Near East
fertilizer-use manual

Cover photographs:

Background: High yielding variety of Mexican wheat growing at the Ouled M'Hamed experimental and demonstration centre in Central Tunisia. FAO/7403/F. Botts.

Top: Harvesting greenhouse tomatoes, Kuwait. FAO/10418/F. Mattioli.

Middle: Wheat harvest being checked and bagged at one of many collection depots by National Wheat Board workers - a typical scene along Tunisian roads in June. 1987 was a bumper year for Tunisia, the average wheat yield being 30 quintals per hectare. Tunisia. FAO/14152/F. Botts.

Bottom: Farmer Mushim Khaier, who gets extension assistance from the project, examines cucumber seedlings grown in a nursery on his farm near the village of Bani-Jamara. Bahrain. FAO/10412/F. Mattioli.

Near East
fertilizer-use manual

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Foreword

The FAO Regional Office for the Near East in Cairo is pleased to present this publication. It constitutes an example of the collaborative and fruitful efforts of the three co-sponsoring agencies: the FAO Regional Office, the Arab Fertilizer Association in Cairo and the International Fertilizer Industry Association in Paris. Twelve soil scientists, plant nutrition experts and fertilizer specialists from across the Near East collaborated to enrich this document with their expertise and results from field-tested trials and recommendations.

The Near East region, which embraces about 10 percent of the world population, enjoys only about 2 percent of the global internal renewable water resources. The average arable land for the region is barely 0.2 ha/capita and likely to decline further with the ongoing expansion of urban, industrial and tourism activities. In a context of scarce land and water resources, the scientific use of mineral fertilizers assumes significance because of its immense potential to raise agricultural production and, thus, meet the foodgrain needs of the growing population. The dissemination of knowledge for the scientific application of mineral fertilizers is important not only to boost crop production but also to address environmental concerns relating to pollution risks arising out of the possible inappropriate use of such inputs in certain situations.

The generous contribution of the Arab Fertilizer Association and the International Fertilizer Industry Association towards the production of this manual symbolizes the lasting commitment of the fertilizer industry to promoting the rational use of mineral fertilizers, in close cooperation with the scientific and academic world.

This manual is being brought out in both Arabic and English in order to serve more specifically the needs of the Near East region. It is hoped that the manual will prove a useful resource for fertilizer users, agronomists, plant nutrition specialists, extension workers and fertilizer industry personnel.

This being the first edition of the manual, suggestions from readers for bringing further improvements to the publication are most welcome. With more knowledge and information sharing, it is our sincere hope that we will reach our common goal of "promoting safe and efficient fertilizer use in the Near East region".

Acknowledgements

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The generous contribution and genuine interest and sponsorship of the Arab Fertilizer Association (AFA), in Cairo, and the financial assistance of the International Fertilizer Industry Association (IFA), in Paris, are all appreciated.

List of acronyms and symbols

AEZ	Agro-ecological zone
Al	Aluminium
AN	Ammonium nitrate
APP	Ammonium polyphosphate
AS	Ammonium sulphate
ATP	Adenosine triphosphate
B	Boron
BNF	Biological nitrogen fixation
C	Carbon
Ca	Calcium
$CaCO_3$	Calcium carbonate
CAN	Calcium ammonium nitrate
CEC	Cation exchange capacity
Cl	Chlorine
Co	Cobalt
Cr	Chromium
Cu	Copper
DAP	Di-ammonium phosphate
DNA	Deoxyribonucleic acid
DTPA	Diethylene triamine penta acetic acid
EC	Electrical conductivity
EDDHA	Ethylene diamine di-o- hydroxyl Phynel acetic acid
EDTA	Ethylene diamine tetra acetic acid
Fe	Iron
FUE	Fertilizer-use efficiency
FYM	Farmyard manure
H	Hydrogen
H_2SO_4	Sulphuric acid
H_3PO_4	Phosphoric acid
HYV	High-yielding variety
I	Iodine
K	Potassium
LV/ULV	Low volume/ultralow volume
MAP	Mono-ammonium phosphate
Mg	Magnesium
MKP	Mono-potassium phosphate
Mn	Manganese
Mo	Molybdenum
MOP	Muriate of potash
N	Nitrogen
Na	Sodium

NADP	Nicotinamide adenine dinucleotide phosphate
Ni	Nickel
O_2	Oxygen
OM	Organic matter
P	Phosphorus
PGPR	Plant-growth-promoting rhizobacteria
RNA	Ribonucleic acid
S	Sulphur
SCU	Sulphur-coated urea
Se	Selenium
Si	Silicon
SOM	Soil organic matter
SOP	Sulphate of potash, or potassium sulphate
SSP	Single superphosphate
TSP	Triple superphosphate
UAN	Urea ammonium nitrate
USG	Urea super granule
VAM	Vesicular-arbuscular mycorrhizae
Zn	Zinc

Chapter 1
Introduction

The Near East is predominantly arid or semi-arid, with just 4.5 percent of the total surface area as cultivable and with limited renewable water resources, in addition to a high rate of population growth. Agriculture is mainly rainfed, with extreme fluctuations in rainfall often resulting in steep drops in food production. Increasing demand for food and fibre in the region means that agriculture has to achieve higher yields from limited cultivated land and with less water. Although the Near East was food self-sufficient in the 1960s, most countries of the region now face a food gap (cereals). The region needs new agricultural technologies, improved use of its limited land and water resources, a more rational application of agricultural inputs, and improved strategies for the protection of its environment.

Fertilizer application continues to be the single most important agricultural input. Mineral fertilizers play an important role in raising agricultural production. Enhancing the role of fertilizers in terms of crop response to plant nutrient addition assumes added importance. To attain this goal, the decision was taken to produce this manual, suited to the agricultural and agronomic conditions and practices in the Near East. The manual serves two main objectives. The first is to provide up-to-date knowledge on plant nutrition aspects of the major crops in the Near East. These include field crops (cereals and food legumes), horticultural crops (fruits, vegetables, roots and tubers), and industrial crops (edible oils and fibres). The second objective is to provide practical fertilizer recommendations and up-to-date technological information in order to assist in increasing sustainable production.

This manual is structured as follows. Chapters 1-4 present the principles of plant nutrition and fertilizer use. Chapters 5-12 examine efficient fertilization programmes under Near East conditions. They discuss local and unique conditions of arid and semi-arid regions (as prevalent in most of the Near East) in relation to fertilizer use. The subjects covered include:

- fertilizer-use practices for calcareous, gypsiferous and salt-affected soils;
- fertilizer-use practices for highly sandy soils;
- fertilizer use under rainfed conditions;
- fertigation;
- foliar fertilization;
- treated wastewater for irrigation;
- the environmental impact of mineral fertilizer use.

Chapters 13-18 describe the fertilizer recommendations for crops grown in the region. They focus on the main crops of agronomic and economic significance to the Near East. However, in order to avoid repetition, some crops (e.g. leguminous crops, vegetable crops under open culture, mango and strawberry) are not covered as they are already the subject of chapters and sections in the *World fertilizer use manual* (IFA, 1992). Hence, the present manual could be used in conjunction with the earlier IFA publication.

The attached annexes contain relevant summary data on soil nutrient ranges, crop nutrient concentrations and nutrient-deficiency symptoms.

Chapter 2

Plant nutrition - essential nutrients

Plants need different growth factors in order to achieve normal growth and produce good yields, within their genetic potential. The required growth factors are water, light, temperature, and essential nutrients in sufficient quantities. Sixteen nutrient elements are necessary for crop growth. Three essential nutrients, i.e. carbon (C), hydrogen (H), and oxygen (O_2), are taken up from atmospheric carbon dioxide and water. The other 13 essential nutrients are taken up from the soil and they are termed mineral nutrients because they are taken up in mineral (inorganic) forms. They are classified traditionally into two groups according to the amounts required:

- Macronutrients: Plants require these elements in relatively large quantities. This group includes nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca) and magnesium (Mg).
- Micronutrients: Plants require these elements in small quantities. This group includes iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), boron (B) and chlorine (Cl).

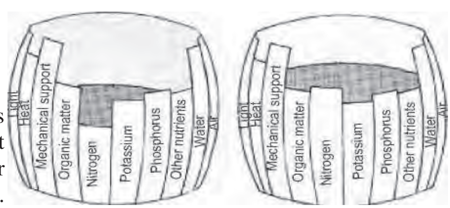
NUTRIENT BALANCE

Nutrients should be available in sufficient quantity and also in a ratio that is balanced according to the specific plant requirements. A low quantity of one nutrient can cause a decrease in crop yield even where all the other plant nutrients are present in adequate quantities.

This proposition has been propounded as the concept of the law of the minimum. The concept is illustrated with an old-fashioned water barrel with staves of different length, whereby the length of the shortest stave determines its capacity (Figure 1).

When crop yields increase as a result of a single nutrient application (usually N), the need for other nutrients also increases. Meanwhile, the uptake of some nutrients is dependent on their

FIGURE 1
The law of the minimum illustrated by barrel staves of varying lengths



Source: http://www.ext.colostate.edu.

ratio in soil solution. For example, higher K concentrations in soil solution reduce Mg availability. While plants differ in the quantities of nutrients they need for high yields, they also differ in their nutrient requirements at various growth stages. Crop usage (e.g. potatoes for fresh consumption or for processing) also affects the crop nutrient needs.

METABOLIC ROLE OF NUTRIENTS

Nitrogen

Nitrogen plays an important role in plant metabolic processes as it is an important constituent of chlorophyll, protoplasm, amino acids and nucleic acids. Amino acids are the basic blocks for protein synthesis. Nitrogen promotes rapid growth and development of all living tissues. It improves the quality of leafy vegetables and fodders, and increases leaf size and quality.

Phosphorous

Phosphorus is a constituent of nucleic acids, phospholipids, and the coenzymes such as deoxyribonucleic acid (DNA), nicotinamide adenine dinucleotide phosphate (NADP) and, most importantly, adenosine triphosphate (ATP). It activates coenzymes for amino acid production. It is involved in many metabolic processes for normal growth, such as photosynthesis, glycolysis, respiration, and fatty acid synthesis. It enhances seed germination and root growth, stimulates blooming, enhances bud set, aids in seed formation, and hastens maturity.

Potassium

Potassium has many functions in plant metabolism. It is essential for photosynthesis, activates enzymes to metabolize carbohydrates for the manufacture of amino acids and proteins, and facilitates cell division and growth. Potassium regulates many metabolic processes required for growth, fruit and seed development. As well as providing stalk and stem stiffness, it increases disease resistance; regulates the opening and closing of stomata; improves drought tolerance, firmness, texture, size and colour of fruit crops; and enhances the oil content of oilseed crops.

Calcium

Calcium is essential for the formation of plant cells as it is a constituent of cell walls and is involved in the production of new growing points and root tips. It provides elasticity and expansion of cell walls. It acts as a base for neutralizing organic acids generated during the growing process and plays an important role in carbohydrate translocation and N absorption.

Magnesium

Magnesium is a constituent of the chlorophyll molecule, which is essential to the photosynthetic process and plays an important role in the metabolism of carbohydrates. It is an enzyme activator for the synthesis of nucleic acids (DNA and ribonucleic acid [RNA]). It also serves as a carrier of phosphate compounds, and enhances the production of oils and fats.

Sulphur

Sulphur is required for the synthesis of amino acids and proteins. It is also required for production of chlorophyll and utilization of P. It improves the yield and protein quality of forage and grain crops as well as the production and quality of fibre crops.

Iron

Iron is essential for the synthesis and maintenance of chlorophyll in plants. It is an integral component of many enzymes and plays an indispensable role in nucleic acid and chloroplast metabolism.

Manganese

Manganese acts as an enzyme activator for N assimilation. It is essential for the manufacture of chlorophyll. It serves as a catalyst in several enzymatic and physiological reactions in plants and is involved in their respiratory process. It also controls the redox potential in plant cells during the phases of light and darkness.

Zinc

Zinc is involved in the biosynthesis of plant hormones, such as indole acetic acid, and is an essential component of a variety of metallo-enzymes. It plays an important role in nucleic acid and protein synthesis besides helping in the utilization of P and N in plants.

Copper

Copper is involved in chlorophyll formation and is a part of several enzymes, such as cytochrome oxidase. It participates in lignin formation, protein and carbohydrate metabolism, and is possibly required for symbiotic N fixation. Copper is a part of plastocyanin, which forms a link in the electron transport chain involved in photosynthesis.

Boron

Boron has a key role in membrane integrity and cell-wall development, which affect permeability, cell division and extension, as well as in pollen tube growth, which affects seed/fruit set and, hence, yield. Boron has an important role in sugar transport to meristem regions of roots and tops.

Molybdenum

Molybdenum is required for symbiotic N fixation (nodulation) by legumes and reduction of nitrates for protein synthesis. It is involved in several enzyme systems, particularly nitrate reductase, which is needed for the reduction of nitrate, and nitrogenase.

Chlorine

Chlorine is considered to be involved in the production of O2 during photosynthesis, in raising cell osmotic pressure and in maintaining tissue hydration.

Beneficial nutrients

Several elements other than the essential nutrients have beneficial functions in plants. Although not considered essential, beneficial nutrients can improve the growth of some crops in some respects. They include nickel (Ni), sodium (Na), silicon (Si), cobalt (Co) and aluminium (Al).

Nickel is a part of the enzyme urease, which breaks down urea in the soil. It also plays a role in imparting disease resistance and is considered essential for seed development. Sodium can replace K in some crops such as sugar beet as well as some tropical crops. Silicon is beneficial for cereals (particularly rice), for regulating transpiration and strengthening cell walls. Cobalt is beneficial for biological nitrogen fixation (BNF) by bacteria. Aluminium has been found to be beneficial for tea plants.

Other important nutrients

In addition to those essentially required by the plants, some nutrients are needed for humans and domestic animals. Such elements include: Co, selenium (Se), chromium (Cr) and iodine (I). These additional nutrients should also be considered for food and feed production, and their deficiencies corrected through appropriate inputs.

Chapter 3
Soil and plant tissue sampling methods

Soil testing and plant tissue analysis provides the basis for fertilizer applications aimed at profitable and quality crop yields. Proper collection of samples and correct interpretation of analytical results is vital for correct assessment of crop fertilization needs. This chapter provides farmers and fertilizer users with background information on proper methods for collecting representative soil and plant tissue samples and for interpreting the results of analysis in order to estimate crop fertilizer requirements.

SOIL SAMPLING

Soil analysis is recommended before establishing agricultural activities. For most soils in arid and semi-arid regions, a soil test of physical and chemical properties should be conducted before making a decision regarding the suitability of the land for agricultural development. In addition, soil sampling should be carried out every three years in order to develop suitable fertilization programmes.

DEPTH OF SAMPLING

Samples are usually collected from the soil surface to the plough depth of 15 cm in cultivated fields. Where farmers plough to a depth of 30 cm, the samples should be collected to a depth of 30 cm.

With field crops and vegetables, it is advisable to collect soil samples from the soil surface 0–15 cm and subsurface 15–30 cm. Soil analysis is appropriate before an orchard is planted; the depth of soil sampling should be extended to the depth of the rootzone, 0–30, 30–60 and 60–100 cm where the root system reaches about 100 cm of depth. However, in established orchards, leaf analysis is the most reliable indicator of nutrient levels in fruit trees.

METHODS OF SOIL SAMPLING

Representative soil samples should be collected properly from the field. A good soil test, no matter how accurate, cannot compensate for a poor sample. It is the sample taker's responsibility to take a truly representative composite soil sample from the field.

In order to be able to use the results of soil testing as a reliable guide for the addition of fertilizers, the collected soil samples must represent the soil condition of the area sampled, and the specific purpose of the test must be kept in mind. Truly representative and unbiased samples can be taken by considering the following:

FIGURE 2
Sampling pattern for fertility testing in a non-uniform land

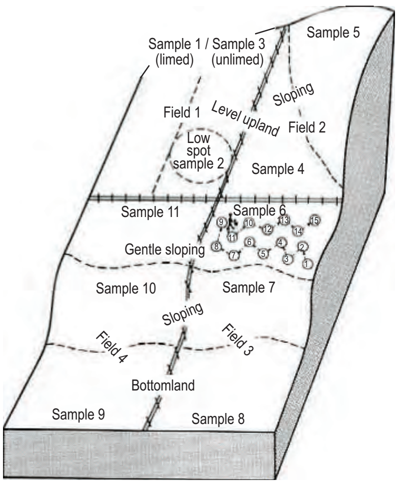
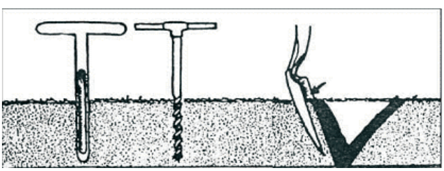


FIGURE 3
Some soil sampling tools



- Soil spots that differ in soil type, appearance, crop growth or past treatment should be sampled separately. Where available, a soil map or land cover map can be of help in distinguishing areas and in recording locations of samples (Figure 2).
- Several different tools (e.g. an auger, a soil sampling tube, and a spade) may be used in taking soil samples (Figure 3).
- Scrap away surface litter. Where using an auger or soil sampling tube, obtain a small portion of soil by making a boring about 30 cm deep, or if ploughing deeper, sample to the plough depth. Where using a tool such as a spade, dig a V-shaped hole to the sample depth; then cut a thin slice of soil from one side of the hole.
- Avoid areas or conditions that are different, such as areas where fertilizer or other materials have been spilled, gate areas, poorly drained areas, dead furrows, tillage or fertilizer corners or fertilizer band areas of the previous year's crops. It is also advisable to stay at least 25 m away from barns, roads, lanes, irrigation canals and fences.
- Because of soil variations, it is necessary that each sample consist of small portions of soil obtained from about 15 locations (minimum 7) in the soil area, as illustrated in Figure 4. After obtaining these portions of soil, mix them together to make a representative sample. Air-dry the samples and place about 500 g of soil in a clean plastic bag. This method of sampling and analysis will give an average field fertility value.

- After the sample has been taken, the soil sample bag should be marked clearly with the name of the collector, address, sample number and identification of the field; this information should be kept in a record book.
- Where recommendations are desired, fill out the soil information sheet (Figure 5) as completely as possible (this helps in making recommendations). The sample numbers on the soil information sheet should correspond to the numbers on the sample bags.

FIGURE 4
Soil sampling methods for fertility tests

INTERPRETATION OF SOIL ANALYSIS RESULTS

From the results of soil analysis, farmers can predict fertilizer requirements. Soil analysis measures the amount of elements extracted by certain chemical solutions that are correlated to the quantity of nutrients available for plant uptake in a certain soil (Table 1 and Annex 1). Therefore, fertilizers are applied only where a crop is expected to respond to fertilization. Soil analysis should be performed by an experienced analyst in a well-equipped laboratory. Portable field kits are of limited benefit to farmers and should be always checked through field calibration.

The prevailing soil properties under arid climate are generally characterized by neutral to slightly high pH and $CaCO_3$ content, as well as low organic matter

TABLE 1
Recommended soil analysis methods and expected nutrient concentrations in soils of arid regions

	Method	Very low	Low	Medium	High	Very high
				(ppm)		
Residual nitrate (NO_3) nitrogen	Kjeldahl	0–10	10–20	20–40	40–60	> 60
Calcium [1]	Extracted in 1N NH_4OAc	0–500	500–1 200	1 200–2 500	2 500–3 500	> 3 500
Phosphorous	$NaHCO_3$ Olsen	0–7	7–15	15–30	30–50	> 50
Potassium	Extracted in 1N NH_4OAc	0–85	85–170	170–300	300–500	> 500
Magnesium	Extracted in 1N NH_4OAc	0–85	85–200	200–300	300–500	> 500
Sodium	Extracted in 1N NH_4OAc	–	–	0–300	> 300	–
Iron	Extracted with DTPA	0–2	2–4	4–6	6–10	> 10
Manganese	Extracted with DTPA	0–0.5	0.5–2	2–5	5–10	> 10
Zinc	Extracted with DTPA	0–0.5	0.5–1.5	1.5–4	4–6	> 6
Copper	Extracted with DTPA	0–0.1	0.1–0.3	0.3–0.8	0.8–3	> 3
Boron	Extracted with hot water	0–0.5	0.5–1	1–2	2–4	> 4
Molybdenum	Extracted in 1N NH_4OAc	–	0–0.1	0.1–2	2–5	5–10 [2]
Sulphur	Extracted with water	0–10	10–20	20–35	35–50	> 50
Calcium carbonate (%)	Acid neutralization	–	0–5	5–15	15–25	> 25

[1] In calcareous soils, exchangeable Ca values could be 50–100 percent higher than the above values.
[2] Molybdenum levels > 10 ppm are toxic to plants.
Soil salinity (EC of soil saturated extract, in mS/cm): 0–4 no hazard; 4–6 low hazard; 6–8 medium hazard; 8–10 high hazard; > 10 very high hazard.

FGURE 5
Field data sheet

FIELD DATA SHEET
(For soil samples)
Sample no.

Collector	Address		Owner
Area	Location		Date
Farm size		Vegetative cover	
Source of water		Water quality	
Sample depth		Previous crop	
Site selection method:	☐ Random	Sample type:	☐ Individual
	☐ Zig zag		☐ Composite
	☐ Two-way diagonal		☐ No. of cores
	☐ Two-way cross-strip		
	☐ Test plot		
Purpose of analysis:	☐ Capability assessment	Slope:	☐ 1–2%
	☐ Fertility evaluation		☐ 2–5%
	☐ Salinity appraisal		☐ 5–10%
	☐ Soil classification		☐ 10–25%
			☐ > 25%
Irrigation method:	☐ Flood	Years of irrigation:	☐ Never irrigated
	☐ Furrow		☐ 1–5
	☐ Sprinkler		☐ 5–15
	☐ Centre pivot		☐ > 15
	☐ Drip		
	☐ Rainfed		
Years of cultivation:	☐ Never cultivated	Drainage:	☐ Good
	☐ 1–5 years		☐ Moderate
	☐ 5–15 years		☐ Poor
	☐ > 15 years		
Manure		Rate	
Fertilizers (chemical)		Rate	

FNote: Questions for which accurate answers cannot be provided should be left unanswered.
Source: Tarzi, 1985.

TABLE 2
Reasons for insufficiency of soil micronutrients in plants

Nutrient	Source of loss	Soil factors affecting availability to plants	
	Leaching	Enhancing factors	Reducing factors
Zn	Negligible	Microbial activities, adsorption on clay, medium soil texture.	High clay, low OM, high pH, high N, P, $CaCO_3$ and salinity.
Mn	Loss in highly porous soils owing to high oxidizing activity	High contents of OM, P, small-sized soil particles.	High values of: pH, salinity, $CaCO_3$, poor drainage.
Fe	Negligible	Microbial activities, small-sized soil particles, high OM.	High values of: pH, salinity, $CaCO_3$, P, Mn level in soil, poor drainage.
Cu	By excessive irrigation in sandy soils	Microbial activities, small-sized soil particles, high cation exchange capacity in soil.	High values of: pH, salinity, $CaCO_3$, Zn, P and high OM in soil.

Source: El-Fouly, 1983.

(OM) content, which together cause the reduction in N, P and micronutrient availability that is accentuated further in some soils by the occurrence of high salinity. Therefore, in most Near East countries, micronutrients are insufficient for meeting the crop genetic potential, especially for high-yielding varieties (HYVs). Table 2 shows reasons for such insufficiency.

VISIBLE NUTRIENT DEFICIENCY SYMPTOMS OF PLANTS

Every nutrient plays a specific role in plant physiological processes. The absence of the nutrient from the growth medium interrupts these processes. The plant shows such absence by certain symptoms, usually specific for each nutrient and crop. Main features of visual deficiency symptoms of different nutrients are given below. (For images of visible deficiency symptoms of nutrients, see Annex 2).

Nitrogen

In most crops, the green colour of leaves fades, then turns completely yellow starting from the older leaves, with the advancement of N deficiency severity. This is accompanied by: increased leaf shedding; new shoots emerging with smaller, yellowed leaves and branches; and/or dieback of tillers. The crop yield is markedly lower than normal.

Phosphorous

Phosphorus deficiency shows in decreased plant size, with red or brown–reddish colouring of the older (lower) leaves. It usually happens in winter when lower soil temperatures retard its acropetal translocation to the actively growing tips, and also slow plant absorption.

Potassium

Deficiency symptoms of potassium start with whitening and/or yellowing of leaf margins and between green veins to reach a complete yellow colour. This is followed by necrotic spots on the blades of young leaves. The margins tend to bend upwards and, finally early leaf shedding occurs.

Calcium

Calcium deficiency appears as reduction in plant growth rate, accompanied by deformation and yellowing of young leaves followed by the death of root tips. This is followed by the accumulation of brown substances at leaf margins, and the occurrence of brown pits on the surfaces of fruits and/or vegetables.

Magnesium

Magnesium deficiency appears on the older (lower) leaves, which turn red-crimson, except for the veins, which remain green. Meanwhile, premature leaf shedding occurs.

Sulphur

Symptoms of sulphur deficiency appear as fading of the leaf green colour, with yellow interveinal blotches (“tea yellow”). These symptoms are not frequent in the Near East area owing to the frequent application of S-containing fertilizers. However, they are observed on some crops grown on sandy soils of some parts of the West Asia and North Africa region, particularly on crops grown on sandy S-deficient soils.

Iron

The colour of the uppermost leaf blade becomes golden yellow, while that of the vein-net remains green.

Manganese

Manganese deficient plant leaves show interveinal, small yellow spots.

Zinc

Leaves have unequal areas of the two halves, with interveinal yellow or white spots. Meanwhile, the uppermost leaves are small and rosette-shaped, owing to dwarfed internodes.

Copper

A typical symptom of Cu deficiency is twisting, whitening and narrowing of the leaf tip, accompanied by depression of internode growth and pollen sterility. Impairment of lignin synthesis may cause “pendula” forms in fruit trees.

Boron

Boron deficiency symptoms are an abnormal or retarded growth of the apical growing points, evidenced by misshaping, wrinkling, leaf-thickening and darkish-blue leaves, as well as irregular chlorosis between intercoastal regions. Meanwhile, transpiration is disturbed, as indicated by leaf and stem brittling.

TABLE 3
General symptoms of nutrient deficiency disorders based on their first appearance

First appearance on older (lower) leaves	First appearance on the younger (uppermost) leaves
N: Chlorosis, starting from leaf tips.	Ca: Leaf yellowing extending to half length of midrib; bud death.
P: Reddish colour on stem, green leaves.	S: Mottled yellow-green leaves with yellowish veins.
K: Necrosis on leaf margins while leaves remain green.	Mo: Premature deformation, with fading of their green colour.
Mg: Interveinal chlorosis.	Fe: Mottled yellow-green leaves with green veins.
Mn: Brownish, greyish-whitish spots (in cereals).	Mn: Brownish-black spots.
Excess soil salinity & B content: Burns of leaf margins, extending thereafter to cover the whole leaf.	Zn: Rosette-shaped shoots; and inequality in the two-leaf halves area.
	Cu: Youngest leaf has a white tip, shoots become S-shaped; gummosis occurs.
	B: Youngest leaf is brownish or dead.

Sources: IFA, 1992; El-Fouly and Fawzi, 1992.

Molybdenum

Molybdenum deficiency appears on the younger leaves as premature deformation, with fading of their green colour.

Table 3 lists the general symptoms of the most widespread nutrient disorders in the Near East region.

PLANT TISSUE ANALYSIS

Every plant has its specific part (leaf, petiole, etc.) as well as a method and physiological age for sampling. Certain guidelines for sampling measures (Table 4) should be applied carefully in order to reach a correct diagnosis of the plant nutritional status (Annex 3):

- Leaf samples should be taken from the same sites of sampled soils.

TABLE 4
Recommended guidelines for plant tissue sampling

Plant	Growth stage	Sampled part	No. leaves sampled
Citrus	4–7 months old	Mature, spring-cycle leaves	30–40
Other fruits & nuts	Mid-season	Leaves, from mid-current season terminal shoots	30–40
Date-palm	Prior to bloom	Leaflets around the young pinnate leaves	20–30
Olive	Initial bloom	Young mature leaves	20–25
Fig	Initial fruit-set	Leaves from mid-current season shoots	20–25
Legumes	Initial bloom (start)	Uppermost third of the plant	40–50
Maize/Corn	Silking–tasselling	1st leaf below or above primary ear shoot	20–25
Cotton	1st bloom/ 1st square	Youngest mature leaves on main stem	30–40
Peanut	Early bloom	Mature leaves from main stem/cotyledon branches	40–50
Potato	1st tuber formed	3rd–6th uppermost mature leaves	40–50
Cereals	Tillering–booting	Top 3–4 leaves	30–40
Vegetables	Mid-season	Top 3–4 mature leaves	40–60

Source: Summarized from Havlin *et al*., 2005.

- The sample should be taken from the specific part of the plant at the specific physiological stage according to specific and well-defined instructions.
- The sample must be transported to the laboratory to be analysed on the same day.

Chapter 4

Fertilizer application techniques and their impact on produce quality

FERTILIZER APPLICATION METHODS

Traditional methods

Solid and dry fertilizers, and sometimes liquid fertilizers, can be applied through the following techniques, which are more associated with traditional irrigation systems:

- Broadcasting: The fertilizer is distributed in a way that ensures its homogeneity in the field. This method may be adopted in combination with land preparation or applied along with seeds through the seed drill.
- Deep placement in ploughed ridges: The fertilizer is placed in narrow bands along the ridges, 5–7 cm apart from the crop furrow, such as in cotton or maize.
- Side application: The fertilizer is placed into pits between plants, within the crop furrows, under the seed level, or in the row basement, before seed sowing (for solid and liquid fertilizers).
- Ring placement: For fruit trees, the fertilizer is placed in a ring around the tree.

Application through modern irrigation system

Fertilizer application methodologies have undergone a transformation along with the modernization of irrigation techniques. Modern irrigation systems are designed to integrate the application of water and plant nutrients to the crops in accordance with their needs at various physiological stages of crop growth. Salient features of these systems are:

- Fertigation: Application of fertilizers through irrigation water is termed fertigation. For fertigation, liquid or fully soluble fertilizers are used as a plant nutrient source in trickle/pressurized irrigation systems (drip/sprinkler), particularly in greenhouse and protected farming regimes. This technique has proved cost-effective and results in less pollution of the environment (more detail in Chapter 7). Fertigation makes split applications much easier. The total amounts of fertilizers are spread over the crop growth stages at times and amounts appropriate for the requirements at each stage.

- Partially water-soluble fertilizers should be dissolved in warm water by adding a suitable volume of water gradually in a container, accompanied by one of the acids (HNO_3 or H_3PO_4) at concentrations ranging from 1 to 2 litres per 10 m^3 water with continuous stirring, for half an hour, until dissolved completely.
- Micronutrient fertilizers should be used in chelated forms (such as ethylene diamine tetra acetic acid [EDTA], diethylene triamine penta acetic acid [DTPA], or amino acids) and preferably not applied directly to the soil (in order to avoid fixation by soil carbonates). It is also advisable to follow the technique of injecting these fertilizers in the irrigation systems (drip, sprinkler, etc.).
- Foliar application: This is an efficient technique for the application of nutrients, especially micronutrients, that are fixed easily under the high pH soil conditions prevailing in the region. Furthermore, it is less costly than other application methods. It can provide the rapidly growing crop with its urgent needs at the stage of its high demand. However, it cannot be used to provide all nutritional requirements and should be used only as a supplement to conventional fertilization (more detail in Chapter 10).

IMPACT OF FERTILIZERS ON NUTRITIVE VALUE AND FOOD QUALITY

Adequate supply of N increases amounts of total and pure protein, protein quality (more of the essential amino acids), and some vitamins, especially vitamin B. Excessive N supply tends to increase amide content, resulting in bad flavour after cooking, or in raising the nitrate content to unacceptable levels, especially in vegetables grown under protected culture systems.

Phosphorus improves protein quality and increases the content of some vitamins and of mineral phosphate, which is an essential plant mineral nutrient.

Low N in relation to high P supply causes premature ripening, while high N causes delayed ripening and increases water content in plants.

Adequate K supply increases carbohydrates synthesis and vitamin C. Potassium also has positive effects on firmness and texture, and can decrease transport damage. However, a high K amount leads to decreases in Ca and Mg contents, which might have a negative effect on produce quality.

Where supplied in excess amounts, nutrients such as Zn and Cu may affect crop quality adversely.

Adequate supply of some of the plant nutrients builds up resistance against drought, frost and cold, and counteracts the adverse impacts of ultraviolet radiation in crops, thus contributing to crop quality in the long run:

- Drought: A good supply of K improves waterholding capacity, and P encourages early root growth, thus enhancing survival during dry spells.
- Frost and cold: Tolerance to frost and cold improves with a better supply of K, P and some micronutrients, e.g. Mn and Cu.
- Ultraviolet radiation: A good supply of Zn counteracts radiation-induced destruction of growth regulators.

Regarding market value, balanced nutrition of the crop improves its easily recognizable external characteristics, such as colour, aroma, flavour and shelf-life. Crop quality features for industrial use concern aspects such as the content of protein and sugar, and are dependent on the plant uptake of various nutrients.

As regards the nutritional value, the palatability (taste and smell), organic and mineral nutritional constituents, and absence of undesirable/toxic substances are all subject to positive and negative influences of individual mineral nutrients.

Some examples that illustrate the impact of plant nutrition on the nutritive and industrial quality of individual crops are:

- Wheat: Baking quality is influenced directly by N content, within the same variety, while S deficiency results in weak dough.
- Potatoes: High amounts of N and K decrease dry matter and starch content and affect the quality of starch in potatoes. Low K affects the coloration of fried potatoes negatively and causes black spots in fresh potatoes.
- Sugar beet: Excessive N in later stages decreases sugar content and increases amino acid content in the roots, which has adverse effects on the processing of beets to sugar. Excessive K and Na have similar negative effects.
- Fresh fruits and vegetables:
  - Adequate Ca supply leads to high quality of different fruits and vegetables.
  - Banana: Adequate N increases fruit size and bunch weight. Ca deficiency causes low quality (fruit peels and splits at ripening).
  - Juicy processing fruits need more N in order to produce more juice.
  - Boron deficiency leads to splitting open of carrots; while cauliflower develops brown hollow stems.

NUTRIENT SUPPLY AND RESISTANCE TO PESTS

A good supply of K improves resistance to some insect pests, as a result of better mechanical protection and a decrease in cell constituents attractive to insects.

An adequate B level increases resistance to fungal attack.

Improved soil fertility encourages soil fungi to produce a better supply of antibiotics, which protect plants therapeutically against some bacterial diseases. Further research is needed in this border area between plant nutrition and plant protection, with the aim of minimizing the need for protective sprays.

Chapter 5
Fertilization of calcareous, gypsiferous and salt-affected soils

CALCAREOUS SOILS

General characteristics of calcareous soils

Soils whose parent material is calcareous sediment occur extensively in the Near East region. The main determinants of the characteristics of these soils are: climate, parent material, topography, and hydrological history of the terrain. Calcium carbonate ($CaCO_3$) is a major component in most soils of arid and semi-arid regions. Its content ranges from a low percentage in slightly calcareous soils to more than 80 percent in some extremely calcareous soils.

The amount and form (active portion) and its distribution in the profile affect both physical and chemical characteristics of soils. The retention of certain elements, such as P, Mn, Zn and Cu, is related directly to the carbonate content. The limit of 10 percent active $CaCO_3$ (usually defined as the fraction of particle size less than 50 microns) could contribute significantly to the retention of certain essential elements in these calcareous soils. The pH of calcareous soils varies between 7.4 and 8.5, and its crystalline form influences: the solubility of $CaCO_3$, impurities (such as Mg in the crystals), particle size, surface area, hardness, and porosity and surface irregularities.

Effect of $CaCO_3$ on plants

A major fertility problem in calcareous soils is the so-called lime-induced chlorosis phenomenon. This is a complex disorder in plants that manifests as a "yellow colour" on fruit trees. The basic cause of this phenomenon is low Fe availability as a result of high pH.

In Lebanon, it was observed that most plants growing on marl soils developed chlorosis in winter. In addition, in the Jordan Valley, the citrus trees become temporarily severely chlorotic under high temperatures (above 30 °C). Continuous horizons of carbonate accumulation may prevent root development and reduce yields.

The sensitivity of crops to $CaCO_3$ may be classified in three groups:

- tolerant crops: alfalfa, dates, figs, olives and wheat;
- moderately tolerant crops: artichokes, barley, beans, clover, cotton, grapes, lettuce, maize, millets, onions, rice, sugar beet, sugar cane, tobacco, tomatoes and watermelons;

- sensitive crops: bananas, citrus and potatoes.

GYPSIFEROUS SOILS

Gypsiferous soils in the Near East region occupy about 13 000 km^2, which is about 20 percent of such soils worldwide (FAO, 1997). These soils contain high amounts of gypsum (calcium sulphate), which interferes with plant growth. These soils usually occur under arid situations (less that 400 mm of rainfall). In many cases, the gypsum is also associated with other Mg and Na salts.

Effect of gypsum on soil physical properties

The presence of gypsum in soil interferes with the measurement of soil texture. Comparing field and laboratory results, the texture of gypsiferous soils is quite misleading in the field owing to the presence of gypsum crystals in the different sand-size fractions. Consequently, field texture is always coarser than laboratory determination. One of the most damaging effects of gypsum in soils is the collapse of soil layers owing to dissolution of gypsum in water. This soil collapse poses serious problems in the installation of irrigation canals and similar civil structures. The collapse zone phenomenon of gypsiferous soils is widely observed as "lakes" (also called "sink holes") that occur in several countries (e.g. Iraq, Libyan Arab Jamahiriya, Saudi Arabia and the Syrian Arab Republic).

Effect of gypsum on plants

The performance of plants grown on shallow soils depends to a large extent on their root system, the gypsum content, the fertility level of the topsoil, and the water availability during the growing season. In particular, the presence of a hard impervious gypsic layer has a strong effect on crop production under irrigation. Percolating water dissolves gypsum and salts, and stagnates at the top of the gypsic layer. This creates a perched water table, often resulting in an accumulation of gypsum and salts. The resulting high water table may rise to the soil surface, leaving salts and gypsum on the surface. Under these conditions, the performance of crops will be affected by both gypsum and salinity. Extensive areas of gypsiferous soils in the Syrian Arab Republic, Iraq, Tunisia and elsewhere are considered salt-affected.

The tolerance, yield and product quality of many crops grown on gypsiferous soils are not well known. As a first approximation, the main crops are classified into four main groups in relation to gypsum tolerance based on the available data:

- Group I: tolerant to gypsum – crops that show tolerance up to 40 percent of gypsum in soil without a significant decrease in yield. This group includes alfalfa, barley, clover, lentil, oats, onions, tomatoes and wheat.
- Group II: semi-tolerant to gypsum – crops that show tolerance up to 20 percent of gypsum in the soil without a significant decrease in yield. The yield may drop by about 50 percent at higher levels of gypsum (e.g. 40 percent gypsum). This group includes broad beans, corn, sesame, sorghum, soybean and sugar beet.

- Group III: semi-sensitive to gypsum – crops that show tolerance up to 10 percent of gypsum without a significant drop in yield. This group includes cotton, groundnut, potato and sunflower.
- Group IV: sensitive to gypsum – this group includes other crops that could be called test crops, e.g. tobacco, that are sensitive to gypsum.

Regarding fruit trees, work carried out in the Euphrates Basin in the Syrian Arab Republic has shown that grapevine tolerance to gypsum depends on the variety grown. More research is needed in order to determine grapevine varieties and rootstocks tolerant to gypsum. Observations on other fruit trees grown in the moderately deep gypsiferous soils of this basin show that many species tolerate gypsum, including pomegranate (*Punica granatum*), peaches (*Amygdalis persica*), plums, figs (*Ficus carica*) and apricots. However, pistachio (*Pistacia vera*) shows poor adaptability to gypsiferous soil conditions. Only 3 out of 46 trees of local pistachio cultivars remained alive after four years. Pines in gypsiferous soils in Tunisia were observed to be poor in all mineral nutrients, especially K and Ca. The low levels of nutrients in pines make them quite successful and adaptable to all types of soil environments including gypsiferous ones. Much more information is needed on the performance and adaptation of various tree species to gypsiferous soils, and on the effect of gypsum on fruit yield and quality.

FERTILITY MANAGEMENT OF CALCAREOUS AND GYPSIFEROUS SOILS

Surface layers of calcareous and gypsiferous soils are poor in N, P and many of the micronutrient elements.

K fertilization

The generally accepted concept is that soils of the arid and semi-arid regions are rich in K. However, while the K content in these K-rich minerals may be extractable in routine laboratory tests, it may not be easily extractable by plants under field conditions. Therefore, the application of K fertilizer is necessary on calcareous and gypsiferous soils where vegetables, fruit trees and grasses are grown and where there is intensive cropping.

P fertilization

Calcareous and gypsiferous soils are generally very low in P owing to the immobilization of added P. Applied P reverts quickly to insoluble forms, and phosphate retention would be more severe in gypsiferous soils because of their higher Ca activity. Applied P fertilizers should be about 50 percent water soluble in order to be effective on gypsiferous–calcareous soils. Combinations of water-soluble and citrate-soluble phosphates have proved to be the most advantageous for the supply of P to plants. The retention of P in soils is the result of chemical precipitation and physico-chemical sorption. Its subsequent availability to crops depends on the rate at which the P is released to the soil solution. In fact, soils do not have a well-defined capacity to retain phosphate. The extent and rate of immobilization are subject to several factors, including:

- P concentration in soil solution: An increase in phosphate concentration is accompanied by an increase in its immobilization.
- Reaction time: Reactions between the phosphates and the soil surface are completed quickly. In some tropical soils, 95 percent of the applied P is immobilized within 5 minutes. In calcareous and gypsiferous soils, some reaction products are formed slowly, following the initial rapid stage in the reaction leading to a decline in P solubility.
- Mineralogical nature of the soil: The amount and forms of iron and aluminium oxides and the amount and type of $CaCO_3$ present influence P retention.

N fertilization

The addition of N fertilizers is essential on these soils as their OM content is relatively low – 0.4–1.5 percent for surface layers, and negligible in subsurface layers. The problems associated with application of N fertilizers are losses through leaching of nitrates and ammonia volatilization and/or fixation by the soil clay minerals. To prevent the loss of ammonia, N fertilizers should be incorporated well into soils, especially those with a pH higher than 7. Little is known about the ammonium-fixing capacity of the soils and the possible economic implications where N fertilizer is added in ammonium forms. Some soils with alkaline reaction (pH higher than 7.0, which is the norm in arid and semi-arid zones) can fix up to 46 percent of the applied ammonium fertilizer. This corresponds to about 200 kg of N per hectare, which is equivalent to the usual amount added by local farmers. Three main factors should be considered in the management of N fertilizer applications: form of the N applied; clay content and clay mineralogy of the soil; and the amount and type of $CaCO_3$ present.

No work has been reported on the effect of gypsum content on ammonium fixation of gypsiferous soils. As a rule of thumb, N needs to be applied at rates of 1.5–2.0 times the anticipated removal by the crop. Where generous amounts of N have been applied and where soils contain hardpans that impede leaching, large amounts of nitrate may accumulate in the soil. Winter crops such as wheat are sown in the cold season when nitrification is inhibited. It is more profitable to apply complex fertilizers containing about half of their N content in the form of nitrate rather than applying ammonium or urea fertilizers. This is because the nitrate-N is the preferred form for uptake by wheat before the soil warms up.

MICRONUTRIENTS IN CALCAREOUS AND GYPSIFEROUS SOILS

The high concentration of soluble Ca in soils affects the availability of micronutrients and some macronutrients (P, K and Mg). Some studies in the Syrian Arab Republic have shown that the effect of gypsum on the micronutrient contents of crops depends to a large extent on plant species. Crops tolerant to gypsum, such as alfalfa, resist any significant changes in their macronutrient and micronutrient content. However, for semi-tolerant crops, such as corn, high levels of gypsum in soils (more than 20 percent) lead to a significant drop in Mn content in plant tissue. In conclusion, the availability of micronutrients in gypsiferous and calcareous soils could be the limiting factor for the growth of many plant species. The need to fertilize these soils in order to maintain their productivity requires extensive field research programmes to determine the optimal level and kind of nutrients needed by different crops. It is rare that one micronutrient is the only factor limiting yield. The main factors influencing the micronutrient status and needs include: soil pH, irrigation water quality, its amount and application system, HYVs and climate conditions.

SALT-AFFECTED SOILS

General characteristics of salt-affected soils

The rate and distance of movement of the salts from the points of application depend on the fertilizer type, application rate, soil properties and climate conditions. As the soil dries out, the salt concentration of the soil solution increases, and soil water moves upward by capillary movement, carrying the salts to the top. In many instances, these salts are deposited on the soil surface just above the fertilizer band as a white deposit or light-brown deposit coming from dispersed OM. Immediate rain or irrigation after planting followed by a long dry period is conducive to upward salt movement. However, with sufficient rain or application of irrigation water, the soluble salts move down in the soil profile. The ideal situation requires that these accumulated salts should be drained out of the field by an efficient drainage system.

Crop tolerance to salinity

The tolerance of various crops to salinity as measured in the soil saturation extract is summarized in Maas and Hoffman (1977). The causes restricting crop growth under saline conditions are osmotic and toxic effects. Plants affected by salinity show large variability in size and yield. For some plants, such as alfalfa and maize, the yield reduction is roughly proportional to the decrease in plant size. However, the yield of the seed of barley and the fibre of cotton declines much less than the size of the plants. Fruit trees are more sensitive to toxic effects of specific salts than are forage and field crops. Table 5

TABLE 5

Soil chloride tolerance levels of fruit crops

Fruit Crop	Rootstock	Content in saturation extract (meq/litre)
Citrus [2]	Rangpur lime, Cleopatra mandarin	25
	Rough lemon, Tangelo, Sour orange	15
	Sweet orange, Citrange	10
Stone fruit	Marianna	25
	Lovell, Shalil	10
	Yunnan	7
Avocado	West Indian	8
	Mexican varieties	5
Grape	Thompson Seedless, Perlette	25
	Cardinal, Black Rose	10
Berries [2]	Boysenberry	10
	Olallie blackberry	10
	Indian Summer raspberry	6
Strawberry	Lassen	2
	Shasta	5

[1] meq Cl/litre × 35.5 = mg Cl/litre.
[2] Data available for varieties listed only.
Source: USDA, 1980.

shows the tolerance of certain fruit crops to chloride concentration in the soil saturation extract.

CONSIDERATIONS ON FERTILITY MANAGEMENT

Fertilizer placement

Soil characteristics have a profound influence on the depth of root penetration. Soils with compact B horizons are highly restrictive. A number of factors, including bulk density, OM content, pH, plant nutrient content, aeration and moisture level, cause rooting differences in soils.

Plants absorb nutrients only from those areas in the soil in which roots are active. Plants cannot absorb nutrients from a dry soil. Thus, root systems modified by shallow applications of fertilizer are less effective in calcareous soils in times of drought. In general, fertilizer should be placed in that portion of the rootzone where stimulation of root growth is desired. Therefore, deep placement is necessary in drought-prone areas, especially for P (which is immobile in calcareous and gypsiferous soils).

Placement options generally involve surface or subsurface applications before, at or after planting. Placement practices depend on the crop, degree of deficiency, mobility of nutrient in the soil, and equipment available. The movement of P from the point of placement is generally very limited in soils with high $CaCO_3$ or pH values. Nitrogen fertilizers move with soil solution, whereby NO_3^- moves more readily than NH_4^+, which is relatively immobile in clay soils.

Excessive application of fertilizers can damage roots and germinating seeds – so-called "fertilizer burn", whereby the plant desiccates and exhibits symptoms similar to those of drought.

Fertilizers should not be placed in direct contact with the seeds. The effects of large quantities of fertilizers applied near the seed will increase the salt concentration around the seeds. Urea and di-ammonium phosphate (DAP) may cause more damage than mono-ammonium phosphate (MAP), ammonium nitrate (AN) or ammonium sulphate (AS).

Timing of fertilizer application

The numerous mechanisms of N loss must be considered in selecting the time of application to calcareous and gypsiferous soils. It would be desirable to apply N as close as possible to the time of peak N demand of the crop. However, this is seldom feasible except with side dressing of N or more precisely through fertigation. Nitrogen should be applied in several applications at planting, during crop elongation and at specific development stages.

The majority of P fertilizers should be applied just before planting in calcareous soils, because of the conversion of soluble P to less available forms. On calcareous soils of high P-fixing power, band applied P should be as close to planting as possible in order to give the most efficient results and to maximize recovery of P by crops.

Potassium is commonly applied and incorporated before or at planting, which is usually more effective than side dressing. As K is immobile in calcareous and gypsiferous soils, side-dressed K is less likely to move to the rootzone and benefit the current crop. Maintenance applications of K on forage crops can be made at almost any time. Potassium may also be applied through the irrigation system at early fruit stage in order to improve fruit quality.

Micronutrient deficiency (especially Fe and Zn) is common in calcareous and gypsiferous soils. Micronutrients could be applied either as part of a mixed fertilizer or applied separately in broadcast application, or as foliar spray. The addition of acidic fertilizers helps to improve micronutrient availability in calcareous soils that are nutrient deficient because of high pH values. The use of ammonium thiosulphate, sulphuric acid (H_2SO_4) and phosphoric acid (H_3PO_4) is effective under such conditions. In addition, banding of N sources that have a strong acidifying action will increase markedly the available forms of micronutrients in soils.

Chapter 6
Efficient fertilizer practices under rainfed conditions

GENERAL

The Near East region covers 1 800 million ha (about 14 percent of the area of the world) and hosts about 10 percent of the world population. However, water resources in the region are only 2 percent of the total renewable water resources of the world. Significant differences also exist among various subregions. While the Magreb and Arabian Peninsula suffer from severe water scarcity, some areas in northeast Africa and in Asian countries have surface waters, viz. the Nile, Euphrates, Tigris, Amu Darya, Syr Darya and Indus rivers, that contribute significantly to irrigation. In the region, about 48 million ha are irrigated, while some 52 million ha are rainfed. Irrigation is practised as supplementary in general and provided through sophisticated techniques in drier areas. Some countries in the region do not have enough precipitation for rainfed farming. In such situations, irrigation is a necessity. For example, all agricultural production in Egypt and the Arabian Peninsula depends on irrigation. However, rainfed farming is a major contributor to agricultural production in the Sudan, Turkey, Syrian Arab Republic, Islamic Republic of Iran, and in the Magreb.

LAND USE

The Near East is a vast and diverse region, allowing the growth of numerous crops under irrigated and rainfed conditions. The total cultivated area is almost 106 million ha. Cereals, particularly wheat and barley, are the principal crops of the rainfed areas. Other important crops are food legumes (e.g. lentils, chickpeas and broad beans) and forage crops (e.g. common vetch, lucerne, berseem clover, and Persian clover). Some traditional crops with local significance are: date-palms, olives, pistachio nuts, bananas, figs, grapes, tobacco, watermelons, sesame, sunflower and cumin. Under irrigated conditions, major crops include: wheat, cotton, maize, sugar beet, vegetable crops and citrus. The planting period for cereals is late October to mid-November; and that for the legumes is early spring. Tillage practices vary across the region. In some countries (e.g. Jordan, Pakistan, Islamic Republic of Iran, and Turkey), the mould-board plough is used for the first deep ploughing, and cultivators for the second (Jaradat, 1991). In some cases, supplemental irrigation is practised, such as in Iraq, Islamic Republic of Iran, Turkey and Morocco

DEFINITIONS

Rainfed areas are non-irrigated areas fed only by rainfall and snow. In such areas, the annual rainfall is 200–600 mm. Rainfed areas may be further classified into "favourable rainfed" and "marginal lands". While "favourable rainfed" areas have relatively higher rainfall (more than 350 mm/year) and relatively fertile soils, the "marginal lands" receive low and erratic rainfall (less than 350 mm/year) and often have steep, stony and shallow soils. Rainfall quantity and distribution are the major limiting factors in the rainfed areas.

The contribution of fertilizers in improving the yield and the water use cannot be disregarded. However, only a part of the nutrients applied as fertilizers is taken up by the plants, while the rest remains in the soil in fixed forms or is lost through volatilization, leaching and gaseous emissions. In this context, the results of several studies in the region reveal that only 24–65 percent of N and 5–15 percent of P fertilizers are recovered. Improvements in yield may be achieved by maximizing the recovery and minimizing the nutrient losses, which in a way means a better use efficiency.

Fertilizer-use efficiency (FUE) is often used as a measure of the increase in crop yield per unit of fertilizer nutrient applied. In agronomic terms, FUE is expressed as units of yield increase per unit of nutrient applied. In terms of crop physiology, it is expressed as units of yield increase per unit of applied nutrient absorbed by the crop. From the standpoint of a soil chemist, it is seen as the percentage of applied nutrient recovered in the crop. To an economist, it is the value of crop produced per unit investment in fertilizer. Several factors (e.g. climate, soil, crop characteristics, fertilizer rate, application method and time) affect FUE.

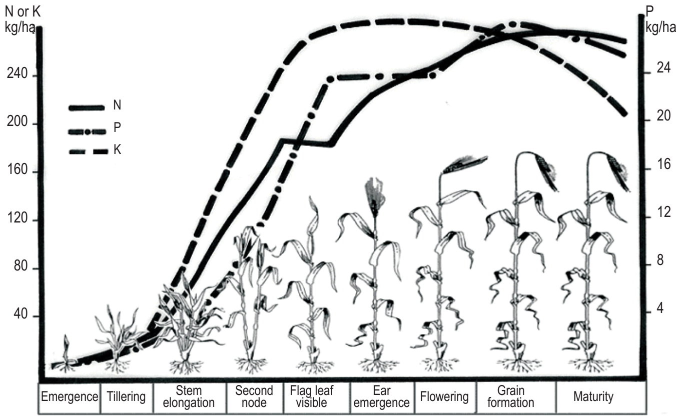
CROP CHARACTERISTICS

The yielding capacity of crops differs according to cultivars/species. The nutrient demand increases with the increase in yield, which is determined by plant genetic and environmental factors. The plant demand or uptake of nutrients differs with respect to growth stages. Figure 6 depicts nutrient uptake of barley at various growth stages. The nutrient demand of barley gradually increases to a maximum during the critical period – stem elongation to grain filling. Different cultivars/species give different responses to nutrients/fertilizers. Moreover, the uptake capability of plant species and their acquisition of the native nutrients also differ. The acquisition of native Zn by the cereal species are in the order: rye > triticale > barley > bread wheat > oat > durum wheat. Rye is referred to as being Zn efficient, and durum wheat as being Zn inefficient. Consequently, it is expected that durum wheat, which is sensitive to Zn deficiency, would give more response to Zn fertilization than would bread wheat and rye.

FERTILIZATION UNDER RAINFED CONDITIONS

Fertilizer source, rate, method and time of application all affect FUE. Comparison of fertilizer sources has been studied extensively. However, no definite differences have been found between the effectiveness of N sources such as urea, AN and

FIGURE 6
Nutrient uptake of barley in relation to growth stages



AS. In calcareous soils, 40–70 percent of N losses occur because of ammonia volatilization. As urea is commonly broadcast as top dressing in the region, the efficiency may be expected to be of a lower order. Generally, ammoniacal fertilizers are recommended for basal dressings because of their energy cost savings and positive acidifying effect on calcareous soils. On the other hand, calcium ammonium nitrate (CAN) might be a beneficial fertilizer in the non-calcareous, light-textured soils. Care should be taken to avoid the contact of the seeds with the fertilizers as well as excessive dosages, which might affect adversely germination and the young seedlings.

Soil reaction is a determining factor in the selection of the P fertilizer source. In calcareous soils with pH > 7.8–7.9, DAP may be suitable at planting because of the positive interaction between NH_4 and P, which improves the efficiency (Table 6).

TABLE 6
Effect of different P sources on wheat yield

Fertilizer	Wheat genotypes							
	Gerek–79		Bezostaya–1		Selçuklu–97		Çakmak–79	
	Yield (kg/ha)	P (%)	Yield (kg/ha)	P (%)	Yield (kg/ha)	P (%)	Yield (kg/ha)	P (%)
DAP	2 700	0.39	5 600	0.41	5 275	0.37	5 548	0.34
20–20–0	2 525	0.33	5 658	0.35	5 221	0.32	5 531	0.33
TSP	1 997	0.39	4 403	0.37	4 497	0.37	3 506	0.39

Note: Soil characteristics: pH = 7.98; $CaCO_3$ = 22.82 percent; rainfall = 389 mm; P in flag leaves.
Source: Gezgin, Dursun and Hamurcu, 1999.

TABLE 7
Effects of P-application methods on wheat yield

Application method	P_2O_5			
	Control	30	60	120
	(kg/ha)			
Broadcasting	2 142	2 502	2 926	3 167
Banding	2 180	2 914	3 380	3 428

Note: Mean of 31 trials.

The response of crops to different fertilizer rates depends on: climate, soil moisture, cultivar, species, cropping history, previous crop, and the residual and initial nutrient content of the soils. Fertilizer-use efficiency decreases with increasing rates of fertilizers. In rainfed conditions, crop responses to N fertilizer are usually obtained up to 50 kg/ha. With supplementary irrigation, significant responses may be obtained even with an N fertilizer dose of 100 kg/ha. Cereals after legumes usually gives less response to N fertilization and would show more response after fallow. In cases where residual P is high, the possibility of response to P fertilization decreases.

Fertilizers are applied either entirely at planting or through split application. The general trend in N application is to split applications, one-half at planting with the remainder being added later at the appropriate growth stage, depending on climate. However, growers in the region practise N fertilization in different ways, usually in accordance with the expected rain. In low rainfall years, abundant N fertilization may enhance the vegetative growth, which might put the plant under water stress. One option in dry years is grazing. On the other hand, in the event of an expected rain, the remaining N can be given as a top dressing. For P, the general trend and recommendation is to apply P at planting time.

Banding and broadcasting are the two main fertilizer application methods under rainfed situations. In most cases, banding is superior to broadcasting, particularly for P application (Table 7). Furthermore, banding P is particularly beneficial in the shallow soils of marginal lands with low initial soil P.

Techniques to apply micronutrients, particularly Zn are: spreading on the soil surface, seed treatment, and foliar spray. Basal dressing of micronutrients can also be effected through the use of enriched fertilizers. The Zn added to the 15–15–15 and 20–20–0 compound fertilizers can be an application alternative. Table 8 shows the results of a relevant study in Turkey.

Zinc deficiency is widespread in the Near East, especially in the soils of Iraq, Turkey, Pakistan, Egypt and Lebanon. In this context, the results of a

TABLE 8
Effect of different Zn-application methods on wheat yield, Turkey

Method	Wheat genotype			Yield increase
	Gerek–79	Bezostaja–1	Mean	
		(tonnes/ha)		(%)
Control	0.74	0.81	0.77	–
Soil application	2.70	2.34	2.52	226
Seed treatment	2.05	1.96	2.00	160
Leaf spray	1.47	1.55	1.51	96
Soil + leaf	2.71	2.33	2.52	227
Seed + leaf	2.77	2.38	2.57	233
LSD (5%)	0.45	0.74	–	–

TABLE 9
Effect of soil Zn applications on wheat yield in central Anatolia, Turkey

Location	Soil Zn	Yield		Yield increase
		Without Zn	With Zn	
	(mg/kg)	(tonnes/ha)		(%)
Konya (Centrum)	0.13	2.81	5.90	109
Konya (Comakli)	0.11	0.21	1.36	554
Eskisehir	0.15	2.51	3.29	31
Sarayonu	0.25	1.97	2.28	16
Sarayonu (Gozlu)	0.38	1.14	1.45	27
Cumra	0.64	5.30	5.63	5
Mean	0.28	2.34	3.31	43

study revealed that in the commonly Zn-deficient soils (< 0.4 mg/kg) of central Anatolia, positive responses to Zn application are distinct and could be as high as 554 percent (Table 9).

Placement depth is also as significant as the above factors. For improved efficiency, nutrients should either be present in the rootzone or should move to the rootzone. The conventional method of shallow placement of P is appropriate under adequate water supply. However, in low rainfall zones, the limited soil moisture may restrict movement of P. Subsoil P application has been found to be more beneficial.

Tillage is practised in order to: preserve soil moisture; break crusts and sods; loosen the soil for a proper seed bed; and eradicate weeds. It should be done at a proper time, neither too early (when the soil is dry) nor too late. Dry tillage may result in structural deterioration. Late tillage may result in prolonged vegetation in the hot season, consequently putting the crops under stress and, thus, resulting in lower efficiency. Generally, farmers in the region start tillage operations after the first seasonal rain.

Rotation is meaningful provided that the previous crop leaves enough moisture and contributes to soil organic matter (SOM) and soil mineral N. The wheat yield ranking according to the previous crop was found to be: fallow > melon > lentil > vetch > chickpea > medic > wheat. The ranking results are largely a reflection of the residual moisture. However, no definite conclusions have been derived yet for the region regarding the OM, N, moisture and economic returns. Temporarily, priority is given to some plants, e.g. vetch, medic and lentil. In view of the low OM content of the soils, the significance of rotation and the crops in the sequence should not be neglected. Weed control and pest management also warrant special attention.

The socio-economic conditions of the growers are important factors in fertilizer utilization. State subsidies generally increase fertilizer consumption. In 1991, the cessation of fertilizer subsidies in Egypt increased the use of less costly N fertilizers in place of the more expensive P and K fertilizers.

The extension of research results to farmers is crucial to the proper use of fertilizers (with impacts on FUE) and to obtaining higher yields.

TABLE 10
Recommended fertilizer rates for rainfed crops in the Syrian Arab Republic

	Rainfall					
	> 350 mm		250–350 mm		< 250 mm	
	N	P_2O_5	N	P_2O_5	N	P_2O_5
Crops	(kg/ha)					
Wheat (high-yielding)	100	80	80	60	–	–
Wheat (local varieties)	80	60	60	60	40	40
Barley	50	40	40	40	20	20
Legumes	30	50	20	40	20	30
Fruit trees (olive, pistachio, almond)	100	60–100	100	60–100	–	–

FERTILIZER USE AND CURRENT PRACTICES IN THE REGION

In recent years, agricultural output in the rainfed areas has been becoming profitable as a result of improvements in farmers' practices, gradual increases in fertilizer consumption, and the introduction of new HYVs. However, traditional fertilization practices still prevail. Fertilizer application rates are low and depend mainly on subsidies. Generally, marginal rainfed areas are not fertilized much compared with the favourable rainfall zones where wheat is the predominant crop. The bulk of the fertilizer in rainfed agriculture is applied to wheat.

The most common fertilizer sources are: urea, DAP, AN, AS, CAN, triple superphosphate (TSP), single superphosphate (SSP) and compound fertilizers, such as 15–15–15, 20–20–0, 28–28–0 and 18–18–5–1.5. Sulphate of potash (SOP) and MAP are also used but to a lesser extent.

Broadcasting is a general fertilization practice for N and P at planting. In the case of top dressing, urea or AN is often used.

Fertilization practices differ significantly among the countries in the region. Some examples are:

- Turkey: The general practice, particularly in rainfed central Anatolia, is 70 kg of P_2O_5 per hectare as DAP at planting, and 40–50 kg of N per hectare as urea or AN as top dressing.
- Jordan: The agricultural cooperatives for cereals recommend 30 kg of N per hectare at planting, and an additional 30 kg of N per hectare at tillering.
- Syrian Arab Republic: The recommendations for different crops in different climate zones are given in Table 10. The common practice for wheat is 91 kg P_2O_5 and 162 kg of N per hectare for the wetter zone, and 67 kg P_2O_5 and 74 kg of N per hectare for the drier areas.
- Pakistan: 70–80 percent of wheat growers use fertilizers, one-third use only N. The recommended rates are 18 kg of N and 12 kg of P per acre (1 acre = 0.405 ha).
- Tunisia: The recommendation is to apply 43 kg of P_2O_5 per hectare in the form of TSP for wheat regardless of the initial soil P.

OVERALL RECOMMENDATIONS

Rate and expected yield

Expected yield and the nutrient supplying capacity of the soils should be considered. It should be remembered that rainfall has a considerable influence on the expected yield, which determines the amount of nutrient uptake. In quantifying the initial nutrient content, a suitable soil test should be used along with relevant information on cropping history. There should be a proper synchronization between the nutrient demand (which is reflected in the nutrient uptake), the crop yields, and the nutrient supplying capacity of the soil. Cultivar/species, climate and soil type should all be regarded as important factors affecting this process.

In general, N recommendations are based on total N and OM analysis. However, the same may not serve as a reliable guide in many situations. Although no consensus exists in regard to an appropriate soil N testing method for the marginal lands with low OM, the estimation of initial NO_3 might provide satisfactory results. For soils with higher mineralization potential, rapid and reliable methods for soil N estimations need to be evolved through concerted research.

Conducting a series of field experiments with different fertilizer rates and interpreting the response curves to find the economic optimum might help in areas with less frequent use of soil testing. In addition, the benefit–cost ratio should be profitable, preferably greater than 3 and not lower than 2.

Fertilizer forms

At planting, the NH_4-containing and NH_4-releasing fertilizers are proposed. In view of volatilization risk during top dressing, AN might replace urea. As a P source at planting, DAP seems to have a greater efficiency in soils with a pH of 7.8–7.9.

Application method

Generally, banding is proposed for P and also for N application in order to minimize volatilization losses.

Application time

Crop nutrient demands should be met precisely at the required time. Splitting the applied N fertilizer is proposed, provided that climate conditions are suitable.

Zinc application

Zinc or Zn-enriched fertilizers should be applied in Zn-deficient soils in order to improve yields.

Foliar application of urea

Urea sprayings at the rate of 2–4 percent (weight/volume) can be advantageous for cereals but have a special significance for the quality of durum wheat.

Fertilization of legumes

Legumes are generally sensitive to P and to micronutrient deficiencies. Therefore, special attention should be given to ensuring an adequate supply of these nutrients. For the efficiency of BNF, an adequate amount of starter N should also be supplied at the initial stage.

Leaf analysis

Parallel to the soil analysis, leaves should also be analysed in order to reveal the nutrient status. Site-specific threshold values should be determined for cultivars/ species.

Balanced fertilization

Generally, K is not a deficient nutrient in the region. However, in order to maintain soil fertility status, the amount of K removed should be replenished. For permanent plants and fruit trees, such as pistachio, olives and vineyards, this assumes greater importance.

FUTURE RESEARCH ON RAINFED FERTILIZATION

The soils of the Near East region are generally calcareous and characterized by high pH, which frequently limits the availability of many plant nutrients, particularly P and micronutrients. To alleviate soil alkalinity, perhaps the cheapest and easiest method of acidification may be the soil application of elemental S. Further studies on this aspect should be undertaken, preferably under "favourable rainfed" conditions.

In order to enhance the availability of nutrients (especially P), micronutrients and water, the selection and inoculation of vesicular-arbuscular mycorrhizae (VAM) and plant-growth-promoting rhizobacteria (PGPR), should be tested under field conditions.

To minimize gaseous losses, especially through volatilization, improved alternative methodologies need to be developed and perfected under field conditions. Manuring is not practised properly in the region owing to other non-agricultural uses (e.g. fuel) and to its non-availability. Measures for the enhancement of organic plant nutrient resources may have to be investigated and planned for field application. Crop rotation is of special significance for maintaining soil productivity. Site-specific crop rotation trials should be conducted in order to evaluate the effect of previous crops on the stored soil moisture, OM and soil N content. Economic analysis of such trials should also be considered in order to support the recommendations.

Efficient plant species/cultivars should be screened in relation to their response to P and micronutrient applications.

Chapter 7
Irrigation and fertigation management

IRRIGATION

Irrigation covers 47.7 million ha in the Near East. Central Asia accounts for 59 percent of this total, although it covers only 21 percent of the total area of the region. Pakistan alone, covering a little more than 4 percent of the region, accounts for 33 percent of the total irrigated area. Overall, 72 percent of the area under irrigation is controlled by five (Pakistan, Islamic Republic of Iran, Turkey, Iraq and Egypt) of the 29 countries, covering only 25 percent of the Near East. The share of irrigated areas in national agricultural land varies considerably between the subregions and between the countries. In the Arabian Peninsula as a whole, 80 percent of the cultivated area is under irrigation. In all of the seven countries in this subregion, except Yemen, the whole of the cultivated area is under irrigation. In Central Asia, 75 percent of the cultivated area is equipped for irrigation, playing a crucial role in the production of cereals (especially wheat) and cotton (FAO, AQUASTAT).

IRRIGATION VOLUME, FREQUENCY AND DELIVERY RATE

The frequency, number of irrigations per day and the volume of irrigation water depend essentially on the type of soil or the growing medium.

Irrigation dose

The daily irrigation dose depends on the daily need, which in turn depends essentially on the reserve of readily available water in the soil or the growing medium. In a loamy clay soil, the dose per irrigation can be 4–6 mm (litre/square metre), while in a loamy soil the dose per irrigation is 2–4 mm. In a light well-drained soil, the irrigation dose is 1–2 mm. However, for growing-medium cultivation, the dose per irrigation is lower than 1 mm and in most cases it ranges between 0.2 and 0.5 mm (litre/square metre).

Where the daily water need is lower than the irrigation dose, it is possible to space the irrigations more widely over time.

Irrigation frequency

The frequency of irrigation is determined by the distribution of daily irrigation dose, depending on the interaction between the daily need and the type of soil or growing medium. It is important to note that the lighter the soil, the lower its daily needs, which implies smaller irrigation doses given at more frequent intervals of irrigations per day.

For loamy or clay soils, one irrigation per day is usually sufficient. In the case of high water requirements and where the climate is very warm, two irrigations per day may be required. Where the water requirements are low, only one irrigation every two days may be necessary.

On very light sandy soils, 2–3 irrigations per day are preferable, even in the case of low water requirements. In this case, the first irrigation is scheduled in the morning with about 40 percent of the needs, the second one (another 40 percent) at noon, and the last irrigation (less than < 20 percent) in the afternoon.

On a growing medium of light sand, it may be necessary to irrigate 3–4 times per day.

Irrigation delivery rate

In general, the recommendation is to irrigate at low delivery rates. However, under certain conditions, higher delivery rates can be adopted, especially to create larger humid surfaces on light soils / growing mediums, or to prevent rapid clogging in drip irrigation systems.

The irrigation delivery rate is usually expressed as water volume per unit of surface. Under intensive cropping, the delivery rates should be equal to or higher than 5 litres/m^2. For cropping in twinned rows (customary for vegetables), the delivery rate should be higher than 2.5 litres/m^2 (or 5 litres per linear metre).

The delivery rate depends on the number of drippers per unit of surface and on the delivery rate of each dripper. The delivery rate of the dripper has to be decided bearing in mind both the soil (or growing medium) and the salinity of the irrigation water.

The soil or the growing medium

The delivery rate depends on the hydraulic conductivity of the medium and the distance between the drippers. Where the soil is fine granular (less than 100 µ), which corresponds to loamy clay, the delivery rate is 1 litre/h. For soils with medium granules (100–200 µ), the delivery rate is 2 litres/h. For growing medium with a granule range of (200–300 µ), the delivery rate is 2–3 litres/h. For growing mediums with coarser granules, the delivery rate limit has to be higher than 3 litres/h. In order to create good humidity with delivery rates of 2–3 litres/h, the drippers should be close to each other and their distance should be between 20 and 30 cm.

Salinity of the irrigation water

Where saline irrigation water is used, it is necessary to create adequate humid zones for the roots to develop without salinity constraints. In general, salts accumulate on the margins of the humid zones. Therefore, care needs to be taken in order to prevent any flaking.

FERTIGATION MANAGEMENT

Conventional or classical fertilization practices involve direct application to the soil surface of the required P, K, Mg, Ca and part of the N before planting. This is usually followed by 2–3 applications of N fertilizer during the cropping period.

On the other hand, fertigation is the application of fertilizers with the irrigation water, through irrigation systems. This could include all crop production systems using nutrient solutions, such as: surface irrigation methods, drip systems, and soil-less cropping systems. In view of its recent wide adoption in the region, fertigation is dealt with in detail in the following text. The management of the fertigation will be based on the irrigation system used (conventional or modern).

In order to carry out the fertigation process successfully, its management should take into account the details of the soil and water analysis, and those on plant nutrient removal and uptake by the crop. Fertigation management needs to consider the aspects detailed in the following sections.

Assessment of fertilizer requirement

A correct assessment of the available nutrient status before planting a crop helps in taking appropriate measures for ensuring adequate nutrient supply for a good crop. The techniques used include soil testing and plant analysis. Soil testing is the most widely used tool for making balanced and profit-maximizing fertilizer recommendations, particularly for field crops. Soil testing as a diagnostic tool is useful only where the interpretation of test results is based on correlation with crop response and economic considerations to arrive at practically usable fertilizer recommendations for a given soil–crop situation (FAO, 2006).

The concentrations of nutrients in the extracted soil solutions are determined by standard methods. The choice of a suitable extractant for available nutrients is important because of the different amounts of nutrient measured and the degree of their correlation with crop response. For N, the water-soluble fraction (nitrate) is most suitable, but the capacity to mobilize organic N can provide additional information. For the nutrient cations (Ca, K and Mg), the exchangeable portion is representative of the whole available fraction in most cases and, therefore, determined by suitable extractants, such as ammonium acetate and barium chloride. In soils that can release non-exchangeable K, a measurement of exchangeable fractions only does not provide a complete picture. For available phosphate estimations, for neutral and alkaline soils, the Olsen method (0.5 N sodium bicarbonate solution of pH 8.5) is more suitable. Among the major nutrients, the soil test methods for P are relatively more reliable. For most micronutrient cations, DTPA is now widely used as an extractant. In the case of anions, the most commonly used extractant is hot water for B, and Grigg's reagent (ammonium oxalate of pH 3) for Mo.

After soil analysis, the concentrations of available nutrients measured must be interpreted into ranges of nutrient supply, and then into the nutrient amounts required to reach a certain yield level. In general, the lower the soil fertility status (soil test value) is, the greater is the need for external nutrient application.

TABLE 11
Interpretation of soil test data for some nutrients in soils of medium CEC

Soil fertility class	Available (extractable) nutrients			Expected relative yield without fertilizer
	P	K	Mg	
	(mg/kg soil)			(%)
Very low	< 5	< 50	< 20	< 50
Low	5–9	50–100	20–40	50–80
Medium	10–17	100–175	40–80	80–100
High	18–25	175–300	80–180	100
Very high	> 25	> 300	> 180	100

Source: FAO, 1980.

For macronutrients, the data are generally classified into categories of supply, e.g. very low, low, medium, high and very high. From these categories, the nutrient amounts required for an optimal or stated yield level are estimated. For micronutrients, a critical level is generally used to decide whether an application of that nutrient is needed.

Table 11 provides a generalized idea of the relation of available nutrient status to expected yields (without external addition) for a soil of medium cation exchange capacity (CEC) (10–20 cmol/kg). The values in the final column of Table 11 indicate the approximate yield level that the existing soil fertility level could support.

Determination of the soil nutrient balance provides indicators for the sustainability of agricultural systems in relation to the long-term nutrient supplying capacity of the soil to meet crop demands. A nutrient balance for a "system" consists of the sum of nutrient inputs minus the sum of nutrient outputs. This system always represents a particular spatial scale. The macrolevel is used for national, continental and global farming-system level. The mesolevel coincides with the province/district/agro-ecological zone (AEZ) level. It can also be defined as an agro-economic entity, e.g. cotton-based or dairy-based farming systems. Finally, the microlevel is defined as the farm or village level. The introduction of mesolevel studies adds value to existing national- and farm-level approaches. Provided that sufficient data are available, mesolevel nutrient balances can be compiled properly to serve as a guide for a nutrient management strategy (FAO, 2003, 2004).

Fertilizer application

Fertilizer application observes the following principles:

- Organic manure is incorporated into the soil during soil preparation.
- Mineral fertilizers are applied partly as basal dressing before crop establishment.
- Additional applications of mineral fertilizers are applied as a routine or maintenance dressing during the crop cycle.

In the first few weeks after planting or sowing, the crop nutrient requirements are rather low. However, the need for nutrients increases with active crop growth (about 14 days after transplantation and about 3 weeks after direct seedling). The supply of nutrients through fertilization should be stopped at a certain point before the end of the crop cycle, as indicated in Table 12.

From the crop life cycle, it is possible to calculate the daily fertilizer requirements, which could be synchronized with the irrigation schedule.

For example, where the irrigation frequency is once a day, then the nutrient inputs are added daily to the irrigation water. Where irrigation is less frequent, then the added fertilizer should compensate for the number of days separating the two consecutive irrigations. In the case of multiple irrigations per day, the quantity of fertilizer should be spread over the different irrigations.

TABLE 12
When to end the nutrient supply to the crop

Addition of nutrients	Time for ending nutrient supply (days before end of crop cycle)
N	7–10
Mg	10–15
K and Ca	15–20
P	25–30

Choice of fertilizers

The total P supply can be given as basal dressing through P fertilizers such as: phosphate rock, di-calcium phosphate or MAP. For top dressing, MAP and DAP are recommended. For P supply by fertigation, the use of phosphoric acid is suggested in view of its pH regulating effect. Where the acid is not available, then the use of MAP and/or DAP is recommended.

Potassium is relatively mobile in the soil and is washed out easily in irrigated crops. Application of K as basal dressing should not exceed 10–20 percent of total requirements. The rest of the K could be provided by top dressing or through fertigation. Potassium sulphate fertilizer can be used, as can potassium nitrate, which also provides N.

For short-season crops, urea can serve as an N source just before crop establishment. Nitrogen supply for maintenance dressing is achieved through AN, potassium nitrate, calcium nitrate, or urea. In fertigation, the main N sources are: AN, potassium nitrate and calcium nitrate, and in some cases nitric acid for pH regulation.

Magnesium is usually supplied as magnesium sulphate, which is mainly applied as a maintenance dressing and sometimes as a leaf spray. Where necessary, Ca can be added in the basic dressing, but in most cases it is given as a maintenance dressing or during fertigation by using calcium nitrate (also as a leaf spray).

MICRONUTRIENTS IN FERTIGATION

In the case of growing medium cultivation, the regular (daily) application of micronutrients is necessary and could be applied through fertigation. Generally, chelated forms are recommended in order to avoid nutrient fixation, particularly in calcareous soils. In very light sandy soils, the application of micronutrients is important. At least one application per week is necessary (by leaf spray or by fertigation).

For rich soils, the application of micronutrients is limited mainly to Fe and sometimes Zn, which are usually added as foliar sprays.

TABLE 13
Quantity of required micronutrient fertilizers

Fertilizer	Tomato	Melon	Cucumber	Pepper	Rose
			(mg/litre or g/m^3)		
Fe-EDTA 13%	6.450	4.300	6.450	6.450	10.750
Fe-DTPA 6%	13.980	9.320	13.980	13.980	23.300
Fe-EDDHA 5%	16.770	11.180	16.770	16.770	27.950
Mn sulphate	1.690	1.690	1.690	1.690	0.850
Zn sulphate	1.440	1.150	1.440	1.440	1.000
B (borax)	2.860	1.910	2.380	2.860	1.910
Cu sulphate	0.187	0.125	0.187	0.187	0.187
Na molybdate	0.121	0.121	0.121	0.121	0.121

Most crops need six micronutrients. In using growing mediums, the nutrient solution should contain the quantities indicated in Table 13.

INJECTION OF THE NUTRIENT SOLUTION INTO IRRIGATION WATER

Where possible, fertigation should be done with each irrigation in order to maintain the soil salinity at a rather stable value. For this reason, the fertigation should provide 0.5–2.0 g/litre of fertilizers. Where the fertilizer quantities per irrigation are known, it is possible to proceed with the distribution of these fertilizers through the irrigation system.

There are different fertilizer injection systems:

- By-pass fertilizer tanks with continuous fertilizer distribution: the concentration of the fertilizer flow changes in time, and at the end of the irrigation there is only clean water going to the greenhouse or to the soil/growing medium.
- Hydraulic injection system with constant delivery rates or with adjustable delivery rates (e.g. Venturi and Dosatron): the delivery rates are adjustable between 0.2 and 2.0 percent. With this system, there is an electric injection mechanism, which allows delivery rates of 500–600 litres/h. The pump works with sequences of 6 seconds, and the injection can be regulated from intermediate to continuous injection by selection of the sequence (from 0.06 to 6 seconds).

The fertigation solution that reaches the crop depends on the concentration and the dilution ratio of the mother solution. To calculate the mother solution, it is necessary to know the initial dilution ratio.

Where working with by-pass fertilizer tanks, the only regulation is through regulation of the by-pass flow (by a valve). This regulation is needed in order to prolong the injection duration when necessary and to dilute the concentration of the injection solution, as when acids are injected.

On the other hand, working with hydraulic injections systems and after the percentage of injection has been selected and controlled, it is easy to calculate the fertigation dose based on the system used (as shown below).

Calculation of the fertilizer needed

Modern fertigation uses standard solutions of a more or less stable concentration, whose injection rate depends on the dilution ratio. The concentration of the mother solution is between 50 (2 percent or 20 percent) and 500. The quantity of each fertilizer to put in the fertilizer tank is obtained by the calculation: [tank volume in litre/concentration of mother solution (in %)] × quantity fertilizer (g/m^3).

For a tank of 60–litres (0.06 m^3) with a dilution ratio of 0.8 percent (or 8 percent) and a need for 80 g SOP and 75 g AN per cubic metre of water, the following amounts should be put in the tank with 60 litres of water:

- (60/8) × 80 = 600 g of SOP.
- (75/8) × 75 = 562.5 g of AN.

Fertilizer solubility

It is necessary that the fertilizer be completely soluble in water. In the event of incomplete solubility owing to low temperature, it is advisable to warm the fertilizer tank. However, it is advisable to reduce the dilution ratio through the hydraulic system described above, as it is provided with a modifiable injection mechanism. Table 14 lists the solubility of different fertilizers at zero and 20 °C.

It is important to determine the solubility in order to select the most soluble fertilizer, or to adapt (increase) the injection ratio where necessary. In general, there are no problems with injection ratios higher than 1 percent.

Potassium sulphate has the lowest solubility of those in Table 14. Therefore, it is advisable to use the hydrosoluble version of this fertilizer. However, also in this form, it is necessary to verify its complete solubility, especially in winter.

As an example, one could put 53.6 kg of potassium nitrate and 19.3 kg of AN in a fertilizer tank with a capacity of 200 litres. At 20 °C, 19.3 kg of AN takes 5 percent of the solubility in a 200-litre tank (19.3/[192 × 2] = 0.05). The potassium nitrate can take 95 percent of the remaining solubility, which is 31 kg × 0.95 = 29.45 kg/100 litres or 58.9 kg/200 litres. At 20 °C, there are no solubility problems.

At 0 °C, there are problems because the AN takes 8.2 percent of the solubility, and the rest of the solubility (91.8 percent) corresponds to only 23.85 kg of potassium nitrate (13 × 2 × 0.918), which is insufficient. Even at 10 °C, there are problems because the AN takes 6.2 percent of the solubility (19.3/310 = 0.0622). The potassium nitrate can take 93.8 percent of the remaining solubility, corresponding to 41.3 kg (22 × 2 × 0.938 = 41.27).

The temperature of the fertilizer solution is an important factor. In

TABLE 14
Solubility and compatibility of fertilizers

Fertilizers	0 °C	20 °C
	(kg/100 litres)	
Ammonium nitrate	118	192
Potassium nitrate	13	31
Magnesium nitrate	2	79
Magnesium sulphate	60	71
Potassium sulphate	7	11
Calcium nitrate	102	122
MAP	23	37
DAP	43	66

some cases, it is necessary to lower the dilution ratio in order to avoid solubility problems.

Compatibility of fertilizers

Most fertilizers can be mixed, with the exception of calcium nitrate, potassium sulphate and magnesium sulphate, because of the possibility of forming calcium sulphate (which is not completely soluble). In this case, it is necessary to use two tanks or to alternate the fertigation inputs of this fertilizer. Chapter 11 provides more information on the compatibility of fertilizers.

Another problem can be the mixture of Ca and P and the risk of formation of tri-calcium phosphate. This precipitant salt causes clogging of the drippers. The risk of clogging depends on the temperature, the solution pH and the contents of both elements.

Quality of irrigation water

The quality of the nutrient solution is largely dependent on the water quality. Good-quality water is needed in order to avoid problems. One of the problems can be the NaCl content, but other ions can also have a negative effect.

Chapter 8
Fertilization of highly sandy soils - desert farming

Deserts occur in most of the Near East countries, and include the North African Desert, the desert areas of the Syrian Arab Republic, Jordan and Iraq, the deserts of Saudi Arabia and the Gulf States and the deserts of the Islamic Republic of Iran, Pakistan and Afghanistan.

The desert environment in the region is characterized by high summer temperatures and high light intensity for most of the year. Thus, the potential biomass production is very high, provided that water and nutrients are satisfactory. Rainfed agriculture faces the risk of drought, which often sweeps through the region. However, precipitation, groundwater and major rivers in the region have been supplying inhabitants of these areas with sufficient volumes of water, which are now decreasing owing to increased demand. Improvement in water resources management is of critical importance in the Near East.

In many countries in the region, 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, the use of mineral fertilizers is required in order to enable rewarding agricultural production.

PROPERTIES OF SANDY SOILS

Many people think of sandy soils as problem soils that can give only low yields and are hard to manage. Soil surveyors used to consider them as being Class 3 or perhaps Class 4 in terms of Land Capability Classification, mainly because of the low waterholding capacity of the soil control section. However, with new agricultural technologies and advances in soil science, the management of sandy soils has become easier, and their productivity can equal or even exceed that of loamy and clay soils.

In deserts, natural vegetation is sparse and, therefore, the SOM content is expectedly low (less than 0.5 percent). Sandy desert soils usually have a profile without distinguished horizons because of the low biological and chemical activities under such dry climates. Sand transportation by wind blowing is common in sandy desert soils, and sand dunes are frequent.

A characteristic of sandy soils is their low moisture retention - most of the water applied through irrigation is lost by infiltration. Available water in a sandy soil ranges between 3 and 8 percent, while in clay soil it ranges between 15 and 30 percent. This characteristic is very important because it determines the frequency of irrigation (in addition to the capacity of the soil to hold nutrients).

The infiltration rate in sandy soils is 2.5-25 cm/h, which is about 250 times the infiltration rate of clay soils (0.01-0.1 cm/h). Surface flood irrigation is not recommended where the infiltration rate is 10 cm/h or more.

Sandy soils are not elastic when moist, and they lose consistency when dry. The soils have a low CEC in the range of 2-5 meq/100 g as compared with 15-45 meq/100 g for clay and loam soils. Therefore, where the soil is sandy to a considerable depth, water and nutrients may penetrate below the rootzone and become unavailable to plants.

FERTILIZATION OF SANDY SOILS

The fertility level of sandy soils is very low. Fertilizers are used to supply nutrients that are not present in the soil in the amounts necessary for achieving profitable crop production. The best method for fertilizer application depends on: the rooting characteristics of the crop grown; the crop demand at different stages; soil properties; water availability; and the type of irrigation system.

Crop production in these soils requires multiple applications of mineral fertilizers. Furthermore, because of the need for different nutrients at different times during the growing season, several methods of applying fertilizers are usually employed. The application methods employed should be economic, accurate and efficient.

Pre-planting applications

Desert soils are generally low in N and P, medium to low in K, low in micronutrients, and usually sufficient in other essential nutrients. Nutrients that are in inadequate supply in the soil should be applied prior to or during planting. One practical method for supplying fertilizer prior to planting is the use of spreaders (broadcast method) to apply dry fertilizers uniformly over the soil surface.

Different types of spreaders are used for broadcasting fertilizers. The simplest is called a "drop spreader". This is a single-unit spreader that is used in small fields or in areas where large application equipment cannot enter. The "self-propelled spreader" is suitable for large areas. Its bin can hold about 10 tonnes of dry fertilizers, and it spreads the material in a swath 20-30 m wide by means of rapidly spinning horizontal discs fixed at the rear of the fertilizer bin.

Fertilizers may be applied before ploughing in order to permit the best possible distribution of nutrients within the rootzone. It is advisable to apply about 50-70 percent of P, 70-80 percent of K and 25-40 percent of N fertilizers at the pre-planting stage. The rest may be applied as split doses during the growing season. Applying liquid fertilizers at pre-planting stage via irrigation water (fertigation) to the soil surface before discing was tested on sandy soils in Saudi Arabia. The test used 15 split applications of liquid fertilizers during the season via the irrigation system, and the results were very encouraging. Many farmers apply liquid and soluble powder fertilizer via the irrigation system on sandy soils planted with wheat, barley, alfalfa, corn, Sudan grass, carrots, onions, potatoes and watermelons.

Application during planting

Fertilizer application during planting and band placement of fertilizers stimulates early growth and reduces phosphate fixation. Application of fertilizers during planting is an ideal way of ensuring adequate availability of nutrients at the early development stage of the crops. Many row crops respond well to fertilizer placed in bands near the seed at planting time. The band may be placed to the side and below the seed, depending on the crop type and its rooting system.

Recommended amounts of nutrients to be applied during planting for sandy desert soils are similar to the quantities recommended for pre-planting applications.

Post-emergence fertilizer application

Application of fertilizers on the soil surface after germination is termed top dressing. Field crops and forages grown in sandy soils respond very well to several top dressings of fertilizers applied during the growing season. Applications are usually made before the growth flush in order to ensure that nutrients are available ahead of the growth demand and to avoid any fertilizer injury to the foliage. The same equipment used for pre-plant broadcast applications of dry fertilizers may be used for top dressing.

Placement of fertilizers beside the crop rows is referred to as side dressing. This may be done at the same time as the rows are cultivated. In sandy soils, a few split applications during the season are generally superior to a single fertilizer application, either broadcast or banded. Equipment for side dressing dry fertilizers usually consists of two large hoppers mounted on tool bars on either side of a tractor, ahead of the operator. The desired amount of fertilizer is metered into a small furrow and covered by the cultivating unit.

Application through irrigation (fertigation)

Applying fertilizer via irrigation water (fertigation) is becoming a more popular method for fertilization in irrigated agriculture, especially in sandy soils. Savings in time, labour, equipment cost, and fuel costs are important factors that have encouraged farmers to adopt this practice. In the past, fertigation was limited to N application. In Saudi Arabia and the Gulf states, where most fields are sandy, sandy loam and loamy sand, crops such as wheat, barley, alfalfa, Sudan grass, potato, onion, garlic, carrots, tomato and watermelon have often responded more profitably to fertigation with N, P, K, Fe, Zn, Cu and Mn than to top dressing with dry fertilizers.

Sandy soils are often irrigated by sprinklers (fixed sprinklers or moving centre pivots) or by drip irrigation systems. Fertigation is a proper method for applying fertilizers, particularly with split applications during the season, to satisfy crop nutrient demands in a timely and controlled manner.

Dry fertilizers should be pre-dissolved before being introduced into any irrigation system. Liquid fertilizers present no problem with respect to ease of injection into irrigation systems. Nitrogen is often applied separately because timing is very important, and supplemental application of N during the growing season is often needed for best results. Some straight N sources, such as urea, are cheaper than the same amount of N in compound fertilizers.

With pressurized irrigation systems, the tank (fertilizer injector) can be set up at the irrigation pump site and the dissolved fertilizer materials are injected directly into the irrigation lines by a high-pressure, low-volume pump. A check (one-way) valve is recommended for preventing fertilizer materials from polluting the main water source.

However, the application of fertilizers through non-pressure systems, such as furrow irrigation, requires less sophisticated equipment. The fertilizer tank could be set up alongside the irrigation ditch and connected to a float box or valve that meters the material into the irrigation water being applied.

Fertigation has many advantages. These include preventing fertilizer from leaching beyond the rootzone or accumulating near the soil surface, and thus becoming inaccessible to crop roots. Fertigation is recommended for sandy desert soils as an efficient and practical method for applying fertilizers. In drip irrigation and fixed sprinkler systems, excellent results have been obtained when fertilizers have been injected in irrigation water towards the middle of the irrigation period and stopped shortly before completion of irrigation. In the moving sprinkler irrigation systems (centre pivots and side-rolls), the application of fertilizers should be continuous during the irrigation period in order to secure a uniform fertilizer distribution.

Foliar fertilization

Fertilizer nutrients that are soluble in water may be applied directly to the aerial (vegetative) portion of plants. The nutrients must penetrate the cuticle of the leaf and then enter the cells. This method provides rapid utilization of nutrients and permits the correction of observed deficiencies in less time than would be required by soil treatments. Where problems of soil fixation of nutrients exist, foliar fertilization constitutes the most effective means of fertilizer application.

The most important use of foliar sprays has been in the application of micronutrients. The greatest difficulty in supplying N, P and K as foliar sprays lies in the fact that in order to apply adequate amounts of these macronutrients, care must be taken not to cause severe burning to the plant leaves. This is in addition to the extra costs inherent in spraying large volumes of solution and performing numerous spraying operations. Nutrient concentrations of generally less than 2 percent are employed in order to avoid injury to foliage. Nevertheless, foliar sprays are excellent supplements to soil applications.

Foliar fertilization can be accomplished by means of overhead sprinkler systems and by using pesticide-spraying equipment. Ground-spray equipment used for foliar feeding is usually of the high-pressure, low-volume type, designed for uniform spraying of foliage and for keeping water volume to a minimum. Droplet size must be controlled carefully as it affects crop response.

Micronutrients lend themselves readily to spray applications because of the small amounts required. Foliar applications have been found to be many times more efficient than soil applications for fruit trees and other crops. Soil applied Fe is often not effective on high pH soil because of precipitation of $Fe(OH)_3$. Therefore, more expensive Fe-chelate sources such as Fe-EDDHA are recommended in order to secure plant response.

Efforts to correct Fe chlorosis have not always been successful, and more than one application may be needed on some crops. Chlorosis is a common problem on field crops, vegetables and fruit trees grown on high pH soils under low rainfall conditions.

Foliar application of urea has been successful with apples, citrus, wheat and other field crops. This is because N is absorbed more rapidly through the leaves than with soil applications.

Foliar applications of P are less used. This is largely because most P compounds are damaging to the leaves when sprayed in larger quantities. The maximum concentration of P in foliar fertilizer should not exceed 0.5 percent.

Various environmental factors, including temperature, humidity and light intensity, also affect the rate of absorption and translocation of nutrients applied to the foliage. To be most effective, 2-5 spray applications repeated at short intervals may be needed.

Foliar fertilization should always be considered supplemental to soil-applied nutrients and should not be seen as a substitute to any of the above-mentioned methods of fertilizer application (see also Chapter 10).

Slow-release fertilizers

Crop recovery of applied N seldom exceeds 50 percent in sandy desert soils. Use of N fertilizers with greater efficiency is desirable because of agronomic and environmental concerns over excessive movement of N into surface waters and groundwater, as well as the effects of gaseous N losses on the upper atmosphere.

Slow-release fertilizers are capable of releasing N over an extended period, thus avoiding the need for repeated applications of conventional water-soluble products. Considerable research has been done with coatings to slow down the rate of nutrient release from the applied N fertilizers. The other path for slowing N fertilizer release involves the use of urease enzyme inhibitors to curb the transformation of N into NO3-, that is water soluble and could leach down easily owing to its negative charge.

Slow release is often considered advantageous for keeping turf grass green and healthy over an extended period of time. Slow release usually has little or no advantage on field crops because they do not release N in accordance with crop needs throughout the season. Most field crops need N during the growing season at a rate that is faster than that of N released from slow-release fertilizers. Therefore, they would respond well to immediately available N fertilizers. In sandy soils in the Central Region of Saudi Arabia, the use of slow-release N fertilizer resulted in 60-70 percent of the yield of a wheat crop as compared with that obtained with equal amounts of split applications of urea fertilizer.

Another disadvantage of slow-release N fertilizers for crop production in sandy desert soils is the high cost of the product itself. It could be concluded that the use of slow-release N fertilizers is not beneficial for crop production in sandy desert soils.

FERTILIZER-PESTICIDE MIXTURES

Fertilizer-pesticide mixtures are used to fertilize crops and control soil-borne insects, diseases, nematodes and weeds. Most of these mixtures are formulated in liquid forms because it is hard to produce uniform mixtures from dry materials. Another issue is that small amounts of pesticides are usually added to large quantities of fertilizers in order to make one homogenous mix. Farmers all over the world have used fluid fertilizer-pesticide mixes successfully. Compatibility problems may occur where liquid or soluble powder fertilizers are combined together or with other materials such as pesticides. It is advisable to perform the "jar test" to check fertilizer compatibility with pesticides before mixing large quantities for field applications. This test involves dissolving the pesticides and the fertilizers in a jar in the same ratio to be used in the field, and watching for any precipitation or milkiness that may occur within one hour or even less. If cloudiness does occur, there is a chance that fertilizer/chemical interaction may occur. If precipitation takes place in the jar, then this indicates that the mixture is not compatible.

Where nutrient compositions are compatible with pesticides, applying both together after running a compatibility test can minimize application costs. The application of nutrients, mainly N, very often engenders a synergistic effect with herbicides, enhancing their effect.

NUTRIENT UTILIZATION BY PLANTS

Adequate fertilization programmes aim to supply the plant nutrients needed to sustain maximum crop productivity and profitability, while minimizing the environmental impact from the nutrients used. It is important to have sufficient nutrient supply in the soil to meet crop needs during the entire growing season, especially during periods of peak nutrient demand.

As roots absorb the majority of plant nutrients, understanding the rooting characteristics in sandy soils is important for the development of efficient fertilization programmes. Where a vigorous tap-root is produced early on, fertilizers may best be placed directly under the seed. However, where many lateral roots form early on, side placement is best. For example, carrot roots are more active than those of onion, peppers and snap beans, especially in deeper soil layers.

Corn and soybean develop extensive root systems and have a great capacity for utilizing nutrients distributed throughout a large soil zone. The roots of corn and soybean exploit the soil more thoroughly than do those of carrots, cotton, potato and other shallow-rooted crops. On sandy soils, corn roots can reach a depth of 2 m and may extract soil moisture down to a depth of 1.5 m. Small grains have an extensive root system in the surface soil. Alfalfa and clover roots may penetrate the soil for a few metres. Therefore, legumes in pastures provide more animal feed during drought periods than do shallow-rooted grass.

Soluble fertilizer salts concentrate in the soil solution surrounding the zone of fertilizer application. The rate and distance of movement of the salts from the point of application in sandy soils depend on the fertilizer used, the application rate, the soil moisture and the soil temperature.

The movement of P from the point of placement in sandy desert soils is slow and may reach only a few centimetres in a season (because of the low mobility of H_2PO4- ions in the soil). Nitrogen salts move in the soil solution with water movement. Nitrate and urea move more readily than does NH_4^+, which would be partially adsorbed at the exchange complex. The movement of K is relatively similar to that of NH_4^+. In irrigated sandy soils, both NH_4^+ and K^+ may move about 20-30 cm in a season because the CEC is low and, therefore, the amounts of cations that can be held on the exchange complex are limited.

In literature, it is often reported that, because P is immobile in the soil, surface applications after the crop is planted will not lead to movement of P near the zone of root activity and will be of little value to annual crops in the year of application. Therefore, placement of P nearer to the roots is recommended. This applies well to medium/heavy-textured soils, especially where the rainfall is not high.

However, many fertilization field trials have been conducted on wheat, barley, alfalfa, Sudan grass, potato, carrots, onion, garlic, tomato and watermelon grown in sandy, loamy sand and sandy loam calcareous soils in Saudi Arabia. They reveal that top-dressed P fertilizers in liquid or solid forms maintain sufficient levels of P in the soil and constitute an efficient method of fertilization.

The P applied with irrigation water comes in contact with less soil than does the disced-in P and, thus, there is less opportunity for P fixation. Thus, applying fertilizers through fertigation is an efficient method of applying P and K and all other required nutrients for sandy desert soils, especially on low-P or low-K soils.

Farmers often want to know whether it is better to use a banding or broadcasting approach for P application in sandy soils. The efficiency of either method depends on the P status of the soil and the application rate. As the P rate increases, broadcast application can be equal or superior to banding. When the application is split between band and broadcast, there is a great advantage of building up the general soil P level. In general, differences between seed-placed and broadcast P diminish with increasing levels of available soil P.

Applying frequent doses of P fertilizers with water will help to minimize the effect of a low P level in the soil and will improve the rate of fertilizer recovery.

The same could be said for N, K and micronutrients. Therefore, the recommendation for irrigated agriculture in sandy desert soils is to combine banded P applications with fertigation or broadcasting because this method will generally be more effective than either treatment alone.

CONCLUSIONS

An efficient fertilization programme for sandy desert soils may be developed as follows:

- ➢ Collect representative soil samples and analyse them at least once every 2-3 years.
- ➢ Collect irrigation water samples and analyse them once every 5 years.
- ➢ Satisfy the crop nutritional requirements based on soil tests.
- ➢ The application of fertilizers should be done in accordance with the following schedule:
- ➢ *Before or during planting:*
    - 25-40 percent of N requirement;
    - 50-70 percent of P requirement;
    - 70-80 percent of K requirement.
- > *During the growing season:*
    - Split the remainder of the fertilizers quantities into 3-5 applications during the growing season to complete 100 percent of crop requirement.
    - Where a sprinkler or drip irrigation system is available, a fertilizer injector should be installed and fertilizers could be applied in 10-15 split applications during the growing season.
    - Spray foliar fertilizers as supplementary nutrient sources, mainly to supply micronutrients.
    - Where economically reasonable sources of organic materials are available (manure, compost, sludge, plant residues, etc.), it is advisable to apply such materials on sandy desert fields in order to improve soil structure, water and nutrient holding capacity, and soil fertility.

The fertilization programme as outlined above has been applied on large farming operations on sandy desert soils in Saudi Arabia and some of the Gulf states. In addition to high yields from vegetables and fruit trees, it has resulted in crop yields of the order of: wheat, 6-8.5 tonnes/ha; barley, 8-10 tonnes/ha; annual alfalfa (dry hay), 20-30 tonnes/ha; potato, 35-5 tonnes/ha; and tomato, 80-100 tonnes/ha.

Chapter 9
Use of treated wastewater as a source of irrigation and plant nutrients

IRRIGATION WITH WASTEWATER

Irrigation with treated wastewater is a well-established practice in many countries in the Near East, North Africa, Mediterranean Europe, and North and South America. In these countries, 70–90 percent of the overall applied water is often used for agricultural and landscape irrigation.

However, reuse of reclaimed wastewaters may have adverse effects on public health and the environment if it is untreated or partially treated. Although the degree of treatment/purification is of prime concern, the method of irrigation and the wastewater-use efficiency at farm level are also important. The lower the water-use efficiency, the higher is the possibility of soil and groundwater contamination. Thus, the selection of the irrigation method and scheduling of irrigation assume considerable importance in the overall system for efficient and safe reuse of wastewater.

ENVIRONMENTAL BENEFITS

Where wastewater is used properly for agricultural purposes, improvements to the environment are possible. The following are some of the environmental benefits:

- conservation of water resources;
- avoidance of discharge to surface waters, thereby preventing occurrence of unpleasant aesthetic situations, anaerobic conditions in rivers and eutrophication of lakes and reservoirs;
- saving groundwater resources in areas where overutilization of these resources in agriculture is causing problems of groundwater depletion and seawater intrusion;
- soil conservation, and soil fertility improvement by the humus and nutrient enrichment of the soil.

POTENTIAL NEGATIVE EFFECTS

Wastewater use for irrigation may also have negative impacts on the environment and human health. The principal hazards associated with wastewater reuse for agriculture are:

- the introduction of chemicals and nutrients into susceptible ecosystems (mainly soil and water sources);

- the spread of pathogens.

STRATEGY TO PROTECT HUMAN HEALTH AND THE ENVIRONMENT

The success of using treated wastewater for crop production depends greatly on adopting strategies aimed at optimizing crop yield and quality while maintaining soil productivity and safeguarding public health and the environment. Several options are available and a combination of them may offer an optimal solution for a given set of conditions. The user should have prior information on wastewater supply and its quality in order to formulate and adopt an on-farm management strategy.

In the past, particular attention was given to wastewater treatment as the only feasible and fully effective measure for reducing the health risks. However, in many developing countries, full treatment of wastewaters is not feasible, mainly owing to economic constraints. Therefore, it is necessary to consider ways of protecting human health and the environment through means other than waste treatment. To achieve this objective, the following options are available:

- ensuring at least partial treatment of wastewaters in order to reduce the incidence and intensity of health hazards;
- proper selection of crops, and restrictions on the crops that are consumed directly or eaten raw;
- adoption of safe and efficient methods for applying treated effluent to the crops;
- control of human exposure to the wastewaters, coupled with effective overall hygienic farm management.

While full treatment of the wastewaters prevents pathogens from reaching the field, crop restrictions and human exposure control act later in the pathway to prevent pathogens from reaching the crop consumers and the agricultural workers. An integrated approach to planning wastewater reuse schemes will allow an optimal combination of agrotechnical measures, depending on the local sociocultural, institutional and economic conditions.

The aim of crop restrictions is to protect consumers. However, the do not give protection to farm workers and their families. These remain at high risk as they are still exposed to pathogens in the wastewaters, on the soil and on the crop. Farmers must be advised as to why the crop restrictions are necessary and be assisted in developing a suitable safe cropping pattern. In order to enforce crop restriction measures, it is imperative to have the support of strong legislation and implementing authorities capable of effective monitoring and control.

AGRONOMIC ASPECTS

Because of its plant nutrient content, the fertilizing potential of wastewater is an asset for soils and crops. However, it can also be a source of pollution where not managed properly. The plant nutrient content of wastewater is of particular interest to the farmers. The suspended, colloidal and dissolved solids present in wastewater contain macronutrients and micronutrients that are essential for crop

TABLE 15
Amount of nutrients added with applied wastewater

	Concentration of nutrients in wastewater (mg/litre)								
	5	10	15	20	25	30	35	40	50
Applied wastewater (m^3/ha/year)	Nutrients added (kg/ha/year)								
1 000	5	10	15	20	25	30	35	40	50
2 000	10	20	30	40	50	60	70	80	100
3 000	15	30	45	60	75	90	105	120	150
4 000	20	40	60	80	100	120	140	160	200
5 000	25	50	75	100	125	150	175	200	250
6 000	30	60	90	120	150	180	210	240	300
7 000	35	70	105	140	175	210	245	280	350
8 000	40	80	120	160	200	240	280	320	400
9 000	45	90	135	180	225	270	315	360	450
10 000	50	100	150	200	250	300	350	400	500

nutrition. However, the applied nutrient content (particularly where applied by flood irrigation in excess of crop water requirements) may occasionally exceed plant requirements. This may cause underground and surface water pollution and also problems related to excessive vegetative growth, delayed or uneven maturity, and reduction in quality. Therefore, proper estimation of the nutrients present in the wastewater is an essential part of the overall fertilization programme for irrigated crops.

Table 15 lists the amounts of N, P and K applied per hectare with irrigation water by a typical wastewater. The nutrient load depends on the overall volume of wastewater applied and its nutrient composition. It is assumed that for high nutrient efficiency, irrigation should be based on crop water requirements. With certain crops, no additional fertilizers are needed. In the event of excess nutrients, it is advisable to follow an appropriate cropping pattern and/or mix the treated wastewater with freshwater in order to reduce the nutrient application and solve the problem.

Plant nutrients in wastewater include N, P and, occasionally, K, Zn, B and S. Other macronutrients and micronutrients may also be present, but in lesser amounts. In addition, the OM in the wastewater can have a long-term effect on soil fertility and contribute to soil structure stability.

The N content of municipal wastewater following secondary treatment generally ranges from 20 to 60 mg N/litre. The N in treated wastewater could sometimes exceed crop needs. Knowledge about the N concentration in the wastewater and about the crop nutrient requirements are essential for proper management and for reducing the problems associated with a high N concentration in wastewater. Such problems include: lodging of field crops such as wheat and barley, and excessive vegetative growth of crops.

The P content in wastewater from secondary treatment systems varies from 6 to 15 mg P/litre (15–35 mg P_2O_5/litre) unless removal is accomplished during treatment. Evaluation of P in the treated wastewater should be done in conjunction with soil testing for proper fertilization planning.

The K concentration in wastewater is not known to cause adverse effects on plants or to the environment. It is an essential macronutrient and has a positive effect on soil fertility, crop yield and quality. The range of K in secondary treated wastewater is 10–30 mg K/litre (12–36 mg K_2O/litre). This amount must be taken into consideration in formulating the fertilization programme according to crop needs.

Most wastewaters contain S, Zn, Cu and other micronutrients. Attention must be given to B. Treated wastewater contains enough B to correct B deficiencies. However, this element is occasionally found at excess levels, creating problems of phytotoxicity.

Taking into account the nutrient requirement for a certain yield, the nutrient capacity of soil, the nutrients in wastewater, and the efficiency of nutrient uptake by crop under different irrigation systems, the following formula can be used to estimate the amount of N, P and K to be applied to the crops (in kilograms per hectare): (fertilizer recommendations based on soil tests - wastewater nutrient load [kg/ha/season]) / irrigation system efficiency (percent).

CONTROLLING PROBLEMS RELATING TO EXCESSIVE NUTRIENTS IN WASTEWATER

The nutrient that can most probably be found in excessive amounts is N. To avoid negative effects, the following steps and/or measures could be considered.

Estimating the N concentration

Chemical analysis of the wastewater for N is required. Based on this analysis, the amount of N added to the soil during the season through irrigating with the wastewater is determined. This amount is subtracted from the fertilizer amount needed by crops in order to reach the “actual” amount of fertilizer that needs to be applied.

Crop selection based on the N level

Selection of the proper crop, depending on N in treated wastewater, is necessary in order to: (i) make the best possible use of N from wastewater; and (ii) avoid nitrate pollution.

Making the best possible use of N from wastewater

Where the N present in wastewater is not adequate, supplemental fertilizer N is needed for satisfactory crop yield. From the standpoint of long-term application of wastewater, N input levels should be adjusted to compensate for N removal by the harvested portion of the crop plus expected losses from the system by volatilization and leaching through drainage.

Avoiding nitrate pollution

Some crops are highly effective in removing N from the soil. Grasses such as Sudan grass, Bermuda grass, Sudex and Rhode grass remove N efficiently from the soil. These crops are effective at removing nitrates.

Managing toxic concentrations of heavy metals and micronutrients

Before planning wastewater use, it is necessary to conduct a complete analysis of the effluent to be applied to the fields for its micronutrient and heavy metal contents. Wastewaters originating from industrial areas carry a greater risk of toxic concentrations of micronutrients and heavy metals. Great care needs to be exercised in deciding about the use of such effluents for agricultural purposes as they pose risks of a buildup of these elements in the soil and plant tissues.

Irrigation scheduling

As nutrients are always present in treated wastewater, any amount of irrigation water above the crop water requirement could create a problem. The problem could be environmental, agronomic or both. With wastewater irrigation, it is even more important to follow proper irrigation scheduling than with water of good quality.

Volume of water

Crops must be irrigated according to their crop water requirements. As the volume of irrigation water differs from place to place owing to climate conditions, the nutrients in wastewater could be excessive or inadequate for the same crop under the same soil fertility conditions in different places. Similarly, wastewater of the same quality could have an adverse environmental impact in one place but be very safe in another.

Irrigation frequency

With crops at full growth, the volume of water per irrigation must be always the same in order to reach a certain soil depth where the active roots are concentrated. However, as the absolute volume of irrigation water varies with climate conditions, the irrigation frequency should vary. However, the volume of water per irrigation needs to remain the same.

Irrigation system used

To avoid pollution from nitrates, the irrigation system should provide a uniform water application. The higher is the efficiency of the irrigation system, so the higher is the N uptake efficiency of crops. Microirrigation systems (e.g. sprinklers and drip) are superior.

TREATING CLOGGING OF THE IRRIGATION SYSTEM

Some constituents in wastewater may cause clogging of the irrigation system. Clogging problems with sprinkler, mini-sprinkler and drip irrigation systems might be serious. Deposits (slimes, bacteria, etc.) in the sprinkler heads and emitters are common. The most serious clogging problems occur with drip systems (owing to the small openings). Filtration is required before use. This makes management of drip irrigation systems difficult. The injection of diluted acid solution (e.g. HCl or HNO_3) is usually effective in removing the clogging. Mixing wastewater with freshwater can also be considered as a way of reducing the nutrient load of the treated water.

WASTEWATER REUSE PERSPECTIVE

Wastewater use for irrigation has been accepted in many countries. However, it is used mainly for irrigating fodder and industrial crops. The question is whether wastewater should be used only for fodder and industrial crops or whether its use may be extended to more promising and profitable crops including vegetables and flowers. This should be one of the ultimate goals of wastewater reuse, as profitable reuse creates conditions for sustainability. More emphasis should be focused on flowers. With vegetables, there is a perceived risk of pathogen spread and of accumulated heavy metals and nitrates in plant tissues, which may have adverse effects on human health.

Chapter 10
Foliar fertilization

Foliar fertilization entails the spraying of a formulated liquid fertilizer on plant leaves and stems and the absorption of nutrients at these sites. It is a means of supplying complementary doses of minor or major nutrients to plants. Foliar applications are timed to coincide with specific growth periods, using specific fertilizer formulas according to crop and location.

IMPORTANCE OF FOLIAR FERTILIZATION

Foliar fertilization can be used in many different cases for different objectives:

- as partial fulfilment of macronutrient needs;
- for decreasing direct addition of nutrients to the soil in order to minimize pollution risks in certain situations;
- as a remedial measure against visual and hidden nutrient deficiencies (curative and preventive applications, especially for micronutrients);
- improving nutrient availability to plants, particularly the micronutrients and P in high pH soils;
- improving the quality of fresh fruits and vegetables, thus decreasing post-harvest losses;
- increasing nutrient content in tree crops for better growth in the following season.

PENETRATION OF FOLIAR NUTRIENTS THROUGH LEAVES

When liquid fertilizer is sprayed on the foliage, the outer layer of the leaf expands as it becomes wet. The nutrient ions can then penetrate the leaf cuticle and reach photosynthetic apparatus through an uptake process that resembles nutrient uptake through roots (Figure 7).

Isotope studies confirm that plants can absorb nutrients (especially N) through leaves, stems, buds, blossoms and fruits (Dixon, 2003). There is further

FIGURE 7
Nutrient penetration pathway through plant leaf layers

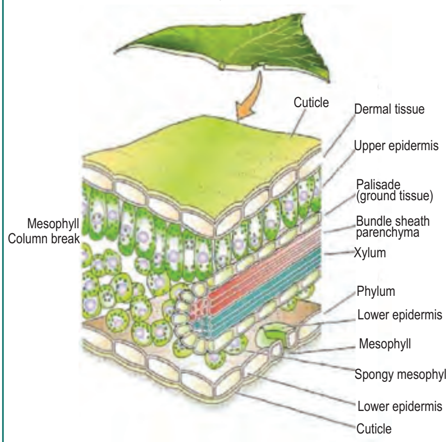


TABLE 16
Time ranges for absorption of various nutrients

Nutrient	Time for 50% absorption
Nitrogen (as urea)	0.5–2.0 hours
Phosphorus	5–10 days
Potassium	10–25 hours
Calcium	1–2 days
Magnesium	2–5 hours
Zinc	1–2 days
Manganese	1–2 days

evidence that nutrients can also be absorbed through the stomata. The entry of various nutrients into plant tissues differs greatly from one nutrient to another (Table 16), as well as from one compound to another.

The penetration times for the nutrients are influenced by various factors (discussed below).

The density of the cuticular pores is higher in cell walls adjacent to the stomata. This could explain the frequently observed positive relationship between the number of stomata and the intensity of mineral nutrient uptake.

FACTORS AFFECTING THE EFFICIENCY OF FOLIAR FERTILIZERS

Foliar fertilization efficacy is influenced by different factors related to the plant, the environment and the spray solution.

Environmental factors, such as the time of day, temperature, humidity and wind speed, influence the physical and biological effects of foliar application. Meteorological conditions favouring foliar applications are:

- time of day: late evening (after 6 p.m.) or early morning (before 9 a.m.);
- temperature: 18–30 °C, 23 °C is ideal;
- relative humidity: greater than 70 percent;
- wind speed: less than 8 km/h.

EFFECTIVE FOLIAR FERTILIZATION

For an effective foliar fertilization programme, the following guidelines should be considered:

- The pH of the spray solution should be maintained between 5.5 and 6.5.
- To avoid “burning” the plant foliage, very dilute solutions (especially in the case of inorganic-based fertilizers) should be used, and the application should be carried out at less than 30 °C.
- Water for preparing solutions should be free from particles, chemicals and harmful organisms.
- To avoid chemical precipitates, which might clog sprayer nozzles, incompatible chemicals should not be mixed together while preparing spray solutions.
- Best results are achieved when the spray solution is applied as mist while the wind velocity is minimal.
- Nutrient absorption is increased when sprays reach the leaf underside, where the stomata are located.
- Addition of surfactants is important for decreasing leaf surface tension and facilitating nutrient absorption,
- Application should be done in accordance with plant nutrient needs.

- Foliar fertilizers should not be applied when the soil is too wet or too dry.

MAJOR ADDITIVES TO FOLIAR-FERTILIZER FORMULATIONS

The addition of special additives enhances considerably the cost-effectiveness and utilization of foliar fertilization. Such additives may be anti-evaporants, surfactants, adhesives or humectants. These play a useful role in successful foliar fertilization, particularly with regard to low-volume/ultralow-volume (LV/ULV) liquids and suspension formulations.

Anti-evaporants

Anti-evaporants are stabilizing agents that prevent microdroplets from evaporating before they reach the leaves during application. This is very important when using LV/ULV application techniques. This is quite significant when foliar fertilization is applied in warm climates.

The anti-evaporants also reduce the evaporation rate of the nutrient solution on the leaf. Thus, the nutrients are in solution for a longer period of time and, hence, more available to the plant.

Surfactants

Foliar-fertilizer formulations may also contain additives to reduce surface tension in order to achieve an optimal distribution of the spray solution on the leaves, ensuring a large contact area between droplets and leaf surface. These additives are called surface active substances. They cover the leaf with a wet film so that the entire leaf surface may take up the nutrients into the plant, particularly via the stomata.

Adhesives

Although the rate of nutrient uptake via the leaf is high, it is essential to use an adhesive or “sticker” in the foliar fertilizer formulations in order to ensure optimal efficiency. The adhesive substances make the nutrient solution stick to the leaf and prevent the nutrients from being washed off easily by rain or sprinkler water.

Humectants

Humectants promote repeated wetting of the nutrient spray cover so that multiple dissolving of the nutrients is ensured. With humectants, a relatively low level of humidity in the air is often enough to trigger the process. Consequently, continuous nutrient uptake by the leaves over longer periods of time takes place.

QUALITY CONTROL MEASURES

The objective of quality control measures for a product is to ensure that the product meets the required specifications laid down for the product as it passes into the hands of the user.

There are two main types of quality measures for foliar fertilizers that are relevant in this context: industrial quality measures, and agricultural quality measures. There is no specific set of specifications governing foliar fertilizer quality in the markets of the Near East region.

At present, many foliar fertilizers are available on the market, both locally produced and imported. Some of these products are well manufactured and provided with informative labels (legal identification and analysis of the components). However, others are still available on the market with substandard nutrient content and without proper labelling or information.

The micronutrient carriers are a good example of the poor presentation and disorganized marketing of fertilizers. The content of the "chelated form" or a "salt form" in the compound is not well specified, and it is often misleading. Regulations are required in order to exercise proper control of the manufacturing, handling, storage, marketing and trade of these new fertilizer types, along similar lines to those for commercial fertilizers.

FOLIAR FERTILIZATION AS A REMEDY FOR NUTRIENT DEFICIENCIES

Foliar fertilizers do not replace soil-applied fertilizers but they do increase their uptake. Generally, where fertilizers are foliar applied to the plant shoots, they provide nutrients to the leaf cells, which in turn leads to more cellular activity.

The choice of the nutrient that could be foliar-applied depends on the existing level of that nutrient in the plant tissues. Foliar-applied nutrients have proved to be 4–30 times more efficient than soil applications. Using labelled P, studies on apple, tomato, potato, beans and corn have shown that multiple foliar sprays can supply 12–14 percent of total P.

There are various options to avoid or remedy nutrient deficiencies. They include: the use of nutrient-efficient cultivars; the addition of fertilizer to the soil; the addition of OM; liming; and foliar fertilization. However, foliar fertilization is a rapid way of addressing deficiency symptoms, especially where uptake through roots is restricted by unfavourable growing conditions. Table 17 provides general guidelines for foliar fertilization to correct nutrient deficiencies. However, there could be variations according to crop situations.

TABLE 17
Foliar fertilization to correct nutrient deficiencies

Deficient nutrient	Type of foliar fertilization required as a corrective measure
N	Application of 0.25–0.50% of urea solution
P	Application of 0.1–0.2% P_2O_5 of the spray solution, best formula is phosphoric acid
K	Application of 0.3–0.5% K_2O in the spray solution
Ca	Application of Ca chelates or Ca nitrate
Mg	Application of Mg-sulphate or Mg-nitrate solutions
Fe	Spray of 2 % Fe-sulphate or 0.02–0.05% Fe-chelate solution or Fe-citrate 0.02–0.05% solution
Mn	Spray of 0.5% Mn-sulphate or 0.01–0.025% Mn-chelate or Mn-citrate 0.02–0.05% solution
Zn	Spray of 0.1–0.5% Zn-sulphate or 0.01–0.025% Zn-chelate solution
Cu	Spray of 0.1–0.2% Cu-sulphate or 0.01–0.02% Cu-chelate solution
B	Spray of 0.1–0.25% borax solution
Mo	Spray of 0.07–0.1% solution of ammonium molybdate

FOLIAR FERTILIZATION AND THE ENVIRONMENT

Because foliar fertilization can increase the uptake of nutrients from the soil, nutrient doses added to soil (especially of N) can be reduced. The benefits of applying N through foliar sprays include: lower N application rates, and an increase in efficiency (which may reach 95 percent). One foliar fertilization benefit is that it minimizes nitrate accumulation in the groundwater. Optimized N fertilization reduces the chance of N_2O enrichment of the atmosphere via denitrification. Total denitrification losses are estimated to be in the range 5–10 percent of the total applied N, of which about 10 percent is as N_2O gas.

THE USE OF FOLIAR FERTILIZATION IN THE NEAR EAST

There are no accurate data on foliar fertilization in the Near East countries. However, micronutrients are usually spayed on cereal crops and fruit orchards on a considerable scale in the Islamic Republic of Iran, Turkey, Saudi Arabia, Iraq, Lebanon, Jordan and the Syrian Arab Republic. Foliar fertilization in these countries and other countries of the region is far from the optimal application.

Chapter 11
Mineral fertilizers in the markets of the Near East

In most Near East countries, the quantity of nutrients available for recycling via plant and animal residues is not sufficient to compensate for the amounts removed by agricultural crops, even in low-productivity situations. Consequently, the use of mineral fertilizers has become necessary for obtaining higher agricultural production and quality produce. The annual fertilizer production in the Near East is about 12 million tonnes, of which about 9 million tonnes are used within the region and about 3 million tonnes are exported to other countries as finished products.

Nitrogen is by far the most consumed nutrient in the region. A steady increase in N-fertilizer consumption has occurred in the past three decades. The use of P fertilizers has also increased, but more slowly. The increase in K consumption has been still slower and has not kept pace with that of N and P fertilizers.

Many large farms have switched from using bagged fertilizers to bulk fertilizers. Increased farm size has resulted in increased mechanization, lower labour costs for bulk application of fertilizers, and lower production and distribution costs. All these factors have contributed to the trend away from the traditional 50-kg bagged fertilizers to the use of bagged products of 1 000 kg. The use of bulk blended fertilizers is expected to expand in the region.

NITROGEN FERTILIZERS

Urea and urea-based fertilizers

Urea is the major sources of N in the region. Its solubility and the high concentration of N (46 percent) compared with other solid N fertilizers make its use more economical. Urea is becoming more popular than other N sources such as AS and AN. The urea currently produced in the Near East has a biuret content of less than 1 percent. Urea should not contain more than 1.2 percent of the toxic biuret for soil application, and not more than 0.3 percent where sprayed on leaves. It is used as a solid N fertilizer for soils, for foliar application, as an ingredient of liquid fertilizers, and in NP/NPK complexes.

In some of the countries of the region, the production of urea phosphate (obtained from the reaction of urea and phosphoric acid) is becoming more common. Crystalline urea phosphate (14–44–0) is being used in the production of soluble acidic powder fertilizers and suspension fertilizers. Liquid urea phosphate (8–22–0) is being used for the production of liquid acidic fertilizers for fertigation. The use of acid-based fertilizers, mainly as urea phosphate, is expected to increase because of the alkaline nature of most of the soils in the region.

Ammoniacal N fertilizers

Ammonium sulphate contains about 21 percent N (as ammonium) and 23–24 percent S (as sulphate). It has long been in use. It is an acid-forming fertilizer and is highly soluble in water. It is used both directly and as an ingredient in fertilizer mixtures. It is used as part of the basal dressing or as top dressing.

Nitrate fertilizers

Potassium nitrate (KNO_3) (13–0–45) and calcium nitrate ($Ca[NO_3]_2$) (15 percent N) are being used to a limited extent as special compounds for supplying K, N and Ca to crops, particularly for greenhouse production. Potassium nitrate is particularly used for intensively grown vegetables and fruits, such as tomato, potato, leafy vegetables, and citrus, under protected farming.

Calcium nitrate is a hygroscopic salt and used as a source of N and Ca, mainly for foliar application and fertigation. It is used as a foliar fertilizer for apples and watermelon. Nitrate fertilizers are fast-acting compounds, and farmers often use them because of their quick reaction. The use of calcium nitrate will probably decrease owing to the increasing use of urea and potassium sulphate.

N fertilizers containing ammoniacal and nitrate forms

Ammonium nitrate (NH_4NO_3) (33.5 percent N) is produced by neutralizing nitric acid with ammonia. Fertilizer-grade AN has 33–34.5 percent N, of which 50 percent is present as ammonium and 50 percent as nitrate. It is also used to produce liquid fertilizers. Ammonium nitrate leaves behind an acidic effect in the soil. The share of AN in the fertilizer market is likely to decline as it is replaced by urea.

Other N fertilizers

Urea ammonium nitrate (UAN) and liquid N solutions are used only on a very limited scale in the Near East. Their use is not expected to increase.

Slow-release N fertilizers

Crop recovery of applied N fertilizers rarely exceeds 50–60 percent and is often as low as 40 percent. Because of increasing concerns over water and groundwater pollution, it is desirable to produce fertilizers that release N slowly and in accordance with plant needs at various growth stages. Sulphur-coated urea (SCU), Ureaform and N-serve are the main slow-release N fertilizers available in the markets of the Near East.

The use of these products may register a slow increase (mainly for turf grass fields). However, their use will always be minimal compared with other N sources, perhaps because of their high costs. The use of slow-release N fertilizers has no advantage for field crops because it does not supply N at a rate that is fast enough to meet crop needs during the growing season. Split application of N fertilizers has been found to be a better method for supplying N to field crops, as well as being much cheaper.

PHOSPHATE FERTILIZERS

Available P in Near East soils is usually low although the total P is often very high. Therefore, understanding the relationships and reactions of various forms of P in different soil types is essential for efficient management of P-fertilization programmes.

Phosphate rock

Phosphate rock (apatite) is the only raw material for P fertilizers. The major producers of phosphate rock in the Near East are Morocco, Tunisia, Algeria, Jordan and Iraq. About 50 percent of the world's phosphate rock reserves are in Morocco.

The solubility of phosphate rock in alkaline or calcareous soils is very low and, therefore, it is of very limited value to plants, even where applied in large quantities. The phosphate rock in the region will continue to be a source for the P fertilizer industry. Its direct use as a fertilizer will always be very limited because of its low efficiency (which can be less than 2 percent).

Single and triple superphosphate

Single superphosphate (17 percent P_2O_5) and TSP (46 percent P_2O_5) are the most important P sources in the region. In addition to its P content, the SSP fertilizer contains 12 percent S and 21 percent Ca. It is a good source of P, but its low P analysis limits its use. The TSP is an excellent source of P and was the most common source of P fertilizer in the region until the early 1990s, when ammonium phosphates became popular.

Phosphoric acid

Phosphoric acid (H_3PO_4), used largely in the fertilizer industry, is manufactured by treating phosphate rock with H_2SO_4. The injection of phosphoric acid in irrigation water is becoming more popular in irrigated agriculture in the Near East. Moreover, the production of liquid and suspension formulations, using phosphoric acid as a base for P, to produce highly acidic fertilizers for alkaline and calcareous soils is gaining in popularity. It is expected that the use of phosphoric acid will expand for fertigation, especially in drip irrigation systems.

FERTILIZERS CONTAINING NITROGEN AND PHOSPHORUS

Ammonium phosphates

The use of MAP (10–50–0) and DAP (18–46–0) has increased significantly in the region in the past decade. DAP is becoming more widely used than any other P fertilizer. Ammonium phosphates have the advantage of a high nutrient content of N and P, and it can be used in the formulation of dry bulk-blended fertilizers.

Ammonium polyphosphate (APP) is used in some markets of the region as a liquid formulation (10–34–0). Its use is very limited and not expected to grow much in the future because of the availability of phosphoric acid (52 percent P_2O_5) and urea (46 percent N) in the market at very competitive prices.

POTASSIUM FERTILIZERS

Extensive deposits of soluble K salts are found beneath the surface of the Earth and in the brines of dying lakes and seas. In the Near East, K production is located around the Dead Sea in Jordan. As with N and P, there has been an increase in K consumption in recent years in the Near East, but not of the same magnitude. All powder forms of K fertilizers are water soluble.

Potassium chloride

Potassium chloride (KCl), also known as muriate of potash (MOP), contains about 60 percent K_2O and 47 percent Cl. It varies in colour (white, pink, red or brown) according to the mining and recovery process. Its use as a fertilizer is forbidden in many countries in the Near East because of its high Cl content. However, elsewhere in the world, it is widely used because of its high K content, lower price and quick solubility in water. The use of potassium chloride in the Near East is not expected to increase significantly in the near future. However, it has been observed that frequently irrigated sandy desert soils could benefit from its use where they are not cultivated with crops that are sensitive to Cl such as potato and tobacco.

Potassium sulphate

Potassium sulphate (K_2SO_4) is also termed sulphate of potash (SOP). It contains about 50 percent K_2O and 17 percent S. This K fertilizer is widely used in the Near East countries because it is almost free of Cl (less than 2 percent) and has the advantage of containing S. It is expected that most of the increase in K usage in the region would be in the form of this fertilizer, especially the powder form (which is used for fertigation).

FERTILIZERS CONTAINING POTASSIUM AND NITROGEN

Potassium nitrate

Potassium nitrate (KNO_3) contains 13 percent N and 44 percent K_2O. From an agronomic viewpoint, it is an excellent source of N and K. It is being marketed largely for fruit trees and vegetables, and is very suitable for cotton as well. The production cost of this K source is higher than that of SOP, and this restricts its use.

FERTILIZERS CONTAINING POTASSIUM AND PHOSPHORUS

Potassium phosphates

In the Near East markets, there are several grades of potassium phosphate fertilizers. The potassium phosphates KH_2PO_4 (0–52–34) and K_2HPO_4 (0–41–54) are completely soluble in water and have a high plant-nutrient content. The most common grade in the Near East markets is mono-potassium phosphate (MKP) (0–52–34). It is used in soluble crystalline fertilizers, mainly for protected agriculture and fertigation of open fields cultivated with high-value crops and vegetables. The prices of the potassium phosphate fertilizers are higher than other single sources of K and P. However, they have several advantages, e.g. high analysis, low salt index, and suitability for use in clear fluid fertilizers. Moreover, they free from fluoride and chloride. These advantages make these K–P fertilizers suitable for all crops that are sensitive to excessive amounts of Cl, e.g. tobacco and potatoes. The use of these fertilizers in the Near East, and in the world at large, may expand if their production costs can be reduced.

FERTILIZERS CONTAINING POTASSIUM AND SULPHUR

Potassium thiosulphate

Potassium thiosulphate ($K_2S_2O_3$) is a relatively new liquid K source (0–0–25–17S). It is compatible with most liquid fertilizers and suitable for foliar applications and for fertigation in drip and sprinkler irrigation systems.

Because of its high cost, its use may continue on a low scale compared with other K sources such as SOP, potassium nitrate and MKP.

CALCIUM AND MAGNESIUM FERTILIZERS

Single superphosphate contains 21 percent Ca, and TSP contains 13 percent Ca. The most widely used Ca source for fertigation and foliar fertilization is calcium nitrate (19 percent Ca). Chelated salts of Ca such as Ca-EDTA (4 percent Ca) is another source of Ca for foliar fertilization. Gypsum ($CaSO_4.2H_2O$) is also widely used as an amendment for the reclamation of sodic soils in many Near East countries.

Magnesium sulphate ($MgSO_4.7H_2O$), which contains 9.8 percent Mg, is the most widely used Mg source in the region. Other Mg sources include magnesium nitrate ($Mg[NO_3]_2$; 16 percent Mg) and Mg chelates (Mg-EDTA; 3 percent Mg). Both of these are suitable for use in fluid fertilizers and as foliar sprays.

IRON, ZINC, COPPER, MANGANESE AND BORON FERTILIZERS

Deficiencies of Fe and Zn are more common in the Near East than are those of Cu and Mn.

Fertilizers containing iron

Iron sulphate ($FeSO_4.7H_2O$; 20 percent Fe) and Fe-EDDHA (6 percent Fe) are the most commonly used Fe sources for correcting Fe deficiencies. Correction of Fe deficiencies using iron sulphate salt as a foliar fertilizer requires several foliar sprays in a season. The application of the stable synthetic Fe chelate, Fe-EDDHA, is preferred for foliar fertilization rather than soil application.

Fertilizers containing zinc

Zinc sulphate ($ZnSO_4$; 35 percent Zn) is the most common Zn-fertilizer source in the region. However, the use of Zn-EDTA has increased in the past decade. Zinc sulphate is usually applied at a rate of 4–15 kg/ha, and Zn-EDTA at a rate of 1–3 kg/ha. The use of Zn-EDTA is expected to increase in the future owing to improved awareness of the effectiveness of chelated micronutrient sources, especially for calcareous and gypsiferous soils.

Fertilizers containing copper

Copper sulphate ($CuSO_4.5H_2O$; 25 percent Cu) and Cu-EDTA (15 percent Cu) are the major sources of Cu used in the Near East. Soil and foliar applications are both effective and the common soil application rates range between 0.5 and 5.0 kg/ha. The use of Cu-EDTA for foliar fertilization is increasing gradually because soil application is more expensive.

Fertilizers containing manganese

Manganese deficiencies are widely corrected with manganese sulphate ($MnSO_4.4H_2O$; 27 percent Mn). This may be applied to the soil or as a foliar fertilizer, while Mn-EDTA (13 percent Mn) is often used as a foliar fertilizer and its use as a soil fertilizer or via fertigation is increasing.

Fertilizers containing boron

Boron is the only non-metal element among the micronutrients. Boron deficiency is not common in the Near East because B is usually available in sufficient concentrations in arid soils. Indeed, it may sometimes reach high or toxic levels, mainly from the high B content of saline irrigation waters. Where Ca availability is high, there is a greater requirement for B.

Sodium tetraborate ($Na_2B_4O_7.5H_2O$; 11 percent B) and boric acid (H_3BO_3; 17 percent B) are the most commonly used B sources. Rates of B fertilization depend on plant species, cultural practices, rainfall, and the calcium carbonate and OM content of the soil. Application rates of 0.5–5.0 kg B/ha are generally recommended for soil addition. Recommended foliar fertilization rates are 0.5–5.0 kg B/ha. Its use is expected to increase slightly for some specific irrigated crops, e.g. sugar beet.

FERTILIZER LEGISLATION

Most countries in the Near East have witnessed rapid development of the agriculture sector. The use of chemical fertilizers in the Near East region increased from about 4.8 million tonnes of nutrients in 1980 to about 10.5 million tonnes in 2002 (FAOSTAT).

Most countries in the region have established specifications for some of the fertilizer materials present in their markets. There are also fragmented regulations related to safety requirements. It would be useful if uniform fertilizer legislations were developed for the region, especially as many of the countries are involved in the production and export of fertilizers as raw materials and finished products. In addition, it is of prime importance to develop legislation on the handling and distribution of fertilizer materials. This is because large quantities of solid and liquid fertilizers are frequently transported by sea and by truck across the borders of different countries in the region. Some of the materials transported are of a hazardous nature, e.g. various acids and liquid ammonia.

At present, the fertilizer industries involved in the production and transportation of these materials in the Near East are following self-imposed safety regulations. Therefore, the results depend on the experience and concern of the personnel involved in the process. The development of regional regulations would be beneficial for producers, transporters and end users. The application of certain fertilizer materials is not without risk. Therefore, it is important to understand and follow safe handling techniques for these materials. With proper precautions, fertilizers are safe agricultural products and can be used safely by millions of farmers in the region.

Quality control of the raw materials and the finished products, and the reliability of information on the label, is inadequate in many countries in the Near East. Nutrient concentrations are sometimes stated ambiguously, the units are not uniform and the information on the label is often misleading to the user.

There is an imperative need for the development and promulgation of fertilizer legislation in order to guarantee quality fertilizers to users and to curb trade malpractices in the region.

Chapter 12
Environmental impact of mineral fertilizer use under irrigated conditions in the Near East

MINERAL FERTILIZER USE AND THE ENVIRONMENT

Fertilizer use is an integral part of the crop production system of irrigated agriculture in the Near East. The increased demands for food will require the world's farmers to produce 50 percent more cereals in 2030. Most of the increase in cereal production will have to come from the existing land under cultivation. This can be achieved only through improvements in crop yield, which would require a 30-percent increase in mineral fertilizer use. Fertilizer use has been responsible for more than 55 percent of the agricultural growth (especially in cereal yields) in the last three decades. Fertilizers replenish the nutrients removed from soils by harvested crops; encourage adoption of HYVs, and increase biomass in nutrient-poor soils. However, increased fertilizer use has to be synchronized with better management of nutrients "on-farm".

Current environmental concerns relevant to fertilizers centre on emissions of ammonia, nitrous oxide gases, and nitrate pollution of groundwater. Of equal importance is the eutrophication of lakes and streams resulting from surface runoff of nutrients (particularly P), and the heavy-metal content of finished P-fertilizer products.

Improved agricultural practices may alleviate many of the environmental problems associated with fertilizer use. Increased efficiency for N fertilizers could reduce the release of N compounds into air and water significantly. To improve N-use efficiency, improved agronomic management practices and the use of controlled release fertilizers, enzyme inhibitors, etc. are being propagated. A great challenge lies ahead in feeding the growing global population and simultaneously protecting the natural resources.

Irrigated agriculture in the arid and semi-arid areas of the world relies on subsurface drainage in order to sustain its productivity. In places where natural drainage is inadequate, artificial drainage has been provided using open ditches, clay tiles and, more recently, corrugated tubing. Besides preventing waterlogging, drainage is needed in order to permit leaching from the crop rootzone of salts, both those transported by the irrigation water and those occurring naturally in the soil. In arid and semi-arid regions, irrigation is necessary to meet crop evapotranspiration requirements and, subsequently, drainage is required in order to remove any excess water from the soil profile. Highly productive lands usually receive large applications of mineral fertilizers. Part of the plant nutrients applied through fertilizer can be leached by the irrigation water into the drainage system. Where not managed properly, fertilizer applications in such situations can be potential sources of environmental pollution.

Fertilizer consumption has increased considerably in the Near East countries in the last three decades. While this has contributed significantly to agricultural production, it has also raised concerns about possible nutrient releases in the environment and their impact on the overall environment.

The issue is more pronounced in countries where flood irrigation is practised, e.g. Egypt. In other areas where water is provided through "pressurized irrigation systems", more control over water and added fertilizer can be exercised. It is quite customary in the region to find a "fertilizer injection tank" installed as part of the fertigation system.

ENVIRONMENTAL IMPACT OF NITRATES

The loss of N to surface waters from agricultural fields via surface or subsurface drainage has been of universal concern. The most critical problems associated with excessive N in surface water are the possible contamination of drinking-water and eutrophication problems. Nitrate concentration in water draining from many subsurface drainage systems in many situations could be high enough to cause concern for drinking-water supplies. Research has progressed from identifying the problem to understanding the factors influencing the fate of N in relation to drainage design management options. Several reports summarizing research on this topic have been published worldwide. However, only a few reports are available on the problem as it concerns the Near East.

Nitrate concentrations were studied in a heavy soil (50 percent clay) in the Mashtul pilot area in Eastern Delta of Egypt. The concentration of nitrates in groundwater and drainage water in winter and summer was very small and seldom exceeded 25 ppm. This may be because berseem (Egyptian clover), as a common legume crop, is generally not fertilized with N sources, and its biomass turnover along with the nutrient uptake is quite rapid.

To minimize any possible negative environmental effect resulting from improper fertilizer use, it is advisable to apply the correct amount of plant nutrients at appropriate times suited to the nutrient requirements of the crop at various growth stages and in the desired manner, coupled with improved agronomic practices tailored to meet the specific agro–soil–climate situations.

REUSE OF NITRATE-POLLUTED DRAINAGE WATER FOR IRRIGATION PURPOSES

At a global level, only 37 percent of irrigation water is consumed by crops. The rest is wasted, contributing to salinization and waterlogging problems in situations of inadequate drainage. Drainage systems are often constructed to collect and remove the excess irrigation water in order to prevent such problems. The disposal of drainage water may be difficult where a natural outlet is not available. In some instances, drainage water could cause pollution of waterbodies because of its high load of salt or toxic residues. However, in Near East countries with increasing scarcity of water resources, the reuse of drainage water for irrigation could be inevitable. Water reuse is a widely accepted practice to satisfy part of the demand for freshwater, provided that adequate management practices are followed.

CONTROLLING NITRATE POLLUTION OF GROUNDWATER

It is often assumed that the majority of nitrates found in groundwater stem from fertilizer use. This is not necessarily the case. High levels of groundwater nitrates have been found in many areas where fertilizer use was not a factor. There are other sources of nitrates, e.g. the use of organic manure and the disposal of domestic wastes. Recent research has shown that the major source of groundwater nitrates is the release of nitrates by OM during periods when crops are not growing actively.

Crop uptake of applied N has been the subject of more research than any other plant nutrition issue, but it remains a subject for further exploration. Crops can generally take up no more than 50 percent of the fertilizer N applied, and little remains in the soil for the next crop. However, it should not be assumed that the other 50 percent is leached into the groundwater. There are numerous other pathways through which the N is lost, e.g. volatilization, runoff and denitrification. In practice, the extent to which these processes occur is difficult to predict and depends on agro–soil–climate and environmental conditions. Irrespective of the mechanisms through which the N is lost, it is essential to reduce the loss through maximizing crop uptake and adoption of improved agronomic practices.

Some guidelines for reducing nitrate pollution of groundwater are:

- Apply no more N than needed. This is a simple rule that is well understood by growers. Soil testing is a useful tool for assessing plant nutrient needs.
- Apply small regular doses. N does not remain in the soil for more than a few weeks. If a high dose is applied, the plant uses only a small part of it and the remainder is lost. Small, regular applications are far more effective, especially where timed to suit the periods of maximum crop uptake.
- Ensure that plants are capable of using the applied nitrogen. N fertilizers can be lost rapidly if applied when plants cannot make use of them. Any problem in the field that restricts plant growth will contribute indirectly to N loss. Proper agronomic practices are essential for controlling nitrate pollution. Balanced nutrition is a critical component of proper agronomic practices. A deficiency in any essential nutrient limits crop growth and thus reduces N uptake. A proper system of soil analysis is necessary in order to predict and prevent nutrient problems that can limit crop growth and N uptake.
- Fertilizer selection. All N fertilizers are converted into nitrates by soil bacteria within a short period, typically two weeks. N from OM is also converted into nitrates in the soil. Some fertilizers are specially coated to release N slowly; ideally, they should release N at the same rate at which the

crop uses it. These materials are little use for field crops because of their high cost.

- Nitrification inhibitors. Several compounds are used to modify the rate at which N transformations occur in the soil, so giving plants more chance to absorb the nutrients. Urease inhibitors slow the conversion of urea to ammonium nitrogen, and nitrification inhibitors slow the conversion of ammonium nitrogen to nitrates that can be leached easily. These products are relatively new and are not in widespread use. They require further research.

Chapter 13
Fertilization of cereal crops

CROPS COVERED

This chapter covers a number of cereal crops, e.g. barley, maize, rice. Other cereal crops (e.g. millet) have already been covered in the *World fertilizer use manual* (IFA, 1992).

BARLEY

Crop data

Barley (*Hordeum vulgare* L.), like wheat, was domesticated in the Near East region about 10 000 years ago. Since then, barley has been used to feed animals and humans because it is high in crude protein (lysine). The grains used for malting should be high in starch and low in crude protein. Barley straw is used for feeding animals or as litter bedding.

In a Mediterranean climate where the rainfall rates are usually not sufficient for wheat (less than 400 mm/year), local varieties of barley are usually grown because barley is more resistant than wheat to low moisture. In addition, irrigated barley usually gives a higher yield than wheat does. The total area planted to barley in the region is about 12.8 million ha, out of some 56.5 million ha under barley worldwide, producing about 138 million tonnes. Major producing countries in the region are Turkey (3.60 million ha), Morocco (2.18 million ha), Kazakhstan (1.79 million ha), Islamic Republic of Iran (1.70 million ha), Syrian Arab Republic (1.33 million ha), Algeria (850 000 ha) and Tunisia (381 000 ha).

The available water (rain plus irrigation) determines the yield of barley; about 750 mm of available water is needed to enable the maximum yield barley.

Soil

Similarly to wheat, barley is usually grown in different soil types, but it performs best in loam fertile soils. The grain yield of barley is related to the amount of water consumption, which increases proportionally with increasing yield. The same is true for nutrient uptake (mainly N uptake). More than 11 tonnes/ha of grain has been obtained in irrigated and fertilized barley in Saudi Arabia, with a seeding rate of 100 kg/ha. If maximum utilization of water and applied nutrients is required for optimal grain yield, then the ratio of the number of plants per area to the number of ears per plant must be optimized. Thus, the crop should tiller heavily. The two-rowed barley varieties have lower ear weights. Consequently a higher ear density than with multiple-rowed varieties is necessary. However, to achieve the same yield, an average of 750–850 ears/m^2 of two-rowed barley as compared with 600–700 ears/m^2 of multiple-rowed barley is required. When the crop is sown for

TABLE 18
Averages of relative N, P and K uptake in irrigated winter barley at different growth stages

Growth stage	N	P	K	Dry biomass (above ground)
	(% of maximum)			
Germination	0	0	0	1
Tillering	30	20	25	10
Jointing	45	30	35	12
Booting	65	50	55	15
Ear emergence	80	75	90	50
Flowering	100	90	100	80
Grain formation	100	100	100	100
Total uptake of whole plant (kg/ha)	225	40	195	19 tonnes/ha yield
Grains (kg/ha)	140	30	60	11 tonnes/ha yield

malting, a suitable variety should be selected.

Sowing time

Winter barley is usually sown between September and December, depending on the occurrence of rainfall.

Seeding rate

The recommended seeding rate for irrigated barley ranges from 90 to 110 kg/ha for multiple-rowed and from 120 to 150 kg/ha for two-rowed varieties. The higher rates are applied to compensate for poor germination, bird and insect damage, and winter kill.

Nutrient requirements

Nutrient uptake usually differs with variety, weather and crop health. Table 18 shows the average relative nutrient uptake for irrigated barley at different growth stages as reported in literature and observed in irrigated healthy barley crops in several countries of the region.

The average nutrient concentrations in barley tissue at the beginning of the stem elongation stage for the whole plant above ground are comparable with the values reported for wheat (below). Moreover, the interpretation of the results of soil analysis is similar to the results reported for cereal crops (below).

Fertilization recommendations

The cultural practices for barley are similar in most aspects to those for wheat. Weed-control measures for barley are about the same as those for wheat and the nutrient requirements are about 90 percent of those for wheat. Barley usually responds to applications of N where ample soil moisture is available. Heavy applications of N may induce lodging and lower the malting quality. Barley yields are also increased by P and K fertilizers on some rainfed soils and on most soils under irrigated conditions. However, where barley is sown in fields following crops that have been well fertilized, little N fertilization is be required. Table 19 shows the recommended fertilizer rates for irrigated barley in the countries of the Near East region.

The recommended fertilizer application schedule for barley is:

- N: applied in at least three equal applications during the season: 1st before sowing, 2nd at tillering, and 3rd at early emergence stage. For sprinkler irrigated crops by centre pivots, N may be applied in 6–8 equal doses (fertigation) during the season at 7–10-day intervals, starting two weeks after germination.

TABLE 19
Recommended fertilization rates for irrigated barley, expected yield 10–11 tonnes/ha

Soil fertility class (soil analysis)	Fertilization rate							
	N	P_2O_5	K_2O	MgO	Fe	Zn	Cu	Mn
	(kg/ha)							
Low	175–200	125–150	75–10	35	3	2	1	2
Medium	125–150	100–125	50–75	25	2	1	0.5	1
High	75–100	30–50	25–50	–	–	–	–	–
Very high	50	25	–	–	–	–	–	–

TABLE 20
Recommended fertilization rates for rainfed barley, expected yield 1–2 tonnes/ha

Soil fertility class (soil analysis)	Fertilization rates							
	N	P_2O_5	K_2O	MgO	Fe	Zn	Cu	Mn
	(kg/ha)							
Low	75	50	30	–	–	–	–	–
Medium	50	30	–	–	–	–	–	–
High	25	–	–	–	–	–	–	–
Very high	–	–	–	–	–	–	–	–

- P and K: applied in two applications: 1st before sowing (75 percent of quantity), and 2nd (25 percent of quantity) at early emergence (through fertigation).
- Micronutrients: foliar application during the elongation stage (in chelated forms).
- Table 20 gives the recommended rates of fertilization for irrigated barley with a low expected yield level of 1–2 tonnes/ha are given in. The recommended application schedule is:
- N: applied in two equal applications during the season: 1st before sowing, and 2nd at tillering.
- P and K: before sowing.

MAIZE (CORN)

Crop data

Maize (*Zea mays* L.) ranks third, following wheat and rice, in world production of cereal crops. The global total output of 721.4 million tonnes is produced from a total harvested area of about 147 million ha. It is perhaps the most completely domesticated of all field crops because it cannot exist as a wild plant. American Indians appear to have practised cultivation of maize about 5 000–6 000 years ago. In the Near East, several countries grow significant areas of maize: Pakistan (981 000 ha), Egypt (840 000 ha), Turkey (800 000 ha), Morocco (245 000 ha), Islamic Republic of Iran (205 000 ha), Sudan (80 000 ha) and the Syrian Arab Republic (50 000 ha) (FAOSTAT, 2005).

Maize is a warm-weather crop and produces its best yield when temperature in the summer varies between 25 and 35 °C. If the mean summer temperature is less than 20 C, the yield will be reduced although the crop is adapted to a wide range of environmental conditions. It is grown in the Near East between April and October. The hybrid varieties grow to reach more than 3 m high, mature in 120–140 days and have few or no tillers. Removal of tillers may injure the plant and reduce the yield.

The harvested grains are used for human and livestock consumption. In recent years, forage maize has been grown in many countries in the region, whereby the entire aboveground plant is harvested at an immature stage in order to be made into silage for animal feed. However, lesser amounts of sweet maize are grown in the region for human consumption.

A suitable plant density for an irrigated and well-fertilized maize crop is 80 000 plants/ha (spaced at 70 cm between rows and 18 cm between plants on the same row).

TABLE 21
Nutrient uptake by various parts of maize crop

Nutrient	Nutrient uptake		
	Grain	Stover	Total
	(kg/ha for 10 tonnes/ha)		
N	150.00	75.00	225.00
P	35.00	10.00	45.00
K	41.00	160.00	201.00
Ca	2.00	52.00	54.00
Mg	12.00	33.00	45.00
S	11.00	8.00	19.00
Fe	0.12	2.20	2.32
Mn	0.07	0.29	0.36
Zn	0.20	0.20	0.40
Cu	0.20	0.10	0.12
B	0.06	0.15	0.21

Source: Data collected from several sources, including field data from Lebanon.

TABLE 22
Intermediate ranges of nutrients in maize leaf tissue at tasselling stage, dry-matter basis

Nutrient	Leaf opposite and below ear at tasselling stage
N (%)	2.80–3.20
P (%)	0.22–0.28
K (%)	1.50–2.50
Mg (%)	0.20–0.25
Ca (%)	0.40–0.60
S (%)	0.15–0.20
Fe (mg/kg)	15–50
Zn (mg/kg)	20–30
Mn (mg/kg)	15–60
Cu (mg/kg)	5–10
B (mg/kg)	5–8

Source: Data collected from several sources including results of field experiments in Lebanon.

Soil

Maize requires an abundance of readily available plant nutrients and gives a good yield in a wide range of soil pH values (6–8.5). The crop grows best in fertile loam soils. Where the soil is poor in nutrient supply, most of the available nutrients are consumed in the vegetative growth at the expense of grain production. The highest yields in Near East countries are obtained from hybrid varieties.

Nutrient requirements

The uptake of nutrients by maize usually differs with the variety, plant density, weather and available water. Tables 21 and 22 show the nutrient uptake in a healthy maize crop and the critical levels of nutrients in the leaves, respectively.

Fertilizer recommendations

Ample amounts of nutrients should be available for maize throughout the growing season because the high plant population requires heavy fertilization.

One tonne of maize grains contains about 40 kg of N, and another 20 kg N are in the associated stover. Therefore, N should be applied in sufficient quantities. Usually, about half of the N quantity is applied during or before planting and the other half about one month after seeds emergence. Under sprinkler irrigation, farmers are advised to apply N fertilizers in successive applications during irrigation (fertigation) of 20–25 kg N/ha each time. For hybrid maize, the recommendation is to apply 180–200 kg N/ha. For maize, Figure 8 shows the nutrient removal, and Figure 9 indicates the N uptake and distribution.

Maize accumulates P throughout the growing season. The usual P-deficiency symptoms appear when leaves turn purple in colour within 3–5 weeks after planting. P fertilizer is best applied near the row at planting time. A maize crop yield of 10 tonnes/ha removes about 45 kg of elemental P (100 kg P_2O_5) as shown in Figure 10.

Most of the K is absorbed by maize plant before the tasselling stage. About one-third of total K is stored in the grain and two-thirds in other plant parts. Where needed, K fertilizer is best applied along with P fertilizers and the first application of N, near the row at planting time. A maize crop yield of 10 tonnes/ha removes about 200 kg of elemental K (240 kg K_2O) as shown in Figure 11.

Deficiency symptoms for Fe and Zn may appear in calcareous coarse-

FIGURE 8
Maize plant nutrient removal, yield of 10 tonnes/ha

Element	Grain Kg/ha	Silage Kg/ha
N	146	224
P_2O	64	90
K_2O	47	262
Ca	17	47
Mg	24	44
Zn	0.17	0.60

FIGURE 9
Nitrogen uptake and distribution in maize

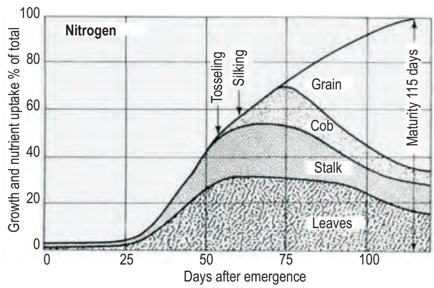


FIGURE 10
Phosphorus uptake and distribution in maize

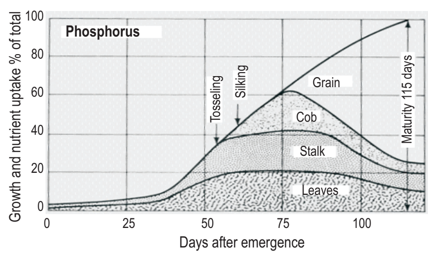
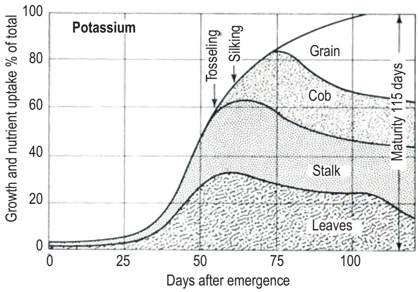


FIGURE 11
Potassium uptake and distribution in maize



textured soils. The deficiencies may be corrected through foliar fertilization or fertigation. Where soil testing shows low available Zn on neutral or alkaline soils, applying zinc sulphate to the soil at a rate of about 20 kg/ha is an effective measure.

RICE

Crop data

Globally, rice (*Oryza sativa* L.) ranks second to wheat in terms of area harvested. It provides the principal food for about half of the world's population. The crop is unique among cereals in being able to germinate and thrive in water. This is because it is able to transport oxygen to the submerged roots from the leaves, where O_2 is released during photosynthesis. Major increases in rice production have occurred in the past 30 years as a result of large-scale adoption of high-yielding semi-dwarf varieties and improved farming techniques.

At global level, the total area cultivated with rice is about 153.5 million ha, with a total production of 614 million tonnes (FAOSTAT, 2005). The crop is grown in the Near East in several countries, notably: Pakistan (2.5 million ha), Egypt (650 000 ha), Islamic Republic of Iran (640 000 ha) and Turkey (80 000 ha). Egypt has a crop productivity record of 12 tonnes/ha, the highest in the world.

Rice grows successfully in regions that have a mean temperature of 22 °C or higher throughout the entire growing season of 4–6 months. Upland rice consists of certain varieties that can be grown without being submerged in water. The yield of upland rice is lower than that of submerged rice.

Rice varieties include short-grain (5.5 mm), medium-grain (6.6 mm) and long-grain (7–8 mm) varieties. Early-maturing varieties require 120–130 days from seeding to maturity, while mid-season varieties require 130–140 days and the late varieties more than 140 days. Most rice in Asia is grown in the wet season starting in June–July. The productivity of irrigated rice is in the range of 6–8 tonnes/ha and may reach 10 tonnes/ha where very well managed; while the productivity of rainfed rice is much lower (about 1 tonne/ha).

Seedlings are usually grown in the nursery for about one month and then transplanted to the field at a spacing of 15 × 15 cm or 20 × 15 cm. This gives a population of 350 000–500 000 hills/ha, where each hill contains 2–3 plants. Direct seeding is also sometimes practised. Rice is sown with ground broadcast seeders or with grain drills at a rate of about 100 kg/ha. After drilling, the field is usually irrigated, then drained and irrigated repeatedly at intervals until the rice seedlings emerge (about one month after seeding). The land is then flooded to a depth of

3–5 cm when the young rice plants reach 15–20 cm. As the plants grow taller, the water depth is increased gradually until it reaches 10–15 cm. The water level is drained prior to harvest.

Soil

Rice can grow on soils that range in pH from 4.5 to 8.5. The best soils for rice are clay and slightly acidic–neutral with a pH range of 6–7. Flooding increases the pH value by 0.5–1.5 units, and releases some of the fixed P as available P. Soils with a heavy texture and with impervious subsoil at 40 cm from the surface are most suitable because water loss by seepage is small in such soils.

The soil for rice production should be ploughed to a depth of 15–20 cm. Seed bed preparation for rice should include removal of weeds as well as good tillage in order to produce a mellow, firm surface layer. Clods may slacken after flooding and bury too deeply the rice seeds that are drilled or broadcast before flooding.

Crop rotation

Rice yields become stabilized at low levels where grown continuously on the same land. Weeds also become abundant after 2–3 years of rice cropping. Where the soil is very heavy and not suitable for other crops, it could be seeded to pasture crops for a couple of years. Crops frequently grown in rotation with rice on better drained soils include sorghum, wheat and barley.

Nutrient requirements

Table 23 indicates critical levels of nutrients in various rice tissues.

TABLE 23
Critical levels of nutrients in rice tissues, dry-matter basis

Nutrient	Tissue	Nutrient level (dry-matter basis)		
		Low	Medium	High
N (%)	Matured leaves	4.2	6.4	–
	Straw (88 days after transplanting)	0.4–0.6	0.74–1.39	3.3
	Leaf blade (tillering)	2.5 (deficient)	–	–
K(%)	Straw (mature)	1.08 (deficient)	2.33	–
	Straw (harvest)	0.53	1.7–2.7	–
	Leaf blade	1.0 (deficient)	0.2	–
P (%)	Straw (mature)	0.016–0.02 (deficient)	0.036–0.046	–
	Leaf blade (tillering)	0.1 (deficient)	0.036–0.046	–
Ca (%)	Leaves (flowering stage)	0.14–0.26 (deficient)	0.16–0.34	–
	Straw (maturity)	0.15 (deficient)	0.16–0.34	–
S (%)	Shoots	0.03–0.07 (deficient)	0.12–0.13	–
Mg (%)	Straw (maturity)	0.10 (deficient)		–
Fe (mg/kg)	Leaves Leaf blade (tillering)	< 63	> 80	300
Zn (mg/kg)	Shoot (tillering)	8 (deficient) 2 000 (toxic)	–	–
Mn (mg/kg)	Straw (tillering)	20 (deficient) 2 500 (toxic)	30–50	–
B (mg/kg)	Straw (maturity)	3.4 (deficient) 200 (toxic)	16–80	–
Cu (mg/kg)	Straw (maturity)	5 (deficient) 40 (toxic)	10–20	–

TABLE 24
Estimated nutrient uptake by rice crop, 7 tonnes/ha yield

Nutrient	Nutrient uptake		
	Straw	Grain	Total
	(kg)		
N	53.00	102.00	155.00
P	4.00	20.00	24.00
K	160.00	18.00	178.00
Mg	10.00	7.00	17.00
Ca	19.00	1.00	20.00
S	4.00	6.00	10.00
Fe	1.00	1.40	2.40
Mn	2.20	0.40	2.60
Zn	0.15	0.15	0.30
Cu	0.02	0.18	0.20
B	0.10	0.10	0.20

The quantities of nutrients absorbed by a rice crop usually vary with the variety grown, the availability of water, the weather, yield, etc. Table 24 shows the quantities of nutrients removed by HYVs.

Fertilizer recommendations

Table 25 lists the recommended fertilizer rates used in some Near East countries.

TABLE 25
Recommended levels of NPK fertilizers for lowland rice in some Near East countries

Country	Fertilizer rate		
	N	P_2O_5	K_2O
	(kg/ha)		
Egypt	110	37	50
Pakistan	120–135	25–40	0–40

The recovery of N fertilizer applied to rice seldom exceeds 35 percent. The N-use efficiency in lowland rice may be maximized through better timing of application to coincide with the peak requirement of the crop, and by proper placement of N in the soil. Other options such as the use of slow-release N fertilizer, urease inhibitor or nitrification inhibitors are very expensive. The use of urea super granules (USGs) for rootzone placement improves N-use efficiency. The recommended quantity of N fertilizer may be applied in three equal split applications: the first as basal, the second at tillering, and the last at panicle initiation.

Although submerging the land with water improves P availability, a significant response of lowland rice to P fertilization is common in many countries, especially in soils with a high P-fixation capacity. The response is usually higher in the cooler months of the dry season.

The P fertilizers may be broadcast and incorporated in the topsoil before planting. In high P-fixing soils, it is better to split P fertilizers into two applications: two-thirds as basal and one-third at the tillering stage. For upland rice, the full rate of P is usually drilled at or before sowing.

Good sources of P fertilizers are SSP (17 percent P_2O_5), TSP (50 percent P_2O_5) and DAP (18–46–0).

Rice responds to K fertilization. Similarly to P fertilizers, the application of K fertilizers is done in full either at or before drilling. It could also be split into two applications: two-thirds basal and one-third at tillering. Potassium chloride (60 percent K_2O) is the most commonly used source of K fertilizer. Where S is low, 30–50 kg/ha of potassium sulphate is applied prior to planting.

Zinc deficiency is the most common micronutrient disorder in alkaline and calcareous soils. Applying 25–50 kg/ha of zinc sulphate with NPK fertilizers is recommended. Foliar spray of zinc sulphate solution (0.5 percent concentration) or 1-percent Zn-EDTA solution at 30, 45 and 60 days after planting usually obtains a good response.

SORGHUM

Crop data

Sorghum (*Sorghum bicolor* L. Moench) is a native of the southern Sahara in Africa. The cultivated type was selected about 5 000 years ago. It is grown in warm and hot regions that have moisture in the summer. The most favourable mean temperature for its growth is 37 °C.

Sorghum is well adapted to hot regions. The plants remain dormant during cold weather or drought periods and resume growth when there is sufficient water. The world total area under sorghum is 42.68 million ha, producing about 37 million tonnes (FAOSTAT, 2005). Sorghum is grown in almost all the countries of the Near East. The major sorghum-growing countries in the region are the Sudan (6 million ha), Yemen (428 700 ha), Pakistan (307 000 ha), Egypt (160 000 ha) and Saudi Arabia (121 000 ha).

Sorghum is grown successfully on all types of soils. It performs best on fertile soils with sufficient water. It tolerates considerable soil salinity and is also resistant to drought and heat, as well as to grasshoppers, rootworms and maize-borers. For these reasons farmers prefer to grow sorghum instead of maize in warmer areas of the region.

Prussic-acid poisoning

Young plants and especially the leaves of older plants of sorghum, Sudan grass and Johnson grass contain glucosides that upon breaking down release prussic acid (toxic hydrocyanic acid). Silage and well-cured fodder (hay) are usually safe for animal feeds.

Fertilizer recommendations

Proper seed bed preparation should be done prior to planting sorghum in order to ensure good seed germination. A suitable seed rate for irrigated sorghum is 25–35 kg/ha, and the seeds can be drilled by normal grain drill.

Irrigated sorghum is usually fertilized with 150–200 kg N/ha, with similar rates and application schedule as recommended for maize. Table 26 gives the fertilizer recommendations for sorghum.

For grain or silage production, the application of N should be split into two doses: 60 percent at sowing, and 40 percent at shooting or the beginning of flowering. For dry-hay production, in a hot summer where the available irrigation water is sufficient and

TABLE 26
Fertilizer recommendations for irrigated sorghum

Condition	N [1]	P_2O_5 (kg/ha)	K_2O
High yield	175–200	50–150	0–100
Green forage	200–250	50–100	0–100
Silage	150–200	50–150	0–1 500

[1] May be suitably adjusted based on soil test results.

fertilization is adequate, 3–5 cuts are usually made. The crop should be fertilized after each cut with a dose of 50 kg N/ha + 15 kg P_2O_5 + 15 kg K_2O/ha. Irrigation should follow fertilization. Where sorghum is irrigated via a sprinkler system (centre pivot), fertilizers are best applied with the irrigation water (fertigation) in three equal applications at intervals of 7–10 days after each cutting.

For grain and silage production, the entire quantity of P and K fertilizers can to be applied as a basal dressing at sowing. However, for dry-hay production, as reported above, the fertilizer quantity should be split (application rate of 15 kg/ha after each cutting).

WHEAT

Crop data

Wheat (*Triticum aestivum* L.) was domesticated in Southwest Asia about 10 000 years ago. From the beginning of its domestication, wheat has been an important component in the diet of the population in the Near East. It is the most widely grown crop in the Near East. Annual variations in rainfall make it difficult to establish definite agronomic practices in the Mediterranean environment. To ensure crop success, soil management and fallow practices that store water in the soil profile are important. Good wheat yields in such a climate require the support of full or supplemental irrigation.

The total world wheat area is about 216.2 million ha area, with a total output of about 626 million tonnes. In the Near East region, wheat is cropped on an area of about 48.7 million ha, producing about 103.47 million tonnes (FAOSTAT, 2005). The main wheat-growing countries in the region are: Kazakhstan (11.78 million ha), Turkey (9.3 million ha), Pakistan (8.34 million ha), Islamic Republic of Iran (6.2 million ha), Morocco (2.97 million ha), Syrian Arab Republic (1.9 million ha), Algeria (1.8 million ha), Uzbekistan (1.21 million ha), Egypt (1.25 million ha), Tunisia (827 000 ha) and Saudi Arabia (462 000 ha). About 10 percent of world wheat production comes from the Mediterranean environments.

In a Mediterranean climate, the soil water is usually not sufficient to supply the crop water requirements to maturity and crops very often suffer post-anthesis water stress, which reduces C assimilation and restricts grain filling and yield.

The available water (rain + irrigation) determines the yield of wheat. The results of several field trials in Lebanon and Saudi Arabia indicate that about 850 mm of water is needed for the maximum yield potential of 100 percent (650 mm for 80 percent, 550 mm for 60 percent, 450 mm for 50 percent, 350 mm for 30 percent, and 250 mm for 10 percent of maximum yield).

Soils

The crop is usually grown on different soil types ranging from loamy sand to clay soils, but wheat performs best in fertile loamy soils. Farmers usually obtain good yields provided they supply the crop with sufficient irrigation water and adequate nutrients through proper use of fertilizers.

Sowing times

In the Near East, winter wheat is usually sown between October and December depending on the occurrence of rainfall. The sowing date should be set at a time to allow the frost season to pass, prior to the start of the booting stage. The tillering stage usually takes 3–5 weeks after germination.

Seeding rate

The recommended seeding rate for winter dryland farming is 140–200 kg/ha. Farmers sow wheat at higher rates to compensate for poor germination, poor vigour, bird and insect damage and winter kill.

Nutrient requirements

Farmers are aware of the need to apply mineral fertilizers in order to increase the yield. The uptake of nutrients usually varies with crop variety and yield levels. Table 27 shows the average relative N, P and K nutrient uptake for wheat at different growth stages as reported in literature and observed in irrigated healthy wheat crops in Saudi Arabia.

In general, 60–70 percent of the maximum total nutrient uptake (N + P + K) has occurred by the end of the booting stage. Therefore, deficiencies should be corrected early in the season. Table 28 lists the concentrations of macronutrients and micronutrients for wheat plants at various fertility levels. These ranges are indicators and could be used by farmers and extension specialists as guidelines. The concentrations of nutrients change rapidly during the growing season, especially prior to the stem elongation stage.

Generally, soils in the Near East are characterized by the following:

- N is the main critical nutrient, and P deficiency is common in highly calcareous and coarse textured soil;
- neutral to slightly alkaline soil reaction (pH), which often reduces availability of Fe and Zn;
- water shortage.

TABLE 27

Relative nutrient uptake for winter wheat at different stages

Growth stage	N	P	K	Dry biomass (above ground)
	(% of maximum)			
Germination	0	0	0	1
Tillering	25	10	20	
Jointing	40	30	40	15
Booting	70	50	60	40
Ear emergence	85	75	100	60
Flowering	90	90	100	80
Grain formation	100	100	100	100
Maximum uptake of whole plant (kg/ha)	240	45	200	Target yield (17 tonnes/ha)
Maximum uptake of grains only (kg/ha)	180	24	40	Target yield (8 tonnes/ha)

TABLE 28
Average nutrient concentrations in wheat tissue at beginning of stem elongation stage for the whole plant above ground

Nutrient	Nutrient concentration		
	High	Medium	Low
N (%)	> 4	3–3.5	< 2.5
P (%)	> 0.5	0.3–0.4	< 0.2
K (%)	> 6	3–4	< 2
Mg (%)	> 0.2	0.10–0.15	< 0.08
Ca (%)	> 0.6	0.3–0.4	< 0.2
S (%)	> 0.5	0.2–0.3	< 0.1
Fe (mg/kg)	> 100	40–80	< 20
Mn (mg/kg)	> 90	30–70	< 15
Zn (mg/kg)	> 80	25–50	< 10
Cu (mg/kg)	> 15	5–8	< 3
B (mg/kg)	> 20	5–10	< 2
Mo (mg/kg)	> 0.8	0.2–0.5	< 0.1

- The results of soil analysis can be used as guidelines for fertilization of intensive cereal crops. For the assessment of available soil nutrients, the following extractants are used during soil analysis:
- for P: 0.5 N $NaHCO_3$, at pH 8.5;
- for K, Ca and Mg: 1 N NH_4OAC, at pH 7.0;
- for Fe, Zn, Cu and Mn: DTPA (0.005 M) at pH 7.3.

Fertilizer recommendations

Farmers should choose a proper variety that is appropriate for the expected yield, prevailing weather conditions and soil type. For irrigated wheat, the fertilizer programme should be based on nutrient balance, crop requirement and the results of soil analysis. Some farmers in the Near East believe that the precise amounts and timing of P and K fertilizers are not particularly important for wheat because it often does not respond to P and K top dressing. This may be true where the soil is rich and well supplied with P and K nutrients.

In cultivated soils in the region, the N concentration varies between 0.01 and 0.3 percent. In the Near East, most virgin soils do not contain high quantities of OM, which is difficult to build up owing to high temperature and good soil aeration. A quick soil test for a representative soil sample shortly before sowing may give a fair idea about the quantity of N that could be released from the soil to the crop, mainly in the early growth stages (from sowing to tillering). As a rule of thumb for irrigated wheat under intensive cultivation, the N applications should be split into in three equal doses: early at sowing, mid-term at tillering, and late application at ear emergence. Each dose should be at a rate of about 1 kg N/ha per 75–100 kg/ha of expected yield of grain. The higher rates (1 kg N/ha per 75 kg grain/ha) are usually applied in countries where the temperature is high and the growing season is relatively short, as is the case in irrigated wheat of Saudi Arabia. The lower rates (1 kg N/ha per 100 kg yield/ha) are applied for irrigated wheat in more temperate Mediterranean countries.

A practical system for the identification of N deficiency during growth is to leave a so-called “fertilizer window” in the field during N application, as shown in Figure 12. If the cereal plants within the window start to lighten in colour, this means that the plant available N released by the soil has been taken up and that the plants surrounding the “window” are benefiting only from the applied N fertilizer.

Where straw or plant residues are incorporated into the soil, an additional 1 kg of N per 100 kg of straw should be applied in order to compensate for the

FIGURE 12
Fertilizer window

Source: Heyland and Werner, 1992.

quantity of N that will be taken up from the soil by micro-organisms during the decomposition process of the residues.

In alkaline and calcareous soils of the Near East, available P levels are often low and P applications gives significant increases in yield. Total P concentration in soils varies between 0.02 and 0.10 percent. However, the quantity of total P content of virgin soils in the Near East bears little or no relationship to the availability of P to plants. Although total P in most of these soils may be more than 1 000 mg/kg (ppm), many of them are characteristically low in plant available P. This condition is often aggravated by low soil moisture early in the growing season. Therefore, an understanding of the interactions and the numerous factors that influence P availability is very important to efficient P management. At least 75 percent of P fertilizers should be placed in the soil prior to sowing, along with the first application of N fertilizers, and 25 percent at early emergence stage. In neutral and alkaline soils, acidic fertilizers produce a good response.

Potassium is absorbed by plants in larger amounts than any other nutrient except N. Most of the cultivated soils in the Near East generally contain sufficient quantities of K and are under conditions of low rainfall. Where soil analysis shows that K is low or where the soil is sandy, K fertilizers should be applied. The P and K fertilizers are usually disced into the soil before or during sowing at a distance lower and apart from the seeds by 2–3 cm. This method is effective in calcareous soils because it reduces P fixation. However, where fertilizers are broadcast, particular attention should be given to maximum possible uniformity of fertilizer distribution. Evenness of distribution is affected by granule size, specific weight and surface characteristics. Moreover, the type of spreaders affects efficiency and uniformity. Single-disc spreaders are less accurate than double-disc spreaders, which in turn are less accurate than those with pneumatic and forced-feed precision systems.

For irrigated crops, fertigation is a suitable method for applying fertilizers at a uniformity equal to the uniformity of irrigation water and at optimal timing.

Foliar application of nutrients has advantages and disadvantages. The main advantage is that of applying nutrients directly to the leaves, which improves the absorption efficiency. The main disadvantage is the limited amount that can be applied at one time (concentration should not exceed 1 percent).

Table 29 gives the recommended fertilizer rates for irrigated wheat in Near East countries, for an expected yield of 6–7 tonnes/ha. Table 30 shows the recommendations for rainfed wheat, for an expected yield of 1–2 tonnes/ha.

Although foliar fertilization obtains a quick response, the amount of fertilizer that can be distributed is limited by the sensitivity of the leaves to osmotic agents,

TABLE 29

Recommended fertilizer application rates for irrigated wheat, expected yield 6–7 tonnes/ha

Soil fertility class	Nutrient application rates							
	N [1]	P_2O_5 [2]	K_2O [2]	MgO	Fe [3]	Zn	Cu	Mn
	(kg/ha)							
Low	200–250	150–180	125–150	50	4		1	2
Medium	150–175	100–125	75–100	25	2	1.5	0.5	1
High	75–100	30–50	25–50	–	–	–	–	–
Very high	50	25	–	–	–	–	–	–

[1] N: Applied at least in three equal doses per season: the first before or with sowing, the 2nd at tillering, and the 3rd at early spike emergence.

[2] P and K: Applied in two doses: the 1st before or with sowing (75 percent of quantity), and the 2nd dose (25 percent) at early spike emergence.

[3] Micronutrients: Foliar application at elongation stage, preferably applied in chelated forms.

TABLE 30

Recommended fertilizer application rates for rainfed wheat, expected yield 1–2 tonnes/ha

Soil fertility class	Nutrient application rates							
	N [1]	P_2O_5 [2]	K_2O [2]	MgO	Fe	Zn	Cu	Mn
	(kg/ha)							
Low	100	75	50	–	–	–	–	–
Medium	75	50	–	–	–	–	–	–
High	50	–	–	–	–	–	–	–
Very high	25	–	–	–	–	–	–	–

[1] N: Applied in two equal doses per season: the 1st before sowing, and the 2nd at tillering.

[2] P and K: Applied before sowing.

such as dissolved salts, and (to a lesser extent) to organic chemicals, such as urea. With the exception of some N fertilizers (owing to a rather high tolerance for urea), foliar application can supply only very limited amounts of the primary nutrients compared with crop requirements. The situation is somewhat better for the secondary nutrients and the best results are obtained with micronutrients.

Nutrient deficiencies

Plant nutrient deficiencies have pronounced retarding effects on the growth of cereal crops. (Annex 2 provides detail on visible nutrient-deficiency symptoms).

Deficiency symptoms that appear on older leaves are:

- N: Stunted growth, yellowish from the tips of older leaves (chlorosis), while the upper leaves remain green. Under severe N deficiency, lower leaves turn brown and die.
- P: Purple discoloration of the leaves or leaf edges or stem.
- K: Necrosis of leaf margins and weakening of stems and plant resistance to infections.
- Mg: Interveinal chlorosis of older leaves; in advanced stages, the leaf tissue becomes uniformly pale yellow.
- Zn: Light green, yellow or white areas between the veins of leaves; shortening of stem internodes, resulting in rosette appearance of the leaves.

Deficiency symptoms that appear on younger leaves are:

- Ca: Tips become colourless and covered with gelatinous material, and they adhere together.
- S: Stunted growth, chlorotic plants, and thin stem. Symptoms resemble those of N deficiency but occur first on younger leaves.
- Fe: Interveinal chlorosis; in severe cases, young leaves turn entirely white.
- Cu: Younger leaves lose colour, then eventually they break and the tips die.

DURUM WHEAT

Crop data

Durum wheat (*Triticum durum* Desf.) has been grown traditionally in many countries in the Near East (Turkey, Islamic Republic of Iran, and the Syrian Arab Republic). A large share of the durum wheat in this region is produced under semi-arid conditions. Durum wheat grains have special properties. They are used for the production of semolina, pasta (noodles), couscous and puffed wheat. The grains of durum wheat are richer than those of ordinary wheat in gluten. In addition, they are harder and glassier than ordinary wheat.

The yield level of durum is about 10 percent lower than that of ordinary wheat (although the individual durum grains are 10 percent larger and heavier). Similarly to ordinary wheat, durum wheat prefers soils that are fertile with sufficient moisture, up to the grain filling growth stage. Vernalization is not necessary for durum wheat. The crop requires a mild winter, and a cool and warm summer that is dry at harvest time. The sowing rate and time are similar to those for ordinary wheat, while the depth of sowing should not exceed 3–4 cm because of the low germination of the durum wheat seeds.

Fertilizer recommendations

The rate and timing of fertilizer applications for durum wheat are similar to those for ordinary wheat).

Chapter 14
Fertilization of fibre, tuber and sugar crops

COTTON
Crop data

Cotton (*Gossypium* spp.) is a major fibre crop at world level. It is grown on an area of 34.9 million ha. In the Near East, it is grown in Pakistan (3.2 million ha), Uzbekistan (1.36 million ha), Turkey (725 000 ha), Turkmenistan (550 000 ha), Tajikistan (299 000 ha), Egypt (270 000 ha), Syrian Arab Republic (215 000 ha), Sudan (200 000 ha) and Islamic Republic of Iran (160 000 ha) under a broad range of climate, soils and cultural practices. Egypt ranks in the top three in the world in terms of cotton productivity. The main species grown are *G. hirsutum* L. and *G. barbadense* L. (tetraploid). The *G. hirsutum* is the most extensively developed species.

Cotton is sown between March and June with variations among countries: March–April in Egypt and Turkey; April in Turkmenistan and Uzbekistan; and April–June in Pakistan. Sowing is done on ridges by dibbling or on flat land in rows. Plant density and seed rate vary depending on the spacing between rows and plants within rows. The seed rate varies from country to country: 15–20 kg/ha in Pakistan; 25–80 kg/ha in Egypt and Turkey; and 60–70 kg/ha in Uzbekistan. In Pakistan, cotton cropping is done as mainly flat cultivation (98 percent), with 2 percent on ridges (bed furrows), with row-to-row spacings of 75 cm, and plant-to-plant spacings of 22.5–30 cm. The average plant population is about 60 000–70 000/ha. Egypt and some other countries in the region favour intensive plant population. The distance between rows is 60 cm and plant-to-plant spacing is 15–20 cm. In such intensive cultivation, the plant population ranges from 66 000 to 100 000/ha.

More than 70 percent of soil preparation and sowing is motorized in the region, while the rest is undertaken using animal-drawn implements.

The appropriate temperature ranges between 22 and 40 °C.

Most of the cotton in the region is irrigated. The crop requires a first irrigation 25–30 days after sowing. The number of irrigations ranges from 8 to 14, depending on sowing method (more irrigations in ridges), plant population, and rainfall. Irrigation is practised as flood or in furrows. Sprinkler and drip irrigation cover about 2–5 percent of the crop area in Egypt and Turkey.

Cotton is grown on a large variety of soils but does best on deep, friable soil with a good supply of humus. Sandy loams, loams and well-granulated clay loams are considered best. Alluvial soils and irrigated delta soils are also very suitable.

TABLE 31
Average cotton yields in Near East countries

Country	Seed cotton (kg/ha)
Turkmenistan	4 000
Turkey	3 545
Uzbekistan	2 592
Egypt	2 778
Pakistan	2 200
Islamic Republic of Iran	1 937
Tajikistan	1 879

The suitable soil pH is 5.5–8.5. The crop is sensitive to soil acidity and excessive water. Excessive accumulation of sodium carbonate also renders soil unsuitable for cotton. Crop picking starts in September and is completed by mid-December. Table 31 lists the average cotton yields for Near East countries.

Nutrient demand/removal

The nutrient demand/removal depends on: variety, location, source of irrigation, plant population, and yield target (Tables 32 and 33).

Sufficiency and critical levels

Sufficiency ranges for cotton have often been used based on observations and the range of nutrient contents of plant tissue from healthy and normal cotton crops. For this reason, sufficiency ranges may be broad and too inclusive. Therefore, use of a sufficiency range for cotton and the implied critical concentration (from low to high) of a nutrient for deficiency or toxicity are not absolute. Several analyses have been reported under different agroclimate conditions and for different varieties. The sufficiency ranges as in Table 34 were compiled from several sources.

Nutrient deficiency symptoms

Lack of N reduces yield and quality. Visible symptoms are: light-green plants; lower leaves turn yellow; and drying to brownish colour.

Plants deficient in P are short and small, growth is retarded, and maturity is postponed. Typical symptoms include loss of chlorophyll and development of red discoloured leaves.

TABLE 32
Macronutrient uptake/removal by cotton crop

	Yield level	N	P_2O_5	K_2O	MgO	S	Source
	(kg/ha)						
Seed cotton (seed, lint, stalks bur)	2 204	69	33.5	86	14	8.5	Makhdum & Islam, pers. com., 2005.
Seed cotton	2 500	156	36	151	40	–	Jones, 2003.
Seed and lint	2 912	70.6	64	42	13	5.6	Havlin *et. al.*, 1999.

TABLE 33
Micronutrient uptake/removal in cotton seeds

Seed cotton yield (kg/ha)	Zn	B	Mn	Fe	Cu	Source
	(g/ha)					
2 500	480	120	190	140	110	PPI, 1995.
2 912	1 076	–	370	–	201	Havlin *et. al.*, 1999.

TABLE 34

Macronutrient and micronutrient contents in cotton plant parts (youngest, mature leaf blade)

		Macronutrients in dry matter					
		N	P	K	Ca	Mg	S
		(%)					
A	Early bloom	3.0–4.5	0.2–0.65	1.5–3.0	2.0–3.5	0.3–0.9	0.25–0.8
	Late bloom / maturity	3.0–4.5	0.15–0.60	0.75–2.50	2.0–4.0	0.3–0.9	0.3–0.9
B	First squares to initial bloom	3.5–4.5	0.3–0.5	1.5–3.0	2.0–3.0	0.3–0.9	0.25–0.8
	Full bloom	3.0–4.3	0.25–0.45	0.9–2.0	2.2–3.5	0.3–0.8	–

		Micronutrients in dry matter				
		Cu	Zn	Fe	Mn	B
		(mg/kg)				
A	Early bloom	5–25	20–200	520–20 050	25–350	20–80
	Late bloom / maturity	–	50–300	50–300	10–400	15–200
B	First squares to initial bloom	5–25	20–200	520–20 050	25–350	20–60
	Full bloom	5–25	20–100	40–300	30–300	20–60

Source: http:/www.ncagr.com.

Plants deficient in K are susceptible to stem blight, leading to premature senescence. Typical symptoms are bronzing and marginal necrosis of leaves adjacent to developing bolls; plants develop fully necrotic leaves and premature defoliation occurs.

Typical symptoms of Mg deficiency are purplish-red lower leaves with green veins.

Sulphur-deficient plants are dwarfed with green leaves.

Manganese-deficient leaves turn yellowish or reddish grey with green veins.

In Zn-deficient plants, small leaves with interveinal chlorosis and shortened stems give the plants a small bushy appearance; leaves lose their green colour and produce necrotic spots.

Plants deficient in B will have dieback of terminal buds, which do not blossom and drop heavily during production; young leaves turn yellowish-green, and flower buds turn chlorotic.

Common nutrition problems

Nitrogen is universally deficient in the cotton-growing countries of the region. Nitrogen nutrition is very important as shortage and oversupply have a significant effect on fibre quality. Shortage results in short and weak fibre, while excess N supply can produce a longer fibre but one that is weak and immature. Timing and method of N application are very important for efficiency and optimal growth.

Phosphorus deficiency has been identified in many areas. For soil P between 7.5 and 15 ppm (Olsen, $NaHCO_3^-$ extraction method), a maintenance application is recommended. For soil P concentrations below 7.5 ppm, recommended rates should be applied. Ideally, leaf P levels should exceed 0.3 percent during the early growth stages. The P deficiency is indicated by dark green foliage early in the season, but leaves may turn purplish as the bolls mature.

Potassium nutrition of cotton has been widely researched recently. While the majority of cotton soils indicate adequate levels of K from testing (> 150 ppm), cotton crops have shown response to applied potash.

Zinc deficiency is a common problem in alkaline soils. Zinc concentrations of less than 0.5 mg/kg (DTPA test) in the soil or 20 mg/kg in the leaf tissue indicate that Zn may be deficient.

Boron plays a significant role in the life of the cotton plant. It affects pollen-tube growth after pollination. It also influences the conversion of N and carbohydrates into more complex substances such as proteins. Soil levels of less than 0.6 mg/kg (hot-water extract), or less than 20 mg/kg in leaves at early bloom, indicate B deficiency.

Sodium is present at excessive levels in many soils of the region. High Na levels reduce plant growth as Na reduces water movement through the soil profile, impedes root growth and interacts with other nutrients. Where Na is excessive in cotton leaves, then salinity depresses plant uptake of P, K and other nutrients.

Use of organic and green manures

The main aims of organic manuring are to improve the physical condition of soil, to increase moisture retention, and to improve nutrient availability to plants. However, manure coverage in different countries varies from 5 to 20 percent. The highest area coverage with organic manure (36 percent) is in Uzbekistan. Few farmers practise green manuring and chopping and ploughing-in of cotton sticks.

Fertilizer recommendations

Table 35 lists the mineral fertilizer recommendations from some cotton-producing countries in the Near East region.

In Pakistan, the application of all the phosphate, potash, and one-third of the N is done at sowing time. Another one-third of the N is given with the first irrigation, and the last dose at flower initiation. It is advisable to drill the fertilizers 5–8 cm from the plant and 4–6 cm deep in the soil. Where N is broadcast, it should be followed immediately by irrigation in order to avoid losses. Research has shown that very little N is used by cotton plants at the seedling stage. The heaviest demand for N is during the fruiting stages of boll formation. Thus, most farmers do not apply N fertilizer at sowing time. The emerging practice is to apply all the phosphate, potash and one-third of the N at the first irrigation. The remaining N is distributed in two parts. One part is applied with second irrigation at square formation. The last and

TABLE 35

Fertilizer recommendations for cotton in Near East counties

Country	N	P_2O_5	K_2O
	(kg/ha)		
Egypt	145–170	55	60
Pakistan			
Short-duration varieties	114–150	57	60
Medium-duration varieties	90–114	57	60
Syrian Arab Republic	200	15	
Turkey	120–200	50–80	60–80
Uzbekistan			
Average-fibre varieties	215–240	145–170	95–110
Fine-fibre varieties	230–250	155–165	100–110

third application of N is applied at flower initiation with irrigation water (as fertigation). Broadcasting or drilling of fertilizer is not possible owing to crop height. For the last dose of N through the fertigation technique, 50 kg N/ha (as urea) is dissolved in 450 litres of water in a tank or drum. This last application is done by mid-August. However, where deficiency appears, then 3-percent urea solution is applied as a foliar application at boll formation in September. The urea could also be mixed with pesticide for application.

Where P fertilizer to a previous crop (wheat, maize or sugar cane) was applied at the recommended rate, the quantity of phosphate for cotton is reduced in order to benefit from the carryover/residual effect. Where the soil P testing range is 7.5–15 mg/kg, P is applied for maintenance. Where P is more than 15 mg/kg, farmers omit its application. Although there is a recommendation for potash application, barely 1 percent of farmers add potash to cotton crop.

With soil Zn testing less than 0.5 mg/kg (DTPA test), about 15 kg/ ha of zinc sulphate is recommended at sowing. For B, where the soil test is less than 0.6 mg/kg (hot-water extract), 8.5 kg B/ha is recommended. However, where Zn and B application are not given at sowing and deficiency symptoms appear, then three foliar sprays of 0.1-percent B plus 0.1- percent Zn solution 45, 60 and 90 days after sowing are recommended. Boron and Zn can also be mixed safely and applied with pesticides as spray solutions.

In Egypt, splitting the N dose into two equal doses, the first before the second irrigation (after thinning) and the second before fourth irrigation, has been found to be the most efficient treatment. Deep side dressing after thinning is an effective method compared with top dressing or banding in the bottom of the ridge.

Conventional fertilization practice involves the application of P, K and part of the N requirements before planting. Applications of phosphate in one single dose either before planting or before the first or second irrigation were almost equal in their impact on crop production. Fertigation is used in Egypt on sandy soils. About 2 percent of farmers also practise foliar fertilization in order to supplement soil-applied nutrients.

Fertigation

Over a five-year period, the International Atomic Energy Agency Regional Project (http://www.iaea.org) in the Syrian Arab Republic showed fertigation to be a very efficient technique for cotton, conserving both water and N fertilizer:

- 36 percent of irrigation water was saved under drip irrigation;
- a 22-percent increase in seed-cotton yield was observed;
- a 93-percent increase in irrigation water efficiency, based on dry-matter yield, was obtained.

Fertigation of complete NPK nutrient blends offers the irrigated cotton producer the flexibility to apply fertilizer based on yield potential and crop development stage. Table 36 gives the recommended fertigation rates after the pre-planting.

TABLE 36
Recommended fertigation rates after pre-planting

Crop stage	N	P_2O_5	K_2O
		(kg/ha/day)	
Vegetative development	0.03–0.10	0.02–0.07	0.03–0.05
1st flower to 2 weeks after flowering	0.25–0.35	0.09–0.18	0.23–0.28
Boll development	0.6	0.09	0.7–0.28

POTATO

Crop data

Potato (*Solanum tuberosum* L.) is grown worldwide on an area of about 19 million ha, producing about 322 million tonnes, with an average yield of 17 tonnes/ha. In the Near East, the total area planted to potato is about 1.3 million ha. The major potato-growing countries in the region are the Islamic Republic of Iran (195 000 ha), Turkey (160 000 ha), Pakistan (112 000 ha), Egypt (100 000 ha), Algeria (90 000 ha), Morocco (65 000 ha), Syrian Arab Republic (25 000 ha) and Tunisia (25 000 ha). Potatoes are also grown in Jordan, Lebanon and Saudi Arabia, usually two crops in a year (FAOSTAT, 2005). Potato crops are cultivated in three seasons: autumn, spring and summer (hilly areas). The total potato production in the region is about 24.5 million tonnes.

The main potato crop is planted in autumn (from mid-September to end October) and harvested in January–February. Potato production in Turkey is geared towards summer periods in the highlands (but to spring and autumn in the lowlands). Farmers in Mediterranean and Aegean regions plant two or even three crops a year. The crop is generally harvested four months after planting. The limiting factor is severe winter, as frost damages the crop. Seeds are selected and graded but not pre-sprouted. Farmers commonly purchase seeds every three years, reserving a proportion of two subsequent crops as seeds.

Cutting of seeds is common for planting in spring. Therefore, the seed rate is 1 200–1 500 kg/ha. For the autumn crop, the seed rate is 3 000–3 500 kg/ha. Tissue-culture potato seeds are also gaining in popularity. Potato is generally sown on ridges, with spacing between rows of 70 cm and between plants of 15–20 cm. The planting depth is 5–10 cm depending on soil type and moisture.

Plant density ranges from 30 000 to 60 000 tubers/ha. Within this range, planting density varies according to the final market requirement in tuber size and to the availability of moisture (especially irrigation).

A potato crop can grow on most soils where mechanical harvesting is operated. It is also grown on sandy soils under sprinkler irrigation and fertigation practices. The soil pH requirement is 5.5–7.5. The crop responds well to moisture, and 6–8 irrigations are common. Irrigation at tuber initiation can affect the skin quality of daughter tubers by influencing phytopathogens either favourably or adversely depending on conditions and the level of moisture present.

Average potato tuber yields in Near East countries are: 24 tonnes/ha in Turkey, 23 tonnes/ha in Egypt, 19 tonnes/ha in Islamic Republic of Iran and about 16 tonnes/ha in Pakistan and Uzbekistan. However, progressive farmers who adopt recommended practices and technology do obtain 30–50 tonnes/ha of potato tubers.

Nutrient sufficiency levels

Nutrient sufficiency levels can vary according to variety, soil type and climate conditions. The sufficiency levels in recently matured potatoes (petiole and leaflets) sampled 45–55 days after emergence are reported in Tables 37–39.

TABLE 37

Sufficiency levels of nutrients in the petiole and leaflets sampled 45–55 days after emergence

Macronutrients	N	P	K	Ca	Mg	S
Content (%)	5.0	0.3	4.5	0.6	0.3	0.2
Micronutrients	**Fe**	**Zn**	**Cu**	**Mn**	**B**	
Content (mg/kg)	51	25	6	30	21	

Source: Rosen, 1991.

TABLE 38

Suggested ranges of nutrient contents for the 4th petiole of Russet Burbank potatoes during tuber bulking

Nutrient	Low	Marginal	Sufficient
Nitrate nitrogen, (mg/kg)	< 10 000	10 000–15 000	15 000–20 000
Phosphorus (%)	< 0.17	0.17–0.22	> 0.22
Potassium (%)	< 7.0	7.0–8.0	> 8.0
Calcium (%)	< 0.4	0.4–0.6	> 0.6
Magnesium (%)	< 0.15	0.15–0.30	> 0.3
Sulphur (%)	< 0.15	0.15–0.2	> 0.2
Zinc (mg/kg)	< 10	10–20	> 20
Manganese (mg/kg)	20	20–40	> 40
Iron (mg/kg)	< 20	20–50	> 50
Copper (mg/kg)	< 2	2–4	> 4
Boron (mg/kg)	< 10	10–20	> 20

TABLE 39

Plant tissue analysis interpretation criteria for potatoes, based on sampling the 3rd to 5th leaf from top

Nutrient	Rating				
	Low	Marginal	Sufficient	High	Excess
Nitrogen (%)	2.4	2.5–2.9	3.0–4.4	4.5–5.4	5.5
Phosphorus (%)	0.14	0.15–0.24	0.25–0.49	0.50–0.9	1.0
Potassium (%)	1.4	1.5–1.9	2.0–5.9	6.0–7.9	8.0
Sulphur (%)	0.14	0.15–0.19	0.20–0.49	0.50–0.9	1.0
Calcium (%)	0.39	0.40–0.49	0.50–3.9	4.0–4.9	5.0
Magnesium (%)	0.19	0.20–0.49	0.50–1.4	1.5–2.9	3.0
Zinc (mg/kg)	11	12–19	20–69	70–149	150
Copper (mg/kg)	2	3–5	6–24	25–74	75
Iron (mg/kg)	24	25–69	70–249	250–49	500
Manganese (mg/kg)	14	15–19	20–99	100–249	250
Boron (mg/kg)	9	10–14	15–39	40–99	100

Source: www.gov.mb.ca

Nutrient demand/uptake/removal

Tables 40 and 41 summarize macronutrient and micronutrient demand by the potato crop at various yield levels.

Organic manures and green manuring

Available organic manure is normally applied before seed bed preparation and ploughed or cultivated into the soil before planting. The quantity varies from 10 to 30 tonnes/ha. The nutrient value of organic manure is generally variable depending on its source. Manure application improves physical condition of the soil and nutrient uptake. Progressive growers depending on crop rotation also practice green manuring. *Sesbania aculeata* or another leguminous crop of two months is incorporated into the soil.

Fertilizer application methods

Potato plants have a relatively shallow root system, with most roots located in the top 60 cm of soil. Common fertilizer application methods are:

- pre-plant broadcasting followed by incorporation;
- banding at planting;
- side dressing after planting;
- foliar nutrient sprays;
- injecting liquid fertilizer through irrigation system (fertigation).

Fertilizers can be applied at planting in bands at close proximity but not in contact with seed tubers. The risks of damage to tubers increase in dry conditions, on light soils, and where pre-sprouted seed is planted. An effective band placement for P and K is 7–10 cm to the side of seed and 2.5–5.0 cm below seed. Side-dressed N fertilizer is often applied during vegetative growth before tuber initiation.

TABLE 40

Nutrient demand/uptake/removal by potato crop, macronutrients

Tuber yield	Macronutrients						
	N	P_2O_5	K_2O	MgO	CaO	S	Cl
(tonnes/ha)	(kg/ha)						
100	250–450	35–65	350–550	100	100	250–450	20–100
50	242	63	314	44	–	20	–
37	113	45	196	–	–	–	–
25	96	31	129	11.0	4.0	8.8	–

Source: IFA, 1992.

TABLE 41

Nutrient demand/uptake/removal by potato crop, micronutrients

Tuber yield	Micronutrients					
	Fe	Mn	Zn	Cu	B	Mo
(tonnes/ha)	(kg/ha)					
100	0.5–2	0.1–2	0.4	0.1–0.2	0.1–0.2	0.1
50	2.0	1.0	0.12	0.1	0.2	–
25	0.59	0.04	0.13	0.04	0.04	–

Source: IFA, 1992.

Timing of fertilizer application

Potatoes use large amounts of N. Most of the nutrient uptake occurs during tuber bulking. Normally, one-third of the N is applied to the seed bed at planting and two-thirds at tuber initiation.

In many counties of the region, the first application (one-third) of N is done after germination is complete (one month after sowing). The second portion of N is applied 45–55 days after germination and irrigated. The third dose is not applied as side dressing or broadcast as it may damage the crop. It is injected with irrigation water (50 kg of urea dissolved in 200 litres of water). This practice provides an opportunity for a higher intensity and efficiency of nutrient management.

TABLE 42
Recommended fertilizer rates for potato

Country	N	P_2O_5	K_2O
	(kg/ha)		
Egypt	300	145	115
Turkey	150–170	80–100	80–100
Pakistan	175–250	112–150	75–100
Syrian Arab Republic	Autumn 150; summer 180	Autumn 120; summer 120	–
Uzbekistan	120–150	85–100	60–75

Even in soils with high P soil test values, potatoes still often need P fertilizer as it can boost yield profitably without influencing processing quality. Potatoes are also heavy feeders of K, whose deficiency affects both yield and quality. Generally, all phosphate and potash is applied and incorporated into the soil before planting. However, in sandy soils, potash is also applied as two splits.

In some areas, micronutrient deficiencies occur and may limit yield. Zinc and B are applied as foliar sprays in such cases. About 370 g of B and 500 g of Zn dissolved in 250 litres of water are applied through foliar spray. The number of doses varies with the severity of the problem.

Fertigation is emerging as an attractive method of fertilization. For potato crops in newly reclaimed areas in Egypt, drip irrigation and fertigation are used. In the Islamic Republic of Iran and Turkey, there is increasing use of pressurized irrigation systems.

Fertilizer recommendations

Table 42 summarizes the recommended fertilizer rates for potato in some selected countries of the region.

For fertigation, recommended rates are:

- Emergence to flower: N and K_2O both at the rate of 2.8 kg/ha/day, with an $N:P_2O_5:K_2O$ ratio of 1:0:1.
- Bulking-up to harvest: N at 0.9 and K_2O at 3.2 kg/ha/day, with an $N:P_2O_5:K_2O$ ratio of 1:0:3.5.

SWEET POTATO

Crop data

Sweet potato (*Ipomoea batatas* Lam.) is grown over an area of 8.6 million ha throughout the world, for a total production of 130 million tonnes (FAOSTAT, 2005). Although Asia is the world's largest producer of sweet potato, it is not a major crop in the Near East. In 2005, the total area cultivated in the region was about 14 000 ha. Of this area, about 10 000 ha were in Egypt (with an average yield of 25 tonnes/ha).

Sweet potatoes yield more and better quality roots on a well-drained sandy loam or silt loam soil. The optimal soil pH for high yields and quality sweet potato is 5.8–7.0. The main propagation method is by stem or root cuttings or by adventitious roots, called slips, that grow out from tuberous roots during storage.

The favourable growth temperature is 20–35 °C. This crop does not tolerate frost. The crop can be grown throughout the year in the tropics and subtropics. In warmer regions, it is grown as an annual. The crop takes 4–6 months to mature. The growth period comprises two stages: the first is a period of extensive growth of fibrous roots, vines and leaves, and initiation of tuberous roots; the second is the swelling of the tubers. Higher temperatures favour vine and leaf growth, while lower temperatures favour tuber swelling.

The planting time in temperate regions is usually May/June for the September/November harvest. Under an arid climate, the crop is planted in September/October. Depending on crop variety, it is planted 20–30 cm apart on beds with a plant density of 45 000–55 000/ha.

The plant is relatively tolerant to drought but cannot withstand waterlogging. The preferred soil moisture content is at 60–75 percent of the soil waterholding capacity. Most sweet-potato fields are furrow irrigated. Irrigation is discontinued 2–4 weeks before the harvest in order to toughen the sweet-potato skin and to minimize harvest loss.

Nutrient demand/uptake/removal

The figures in Table 43 indicate the particular importance of both K_2O and N.

Fertilizer recommendations

It is common practice in traditional agriculture to use organic manure. Under normal cultivation, mineral fertilizers are applied. In Egypt, recommendations are: 70 kg N, 55 kg P_2O_5 and 60 kg K_2O per hectare. The recommended practice is to apply all the P and K before planting and the N in splits. In sandy soils, both N and K are applied as splits.

TABLE 43

Nutrient uptake/removal by sweet potato

	Macronutrients						
	N	P_2O_5	K_2O	MgO	CaO	S	Cl
Plant part and yield	(kg/ha)						
Leaves, 4 tonnes	25.6	8.7	25.4	4.2	2.1	–	–
Tuber, 10 tonnes	26.0	8.5	55.6	2.0	4.2	–	–
Leaves & tuber, 14 tonnes/ha	51.6	17.2	71.0	6.1	6.3	–	–
Tuber, 10 tonnes/ha	23.0	11.7	31.2	4.3	4.1	5.2	1.2

	Micronutrients					
	Fe	Mn	Zn	Cu	B	Mo
	(kg/ha)					
Tuber, 10 tonnes/ha	0.49	0.11	0.59	0.17	0.11	0.82

The low fertilizer rates are:

- Before planting: two-thirds N, all P_2O_5 and one-half K_2O.
- Forty days after planting: one-third N, and one-half K_2O.

The high fertilizer rates are:

- Before planting: one-third N, all P_2O_5 and one-half K_2O.
- Forty days after planting: two-thirds N, one-half K_2O.

SUGAR CANE

Crop data

Sugar cane (*Saccharum officinarum* L.) is an important industrial and cash crop in many countries of the world. Worldwide, 20 million ha are under sugar cane, for an average yield of 65 tonnes/ha. The Near East countries grow the crop on some 1.25 million ha and produce about 76.5 million tonnes. Major producers in the region are Pakistan (966 500 ha), Egypt (135 000 ha), Islamic Republic of Iran (70 000 ha), Sudan (65 000 ha) and Morocco (14 500 ha) (FAOSTAT, 2005).

Egypt ranks first in the world with yields of 121 tonnes/ha, nearly double the world average. The high yields are the result of the combination of the fertile soils of the Nile Delta, a suitable climate, plentiful water, varieties, the high use of plant nutrients (NPK) and pest control. Progressive farmers in Pakistan also obtain more than 120 tonnes/ha of crop. The potential crop yield range is 150–200 tonnes/ha.

Commercial propagation is by cuttings of setts of 2–3 buds or eyes, usually 30 cm in length, planted in long furrows 15–30 cm deep, or in trenches two setts together (2–3-eye/bud setts) 10 cm apart. The soil cover of the setts is 2.5–3 cm.

General crop cultivation practices are:

- Row spacing: High density, 75 cm; general, 90–100 cm, or for mechanized harvesting 125–150 cm.
- Planting time: Mainly in spring (9-month crop) or autumn (15-month crop) in subtropical and arid regions, and throughout the year in the equatorial belt. Maturity is reckoned by age and variety; a hand refractometer reading of at least 18 ° is usually a reliable index.
- Harvesting: Minimum 9–15 months in semi-arid and subtropical, maximum 24 months after planting. The harvesting and planting operations usually overlap in order to avoid storing the planting material.
- Crop cycle: One to three ratoons; time for ratoon is early spring in order to avoid severe cold as it may damage the buds.
- Soil: Medium to heavy with pH 5.0–8.5. Liming is required where pH is less than 5; gypsum is added where soil pH exceeds 9.5. Crop is moderately tolerant to salinity.
- Climate: Optimal temperature range is 25–30 °C, but temperatures of more than 40 °C occur in semi-arid regions, which creates high demand for water and also affects yield. The optimal temperature, with high humidity and moist soil, is favourable for vegetative growth. Ripening requires cool dry weather.
- Irrigation: The crop is adapted to semi-arid conditions with good availability of irrigation water. Requirement: 160–250 cm, with an interval between

TABLE 44
Ranges of macronutrients and micronutrients in sugar-cane leaves

	Deficient	Adequate	High
Macronutrients		(%)	
N	1.8	2.2–2.6	> 3.2
P	0.19	0.22–0.30	> 0.34
K	0.9	1.0–1.6	> 2.2
Ca	0.13	0.18–0.35	–
Mg	0.12	0.15–0.32	> 0.35
Micronutrients		(mg/kg)	
Cu	1.0	4–15	–
Zn	<15	16–32	> 40
Mn	<15	20–200	–
Fe	<5	5–100	–
B	<1	2–10	–

Source: Reuter and Robinson, 1997.

irrigations of 10–15 days in peak summer, but this can be increased to 40 days in winter. Irrigation stops about one month before harvest.

- Critical levels of nutrients in plant: Sampling is done during the "boom" phase of growth, when stalk elongation exceeds 2 cm/day. The "top visible develop" (TVD) third leaf from the shoot apex is sampled. Table 44 lists the ranges of macronutrients and micronutrients in sugar-cane leaves.

Nutrient demand/uptake/removal

IFA (1992) provides tables summarizing the nutrient demand/uptake/removal of sugar cane.

Fertilization recommendations

The nutrient requirements of sugar cane, especially for NPK, are higher than those for other commercial crops because of its high dry-matter production per unit area. There is heavy N demand during early stages of growth. Phosphorus is essential for optimal growth through its influence on root development, the ripening process, plant metabolism and juice purification. Potash promotes cell activity and growth, enhances resistance to lodging, and improves sucrose content. Micronutrients (Zn, Fe, Mn, B and Cu) play an important role in cell division, protein metabolism and enzyme function.

Farmyard manure (FYM) and green manure are applied to improve soil fertility and physical condition of the soil. Some well-decomposed manure at 20–30 tonnes/ha is applied and incorporated into the soil. Press mud (a by-product from sugar mills) is a rich organic source containing nutrients. It is applied at the rate of 2 tonnes/ha at land preparation before planting. After completion of ratoon, crop cycle (2–3 years), the sowing of a green manuring crop (*Sesbania aculeata*, clover, etc.) and its incorporation into the soil followed by irrigation is recommended. The fresh crop in such fields is planted after 20–25 days so that the green manure crop rots well in the soil.

The recommended rates of fertilizers differ widely among countries and within countries depending on soil type, irrigation source, varieties, climate conditions

TABLE 45
Fertilizer recommendations in selected Near East countries

	N	P_2O_5	K_2O
Country		(kg/ha)	
Pakistan:			
Plant crop (9 months)	175	90	90
Plant crop (15 months)	175–250	75–112	120–200
Ratoon crop	175–250	75–125	120–250
Egypt	380	40–110	115

and crop period (Table 45). Generally, the per-hectare rates are 130–500 kg of N, 40–125 kg of P_2O_5, and 90–250 kg of K_2O.

Fertilizer application methods

In low-fertility soils, from one-third to one-half of the recommended N dose is applied as basal. The second dose is applied during vegetative growth (three months after sowing) as two splits. Where three splits are advised, then a first at sowing, a second at sprouting and a third one a month later may be given. Many farmers apply the third dose by dissolving N-containing fertilizer in water and applying it with irrigation water (fertigation). On average-fertility soils; there should not be a basal application of N. One-third should be applied 35–40 days after sowing, and the rest in two splits: in April and May for the spring crop; and in February and March for the autumn crop. The last dose is applied through irrigation water where size of crop does not permit broadcasting.

For the plant crop and subsequent ratoon crop, the entire quantity of P is applied at planting in the furrow below the setts. In some cases, one-third to one-half of the total N is also applied as basal with P.

The crop needs a large amount of K. It is normally all included in the basal dressing. However, there are situations (e.g. on sandy loams) where it is preferable to apply only one-half in the basal dressing and the remainder four months later.

For a sugar-cane crop, the preferred nutrient forms are:

- N: All sources are equally effective;
- P: Water-soluble forms are preferred on alkaline and calcareous soils.
- K: Potassium chloride and potassium sulphate are equally effective. However, potassium sulphate is the recommended source in alkaline and sodic soils in order to avoid the chloride problem.

Fertigation for sugar cane depends on the type of irrigation system. Although the initial investment in subsurface drip irrigation is higher than that for sprinkler or flood irrigation, it is much more efficient. Where drip irrigation is practised, for a crop target of more than 200 tonnes/ha, pre-plant N, P_2O_5 and K_2O may be applied at 40, 90 and 100 kg/ha, respectively. The recommended daily fertigation rate during the active growth period is: 0.5–0.75 kg N/ha and 0.14–0.3 kg K_2O/ha.

SUGAR BEET

Crop data

Sugar beet (*Beta vulgaris* L. ssp. *Vulgaris*) is used for human food, livestock feed and industrial use. Primarily, it is used for the production of sucrose. The total area planted to sugar beet worldwide is 5.2 million ha, producing 242 million tonnes, with an average yield of 40 tonnes/ha. The total sugar beet area in the Near East Region is about 710 000 ha for a production of about 29 million tonnes (FAOSTAT, 2005). Major producers in the region are: Turkey (317 000 ha), Islamic Republic of Iran (175 000 ha), Egypt (70 300 ha), Morocco (58 900 ha) and the Syrian Arab Republic (25 000 ha). The average yields in Egypt and Turkey are 44 and 42 tonnes/ha, respectively.

TABLE 46
Cultivation intensity and variations in nutrient removal by sugar beet

Intensity	Yield (tonnes/ha)	Beet plants (plants/ha)	Nutrient removal				
			N	P_2O_5	K_2O	MgO	S
					(kg/ha)		
Low	20	30 000	100	40	160	28	10
Medium	40	50 000	180	64	240	50	18
High	60	75 000	240	90	300	72	24

Source: IFA, 1992.

Sugar beet requires well-structured and well-drained fertile soils. The crop prefers a temperate climate, with sufficient precipitation (or irrigation) during the growing period up to the ripening phase. The young seedlings are sensitive to frost. A good sugar-beet plant population at harvest should be near 90 000 uniformly spaced plants per hectare. Seeds are planted 2–3 cm deep for maximum germination, and 7.5–10 cm apart in 55-cm row spacing.

Nutrient demand/uptake/removal

Beet yields and nutrient removal figures for various sites may differ considerably Nutrient uptake/removal by 10 tonnes of beets, together with the foliage averages, are estimated at: 40–50 kg N, 15–20 kg P_2O_5, 45–70 kg K_2O, 12–15 kg MgO and 5 kg S; of which, the beets themselves contain only about half. The calculation of nutrient demand must be based on the total removal. This is because the leaves in which the sugar synthesis primarily takes place must not suffer from nutrient deficiency. Where the leaves are incorporated into the soil after harvest, the nutrients they contain may be taken into account in estimating the fertilizer requirements for the next crop (IFA, 1992). Thus, the approximate nutrient removal at an individual site can be calculated readily from the prospective yield and intensity of cultivation (Table 46).

Application of organic manures

Sugar beet utilizes the nutrients from organic manures (FYM, compost, and organic wastes) quite well. They should be well incorporated into the soil before sowing. Their content of plant available nutrients (especially N) has to be taken into consideration when calculating the mineral fertilizer dose.

Fertilizer recommendations

The quality of the sugar beet depends on the sucrose content in the roots and the level of impurities to be removed during sugar refining. Production of high-quality sugar is especially important to growers who are paid on the basis of extractable sugar delivered to factories.

Proper N use increases both root and sugar yield. However, excessive N decreases sugar content. About one-half of the N is applied at sowing in order to maximize early season crop growth, yield and quality.

TABLE 47
Fertilizer recommendations for sugar beet

	N	P_2O_5	K_2O
Country		**(kg/ha)**	
Turkey	140–160	80–100	–
Egypt	60	80	–
Syrian Arab Republic:			
Autumn	200	120	
Summer	180	120	–
Pakistan	112	90	75

A subsequent dressing of N may be applied up to 90 days after sowing. The N supply should drop significantly, particularly in the last third of the growing period, as excessive N and protein content affect sugar extraction adversely. Phosphorus and potash application before sowing is recommended, and the fertilizer should be incorporated into the soil.

Table 47 shows the fertilizer recommendations for sugar beet in some Near East countries.

Sugar beet has a high demand for B and Mn, especially on soils with a high pH (> 6.8–7.0). About 1–2 kg B/ha and 6–12 kg Mn/ha of should be applied before sowing, or these nutrients may be provided through foliar spray.

Chapter 15
Fertilization of oilseed crops

ECONOMIC AND NUTRITIONAL IMPORTANCE OF OILSEED CROPS

Oilseed crops are considered major crops in the world in view of their significant role in the nutrition of both humans (oil and seeds) and animals (residues after oil extraction). In addition to oil, the crops contain proteins and minerals (e.g. Ca, P and Fe) that are necessary for the physiological and biochemical processes in the human body. Moreover, the oils of these crops are used in several industries. In some countries, e.g. the Sudan, oil crops are important agricultural exports.

Fertilizer application is essential for obtaining high yields of oilseed crops. Oilseed crops respond to large applications of N, P, K, S and Ca. The kind of fertilizer, rate, timing, and method of application depend on the crop variety, climate, soil type and its fertility status, as well as on the yield level targeted.

PEANUT OR COMMON GROUNDNUT

Crop data

The vast expansion of peanut (*Arachis hypogaea* L.) in the world reflects its ability to adapt in environments of various soil types and different climate zones. However, it requires a temperature range of 20–30 °C and large amounts of light throughout its life cycle, particularly during the flowering stage. A high level of relative humidity and adequate rainfall (500 mm/year) with a suitable distribution are required for a good crop yield. However, the crop can also be produced in areas with a rainfall of 300–400 mm/year.

In 2005, the world total harvested area was 25.2 million ha (with a global production of 36.5 million tonnes), of which some 2.15 million ha were planted in the Near East (producing some 1.67 million tonnes). The Sudan leads the region in terms of area under this crop with 1.9 million ha, followed by Pakistan (105 800 ha), Egypt (61 000 ha), Turkey (26 000 ha) and Morocco (18 600 ha).

Soils

The most suitable soil types are those that are friable, light-textured and with good drainage. The soil should also contain a good amount of Ca and OM. However, heavy Vertisols, such as the clay soils of the Gezira Scheme in the Sudan, can produce a good yield. However, peanuts grown in such soils suffer from impairment of pod quality. Sandy and loamy soils are most suitable for the crop. Peanuts are produced commercially in soils with a pH of 5.5–8.0. Saline soils are not suitable for peanut production. Table 48 lists the soil properties of the main peanut producing areas in the Sudan.

TABLE 48
Soil properties of major peanut producing areas in the Sudan

Property	Sites		
	Kordofan Goz soil	Gezira soil	Rahad soil
Sand (%)	93	15	10
Silt (%)	3	25	15
Clay (%)	4	60	75
$CaCO_3$ (%)	2	1	1.5
CEC (centimole/kg soil)	5	55	65
pH	7.2	8.5	7.5
EC (ds/m)	0.2	1.1	0.9
Total N (ppm)	300	350	400
Organic C (%)	0.5	0.4	0.84
C:N ratio	18	11	20
Available P (ppm) ($NaHCO_3$)	4.00		0.30
Available K (ppm) (1N-NH_4 acetate)	78	125	137
Rainfall (mm)	350	300	320

TABLE 49
Crop removal of nutrients by peanut at a study site in Niger

	Nutrient removal				
	N	P_2O_5	K_2O	CaO	MgO
	(kg/ha)				
Yield (unshelled)	11.9	7.14	28.6	16.7	11.9

TABLE 50
Peanut hay yield as affected by various fertilizer treatments for three seasons at Gezira, Sudan

	1989	1990	1991	Mean S.E. ± 0.03
Fertilizer treatment	(tonnes/ha)			
Control	7.1	5.6	4.6	5.8
N	9.6	8.9	7.8	8.8
P	9.8	5.7	7.9	7.8
K	9.0	6.9	6.6	7.5
NP	9.1	6.7	9.9	8.6
NPK	9.0	4.9	7.1	7.0
Mean	8.9	6.5	7.3	7.6

Nutrient removal

Peanut requires 10–20 kg of N, 15–40 kg of P and 25–40 kg of K per hectare. Nutrient removal (uptake) varies widely depending on the growing conditions. A study in Niger found the nutrient removal by peanut to be as given in Table 49.

Peanut has the ability to tap a considerable volume of soil and, thus, take up nutrients that are not readily available to other crops. It is preferable to grow peanuts in a rotation with crops that require large amounts of fertilizer application. Peanut benefits more from the fertilizers applied to the preceding crop than from the direct fertilizer applications.

Application of 86 kg N/ha resulted in a significant increase in peanut yield in the Gezira Scheme, which has the largest area for irrigated peanut production in the Sudan. Application of P and K gave erratic and inconsistent responses. Tables 50 and 51 show the hay yield and the uptake of N, P and K by the crop as affected by fertilizer treatments.

Fertilizer recommendations

Although there is no specific fertilizer recommendation for peanut under irrigation in the Sudan, an application of 21.5 kg N/ha banded at planting is found to be beneficial. Peanut comes in the rotation after wheat, which is usually fertilized with 43 kg P_2O_5/ha. Peanut makes use of the residual P in this case.

Application of N, P, K or seed inoculation had no significant effect on peanut production in Kordofan State, Sudan, where very large areas of peanut are under rainfed cultivation. Similar results were obtained in other rainfed areas of the

TABLE 51
N, P and K uptake by peanut crop for three seasons at Gezira, Sudan

Treatment	Nitrogen				Phosphorus				Potassium			
	1989	1990	1991	Mean	1989	1990	1991	Mean	1989	1990	1991	Mean
	(kg/ha)											
N	163	128	140	132	23	13	23	20	108	150	125	128
P	171	110	146	142	26	10	23	20	114	122	104	113
K	145	126	316	129	20	13	18	17	96	163	166	141
NP	147	108	164	140	24	10	23	19	100	147	134	127
NPK	135	77	120	111	201	8	20	16	98	110	104	104
Control	118	47	84	83	18	8	15	14	84	130	66	93
Mean	141	98	128	124	22	7	17	18	100			

Sudan. Therefore, there is no fertilizer recommendation for peanut under rainfed environment.

For Egypt, the general fertilizer recommendations are:

- N: 71.4 kg N/ha is applied in two equal doses, the first at sowing (before the first irrigation), and the second at the second irrigation. In the case of new lands (basically, sandy calcareous soils), the *Rhizobium* strain is inoculated with the seed and applied with the N fertilizer.
- P: The application rate is 71.5 kg P_2O_5/ha, incorporated before sowing or disc-harrowed.
- K: The application rate is 57 kg K_2O/ha, side-dressed at sowing.

However, a study conducted on a sandy soil in Egypt concluded that the per-hectare fertilization rates were 30 kg of N, 74 kg of P_2O_5 and 171 kg of K_2O.

RAPESEED OR CANOLA

Crop data

Rapeseed (*Brassica napus* L.) has an oil content of 30–40 percent, a protein content of 10–40 percent, a carbohydrate content of 25 percent, and a glucosenolate content of 1.4 percent.

In 2005, the world total harvested area of rapeseed was 27 million ha, of which 414 000 ha in the Near East. In the region, the leading rapeseed producers are Pakistan (386 000 ha), Algeria (15 000 ha) and Tunisia (4 000 ha).

Climate conditions

Rapeseed is basically a crop for temperate climates. It prefers moderate temperatures below 25 °C during its growth. It requires an average annual rainfall of 450–500 mm, mainly during the vegetative and flowering period. Maximum seed yield can be produced with annual rainfall of 700 mm. The crop is susceptible to waterlogging.

Soils

Rapeseed can grow on a variety of soil types ranging from heavy clays to light sandy, but with free drainage. Soils that crust after rains are not suitable as they impede seed germination. The crop grows on soils with a pH of 5–8, and it is tolerant to acidity and salinity.

Fertilizer recommendations

Rapeseed responds well to all types of organic and inorganic fertilizers. An N:P:K ratio of 3:2:1 is suitable for spring rapeseed (canola) and one of 4:2:1 is suitable for autumn or winter rapeseed (Weiss, 1983).

Nitrogen is essential for leaf development and for increasing the number of seeds and pods. It affects the oil percentage and protein content. Rapeseed is sensitive to direct contact with chemical fertilizers at germination. Therefore, careful placement of fertilizers is required. Application of 30–40 kg N/ha in the seed bed is recommended. The maximum N uptake occurs at main flowering stage. When plants are about 20 cm tall, 80 kg N/ha are top-dressed, but not later than the bud formation stage (later application affects the crop adversely). In the case of large N applications, a split application is recommended.

Rapeseed is known to be a very efficient user of soil P in the presence of adequate moisture as it has an extensive root system with abundant long root hairs. The crop requires a minimum of 50–75 kg P_2O_5/ha. The source of P is not important, but DAP seems to be superior to other ammoniated phosphates or single-nutrient sources.

Superphosphate is also recommended especially in S-deficient soils. The effects of P on oil content and its characteristics are still undetermined.

For adequate uptake of N and P, K addition is necessary. Rapeseed can make use of residual K (which has been applied to a preceding crop or crops in a rotation). As a general guide, the amount of K applied should be half of the amount of P applied unless there is a deficiency to be corrected. Potassium fertilizer should be applied to the seed bed.

Optimal seed and oil yields were realized by the application of 200 kg N/ha, supplemented with the addition of 20 kg S/ha. At these rates of fertilization, the total plant uptake rates of N, P, K and S were: 140, 250, 170 and 60 kg/ha, respectively. It was also found that 40 kg of N, 30 kg of P and almost 85 percent of the K and S remained in the post-harvest residues.

In Egypt, the fertilizer recommendations for rapeseed are:

- N: 107 kg N/ha, split in two applications, at planting and at bud formation. The source of the N fertilizer is either AN or AS.
- P: 72 kg P_2O_5/ha is applied during land preparation or at planting. The P source is TSP, applied either during land preparation or at planting.
- K: 57 kg K_2O/ha is applied during land preparation or after thinning. Potassium sulphate is the preferred source of K.
- Micronutrients: These elements are applied as foliar spray on recently reclaimed soils, which are mostly sandy calcareous. In the Nile Delta soils, the addition is limited to those deficient in certain nutrients.

SAFFLOWER

Crop data

Safflower (*Carthamus tinctorius* L.) is grown in several countries of the world between latitude 30–45 °N and 35–15 °S. Undecorticated seed contains 25–45 percent oil and 11–20 percent protein, while decorticated seed has a protein content of 40 percent. The seeds can be used as animal concentrate, while the oil is used in several industries.

In 2005, the world total harvested area was 812 000 ha. The four major growers of safflower in the region are Kazakhstan (63 000 ha), Islamic Republic of Iran Islamic Republic (60 000 ha), Kyrgyzstan (17 000 ha) and Uzbekistan (13 000 ha).

Climate conditions

Safflower is basically a crop of warm temperate regions. It requires a rather cool temperature during the initial growth stages, particularly at seed formation. The suitable temperature thereafter is 24–32 °C. The crop is sensitive to high temperatures during the flowering stage. To produce a good crop, safflower requires at least 600 mm of rainfall, but the crop is susceptible to waterlogging.

Soils

Safflower requires fairly deep well-drained soils, preferably of medium texture and a pH of 6–8. The plant is moderately tolerant of salinity.

Fertilizer recommendations

Nitrogen is most often required by safflower and applied in the seed bed at planting or as top dressing. Band placement to the ridge side and below the seed is recommended. The P requirement of safflower is moderate and it can make great use of P applied to the preceding crop, i.e. residual P. Nitrogen and P are combined and banded in the seed bed when safflower is planted. Farmers in the Islamic Republic of Iran, Pakistan and Afghanistan do not find N application to safflower to be economically profitable. Experiments have shown some response to P alone, but a greater response was found when P was applied together with N and K.

SESAME

Crop data

Although sesame (*Sesamum indicum* L.) is one of the oldest oil crops, its international importance has declined as a consequence of its low yield and the competition from other oil crops (such as soybean and rapeseed) that are easier to produce and cheaper. Sesame seeds have an oil content of 44–45 percent and a total carbohydrate content of 18–22 percent.

In 2005, the world harvested area was 7.55 million ha (producing some 3.3 million tonnes), of which 2.02 million ha in the Near East. The total production in the region is 501 000 tonnes, and the major producers are the

Sudan (300 000 tonnes), Pakistan (34 000 tonnes), Islamic Republic of Iran (28 000 tonnes), Turkey (23 000 tonnes), and Yemen (18 590 tonnes).

Climate conditions

Although sesame is basically a tropical and subtropical crop, its cultivation has extended to the temperate zone through availability of suitable sesame cultivars obtained through breeding. Sesame is normally grown at altitudes below 1 250 m. However, the crop is also grown in areas of higher altitudes, where the yields often decrease. Sesame requires hot conditions during growth, and a temperature range of 25–27 °C seems to be the optimum. Sesame is a drought-resistant plant, but requires good moisture at the seedling stage in order to produce a good yield.

The crops can grow entirely on residual soil moisture after rainfall. Therefore, sesame is an important crop in many low rainfall areas. About 500–600 mm of rainfall can produce a very good crop. Sesame is extremely susceptible to waterlogging, and heavy continuous rains during growth increase the incidence of fungal diseases. Under irrigation, the crop requires 900–1 000 mm in order to produce a good yield.

Soils

Sesame can perform well on different soil types, but moderately fertile soils with free drainage are best. Sesame is produced on soils with a pH of 5.5–8.0, and it is affected adversely by salinity.

Fertilizer recommendations

Sesame does not respond significantly to fertilizer application. However, fertilizers added to sesame should consider plant population, available soil moisture, soil type, climate, and crop variety.

In general, fertilizers have little effect on seed composition and oil content. Nitrogen application is usually related to P availability as application of N to a P-deficient soil will depress yield.

Where P is adequate, 20 kg N/ha to sesame is adequate. With HYVs, the crop can be fertilized with up to 50 kg N/ha. Where there is no specific recommendation, the application of 80 kg P_2O_5/ha is suitable. In the case of a rotation where the preceding crop has received P, sesame can be fertilized with 20–40 kg P_2O_5/ha. Superphosphate or other similar types are applied in the seed bed at planting.

The application of K fertilizer is not required unless the soil is deficient in K. However, irrigated sesame, which is fertilized with high amounts of N and P, requires K fertilization in order to maintain nutritional balance.

Table 52 indicates the nutrient uptake by the different plant parts.

TABLE 52
Uptake of N, P and K by different parts of sesame crop in Niger

Plant part	Dry matter (tonnes/ha)	N	P	K
		(kg/ha)		
Roots	0.779	2.84	0.95	4.33
Stem	2.846	10.24	7.94	42.98
Leaves	2.058	34.98	12.30	16.74
Capsules, with seeds	4.429	71.74	10.36	72.42
Total	10.112	119.80	31.82	136.47

The appearance of micronutrient deficiencies in sesame is rare. However, B boron toxicity frequently occurs, showing firing of leaf margins and tips.

In Egypt, the fertilizer recommendations for sesame are:

- N: For a fertile soil or after a legume crop, 71.4 kg N/ha in the form of urea is applied.
- P: 200 kg P_2O_5/ha in the form of SSP (18 percent P_2O_5) is applied during land preparation or at planting.
- K: 50 kg K_2O in the form of potassium sulphate is added.
- Organic fertilizers: The organic fertilizer should be decomposed, free of weed seeds, and added at the rate of 10–15 m^3/ha. However, in sandy soils or soils of poor fertility, the application rate could be 20 m^3/ha (applied during land preparation).

In the Sudan, sesame production is mostly under rainfed agriculture. It has not been confirmed that sesame responds to any of the N, P or K fertilizers under rainfed conditions. Lack of response could be a consequence of inadequate rainfall where sesame is grown. Some experiments on irrigated sesame have shown a response to 100–200 kg of urea per hectare.

SUNFLOWER

Crop data

Sunflower (*Helianthus annus* L.) seeds contain 20–25 percent of good edible oil. In some improved varieties, the oil content exceeds 50 percent. Undecorticated seeds contain 30 percent protein, while decorticated seeds contain 40 percent.

In 2005, the world total harvested area was 23.4 million ha, of which about 1.36 million ha in the Near East. The total sunflower seed production in the region was 1 866 000 tonnes in 2005. The main producers in the region are Turkey (480 000 ha), Kazakhstan (350 000 ha), Pakistan (233 500 ha), Morocco (100 000 ha), Islamic Republic of Iran (80 000 ha), Sudan (16 000 ha) and Egypt (15 600 ha).

Climate conditions

Sunflower has a strong root system that enables it to grow in areas where the rainfall is too low for other crops. It was found in South Africa that 250 mm of rainfall of good distribution could support short-maturing varieties. Generally, the crop water requirement is about 500 mm or more per season.

Sunflower requires relatively hot weather, especially during seed formation. Temperature affects the oil content and its characteristics, with an optimal range of 20–30 °C. A rise in temperature reduces the oil percentage, lowers the acidity and increases the oleic acid content.

Soils

The crop can be cultivated on soils ranging from sandy to clayey, but they should be deep and with good drainage. Light soils are preferable to heavy-textured ones. Sunflower grows well on neutral to alkaline soil (pH 6.5–8.0), but does not perform well on acid soils.

Soils salinity impairs plant growth, nutrient uptake and oil content. Soil sodicity also affects sunflower growth and yield adversely.

Fertilizer recommendations

Sunflower is known to be an inefficient converter of plant nutrients, and this is explained by the low harvest index of the crop. However, the N requirement for sunflower is estimated at 50–100 kg N/ha.

A positive response to N application can only be expected where P and K are adequate. In soils deficient in P and K, the N application depresses the seed and oil yields. If the soil were of medium fertility, a small amount of N applied to the seed bed would help seedling growth, which in turn would increase the uptake of other nutrients.

Adequate application of K fertilizers increases the seed yield of sunflower. Potassium sulphate is known to be the fertilizer of choice for sunflower. The K requirements for sunflower are 60–125 kg K_2O/ha.

Generally, sunflower does not respond to the application of micronutrients unless there is a deficiency. In the case of a deficiency, the micronutrient is applied in combination with the macronutrient fertilizer at the seed bed preparation stage. Very small amount of micronutrients can be applied as seed dressing or as foliar spray.

In the Sudan, a study conducted at Nuba Mountain in southern Kordofan State found that the application of N to sunflower grown under rainfed conditions on a Vertisol soil (clay 44 percent) had no significant effect on seed yield. On the other hand, a P application increased the seed yield and yield components significantly. The application of 88 kg P_2O_5/ha increased the seed yield from 639 to 874 and 902 kg/ha. The response to P was high with the hybrid cultivar and with good rainfall (more than 500 mm) in terms of amount and distribution. It was concluded that hybrids such as Hysum–33 should be used in order to obtain a high seed yield in this region of the Sudan.

In a clay soil of pH 8.5 at Shambat Experiment Station in the Sudan, it was found that an application of 50 kg N/ha increased the seed protein of sunflower under irrigation significantly (from 10.8 to 26.7 percent). A P application at the highest rate (50 kg P_2O_5/ha) increased the oil content significantly. Urea and TSP fertilizers were applied at sowing, placed 7 cm deep on the side of the ridge, and the plant variety was Rodes.

A study in Turkey reported that the application of 70 kg of P_2O_5/ha gave the optimal seed yield of sunflower (1 725 kg/ha) planted in autumn or spring.

For the Islamic Republic of Iran, Gorttappeh *et al*. (2000) reported that the optimal seed yield and oil percentage were attained by the application of 200 kg N/ha and about 30 tonnes of organic fertilizer per hectare. The varieties used were Hysum–33 and As–508 hybrid cultivars.

Another study conducted at the experiment station of Shivas University in the Islamic Republic of Iran showed that an application of 69 kg N/ha and a spacing of 25 cm between plants of sunflower (cv. Mehr) gave optimal yields of seeds and oil.

An experiment in Pakistan showed that a per-hectare application of 180 kg N and 120 kg P_2O_5 gave the highest yield (1 249 kg/ha) of sunflower seeds from a crop intercropped with sugar cane.

For Egypt, the general recommendations for fertilization of sunflower are:

- N: 142 kg N/ha split into three equal doses: the first is applied during land preparation; the second after weeding and thinning of the crop, and the third before the formation of the flower buds.
- P: 53.6 kg P_2O_5/ha as SSP (15 percent P_2O_5) is applied during land preparation. In addition, two sacks of phospherin inoculum are mixed with the seeds at sowing.
- K: 57 kg K_2O/ha as K_2SO4 is applied with the second dose of N after the thinning of the crop.
- Organic fertilizer: An application of 20 m^3/ha of old decomposed manure with the SSP fertilizer during land preparation is recommended.

El-Sadik *et al.* (2004) reported that raising the N dose to 190 kg N/ha, coupled with adding 0.2 kg/ha of borax (foliar spray) resulted in a significant sunflower yield increase at El-Kharga Oasis, Egypt.

Effect of nitrogen fertilization on sunflower

In a study carried out in the Sudan as "farmer-managed trials" at the Al-Rahad Irrigated Scheme in 2001, it was found that both N and P fertilizer application had a significant effect on the seed yield of irrigated sunflower grown on a clay soil (45 percent clay). Table 53 shows the effect of fertilization on crop yield at various fertilizer levels.

Khashem Elmouse (2003) reported that sunflower responded significantly to N fertilization alone and in combination with P in Sennar in a heavy clay soil (65 percent clay) and under low total N (400 ppm N). The additional N fertilizer caused a significant increase in plant height, stem diameter, seed weight, seed yield and increase in filled seeds. The recommendation was to apply about 86 kg N/ha as urea and 43 kg P_2O_5/ha as TSP to sunflower. The urea was found to be the best N source (followed by AS).

Table 54 lists the uptake of N, P and K by sunflower during the different growth stages of the crop.

TABLE 53

Effect of source and rate of fertilizers on grain yield of sunflower in farmer-managed trials at Rahad Project, Sudan, 2000/01

No. of farms	Treatment	Grain yield (kg/feddan)[1]	Yield increase (%)
1	Control (0N)	336	
	Urea (2N)	504	50
2	Control	364	
	Nitrophoska (1N) [2]	532	46
3	Control	392	
	Ammonium sulphate (1N)	672	71
4	Control	420	
	Ammonium sulphate – nitrate (1N)	532	27
5	Control	476	
	Nitrophoska (2N)	700	47
6	Control	504	
	Ammonium sulphate (2N)	784	55
7	Control	476	
	Ammonium sulphate – nitrate (2N)	644	35

[1] A feddan is equivalent to an acre (0.405 ha).
[2] 1N = 43 kg N/ha.
Source: Babiker, 2001.

TABLE 54

NPK uptake at different stages of plant growth as affected by N source and level

N source	N level	Vegetative growth			Flowering stage			Maturity stage		
		N	P	K	N	P	K	N	P	K
		(kg/ha)								
Urea	0N	82	16	17	87	26	21	90	27	22
	1N	84	20	21	90	28	23	98	29	24
	2N	87	25	27	94	29	25	107	30	26
	Mean	84	20	22	90	28	23			
NPK	0N	84	14	28	84	18	17	96	18	22
	1N	87	32	32	92	22	25	102	23	25
	2N	90	34	33	95	31	33	105	32	34
	Mean	87	27	31	90	24	25			
AS	0N	85	16	25	86	17	21	91	18	21
	1N	89	18	21	91	21	24	101	21	24
	2N	91	19	23	95	22	29	104	23	29
	Mean	88	18	23	91	20	25	99	21	25
ASN	0N	84	19	21	84	16	20	97	17	20
	1N	90	24	18	902	22	25	107	23	25
	2N	93	24	20	96	28	21	109	30	29
	Mean	89	22	20	91	22	22	104	23	25
SE+		0.20ns	2.4**	3.0**	0.22ns	2.9**	3.1**	0.24ns	3.0**	3.0**
CV (%)		15.5						13.8		

ns Not significant.

** Significant at 5 percent.

Chapter 16

Vegetable crops under protected cultures

The protected farming area (greenhouses and low tunnels) in the countries of the Near East and North Africa was about 72 500 ha in 1995 and 113 850 ha in 1999 (Table 55).

In the greenhouses and low tunnels, vegetables are the major crops, mainly tomato and cucumber, in addition to sweet pepper, squash, lettuce and other fresh products.

Compared with the open field, vegetables produced under protected culture result in early and high yields of good quality. In order to ensure these outcomes, the crops require special types and dosages of mineral fertilizers. The fertilization programme is usually based on estimating plant nutrient needs through soil

TABLE 55
Protected cultivation in countries in the Near East and North Africa

	1995		1999	
	Greenhouses	Low tunnels	Greenhouses	Low tunnels
Country	(ha)			
Algeria [1]	5 005		5 505	
Bahrain [1]	54			
Cyprus [2]	234	227		
Egypt [2]	1 200	17 600	1 350	50 000
Iraq [3]	31			
Jordan [2]	1 138		2 000	
Kuwait [3]	560			
Lebanon [2]	1 100	750	1 250	
Libyan Arab Jamahiriya [1]	2 000			
Malta [4]	35		35	
Morocco [2]	8 540	280	10 000	2 500
Qatar [3]	64			
Saudi Arabia [3]	1 400		1 550	
Syrian Arab Republic [3]	2 164	15	2 164	
Tunisia [2]	1 118	2 395	1 191	
Turkey [2]	7 500	19 615	14 219	21 803
Yemen [3]			60	
United Arab Emirates [3]			223	
Total	31 633	40 882	39 547	74 303
Overall protected		72 515		113 850

Sources:
[1] Latest available.
[2] Abou-Hadid, 1997.
[3] AOAD, 1998.
[4] Castilla and Hernandez, 1995.

testing. Macronutrient fertilizers (NPK) are applied at pre-planting and during the growing season; while micronutrients are mainly applied through foliar sprays.

Fertigation minimizes nutrient leaching and, thus, prevents groundwater pollution. It improves the nutrient-use efficiency; ensures saving in labour, equipment, energy and fertilizer costs; and allows increases in yields. For efficient fertilizer use, fertigation is used in almost 90 percent of the protected farming area in the region.

Crops could be planted directly in the soil, where appropriate for growth. Alternatively, a growing medium can be used, e.g. sand, gravel, vermiculite or even water (hydroponics). The cultivation of crops in such media is termed "soil-less culture" and is common in protected cultures. Various vegetables are produced in greenhouses or low plastic tunnels in almost all countries of the region.

THE FERTIGATION SYSTEM

The fertigation system consists of a control head unit and an irrigation network (mainlines, submains, drip or lateral lines and emitters). The control head unit consists of a water source, a filtration system, fertilizer injection tanks and other devices, such as pressure and flow regulating valves, control valves, water meters and pressure gauges (Plate 1).

The mainlines deliver water coming from the control head unit to the emitters through submains and drip lines.

Filtration equipment

Adequate filtration is necessary in order to ensure clean water. Many types of filter systems are available. Where using surface water from lakes, dams and rivers, a sand separator or centrifugal filter (hydrocyclone), and screen or disc filters are uses. For underground water from wells, the appropriate filters are disc filters, and sand separators may sometime be needed where the water turbidity is high. Hydrocyclones use centrifugal force to remove particles heavier than water.

Sand filters (Plate 2) are made up of layered beds of graduated-size sand and gravel, or single-size sand. Screen and disc filters stop particles larger than 100 microns. The filtration system requires regular checking and cleaning.

Plate 1
The control head unit of a fertigation system.

Fertilizer injection equipment

Three types of equipment exist for injecting fertilizer solution into the irrigation system: Venturi injector, fertilizer pumps, and fertilizer tanks. In a fertilizer tank, part of the irrigation water flows through the tank and dilutes the nutrient solution by creating a pressure differential between the tubes entering and leaving the tank. The Venturi injector (Plate 3) is an injector installed around a point of restriction, such as a regulator valve or a gate, which creates a differential pressure, thereby allowing creation of a vacuum responsible for the injection of the solution into the system. The proportional injector pump is operated by the water pressure of the irrigation system. Another injection pump powered by an external electrical source may be used to obtain the desired dilution.

Plate 2
Sand filters.

Fertilizer distributors or emitters

In greenhouses and nurseries, the filtered nutrient solution is distributed to plants by emitters or drippers that are connected to the drip line (online drippers) or are a part of it (inline drippers). The flow rates of the drippers range from 1 to 10 litres/h, and the dripper water flow rate should be checked regularly in order to prevent clogging.

Plate 3
The Venturi injector used for fertigation.

MANAGEMENT OF THE FERTIGATION SYSTEM

The prepared stock solution (containing fertilizers) is injected into the drip irrigation system and delivered to the rootzone through the emitters. For proper functioning of the fertigation system, a number of controls should be in place.

Control of equipment functioning

Where necessary, filters, injectors and emitters should be checked and cleaned on a daily basis.

Clogging of lines and drippers should be prevented by flushing sublines and laterals (drip lines), by filtering irrigation water, as well as by using soluble nutrient solutions with no precipitation.

Damaged pipes and accessory equipment should be repaired or changed immediately.

Water pressure control

Water pressure at different parts of the irrigation system should be maintained at the design level designed in order to ensure a uniform water flow from all drippers along the drip line.

When the pressure gauge indicates a lower reading than that given by the network design, this means that there is a malfunction somewhere in the system.

Control of the dripper flow rate

When the flow rate of emitters is lower than expected and the uniformity coefficient is lower than 90, it is necessary to check the system and to clean the plugged emitters. Some plugged emitters might need replacing.

Nutrient solution salinity and pH control

Nutrient solution pH and electrical conductivity (EC) should be verified at the emitter site using a portable pH meter and an EC meter.

The measured EC brought by the<fertilizers and the theoretical EC of applied fertilizers (Salt Index) need to be compared.

Tests should be conducted regularly on the drained water in order to detect whether there is any excess salinity or nitrate leaching. A lysimeter facilitates this task.

RECOMMENDATIONS FOR OPTIMIZING FERTILIZER INJECTION PRACTICES

In order to maintain a properly functioning fertigation system, it is necessary to choose the correct fertigation material and equipment and to ensure proper maintenance of the system.

Washing and cleaning of filters

For optimal performance, drip irrigation systems need clean water. Filters must be kept clean in order to be effective. Back flushing with automatic or manual control valves keeps sand filters and some screen filters clean. Cleaning should be done whenever necessary, as determined by any pressure drop or at intervals determined by previous experience, in accordance with the manufacturer's instructions.

Flushing the fertigation network

The capability for flushing the submains and laterals should be part of the system design, and a regular programme should be established. The appearance of the flushed water can act as a check on other maintenance procedures. Lateral pressures should be checked regularly. Plugged lines as well as leaks and line breaks will show up as pressure changes.

Treatment to prevent clogging

Many cases of chemical clogging can be solved by injecting acid into the system. In severe cases, emitters must be soaked in dilute acid solution (1 percent) and even cleaned individually. For less severe cases, injection of acid to bring the water to a pH of 1–2 should be sufficient. The injection should be repeated until the flow rate from the emitters has returned to normal. When bacterial slime or algae clog the drip system, the standard treatment is the injection of a biocide followed by a thorough flushing in order to clear any OM from the system. Hypochlorite solutions ($HOCl^-$) are the most commonly used biocides. Flushing rates range from 20 to 50 ppm Cl_2 depending on the severity of the problem, and such rates should be maintained in the lines for at least 30 minutes.

PREPARING THE NUTRIENT SOLUTION

Plant requirements of water and fertilizers

It is important to know the macronutrient and micronutrient needs of the plants at various growth stages and also their water requirements. This information helps in determining a proper nutrient solution and, thus, enables enhanced efficiency in terms of water and fertilizer. In order to allow adequate micronutrient absorption and to avoid any precipitation, the pH of the nutrient solution has to be maintained between 5.8 and 6. The required concentration of the nutrient solution for each growth stage should be measured (using an EC meter). Checking the EC of the nutrient solution helps in adjusting the amount of nutrients to inject into the irrigation system with the proper timing.

Fertilizer quality

The fertilizers used to prepare stock solutions have to be completely soluble and when mixed they must be compatible (to avoid any precipitation). As a basic rule, phosphate- and sulphate-based fertilizers should not be mixed with calcium-based fertilizers. Tables 56 and 57 show the solubility in water of some fertilizers and their compatibility when mixed together.

Water and soil testing

It is important to test the nutrient content of the irrigation water and that of the soil, which should be deducted from the calculated plant nutrient needs. The water test shows the pH, the EC and the amount of bicarbonate ion (HCO_3^-). In general, nitric acid, which has beneficial qualities of clearing clogging, could be used for neutralizing the bicarbonate ion.

IMPROVING TECHNICAL SKILLS OF THE IRRIGATION SYSTEM OPERATORS

To achieve optimal performance of the fertigation system, the farm manager has to be trained in practical fertigation management. System operations involve: opening valves, preparing and injecting stock solutions into the irrigation system, cleaning filters, reading pressure gauges, controlling the pH and the EC, and

TABLE 56
Solubility of some commercial fertilizers

Fertilizers	Solubility		Part of nutrient elements contained in the fertilizer
	At 0 °C	At 20 °C	
	(kg/100 litres)		(% of weight)
Liquid fertilizers	Highly soluble		
Ammonium nitrate (33%)	118	192	16.5% N-NO_3^- + 16.5% N-NH_4^+
Ammonium sulphate (21%)	70.6	75	21% N-NH_4^+ + 72% SO_4^{--}
Calcium chloride	-	40	39.2% CaO + 49.6% Cl
Calcium nitrate	102	122	17% N-NO_3^- + 33.6% CaO
Di-ammonium phosphate	43	66.1	20.5% N-NH_4+ + 53% P_2O_5
Magnesium sulphate (16%)	60	71	16% MgO + 36% SO_4^{--}
Magnesium nitrate	-	279	10.9% NO_3N + 15.7% MgO
Mono-ammonium phosphate	23	37	12% NH_4N + 60% P_2O_5
Mono-potassium phosphate	14	23	51% P_2O_5 + 34% K_2O
Potassium chloride	27.6	34	61% K_2O + 46% Cl
Potassium nitrate	13.3	31.6	13% NO_3N + 46% K_2O
Potassium sulphate	7.4	11.1	50% K_2O + 51% SO_4^{--}

Source: Letard, Erard and Jeannequin, 1995.

TABLE 57
Compatibility for mixing commercial fertilizers

Fertilizers	$(NH_4)_2SO_4$	$Ca(NO_3)_2$	$Mg(NO_3)_2$	$MgSO_4$	$NH_4H_2PO_4$	KCl	KNO_3	K_2SO_4
Ammonium sulphate $(NH_4)_2SO_4$	–	No	Yes	Yes	Yes	Yes	Yes	Yes
Calcium nitrate $Ca(NO_3)_2$	No	–	Yes	No	No	Yes	Yes	No
Magnesium nitrate $Mg(NO_3)_2$	Yes	Yes	–	Yes	Yes	Yes	Yes	Yes
Magnesium sulphate $MgSO_4$	Yes	No	Yes	–	No*	Yes	Yes	Yes
MAP $NH_4H_2PO_4$	–	No	Yes	No*	–	Yes	Yes	Yes
Potassium chloride KCl	Yes	Yes	Yes	Yes	Yes	–	Yes	Yes
Potassium nitrate KNO_3	Yes	Yes	Yes	Yes	Yes	Yes	–	Yes
Potassium sulphate K_2SO_4	Yes	No	Yes	Yes	Yes	Yes	Yes	–

* Compatible in acid medium.
Source: Musard, 1991; Letard, Erard and Jeannequin, 1995.

TABLE 58
Element concentration in nutrient solution in sand soil-less culture for protected tomatoes, Abu Dhabi, United Arab Emirates

Element	Dose (ppm)	Fertilizers
N	200	Calcium nitrate, potassium nitrate
P	62	Monobasic potassium phosphate
K	156	Potassium nitrate, monobasic potassium phosphate
Mg	48	Magnesium sulphate
Ca	247	Calcium nitrate

Source: Eisa and Jensen, 1974.

reading water pressure in different parts of the system and cleaning pipes and emitters in order to prevent clogging.

INDICATIVE DATA ON RECOMMENDED FERTILIZER APPLICATION RATES

As shown above, there is an important link between the crop water requirement and fertigation. Eisa and Jensen (1974) reported the element concentration in nutrient solution in sand soil-less protected tomatoes in Abu Dhabi, United Arab Emirates (Table 58). In Cyprus, Papadopoulos (1999) developed some fertigation recipes (Table 59). Table 60 shows the fertigation programme for different growth stages of tomato in greenhouses in the Agadir area in Morocco. These recipes and others should be considered as approximate guidelines to be modified and adjusted according to the water quality, soil fertility, climate and cultural conditions.

TABLE 59
Recommended concentrations of nutrients in irrigation water in Cyprus

Crop	N	P	K
	(g of nutrient per m^3 water)		
Cucumber	150–200	30–50	150–200
Eggplant	130–170	50–60	150–200
Bell pepper	130–170	30–50	150–200
Tomato	150–180	30–50	200–250
French bean	80–120	30–50	150–200
Strawberry	80–100	30–50	150–200
Banana	15	–	45

Source: Papadopoulos, 1999.

TABLE 60
Absorption of nutrient elements by greenhouse tomatoes, Agadir, Morocco

Period	Duration (days)	N	P_2O_5	K_2O	CaO	MgO
		(kg/ha/day)				
Transplanting – 1st cluster fruit set	30	1.87	0.85	4.00	1.87	0.70
1st cluster fruit set – 1st harvesting of 4th cluster	90	4.28	1.49	9.50	3.66	1.41
First harvesting of the 4th cluster – 1st harvesting of 9th cluster	60	3.27	0.60	6.50	3.03	1.73
First harvesting of the 9th cluster – End of harvest of 16th cluster	60	1.05	0.28	2.25	2.21	1.19

Chapter 17
Fruit crops

TISSUE SAMPLING OF FRUIT TREES

Understanding the nutritional status of plants is critical to producing an excellent fruit crop. Tissue analysis is a valuable tool for assessing the nutritional status of a crop. It reveals the extent to which the absorption of the nutrients is taking place and whether this is adequate to support the ideal crop growth. Thus, tissue analysis can facilitate fine tuning of fruit crop fertilization. It provides important clues regarding potential nutrient deficiencies before they manifest as symptoms. Thus, timely correction of the problem is feasible, so ensuring fruit quality and good yields.

Table 61 summarizes guidelines on when and how to collect good tissue samples from fruit trees.

Figure 13 shows the appropriate methods for sampling selected horticultural crops. The figure indicates the plant part to be sampled along with the location of the leaves to be taken for analysis.

ALMOND

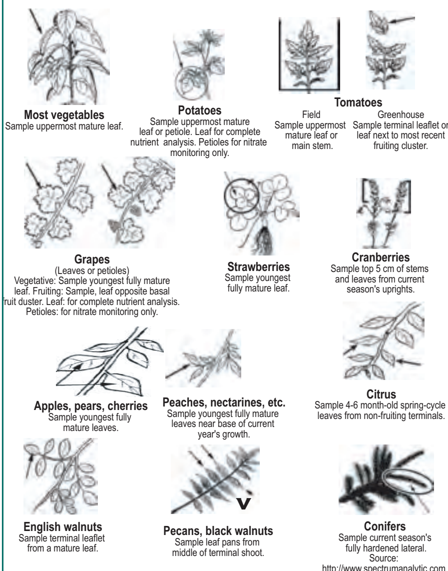
Crop data

Almond (*Prunus amygdalus*) is a commercial crop in many countries on a total area of about 2 million ha. The average yield of rainfed almonds is about 25 tonnes/ha. The total area of almonds in the Near East region is about 745 800 ha, producing some 500 000 tonnes (FAOSTAT, 2005). The main almond producers in the region are Tunisia (350 000 ha), Morocco (132 000 ha), Islamic Republic

TABLE 61
Collection of tissue samples from fruit trees

Plant	Stage of growth	Plant part to sample	Number of plants to sample
Apple, apricot, almond, prune, peach, pear, cherry	Mid-season	Leaves near base of current year's growth or from spurs	50–100
Pecan	6–8 weeks after bloom	Leaves from terminal shoots, taking the pairs from the middle of the leaf	30–45
Walnut	6–8 weeks after bloom	Middle leaflet pairs from mature shoots	30–35
Lemon, lime	Mid-season	Mature leaves from last flush of growth on non-fruiting terminals	20–30
Orange	Mid-season	Spring cycle leaves, 4–7 months old from non-bearing terminals	20–30
Grapes	End of bloom period	Petioles from leaves adjacent to fruit clusters	60–100
Raspberry	Mid-season	Youngest mature leaves on lateral or "primo" canes	20–40

FIGURE 13
Methods for sampling horticultural crops



Source: http://www.spectrumanalytic.com.

TABLE 62
Critical nutrient levels in almond leaves, dry-weight basis

Nutrient	Nutrient status	Nutrient level
Nitrogen)	Deficient	< 2%
	Adequate	2.2–2.5%
Phosphorus	Adequate	0.1–0.3%
Potassium	Deficient	< 1%
	Adequate	> 1.4%
Calcium	Adequate	> 2%
Sodium	Excessive	> 0.25%
Chlorine	Excessive	> 0.30%
Boron *	Deficient	< 30 ppm
	Adequate	30–65 ppm
	Excessive	> 100– 300 ppm
Copper	Adequate	> 4 ppm
Manganese	Adequate	> 20 ppm
Zinc	Deficient	< 15 ppm

* Leaf sampling is not effective for determining excess B.
Source: Micke, 1996.

of Iran (95 000 ha), Libyan Arab Jamahiriya (50 000 ha), Algeria (41 000 ha), Syrian Arab Republic (27 000 ha), Turkey (19 750 ha) and Lebanon (6 400 ha).

Almonds produce best on deep, loamy, well-drained soils, but tolerate poor soils. They are intolerant of wet, poorly drained soils. In the Mediterranean area, almonds can be cultivated on calcareous, rocky and drought-affected soils. Although almonds are often grown on drylands in the region, they do best when irrigated. They are sensitive to high salinity levels.

Trees are planted at a spacing of 5–6 m at a density of 275–400 trees/ha. Transplanting usually takes place during the dormant season. Almonds are self-incompatible and require cross-pollination. A few self-fertile cultivars are available, but they are generally inferior in quality. At maturity, pruning consists of water sprout removal, removal of dead and interfering branches, and limb thinning. Fruiting begins when the trees are 3–4 years old, with maximum production in 6–12 years.

Leaf analysis is a very useful tool in diagnosing mineral deficiencies and toxicities. The nutrient concentration at which the plant yields 90 percent of the maximum is termed "critical value". Table 62 indicates the critical nutrient levels in almond leaves. The critical values are based on fully expanded non-fruiting spur leaves collected at 1.75–1.85 m above the ground in mid-season.

Fertilization of rainfed almonds

Fertilizer should be applied to rainfed almonds in the rainy season close to the bud-breaking stage (February/March). The recommended compound fertilizer grade is 30–10–10 (or a similar grade) and this should be applied according to the schedule in Table 63.

The fertilization programme for almond is suitable for apricot, plum and peach trees. Foliar fertilization is recommended in order to correct deficiencies of Zn and other micronutrients.

TABLE 63
Fertilization of rainfed almonds

Age of tree (years)	Compound fertilizer 30–10–10 (kg/tree)
1	0.1–0.2
2	0.2–0.3
3	0.3–0.4
4	0.4–0.5
5	0.5–0.7
6	0.7–1.0
7	1.0–1.5
8	1.5–1.8
9	1.8–2.0
10	2.0–3.0

Fertilization of irrigated almonds

The recommended compound fertilizer grades are 20–10–10 and 20–10–20, or similar grades, according to results of soil and tissue analysis of the previous year (Table 64). Single-nutrient fertilizers (viz. AS, AN, urea, TSP, DAP, MAP and potassium sulphate) could also be used at the same nutrient rates as that of compound fertilizers, except where tissue analysis indicates certain nutrient deficiencies that should be corrected.

TABLE 64
Fertilization of irrigated almonds

Age of tree (years)	Before bud breaking 20–10–10	Early fruit setting 20–10–20
	(kg/tree)	
1	0.1–0.2	–
2	0.2–0.3	–
3	0.2–0.3	0.2–0.3
4	0.3–0.4	0.3–0.4
5	0.4–0.5	0.4–0.5
6	0.5–0.6	0.5–0.6
7	0.7–0.8	0.7–0.8
8	0.9–1.0	0.8–0.9
9	1.0–1.3	1.0–1.3
10	1.3–1.5	1.3–1.5

Zinc and other micronutrients may be applied with irrigation (fertigation) or by foliar spray. To avoid leaf burn, the total concentration of dissolved fertilizers should not exceed 1 percent.

The almond fertilization guidelines are also suitable for irrigated apricot, plum and peach trees.

APPLE

Crop data

Apples (*Malus* spp.) grow in temperate climate zones and in a wide range of soil types. Some varieties that require a long growing season, such as Granny Smith and Fuji, are heat-tolerant cultivars. Advances in irrigation technology have permitted apple production in warm climates.

In the Near East region, the total area under apple cultivation is 741 000 ha, for a production of some 8 million tonnes (FAOSTAT, 2005). The major

TABLE 65
Bloom stages of apple, Red Delicious

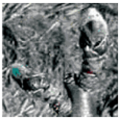
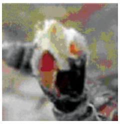
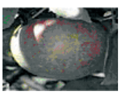
Stage		Characteristics
Dormant		No swelling visible
Silver tip		Swollen buds become noticeable and silvery fuzzy leaf tissue begins to emerge from the tip of the bud.
Green tip		Green leaf tissue is visible at the tip of the bud.
Tight cluster		The spur leaves have folded back exposing the flower cluster inside the bud.
Pink		The flower buds have grown enough to expose the petals of the flowers.
Open cluster		The individual flower buds have separated.
King bloom		The central “king bloom” has opened. The king bloom has the potential to have the largest fruit.
Full bloom		80 percent or more of the flowers on the tree or in the orchard are open.

TABLE 65
Bloom stages of apple, Red Delicious (continued)

Stage		Characteristics
Petal fall		Flower petals are falling from the tree.
8-mm fruit		The number refers to fruit diameter. 6–8 mm is the beginning of the apple thinning window.
18-mm fruit		By the time the fruits are this size, they are hard to thin and growers use other methods to reduce the crop bearing load.
2.5-cm fruit		By the time the fruit is 2.5 cm in diameter, the final fruit count has been determined. Some growers will thin by hand.
5-cm fruit		
Harvest		Final fruit size is a result of the number of fruit on the tree and the growing conditions that year.

Source: http:/www.ipm.ucdavis.edu.

producers in the region are the Islamic Republic of Iran Islamic Republic (150 000 ha), Turkey (116 500 ha), Pakistan (51 000 ha), Syrian Arab Republic (48 000 ha), Tunisia (34 000 ha), Morocco (26 100 ha), Egypt (26 000 ha) and Lebanon (9 400 ha).

Apple trees produces flowers and fruits from mixed buds, which are usually formed only at the ends of short shoots; an inflorescence contains 5–7 individual flowers. The centre bloom opens first, and later produces the largest fruit. Fruiting begins 3–5 years after budding, although a few fruits may be produced in the second year (this varies with rootstock and cultural practices). Excessive pruning delays fruit set.

Flower fertilization is essential for fruit set although some varieties are self-fruiting (cross-pollination is required). The growth habits of most apple cultivars fall between spur types and those of extensive branching and the formation of shoots.

Dormancy and growth are two major phases in the yearly cycle of a deciduous fruit tree. The tree rests during the dormant period. In the growing season, which begins with bloom, several processes take place: fruit set and development; shoot growth; and bud initiation and differentiation (Table 65).

The optimal economic tree density is 400–500 trees/ha. New apple orchards are developed with vertical conic shaped trees using M.9 rootstock planted 4 m apart and with 5 m between rows. The average yield per tree is about 70 kg.

Trickle irrigation has enabled the successful establishment of high-density orchards in many countries. Sprinkler irrigation has also helped the establishment of new orchards, and it may be used for frost control.

Annual pruning is essential for apple trees; the number and kind of prunings are related to the growth and fruiting habits of the cultivars.

Apple trees set too many fruits, such that they require thinning within 25–30 days of full bloom. Thinning is used to increase fruit size and also to avoid biennial bearing.

TABLE 66

Critical leaf and fruit nutrient concentrations for apple

Nutrient	Unit	Deficient [a]	Normal	Toxicity
Leaf analysis (dry-weight basis)				
Nitrogen	%	< 1.5	1.7–2.5	
Phosphorus	%	< 0.13	0.15–0.3	
Potassium	%	< 1	1.5–2.5	
Calcium	%	< 0.7	1.2–2	
Magnesium	%	< 0.20	0.26–0.36	
Sulphur	%	< 0.1	0.1–0.3	
Manganese	ppm	< 25	25–120	> 120
Iron	ppm	< 45 [b] or > 500	45–500	
Boron	ppm	< 20	20–60	> 70
Copper	ppm	< 5	5–12	
Zinc	ppm	< 14	15–120	130–160
Molybdenum	ppm	< 1.16	0.1–0.2	
Fruit, harvest analysis [c] (fresh weight)				
Nitrogen	mg/100 g		50–70	
Phosphorus	mg/100 g	7–9 [d]	> 11	
Calcium	mg/100 g	< 4	> 5	
Boron	mg/100 g	< 0.8		

[a] Severely deficient leaves can sometimes have unexpectedly higher leaf concentration because Fe is present in inactive form in tissue (precipitate).
[b] = Total leaf iron concentrations not correlated with Fe deficiency.
[c] = Whole-fruit concentrations minus stems and seeds.
[d] = Appropriate for cultivars susceptible to low-temperature breakdown.
Source: Ferree and Warrington, 2003.

Plant analysis data

Leaf nutrient concentration is a good tool for monitoring and adjusting the nutritional status of apple trees, as shown in Table 66.

Fertilization of irrigated apples

Apple trees are fertilized according to the results of soil analysis, tree age and expected yield. For an average yield of 75 kg/tree and a density of about 450 trees/ha, compound fertilizers such as 30–10–10, 17–17–17 and 14–14–28, or similar grades, could be applied in three doses per year (Table 67).

TABLE 67
Fertilization of irrigated apple trees

Tree age (years)	30–10–10 bud-breaking stage (March/April)	17–17–17 early fruit setting (May/June)	14–14–28 during maturity (July/August)
		(kg /tree)	
1	0.1–0.2	–	–
2	0.2–0.3	–	–
3	0.3–0.4	0.3–0.4	0.2–0.3
4	0.4–0.5	0.4–0.5	0.2–0.3
5	0.5–0.7	0.5–0.7	0.3–0.4
6	0.7–1.0	0.7–1.0	0.3–0.4
7	1.0–1.25	1.0–1.25	0.4–0.5
8	1.25–1.50	1.25–1.50	0.5–0.8
9	1.50–2.00	1.50–2.0	0.8–1.0
10+	1.50–2.00	1.50–2.0	0.8–1.0

Composted manure may be applied at a rate of 10–20 kg/tree every other year.

Any Fe and Zn deficiencies should be corrected by applying chelated sources such as Fe-EDDHA (50–100 g/tree), Zn-EDTA (50–100 g/tree), or $ZnSO_4$ (200–300g/tree). Foliar fertilization with solutions containing Fe and Zn is also beneficial.

Calcium deficiency can be corrected by foliar spray of $Ca(NO_3)_2$ solution or by applying $Ca(NO_3)_2$ to the soil (fertigation) at a rate of 200–250 g/tree between bud-breaking stage and early fruit setting.

For rainfed apples, compound fertilizer 20–10–20 or similar may be applied during the rainy season at a rate of 1.5–3.0 kg/tree (for trees aged 5–10 years). Composted manure may also be applied during the winter season at a rate of 15–30 kg/tree.

The above fertilization guidelines are also suitable for irrigated pears.

APRICOT

Crop data

Apricots (*Prunus armeniaca* L.) grow most successfully in a mild Mediterranean climate, with limited risks of spring frost. They require fertile, deep, well-drained loam soil. The soil pH may range from 6 to 8.2.

The total area under apricot in the Near East is 257 000 ha, for a production of some 1.45 million tonnes (FAOSTAT, 2005). The major producers in the region are Turkey (64 000 ha), Algeria (40 000 ha), Islamic Republic of Iran (32 000 ha), Pakistan (29 000 ha), Tunisia (13 000 ha), Syrian Arab Republic (12 600 ha) and Morocco (12 500 ha).

Trees begin fruiting in their second year, but substantial bearing does not begin until 3–5 years. Fruit is borne mostly on short spurs on mature, less vigorous trees. The average yield per tree is about 50–75 kg.

TABLE 68
Leaf nutrient standards for apricot

Nutrient	Concentration range				
	Deficient	Marginal	Adequate	High	Toxic or excessive
N (%)	< 1.7	1.7–2.3	2.4–3.0	3.1–4.0	> 4.0
P (%)	< 0.09	0.09–0.13	0.14–0.25	0.26–0.40	> 0.4
K (%)	< 1.0	1.0–1.9	2.0–3.5	3.6–4.0	> 4.0
Ca (%)	< 1.0	1.0–1.9	2.0–4.0	4.1–4.5	> 4.5
Mg (%)	< 0.2	0.2–0.29	0.3–0.8	0.9–1.1	> 1.1
Na (%)	–	–	< 0.02	0.02–0.5	> 0.5
Cl (%)	–	–	< 0.3	0.3–1.0	> 1.0
Cu (mg/kg)	< 3	3–4	5–16	17–30	> 30
Zn (mg/kg)	< 15	15–19	20–60	61–80	> 80
Mn (mg/kg)	< 20	20–39	40–160	161–400	> 400
Fe (mg/kg)	< 60	60–99	100–250	251–500	> 500
B (mg/kg)	< 15	15–19	20–60	61–80	> 80

Source: Reuter and Robinson, 1986.

Flood and drip irrigation are preferable to sprinkler as they reduce water splash, a common cause of fungal-spore dispersal. Where sprinklers have to be used, the heads should be adjusted to angle water low and away from the trunk.

Thinning is especially important and may be carried out when the fruit reaches 2–2.5 cm in diameter, leaving 5–6 cm between fruits. Very little pruning is usually needed (during spring). It consists of removing dead or diseased wood and any overcrowded branches.

Plant analysis data

Table 68 provides leaf analysis data for apricot.

Fertilization of irrigated apricot

Irrigated stone fruits are fertilized according to the results of soil and tissue analyses. For a density of about 450 trees/ha, compound fertilizers 30–10–10, 14 –14–28 and similar grades may be provided in two applications per year according to tree age (Table 69).

Composted manure may be applied at a rate of 10–20 kg/tree every other year.

Any Fe and Zn deficiencies should be corrected by soil application of chelated sources such as Fe-EDDHA (50–100 g/tree), Zn-EDTA (50–100 g/tree) or $ZnSO_4$ (200–300 g/tree). Foliar fertilization with solutions containing Fe and Zn is also beneficial.

TABLE 69
Fertilization programme for irrigated apricot and stone fruits

Tree age	30–10–10 bud-breaking stage	14–14–28 early fruit setting stage
(years)	(kg/tree)	
1	0.1–0.2	–
2	0.1–0.2	–
3	0.2–0.3	–
4	0.3–0.4	0.2–0.3
5	0.4–0.5	0.2–0.3
6	0.5–0.6	0.2–0.3
7	0.6–0.7	0.4–0.5
8	0.7–0.8	0.4–0.5
9	0.8–0.9	0.4–0.5
10+	0.9–1.0	0.4–0.5

The above fertilization guidelines are suitable for other irrigated stone fruits (e.g. plum and peach).

For rainfed stone fruits, compound fertilizer 20–10–20 or a similar grade may be applied during the rainy season at a rate of 1.0–2.0 kg/tree (for trees ages 5–10 years). Composted manure may also be applied at a rate of 20–30 kg/tree during the winter season.

AVOCADO

Crop data

The avocado pear (*Persea americana Mill.*) is a highly nutritious fruit with a fat content of 20–30 percent and with mineral and protein contents that are higher than other fruits. It is a woody perennial tree that grows successfully on many types of well-drained soils with a pH of 5–8. Only grafted plants should be planted because they bear earlier and more regularly (and also produce better quality fruits) than do seedling trees. Grafted trees are generally more compact and shorter than seedling trees. Two or more varieties of avocado should be planted in order to ensure good pollination.

Avocado is not a significant crop in the Near East region – 1 540 ha in Morocco, 300 ha in Lebanon, and smaller areas in some other countries (FAOSTAT, 2005).

Plant tissue analysis

In the Near East, leaf samples collected in August/September can be used to estimate the amounts of fertilizer needed in the following spring. Where N is found to be more than 2 percent, less N should be applied than in the previous year. Where N is less than 1.6 percent, more N should be applied. With N at 1.6–2 percent, the programme should stay the same (Table 70).

Fertilizer recommendations

Fertilizers should be applied as per the guidelines in Table 71. Fertilizers should be split evenly into four or more applications per year, and be broadcast or applied through fertigation.

Foliar fertilization with solutions containing 0.5 percent N, 0.2 percent Mg, 0.1 percent Zn and 0.1 percent Fe during the fruit-setting stage should help the trees and may often increase yields. Applying urea with the fungicidal sprays (usually used from February to July) has increased the yield of avocado trees in the United States of America.

TABLE 70
Leaf analysis data for avocado (variety Fuerte) in California, USA (optimal levels)

N	P	K	Mg	Ca	S	Fe	Mn	Cu	Zn	B	Mo
(% dry matter)						(mg/kg dry matter)					
1.6–2	0.1–0.3	0.8–2	0.25–0.8	1–3	0.2–0.6	50–200	30–500	5–15	30–150	50–100	0.05–1

Source: Goodall, Embleton and Platt, 1979.

TABLE 71
Fertilizer applications for avocado

Age of tree	N	P_2O_5	K_2O
		(kg/ha)	
Non bearing (Small)	100–125	150–200	100–125
Young (bearing)	150–200	150–200	200–250
Mature (bearing)	200–250	100–125	300–350

Zinc deficiency can occur in the Near East. It causes mottled leaves with light-yellow areas between the veins and abnormal development of the growing shoots; and in severe stages "little leaf" and "rosetting".

Where the results of leaf analysis indicate that Mg, Zn or Fe are low, providing 100–200 g of $MgSO_4.2H_2O$, 50–100 g of Zn-EDTA or 50–100 g Fe-EDDHA per tree, either as soil application or through fertigation, should correct the deficiencies. The application of foliar fertilizer sprays also corrects deficiencies of these nutrients.

BANANA

Crop data

Bananas (*Musa* spp.) are grown in every humid tropical region. A suitable banana climate has a mean temperature 25–28 °C and mean rainfall of 100 mm per month. Irrigation is required in regions where the dry season is two months or longer.

Banana is economically productive in deep, well-drained soils such as loam, marl, red laterite, volcanic ash, sandy clay, and even in heavy clay, but not in coarse sand that does not hold water. Although bananas can grow in soils with a pH of 4.5–8.5, a pH of about 6 may be considered optimal.

The Near East region produces about 1.7 million tonnes of banana, from a total cultivated area of about 84 200 ha (FAOSTAT, 2005). The main producers are Pakistan (33 000 ha), Sudan (2 300 ha), Egypt (21 000 ha), Yemen (11 000), Morocco (5 200 ha), Turkey (3 000), Oman (2 600 ha), Lebanon (2 600 ha) and Jordan (1 800 ha).

Spacing distances for Dwarf Cavendish range from 3 × 1.7 m (2 000 plants/ha) to 4.5 × 3.5 m (600–650 plants/ha). A spacing of 3.5 m between rows and 2.5 m between plants allows 1 150 plants/ha.

The annual yield of banana varies according to many factors such as: soil and agronomic practices, cultivar, spacing, type of propagating material, and the management of sucker succession. For example, Dwarf Cavendish produces no more than 150–200 fruits, while a Giant Cavendish bunch may weigh 50 kg and have a total of 360 marketable fruits (yield ranges from 100–300 tonnes/ha).

Banana plantations are renewed every 3–30 years and, thus, fertilization varies according to region and cropping system.

Plant analysis data

Ta ble 72 lists the nutrient content in banana leaves as an indicator of the nutritional level of the plant.

The required concentrations of nutrients in tissues for high yields are: N at 4 percent; P_2O_5 at 0.5 percent; K_2O at 4 percent; and Mg at 0.3 percent.

TABLE 72
Nutrient contents in the third leaf from top, banana

	N	P	K	Mg	Ca	S
Level	(% dry basis)					
Near maximum	3.4	0.19	3.5	0.25	0.7	0.26
Intermediate (75%)	2.7	0.16	2.8	0.21	0.6	0.20
Low (50%)	2.0	0.14	1.8	0.15	0.5	0.10

Source: Morton, 1987.

TABLE 73
Fertilization programme for irrigated bananas in Lebanon

	17–17–17 (granular)	20–20–20 + TE (soluble)	13–0–45 (soluble)	$MgSO_4.7H_2O$ (soluble)
Month	(kg/ha)			
March	1 000	–	–	–
April	–	200	–	40
May	–	800	200	40
June	–	400	200	80
July	–	400	200	80
August	–	200	200	80
September	–	–	200	80
Total	1 000	2 000	1 000	400
Rate (g/tree)	500	1 000	500	200

Fertilizer recommendations

In Lebanon, for an orchard with density of 2 000 plants/ha, the following rates of nutrients are applied per tree per season: 200–300 g N; 100–200 g P_2O_5; 400–500 g K_2O and 50 g MgO. Table 73 provides the fertilization programme for irrigated bananas in Lebanon.

The granular fertilizer 17–17–17 or similar grades need to be spread around the tree and incorporated in soil. Other fertilizer grades (as in Table 73) are to be applied by fertigation.

CITRUS

Crop data

Most citrus cultivars (*Citrus* spp., etc.) are budded onto rootstock. Table 74 indicates the principal scions and rootstocks.

Orange is one of the major fruit trees grown in the Near East. In 2005, the region had a total area of 539 000 ha, which produced some 8.36 million tonnes (FAOSTAT, 2005). The main producers in the region are Pakistan (130 000 ha), Islamic Republic of Iran (125 000 ha), Egypt (88 000 ha),

TABLE 74
Citrus scions and rootstocks

Scions	Rootstock
Orange (*C. sinensis* Osbeck)	Rangpur lime (*C. limonia* Osbeck)
Mandarin (*C. reticulata* Blanco)	Rough lemon (*C. jambhiri* Lush)
Lemon (*C. limon* [L.] Burm)	Sour orange (*C. aurantium* L.)
Lime (*C. aurantifolia* [Christ.] Swing)	Cleopatra mandarin (*C. reshni* Hort.)
Grapefruit (*C. paradise* Macf.)	Trifoliata (*P. trifoliate* [L.] Raf.)
Pomelo (*C. grandis* [L.] Osbeck)	

Morocco (55 000 ha), Turkey (41 600 ha), Algeria (39 000), Syrian Arab Republic (15 250 ha), Yemen (14 400 ha), Lebanon (10 000 ha) and Tunisia (9 000 ha).

Citrus trees can be grown under diverse climate conditions and in a wide range of soil types (sand to loam to clay), with a pH varying from acidic to alkaline. Soil management is important in order to achieve good productivity.

Citrus fruitful life varies from 15 to 40 years depending on soil type and care. In well-drained sandy soils, trees could live longer than those on loam or clays. The plant density is 300–400 plants/ha with a spacing of about 6 m between rows and 5 m between trees.

Salinity, excess water and lack of water are three common stresses that can affect citrus growth and production. Proper irrigation practices play a major role in reducing these stresses.

Pruning is necessary in order to produce premium fruit and reduce the level of insects and disease. Foliage is removed by hand pruning, skirting or hedging and topping.

Thinning is carried out to improve fruit size. Hand thinning is regarded as the most effective method as chemical thinning may be unreliable.

Plant analysis data

Citrus growers can find out if their trees have the optimal level of nutrients needed to produce heavy crops of good-quality fruit by analysing their citrus leaves. The third and fourth leaf from 5–7-month-old spring-flush, non-fruiting terminals should be selected. About 4–6 leaves from 25 trees are collected in mid-season, with an equal number of leaves from the north and south sides of the trees. Leaf analysis should be carried out for two or more consecutive years in order to establish trends and to enable fine tuning of fertilizer programmes. The data from Riverland and Sunraya (Australia) can be used as guidelines for interpreting the results of analysis of citrus plant tissue in the Near East (Table 75). These data

TABLE 75
Leaf analysis standards for citrus leaves

Nutrient	Deficient	Low	Satisfactory	High	Excess
N (%)	< 2.2	2.2–2.39	2.4–2.69	2.7–3.0	> 3.0
P (%)	< 0.09	0.09–0.13	0.14–0.16	0.17–0.30	> 0.30
K (%)	< 0.4	0.40–0.69	0.70–1.49	1.5–2.0	> 2.0
Ca (%)	< 2.0	2.0–2.9	3.0–5.5	5.6–7.0	> 7.0
Mg (%)	< 0.15	0.15–0.29	0.30–0.69	0.7–1.0	> 1.0
S (%)	< 0.14	0.14–0.19	0.20–0.39	0.40–0.50	> 0.50
Na (%)	–	–	< 0.16	0.16–0.25	> 0.25
Cl (%)	–	–	< 0.30	0.30–0.60	> 0.60
B (ppm)	< 20	20–30	31–l29	130–250	> 250
Zn (ppm)	< 16	16–24	25–60	61–300	> 300
Mn (ppm)	< 16	16–24	25–60	61–300	> 300
Fe (ppm)	< 35	35–49	50–129	130–400	> 400
Cu (ppm)	< 3	3–5	6–15	16–20	> 20
Mo (ppm)	< 0.06	0.06–0.09	0.1–3.0	3.1–100	> 100

Source: SARDI, 2001.

are similar to leaf analysis data in Lebanon and Saudi Arabia.

Fertilization of irrigated citrus

The types and quantities of fertilizers to be applied to citrus trees depend on the age of the trees and the results of tissue and soil analysis. The compound fertilizer grades that are recommended for use are 30–10–10, 20–20–20, 20–10–20 or similar grades Single N, P and K sources may also be used at similar nutrient rates.

TABLE 76
Fertilization of irrigated citrus trees

Tree age (years)	March application 30–10–10	June application 20–20–20	September application 20–10–20
	(g/tree)		
1	50–100	–	–
2	100–200	–	–
3	200–300	100–200	100–200
4	300–400	200–300	200–300
5	400–500	300–400	300–400
6	500–600	300–400	300–400
7	600–700	400–500	400–500
8	700–800	400–500	400–500
9	800–1 000	500–700	500–700
10 +	1 000–1 250	500–1 000	500–1 000

The fertilizers should be applied in three equal doses (March, June and September) according to the schedule indicated in Table 76.

Well-decomposed manure may be applied at a rate of 20–25 kg/tree, every 2–3 years.

Any Fe or Zn deficiency symptoms should be corrected by applying chelated sources of Fe-EDDHA (50–100 g/tree), Zn-EDTA (50–100 g/tree) and $ZnSO_4$ (250–300 g/tree – fertigation). Foliar fertilization with solutions containing Fe and Zn is also beneficial.

DATE-PALM

Crop data

The palm tree (*Phoenix dactylifera* L.) is a typical tree of desert oases. It responds well to high temperature, dry air and it is resistant to salts. It can tolerate up to 3 percent of salt but prefers less saline soils. High salinity reduces the yield. It thrives on any kind of fertile soil. It is sometimes grown as an ornamental plant on account of its slender habit and foliage. In order for its fruits to come to a complete maturity, high temperatures (40 °C) and copious volumes of water are required.

The Near East accounts for more than 88 percent of world date production, about 5.8 million tonnes, produced from a total area of about 1 million ha (FAOSTAT, 2005). The main producers of the region are Egypt (1.17 million tonnes), Saudi Arabia (900 500 tonnes), Islamic Republic of Iran (880 000 tonnes), United Arab Emirates (760 000 tonnes), Pakistan (625 000 tonnes), Algeria (470 000 tonnes), Sudan (330 000 tonnes), Oman (238 000 tonnes), Libyan Arab Jamahiriya (150 000 tonnes), Tunisia (125 000 tonnes), Morocco (69 400 tonnes) and Yemen (33 300 tonnes).

In terms of area, the major countries are the United Arab Emirates (186 000 ha), Islamic Republic of Iran (185 000 ha), Saudi Arabia (145 000 ha), Algeria (135 000 ha), Pakistan (82 000 ha), Morocco (48 000 ha), Tunisia (46 000 ha), Egypt (35 000 ha), Oman (34 000 ha), Libyan Arab Jamahiriya (28 000 ha) and Yemen (23 600 ha).

TABLE 77
Plant analysis data, date-palm

Plant part	N	P	K	Mg	Ca	Na	SiO_2
Leaves (nutrients in leaves)	(% dry basis)						
38–43% dry matter	0.68–1.04	0.08–0.12	2.1–3.9	0.2–0.5	0.2–0.5	0.02–0.1	0.2–0.3
Fruit (in edible portion)							
22.5% dry matter	0.35	0.063	0.65	–	0.059	0.001	–

Source: De Geus, 1967; IFA, 1992.

Plant density under good growth conditions is 100–140 bearing trees/ha. The yield is 30–50 kg of fruit per tree per year in a hot desert area with restricted water supply. However, the yield can reach 100–125 kg/tree under intensive management. Egypt has been reported as achieving about 12 tonnes of dates/ha.

Fruit thinning is necessary because it reduces the size and weight of the fruit bunch, and helps increase the size and quality of fruit. It also ensures full flowering each season.

Irrigation is necessary where rainfall alone is insufficient, e.g. hot places with a high evaporation rate. Where date-palm is grown where the soil and water are saline, irrigation management must always be considered in relation to this problem. Moreover, some added water requirements for the leaching of salts and drainage should be taken in account.

Plant analysis data

Table 77 lists the nutrient content of date-palm leaves and fruits.

Fertilization of irrigated date-palm

Soils in semi-arid areas often contain sufficient amounts of K and P for date-palms. However, some soils may need more available P. Dates respond to N application and to manuring. The quantities of fertilizer to be applied depend on the age of the trees, the results of soil analysis and the expected yield. The recommended compound fertilizer grade is 30–10–10 for soils with sufficient levels of P and K, or 20–10–20 for soils with available K of less than 150 mg/kg and irrigation water of less than 7 mg/litre.

It is advisable to apply fertilizers in two equal applications (March and June) according to the schedule indicated in Table 78.

Well-decomposed manure should be applied at a rate of 30–40 kg/tree, annually or every other year.

TABLE 78
Fertilization schedule for irrigated date-palms

Tree age (years)	Rate from 30–10–10 fertilizer (g/tree)
1	100–200
2	200–300
3	300–400
4	500–600
5	600–700
6	700–800
7	800–900
8	900–1 000
9	1 000–1 250
10+	1 250–1 500

The annual water requirements of dates are high at 20 000–30 000 m^3/ha. Dates are sometimes planted in areas where the roots may reach the groundwater level at a depth of 2–4 m.

A high yield followed by a few years of moderate yields is an indication of nutrient insufficiency.

FIG

Crop data

The fig plant (*Ficus carica* L.) is indigenous to the Islamic Republic of Iran, Syrian Arab Republic and Turkey. The total area of figs in the Near East is about 267 000 ha, for an annual production of 760 000 tonnes (FAOSTAT, 2005). The major fig-growing countries in the region are Turkey (65 000 ha), Algeria (53 000 ha), Islamic Republic of Iran (45 000 ha), Morocco (42 700 ha), Egypt (29 000 ha), Tunisia (15 000 ha), Syrian Arab Republic (10 100 ha), Libyan Arab Jamahiriya (3 000 ha) and Lebanon (2 000 ha).

Ficus carica rarely grows taller than 6 m and it is tolerant to drought and salt. There are two main commercial types of figs. The common fig produces fruit without pollination, while in order to set fruit the Smyrna fig requires pollination by a fig wasp (*Blastophaga* spp.), which lives in the caprifig (male fig). The common fig is the more commonly grown of the two types.

Trees are normally planted 4 m apart with 5–6 m between rows. Fruiting begins after about three years. Pruning may be necessary in order to maintain a balance between new and old wood, as well as to remove suckers and to keep the tree canopy at a reasonable size for easy harvesting.

Plant analysis data

Table 79 gives the nutrient content of the fig leaves and fruits.

Fertilization

Table 80 presents a fertilization schedule for fig trees.

Well-decomposed manure should be applied every other year at the rate of 15–20 kg/tree. Where P and K levels are sufficient in plant tissue, then only N fertilizers need be applied.

TABLE 79
Plant tissue analysis, common fig

Plant part	Nutrient content					
	N	P	K	Mg	Ca	Na
	(% of dry matter)					
Leaves	2.0–2.5	0.1–0.3	1.0–1.6	0.8	3.0–3.6	–
Fruits	0.47	0.057–0.07	0.57–0.68	0.06	0.13–0.17	0.01

Source: IFA, 1992.

TABLE 80
Fertilization schedule for fig trees

Tree age (years)	N	P_2O_5 (g/tree/year)	K_2O
1	–	–	–
2	100	–	–
3	150	30	75
4	200	40	100
5	250	50	125
6	300	60	150
7	350	70	175
8	400	80	200
9	450	90	225
10+	500	100	250

TABLE 81
Total nutrient uptake of grape, yield 20 tonnes/ha

Nutrient	Uptake (kg/ha/year)
N	90
P_2O_5	40
K_2O	150
Ca	150
Mg	15
B	0.2
Cu	0.4
Mn	0.6
Zn	0.5
Fe	1.0

Source: IFA, 1992.

GRAPE

Crop data

Grape (*Vitis vinifera* L.) is the most widely cultivated fruit crop in the world (more than 10 million ha). It grows from temperate to tropical regions, but is planted mainly in areas with temperate climates.

Grapes are grown in almost all the countries in the Near East region, with a total output of 10.2 million tonnes from an area of about 1.324 million ha (FAOSTAT, 2005). The major grape-producing countries in the region are Turkey (530 000 ha), Islamic Republic of Iran (275 000 ha), Algeria (60 000 ha), Morocco (50 000 ha), Syrian Arab Republic (43 000 ha), Tunisia (24 000 ha), Yemen (23 000), Cyprus (17 000 ha), Lebanon (14 000 ha), Pakistan (13 000 ha), Saudi Arabia (8 500 ha) and Libyan Arab Jamahiriya (8 000 ha).

Grapes are a perennial fruit crop. The leaves expand laterally from the shoot and consist of a blade, petiole and a pair of stipules. Rainfed grapes are cultivated at a density of 600–700 vines/ha, yielding about 30 kg/plant. Spacing varies from 1 to 2 m apart according to the expected vine size and vegetative vigour of a particular cultivar.

Pruning during the dormant season is essential to vine production. It consists of removing 70–90 percent of the previous year's vine growth. There are two types of pruning. The first is vine shaping, which aims to arrange vines on the trellis in order to facilitate maximum exposure of the leaves to light and aids in other operations such as disease and insect control. The second is used in crop regulation and controls the size in addition to the quality of the crop.

Plant analysis data

Leaf analysis is preferred to petiole analysis because it provides a better evaluation of all nutrients. Reported values for the total nutrient uptake and removal by grapes vary between varieties, rootstocks, yields, and, possibly, data collection methods.

About 50 percent of the absorbed nutrients are usually returned to the soil by leaves that are reincorporated in the soil. This makes the net removal in the harvested fruits about 50 percent of the values reported in Table 81.

TABLE 82
Fertilization schedule for irrigated grapes

Age of vine	At bud-breaking stage			Early fruit-setting stage
	N	P_2O_5	K_2O	N in vine 5–6 weeks after bud breaking
(years)	(g/vine)			
1	50	50	50	
2	50–100	50	50	
3	100–150	50	50	50–100
4	150–200	50	50	100–150
5	200–250	50–200	50–200	150–200
6	200–250	100–150	100–150	200–250
7	250–300	100–150	100–150	250–300
8	250–300	150–200	150–200	250–300
9	300–350	150–250	150–250	300–350
10+	300–350	200–300	200–300	300–350

In the Near East region, it is estimated that 40–60 percent of plant residues decompose in time to benefit fully the crop of the following year.

Fertilization of irrigated grapes

For fertilization of irrigated grapes, N fertilizers are applied in two or more doses per year: at bud-breaking stage; and at early fruit-setting stage (about 5–6 weeks after bud breaking).

Where fertigation is practised, the same total amounts of fertilizers may be applied in several applications between the bud-breaking stage (spring) and autumn.

Where tissue analysis shows that K is low, 500 g of K_2SO_4 per vine should be applied.

Where leaf analysis shows the P is low, 500 g of TSP or DAP per vine should be applied. Table 82 shows a suitable fertilization programme for irrigated grapes.

Where composted manure is available, it may be applied at a rate of 10–20 kg/vine every other year.

Rainfed grapes are fertilized in the rainy season, before the bud-breaking stage (late February / early March). The application rate is about 50 percent of that for irrigated grapes.

OLIVE

Crop data

Olive (*Olea europaea* L.) is cultivated all around the Mediterranean basin and in similar agro-ecological zones elsewhere. In the Mediterranean basin, it flowers in May and is usually harvested between October and December.

The Near East region accounts for about 43 percent of world olive production (FAOSTAT, 2005). The main producers in the region are Turkey (850 000 tonnes), Tunisia (700 000 tonnes), Syrian Arab Republic (620 000 tonnes), Morocco (450 000 tonnes) and Egypt (310 000 tonnes). In terms of area under olives, the leading countries are Tunisia (1.5 million ha), Turkey (650 000 ha), Syrian Arab Republic (500 000 ha), Morocco (500 000 ha), Libyan Arab Jamahiriya (200 000 ha), Algeria (200 000 ha), Jordan (64 500 ha), Lebanon (58 000 ha), Egypt (49 000 ha), Islamic Republic of Iran (13 000 ha) and Cyprus (8 600 ha).

Olives primarily need a well-drained and aerated soil, but they are frequently grown on poor soils that are more or less unsuitable for other crops.

An olive tree is a perennial evergreen and its leaves live for about three years. The harvested fruits are either consumed after processing as pickles or used for oil extraction. The produce of some varieties is used for both purposes. Planting density varies according to rainfall, variety and cultural practices, ranging from 20 trees/ha (Safax, Tunisia) to 500 trees/ha in intensive and irrigated groves. The most common density in the Mediterranean basin is 250–270 trees/ha.

The yield varies from site to site and from year to year. Biennial bearing is common, especially in semi-arid and unirrigated groves.

Plant analysis data

The value of soil and plant tissue analyses for quantifying the nutrient requirements depends on careful and proper sampling and analysis, in addition to correlating the results with plant response.

The leaves used in foliar diagnosis should be the third or fourth pairs (mature leaves from the middle of the plant in the last flush of growth), taken during the winter.

TABLE 83
Plant tissue analysis of olive trees, macronutrients

	N	P	K	Ca	Mg	S
Range	(% of dry matter)					
Minimum	1.01	0.05	0.22	0.56	0.08	0.02
Mean	1.77	0.12	0.8	1.43	0.16	0.12
Maximum	2.55	0.34	1.65	3.15	0.69	0.28

TABLE 84
Plant tissue analysis of olive trees, micronutrients

	Fe	Cu	Zn	Mo	B
Range	(mg/kg of dry matter)				
Minimum	40	2	4	5	2
Mean	124	9	23	36	12
Maximum	460	78	84	164	25

The optimal levels of nutrients in the leaves collected between 1990 and 2004 in Lebanon were: N, 2–2.5 percent; P, 0.18–0.22 percent; and K, 1–1.5 percent of leaves (dry-matter basis). These values agree with the values reported by Bouat (1968) in France and are a little higher than those for Spain (IFA, 1992). Tables 83 and 84 give the normal ranges found in Mediterranean countries according to Bouat (1968).

TABLE 85
Fertilizer recommendations for olive trees in Morocco

	November			February
	N	P_2O_5	K_2O	N
Type	(g/tree)			
Rainfed	400	350	1 000	700
Irrigated	550	460	1 300	900

Fertilizer recommendations

Table 85 lists the fertilizer recommendations for olive groves in Morocco.

In Lebanon, Bashour (2002) recommended a fertilization programme for rainfed olive groves (Table 86).

Composted manure is applied at a rate of 10–20 kg/tree once every two years.

Where soil and tissue analysis give high values for P and K, then N sources could be used at only 80–100 percent of the recommended rates.

TABLE 86
Fertilizer recommendations for olive trees in Lebanon

Tree age (years)	30–10–10 December	30–10–10 February
	(g/tree)	
1–2	250	250
3–5	500	500
6–8	500–1 000	500–1 000
8–10	1 000–1 250	1 000–1 250
10–15	1 250–2 000	1 250–2 000
15+	2 000–2 500	2 000–2500

WALNUT

Crop data

There are many varieties of walnut (*Juglans regia* L.). They differ in terms of hardness, nut size, and nutshell thickness. They include: *J. regia* (Persian walnut), *J. nigra* (black walnut), *J. cinerea* (butternut), *J. sieboldiana* (Japanese walnut), and *J. cathayensis* (Chinese walnut). The Persian walnut is adapted to the Mediterranean climate (long, warm, dry summer and mild winter). The crop requires irrigation in dry climates and is of significant economic value.

In the Near East region, the total area of walnut is about 156 000 ha, producing some 350 000 tonnes (FAOSTAT, 2005). The main walnut-producing countries are Turkey (70 000 ha), Islamic Republic of Iran (65 000 ha), Egypt (5 000 ha) and Morocco (4 600 ha).

Commercial walnut culture requires: deep fertile soil (pH 6–8); irrigation provisions in semi-arid and warm temperature climate; a minimum temperature above -7 °C in winter; and frost-free spring and fall.

The walnut fruit is a nut, and it is harvested when it is 95 percent hullable. Commercial harvesting starts the third year after grafting, but full maturity is reached after 7–10 years or more.

Standard spacing for the newer cultivars is about 9 × 9 m, close planting is about 7 × 7 m, and hedgerows are about 3.5 × 7 m. The plant density is 120–170 trees/ha, and 550 trees/ha for hedgerow planting.

Plant analysis data

Table 87 provides analytical data for walnut leaves sampled in mid-season.

TABLE 87
Analysis of walnut leaves sampled in mid-season

Macronutrient						Micronutrient			
N	P	K	Mg	Ca	S	Mn	Cu	Zn	B
(% of dry matter)						(mg/kg dry matter)			
2.5–3.5	0.12–0.2	1–1.5	0.3–0.5	1.3–2	0.2–0.3	30–50	5–15	25–40	40–50

Source: IFA, 1992.

Fertilizer recommendations

Once an orchard is established, a regular fertilization programme should be initiated. Each tree in young orchards (3–4 years) should receive about 1 kg of 30–15–15 or 20–10–10 NPK fertilizer. Orchards that are 15–20 years old need 120–150 kg N/ha, 80–100 kg P_2O_5/ha and 80–100 kg K_2O/ha. Fertilizer should be applied to trees in the rainy season (February), as outlined in Table 88.

TABLE 88
Fertilization of walnut trees

Tree age (years)	20–10–10 (g/tree/year)
1	50–100
2	100–200
3	250–400
4	500 – 700
5	800–1 000
6	1 000–1 200
7	1 200–1 500
8	1 500–2 000
9	2 000–2 500
10+	2 500–3 000

Chapter 18
Forage crops

ALFALFA

Proper seeding and stand establishment are extremely important for successful alfalfa (*Medicago sativa*) production. Because alfalfa is grown for at least 2–3 years, it is very important to start the crop with an adequate number of plants per unit area as well as to produce deep-rooted plants. Poor seeding, poor variety, poor inoculation, and poor germination and stand establishment contribute to poor yields in the future. Based on these facts, and in order to ensure high yields of the new alfalfa plantation, maximum attention should be given to the following points.

Seed bed preparation

As the alfalfa seed is small, shallow planting is essential in order to ensure emergence above the soil surface. Therefore, to provide the seed with adequate soil moisture in the upper 2–5 cm of surface soil, the seed bed should be composed of fine and preferably granulated particles. In addition, it should be moist and fairly firm or compact.

To ensure good and rapid emergence of the crop in desert coarse-textured (sandy) soils, the seed bed should be treated as follows:

- The soil surface should be well levelled.
- The soil profile should be wetted to a depth of 1 m.
- Fertilizers should be incorporated in the soil by a shallow disc.
- Compaction of the soil should be done by a suitable packer. It is preferable to do the packing when the soil is slightly moist (and not when it is dry). This practice is essential in order to ensure good seed emergence.

Seeding

The best dates for seeding alfalfa in the Near East are either in October–November or in February. These dates are advanced or delayed depending on the severity of the winter season (March).

Variety

There is limited adaptive research on the use of imported varieties (more resistant to diseases, including viruses) in comparison with the local varieties. CUF–101, Deablo Verdi and a few other imported varieties have performed well in Saudi Arabia and neighbouring Gulf states.

Inoculation

Alfalfa is a legume plant and fixes its own N from the free N of the air only in the presence of specific bacteria of the genus *Rhizobia*. Therefore, in order for the alfalfa plants to fix their own N, the bacteria should be introduced into the soil to come in contact with the roots of the alfalfa plant. The most economical and practical way of introducing the bacteria is through mixing the bacteria inoculum with the seed before planting. A good soil fertility level is required for optimum nodulation. However, high N availability is detrimental to nodulation and N fixation. Moreover, the complete absence of N from the soil will limit plant vigour and total N fixation. Therefore, a low level of N fertilization is usually recommended at planting time, and during the hot summer in desert and dry soils.

Rate of seeding

Only seeds of high quality (high germination and seedling vigour, free of weeds and diseases) inoculated with freshly produced bacteria should be used. The rate of alfalfa seeding may change depending on the type of seeding used (broadcasting or drilling), the type of drill used, and the quality of the seed bed preparation. Seed drills equipped with press wheels contribute to high seed germination, and rapid and uniform seedling emergence. Based on the above-mentioned factors and the quality of the seed bed, seeding rates may vary from 25 to 50 kg of seed per hectare.

However, because alfalfa is a perennial crop and it is established to last for at least three years, and because the number of plants per unit area decreases with age (as a result of disease, competition, etc.), it is advisable to start the alfalfa crop with a relatively high plant population. Therefore, where proper seeding equipment is used on a well-prepared seed bed, a seeding rate of 25–35 kg of seed per hectare is recommended.

Depth of seeding

The depth of seeding is influenced by the quality of the seed bed, method of seeding, and type of seed drill. In addition, soil physical characteristics influence the depth of seeding. A depth of 1 cm is recommended for seeding in heavy soils of fine texture, and one of 2 cm in coarse-textured sandy soils. Seeds may be planted down to 3 cm deep in light soils under limited moisture availability.

Emergence and stand establishment

As reported above, alfalfa seeding should be performed in a field previously wetted to a depth of 1 m or more. Moreover, the soil surface should never be allowed to form a hard crust, as this limits seedling emergence. Therefore, frequent irrigation may be necessary depending on the weather and other environmental factors. Proper and wise management should be able to provide optimal moisture in the soil and at the same time avoid overirrigation, which could harm the germination process and root development.

Fertilizer recommendations

Crop fertilization depends on soil type, soil fertility, water availability and water quality. The following fertilizer recommendations were found to be suitable for coarse-textured, calcareous soils irrigated with water (TDS = 1 000 ppm): 70 kg N/ha, and 200 kg P_2O_5/ha.

The fertilizers were added to the soil before sowing the alfalfa crop as DAP 18–46–0. Additional doses of DAP fertilizer were added every 2–3 cuttings at a rate of 100–150 kg P_2O_5/ha. In fields with modern irrigation systems (sprinklers), it is advisable to split this dose into 2–3 doses (fertigation).

TABLE 89
Water requirements of alfalfa in Saudi Arabia

Month	Irrigation water (mm/day)
January	5–6
February	5–7
March	7–8
April	8–9
May	10–11
June	11–12
July	14–15
August	15–17
September	14–15
October	10–12
November	8–10
December	5–7

The above fertilizer recommendations led to yield levels of 27 tonnes/ha of field-dry alfalfa hay, in 11 cuttings/year.

Irrigation

The water requirement of alfalfa is affected by many factors such as soil type, water quality, and location. As an example, Table 89 provides the irrigation schedule for the same field that produced 27 tonnes/ha of field-dry alfalfa hay in the central region of Saudi Arabia.

FORAGE CORN

Forage corn (*Zea mays* L.) for the production of dry hay or silage has been introduced recently into many countries in the Near East, whereby the entire above-ground plant is harvested at the dough stage to be made into silage or dry hay for animal feed.

Fertilizer recommendations

The nutritional requirement of forage corn is similar to that of maize. The expected yield of dry hay ranges from 5 to 9 tonnes/ha. In the Beqaa Valley, Lebanon, the fertilization rates are:

- Prior to planting:
  - N: 75–100 kg/ha;
  - P_2O_5: 175–200 kg/ha;
  - K_2O: 50–100 kg/ha.
- During the growing season (at plant height of 30 cm):
  - N: 100–125 kg/ha.

In fields irrigated by sprinkler systems, the N dose during the growing season was split into 3–4 doses of 25–30 kg/ha in each application at intervals of about 10 days.

SUDAN GRASS

Sudan grass (*Sorghum vulgare*, var. *sudanese*) endures considerable drought, like all sorghums, and it is sensitive to low temperature. It succeeds in areas where the season is too short to mature sorghum, and in hot desert regions where irrigation is available, such as in the deserts of Saudi Arabia and the neighbouring Gulf states.

Sudan grass is grown on similar lines to sorghum. Planting dates in the Near East region vary from April to July. For hay production, the crop is often drilled in cultivated rows. The germination rate is very often low, but as Sudan grass tillers profusely, it covers the field and compensates for low seed rates. Under humid and irrigated conditions, the seed rate ranges between 25 and 30 kg/ha, while the rate under semi-arid conditions is 15–20 kg/ha.

Sudan grass is cut for hay when the first head appears, being more palatable at this stage than when cut later. Usually, 3–5 cuts are taken during the hot season. For seed production, the first crop is cut early for hay, and the second crop is cut for seed production.

Hybrids of Sudan grass and sorghum are now frequently grown for their higher yields.

Fertilizer recommendations

Like other sorghums, Sudan grass responds to the application of N fertilizers, mainly under irrigated or humid conditions. Little or no benefit from fertilizers is evident in dry regions. On irrigated land, 200–250 kg N/ha plus 70–100 kg P_2O_5/ha and K_2O give a good response in terms of yield. Foliar spraying of Fe-EDTA and Zn-EDTA prevents leaf yellowing in calcareous soils.

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Annex 1
Nutrient ranges in soils

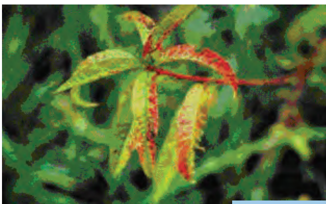
TABLE A1.1
Nutrient ranges in soils

	Very low	Low	Medium	High	Very high
Nutrient			**(mg/kg or ppm)**		
Nitrate	0–5	5–15	15–30	30–40	40+
Phosphorus, Olsen method	0–3	3–8	8–14	4–20	20+
Potassium, KNH_4 OAC extractable	0–85	85–150	150–250	250–450	450+
Magnesium, exchangeable	0–85	85–200	200–300	300–500	500+
Calcium, exchangeable	0–500	500–1 200	1 200–2 500	2 500–3 500	3 500+
Sulphur, water soluble	0–10	10–20	20–35	35–45	45+
Sodium, water soluble	0–300	-	-	-	300+

Annex 2
Visible symptoms of nutrient deficiencies in selected crops

Each nutrient has its own specific role in the plant life cycle. Similarly, each plant nutrient shows some specific symptoms on various parts of the plant – "declaring its deficiency". The following plates were selected (from various sources) in order to highlight particular deficiency symptoms on economically significant crops.

I. NITROGEN DEFICIENCY SYMPTOMS



a. Reddish chlorotic colour on peach leaves (-N)

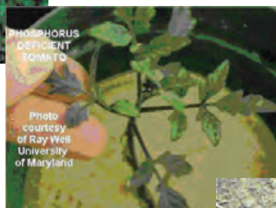
b. Reddish-brown colour on strawberry leaves (-N)

c. Yellowness and death of basal older leaves of sorghum (-N)

d. Complete yellowness of older leaves in tobacco (-N)

II. PHOSPHORUS DEFICIENCY SYMPTOMS

a. Purple colour on pear leaves (-P)



b. Purple bluish colour on tomato leaves (-P)

c. Purple blue colour on corn leaves (-P)

d. Turquoise blue colour on potato leaves (-P)

III. POTASSIUM DEFICIENCY SYMPTOMS

a. Yellow basal leaves in corn (-K)

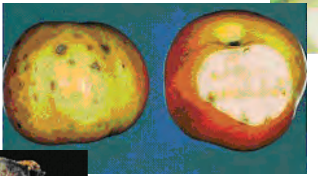
b. Scorched leaf margins in apples(-K) *c. Chlorotic margins in alfalfa leaves (-K)*

d. Scorched leaves of cotton crop (-K)

e. Yellow colour from the midrib of strawberry leaves (-K)

IV. CALCIUM DEFICIENCY SYMPTOMS

a. Blossom end disease (-Ca)



b. Bitter pit on apples (-Ca)

c. Black rings in sugar beet (-Ca)

V. MAGNESIUM DEFICIENCY SYMPTOMS

a. Brown interveinal spots in apple leaves (-Mg)

b. Brown parallel stripes in sorghum leaves (-Mg)

c. Brown and burned interveinal spots on potato leaves (-Mg)

d. Burned margins with green veins in grape leaves (-Mg)

e. Burned interveinal areas in cherry leaves (-Mg)

VI. IRON DEFICIENCY SYMPTOMS

a. Yellow leaves in alfalfa (-Fe)

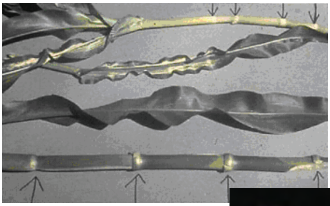
b. Chlorosis in sorghum (-Fe)

c. Chlorotic young leaves in potatoes (-Fe)

d. Interveinal chlorosis in citrus leaves (-Fe)

e. Complete chlorosis on citrus leaves (-Fe)

VII. ZINC DEFICIENCY SYMPTOMS



a. Short internodes on corn stems (-Zn)

b. Rosette shape of apple shoots (-Zn)

c. Unequal halves of potato leaf blades (-Zn)

d. Dark green veins and completely yellow leaf blades in citrus (-Zn)

e. Yellow and curly leaf tips in onion (-Zn)

f. Uneven sized berries in grapes (-Zn)

VIII. BORON DEFICIENCY SYMPTOMS

a. Plumb berry in grapes (-B)

b. Fruit cracking in pears (-B)

c. Green fruits in citrus (-B)

d. Hollow root core in sugar beet (-B)

Annex 3

Optimal levels of nutrient concentrations in leaves of selected crops of the Near East

TABLE A3.1

Fruit trees, macronutrient content

Crop	Yield (tonnes/ha)	N	P	K	Mg	Ca
		(% dry-matter basis)				
Citrus	19–26	2.4–2.6	0.2–0.25	1.2–1.7	0.3–0.5	3.0–4.9
Grape	14–21	2.3–2.7	0.2–0.25	1.3–1.5	0.4–0.55	2.3–2.5
Mango	14–26	1.0–1.5	0.1–02	0.5–2.0	0.2–0.4	3.0–5.0
Banana	10–23	2.7–3.6	0.16–0.27	3.3–5.4	0.7–1.2	0.7–1.2
Olive	8–12	1.5–2.0	0.1–0.3	0.9–1.6	0.2–0.4	1.5–2.5
Pomes *	19–24	2.0–2.7	0.14–0.2	1.2–2.0	0.3–0.5	1.1–2.5
Dates	7–12	0.7–1.2	0.08–0.12	2.1–4.0	0.25–05	0.3–0.46
Stone fruits **	36–48	2.2–3.5	0.14–0.25	1.6–3.0	0.3–0.8	1.5–2.7
Fig	7–11	2.0–2.5	0.1–0.3	1.5–3.0	0.8–1.0	4.5–5.0

* Apple and pear.
** Apricot, peach and plum.

TABLE A3.2

Fruit trees, micronutrient content

Crop	Yield (tonnes/ha)	Fe	Mn	Zn	Cu	B
		(ppm)				
Citrus	19–26	60–120	25–200	25–100	5–16	36–100
Grape	14–21	100–160	35–200	37–100	7–15	30–100
Mango	14–26	70–200	60–500	50–100	70–20	50–100
Banana	10–23	80–360	200–1 000	20–50	6–30	10–25
Olive	8–12	125–460	36–165	25–85	45–80	19–150
Pomes *	19–24	60–300	50–120	30–50	6–20	20–40
Dates	7–12	170–370	55–200	25–60	7–11	
Stone fruits **	36–48	100–250	40–160	20–50	5–16	20–50
Fig	7–11	30–100	20–50	7–20	25–40	

* Apple and pear.
** Apricot, peach and plum.

TABLE A3.3

Vegetable crops, macronutrient content

Crop	Yield (tonnes /ha)	N	P	K	Mg	Ca
		(% dry-matter basis)				
Leafy crops	–	2.8–3	0.4–0.7	2.7–5.9	2.7–5.9	0.4–0.92
Tuber crops	50–71	1.4–8.2	0.16–0.25	0.253.0	0.5- 1.0	1.4–8.2
Flowery crops	37–48	3.5–5	0.14–0.26	2.7–3.9	0.2–0.6	1 –2.9
Bulby crops	50–72	0.1–0.2	0.8–0.2	2.3 –3.3	0.018–0.03	0.1 –0.2

TABLE A3.4
Vegetable crops, micronutrient content

Crops	Yield (tonnes /ha)	Micronutrient content				
		Fe	Mn	Zn	Cu	B
				(ppm)		
Leafy Crops	–	100–291	55–220	29–85	10–16	32–97
Tuber Crops	50–71	99–630	38–243	9–58	4–25	25–75
Flowery Crops	37–48	50–300	50–200	20–200	7–30	25–60
Bulby Crops	50–72	50–100	60–200	25–7 250	5–15	30–100

TABLE A3.5
Other crops, macronutrient content

Crop	Yield (tonnes/ha)	N	P	K	Mg	Ca
				(% dry-matter basis)		
Alfalfa	16	0.3–0.6	0.2–0.4	2–4	0–6	0.15–0.40
Rice	5	2.5–4.0	0.1–0.3	1.0–3.0	1.1–0.3	0.15–0.20
Egyptian clover	16.3	4.4	0.27	3.47	0.36	–
Peanut	3.1	1.3–6.3	0.13–1.02	1–4.9	–	–
Cotton	2.2	3.1	0.17	2.16	0.64	–

TABLE A3.6
Other crops, micronutrient content

Crop	Yield (tonnes/ha)	Fe	Mn	Zn	Cu	B
				(ppm)		
Alfalfa	16	50–200	40–200	20–50	5- 10	5–20
Rice	5	70–250	25–200	15–20	10–25	4–50
Egyptian clover	16.3	313	51	36	15	–
Peanut	3.1	93–105	16–259	16–98	2–28	–
Cotton	2.2	143	43	15	13	–

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Near East
ferilizer-use manual

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