showed that 60% of them needed K. Another study in the same region showed that, for 118 soil samples, the K content was between 300 to 400 mg kg^{-1} (Okan, 1988; Yagmur, 1997; Ozturk *et al.*, 1996).

In the middle Anatolia region, brown soils predominate. In some places, saline and alkaline soils are also found. The main crops grown in the region are wheat, sugar beet, barley and potatoes. Soil analyses from different places of the region showed a considerable range in the K content. In 153 samples, the range was 76 to 928 mg kg^{-1} and in 97 samples from 30 to 1328 mg kg^{-1} in the central region, and 187 to 893 mg kg^{-1} in 18 samples in the northern part of the region. Most of the soils contained >400 mg kg^{-1} K. According to the Sugar Research Institute in the region, 42% of the soils have sufficient K (Aktas and Karaçal, 1988; Usturali, 1995; Aktas, 1978; Gunes *et al.*, 1996; Yalcin *et al.*, 1994).

The Aegean region is covered by some of the most fertile soils of Turkey and is under intensive agriculture. Many crops can be grown on these fertile soils but main ones are olive, grape, cotton, fig and citrus. The results of soil analysis made by the sales cooperative TARİŞ showed the need of K fertilization in deereasing order as fig>grape>olive>cotton. In addition, it was suggested that 80% of the soils need K fertilization. In 391 soil samples taken from vineyards, fig, cotton, olive, potato and tobacco fields, the K content was between 4 to 678 mg kg^{-1}. Within this range, 20% of soils contained less than 100 mg kg^{-1} and 28% were between 100 to 150 mg kg^{-1} (Irget, 1988; Aksoy *et al.*, 1987; Anaç *et al.*, 1992; Coskun, 1989; Saatci and Hakerlerler, 1994; Seferoglu, 1997; Duzbastilar, 1983). Also, Kovanci and Duzbastilar (1987) found that 34% of cotton fields in the region, 54% of wheat fields, 44% of olive orchards and 77% of fig orchards contained less than 15 mg kg^{-1} K. This emphasizes the fact that, if 25% of the soils lack K in a region like Aegean, where most of the farmers are educated and well trained, there is a need to promote the use of K vigorously.

Another region under intensive agriculture is the Mediterranean Region. Terra Rosa and alluvial soils are the dominant soils in this region. The main crops are citrus and cotton together with glasshouses. The range of K in 176 soil samples was 55 to 1891 mg kg^{-1}. Glasshouse soils, 60-65% of the samples, are generally rich in K (Agca and Dinc, 1989; Koseoglu *et al.*, 1995). Also, the concentration of K in the leaves taken from plants growing in the region supported the view that there was sufficient K in the soils (Katkat and Kacar, 1980).

The East Anatolia region is a high plateau mostly covered by chestnut coloured soils. The main crop in this region is cereals. Generally neither the need for irrigation or fertilization of the crops is met. The range of K in 90 soil samples taken from arable land was 70 and 1950 mg kg^{-1} with 30-60% of the soils containing >400 mg kg^{-1} K (Sezen, 1975; Topbas, 1978; Aydemir, 1990).

The Southeast Anatolia region, because of the great dams established in the region, will become an important region for agriculture. Red-brown soils cover the agricultural land and main crops are wheat, barley, watermelon and melon. Dinc (1986) reports that the K contents of soils in the Harran plain ranged from 150 to 3705 mg kg^{-1}. Also, the K content of 152 soil samples taken from the region ranged from 179 and 2145 mg kg^{-1} and 35-80% of these soils contained >400 mg kg^{-1} (Dinc *et al.*, 1991; Guzel *et al.*, 1991; Hakerlerler *et al.*, 1993).

Potassium contents of irrigation waters in Turkey

The economically useable groundwater potential of Turkey is 9×10^9 m^3 $year^{-1}$. Total useable surface and ground water potential is 104.4×10^9 m^3 $year^{-1}$ (DSI). The main source of agricultural water in Turkey, which is a country rich in water, is precipitation, followed by surface and well waters. Table 5 gives the quality parameters and usual range in typical irrigation water.

Table 5. Laboratory determinations needed to evaluate common irrigation water quality problems (FAO).

Water parameter	Symbol	Unit	Usual range in irrigation water
Salinity			
Salt content			
Electrical conductivity	EC_w	dS m^{-1}	0 - 3 dS m^{-1}
Total dissolved solids	TDS	mg l^{-1}	0 - 2000 mg l^{-1}
Cations and anions			
Calcium	Ca^{++}	me l^{-1}	0 - 20 me l^{-1}
Magnesium	Mg^{++}	me l^{-1}	0 - 5 me l^{-1}
Sodium	Na^{+}	me l^{-1}	0 - 40 me l^{-1}
Carbonate	$CO_3^{=}$	me l^{-1}	0 - 1 me l^{-1}
Bicarbonate	HCO_3^{-}	me l^{-1}	0 - 10 me l^{-1}
Chloride	Cl^{-}	me l^{-1}	0 - 30 me l^{-1}
Sulphate	$SO_4^{=}$	me l^{-1}	0 - 20 me l^{-1}

Table 5. Continued.

Water parameter	Symbol	Unit	Usual range in irrigation water
Nutrients			
Nitrate-nitrogen	NO_3-N	mg l^{-1}	0 - 10 mg l^{-1}
Ammonium-nitrogen	NH_4-N	mg l^{-1}	0 - 5 mg l^{-1}
Phosphate-phosphorus	PO_4-P	mg l^{-1}	0 - 2 mg l^{-1}
Potassium	K^+	mg l^{-1}	0 - 2 mg l^{-1}
Miscellaneous			
Boron	B	mg l^{-1}	0 - 2 mg l^{-1}
Acid/basicity	pH	1-14	6.0 - 8.5
Sodium adsorption ratio	SAR	me l^{-1}	0 - 15

Table 5 shows that the K content of the irrigation water is usually very low. When worldwide data on the irrigation water analysis is studied, the results show that the K content in 250 water samples ranged between a trace and 3 me l^{-1}; the maximum value was in a groundwater sample from Ethiopia. The irrigation waters in Turkey are also very low in K generally. However, in some rivers and the some irrigation waters polluted by industrial and domestic wastewaters, the K level can be high.

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