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Abstract: The demands on agriculture to produce food and fibre are driven by the inexorable increases in the world's population. However, advances in agricultural science in the past century have helped food production to keep pace with population growth, thus keeping hunger and malnutrition at bay. The achievements in enhanced agricultural output, especially in the developed world, are attributed to 3 main factors: *expansion of irrigation, development of improved higher-yielding, disease-resistant crop cultivars,* and *chemical fertilizers*. Fertilizers are fundamental to producing more crop output from existing land in cultivation. Along with increased fertilizer use comes greater concern about the environment in view of the potential for pollution arising from excessive and inappropriate nutrient use. The past half century has seen a rapid expansion in the Western world in the use of chemical fertilizers, especially nitrogen (N) and phosphorus (P), and potassium (K) to a lesser extent. These developments are more recent for lesser-developed countries, but have nonetheless stimulated major increases in crop yields, and indeed crop quality. In the West Asia-North Africa (WANA) region, most countries have experienced increases of 10-20-fold in the use of N and P fertilizers in the past 3 decades in both dryland and irrigated agriculture. Viable agricultural production in the Mediterranean region is not possible without chemical fertilizer use. Applied research has shown the benefits of the major nutrients, and their requirements for maximum economic crop production; it also has identified new production constraints, such as micronutrients, for a range of crops, as the yield possibilities are raised by irrigation, improved varieties, and better management. The fact that crops need variable amounts of nutrients and that no one essential nutrient can substitute for another, in addition to the economic and environmental implications of excessive nutrient use, raises the issue of "balanced fertilization". This concept, in essence, implies tailoring individual nutrient needs of crops according to their physiological requirements and expected yields. As fertilizer use is universal and is influenced by soil and climatic factors, in addition to crops, the issue of nutrient balance is particularly relevant. In this presentation, the author briefly examines balanced fertilization in the context of the Middle East region, with particular emphasis on experiences in Syria, which hosts the International Center for Agricultural Research in the Dry Areas. Future challenges for the agricultural research and fertilizer sectors are highlighted in order to most effectively combine efficient crop production with environmental protection.

Key Words: Dryland agriculture, irrigated crop production, cropping intensification, nutrient use efficiency, Middle East region, rational fertilization, fertilizer use

Introduction

Despite the advances that have been made in agricultural production through research and technology transfer in the past half century, many areas of the world still fail to meet the nutritional needs of their people; in some countries the spectre of hunger and malnutrition looms large. The food supply-demand equation is unbalanced by excessive population growth. Many of the world's poorest countries lie in the low rainfall arid to semi-arid regions. As we ponder the question of how mankind can adequately feed and clothe today's world population of over 6 billion people, with the likelihood that this figure will increase further to 10 billion, given burgeoning populations in several developing countries, it is heartening to reflect on the optimism expressed by Norman Borlaug, the father of the "Green Revolution" that staved off hunger and malnutrition through improvements in rice and wheat production technologies, especially in Asia. In his view (Borlaug, 2003) "The world has the technology to feed 10 billion people. Improvements in crop production can be made in tillage, water use, fertilization, weed and pest control, and harvesting. Both conventional breeding and biotechnology will be needed".

In a previous thought-provoking article based on his keynote lecture at the World Soil Congress in Acapulco

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(Borlaug and Dowswell, 1994), the Nobel Laureate singled out commercial chemical fertilizer as a key element in providing the food and feed needs of our planet, citing the spectacular achievements that had been made in agriculture in India and China, countries that in the past were plagued by famine and malnutrition. If low-income, food-deficit nations are to be able to feed themselves, Borlaug estimated that chemical fertilizer would have to increase several fold in the coming decades. Linking agriculture to the broader world scene, Borlaug stated that "For those of us on that food production front, let us remember that world peace will not be built on empty stomachs and human misery. Deny the small-scale, resource-poor farmers of the developing world access to modern production factors—improved varieties, fertilizers, and crop production chemicals—and the world will be doomed, not from poisoning, as some say, but from starvation and political chaos. Given the erroneous public perception that organic nutrient sources could replace chemical fertilizers, Borlaug cautioned that replacing chemical fertilizers would have immediate and drastic consequences on world food output with an even greater increase in food prices, which would put it out of the reach of many.

Given these sobering facts, it was hardly any surprise that a recent analysis of fertilizer use concluded that *at least 50% of crop yields are attributable to commercial fertilizer nutrient* use. The remaining crop nutrients come from organic sources, native soil reserves, and biological nitrogen fixation (Stewart et al., 2005). As future increases in crop production will have to come from higher yields from land already in production, *the contribution of added fertilizer nutrients is going to be proportionally greater in the future*. This scenario underlines the need for emphasizing efficient fertilizer use in order to produce an adequate and quality food supply based on increasing input and energy costs, bearing in mind environmental implications of excessive or inappropriate fertilizer use, especially N and P, the 2 main fertilizer nutrients required by crops.

Despite the global resources available to produce food and fibre, great geographical disparities exist in terms of societal wealth, access to food and medicine, and general wellbeing and living standards. In many ways, the disparities between rich and poor were never greater. While considerable strides have been made in Asia in bringing living standards up to those in the developed countries of the West, some areas of the world, notably Africa, lag far behind. Indeed, in some African countries, per capita food production is less than it was decades ago (Borlaug, 2003). While there are many historical, cultural, and economic factors associated with such poverty, climatic and associated biophysical factors are invariably major constraints in Africa, as they are in after developing regions of the world.

One such region is West Asia and North Africa, or WANA as it is commonly referred to (Ryan et al., 2006). The region today is generally a food-deficit one, with only a few countries approaching anywhere near self-sufficiency, e.g., Turkey and Syria. Adverse climatic conditions and a host of other socio-economic, political, and biophysical factors plague agriculture in the region (Kassam, 1981). Today's conditions are ironic in view of the fact that the region is the centre-of-origin of many of the world's crops, e.g., cereals, pulses, and nuts, and where settled agriculture and civilization as we know it began (Damania et al., 1998).

Despite the advances that have taken place in the region's agriculture, population growth in most countries of the region has outpaced its capacity to produce food. Recognition of the urgent needs of the region to accommodate demographic changes has underpinned efforts by the various national governments to give impetus to the region's agricultural development through applied research (Rao and Ryan, 2004). The establishment of the International Center for Agricultural Research in the Dry Areas (ICARDA) in Aleppo, Syria, in 1977 was a milestone in this endeavour.

As an introduction to the topic of balanced fertilization in the WANA region, it is pertinent to describe briefly the general agricultural sector of the region along with the climate and soil resources that dictate the region's particular farming systems. Subsequently, a brief discussion hinges around ICARDA's efforts in agricultural research, particularly in dryland agriculture, in collaboration with the national agricultural research and development programmes of the various governments of the WANA mandate region. This then leads to the central issue of the paper: the concept of balanced fertilization and fertilizer use trends in some countries of the region and implications for balanced crop nutrition, culminating in ways to achieve fertilizer use efficiency through balanced fertilization in the interest of economic and environmental protection. The paper is a modified version of that presented at a Workshop on Balanced Fertilization (Feb. 8, 2007) at The 13th International Annual Fertilizers Forum (Sponsored by The Arab Fertilizer Association (at Sharm El-Sheikh, Egypt, and which was published online (http://www.ipipotash.org/udocs/Ryan_IPI_AFA_IMPHOS_PROCEEDING.pdf or http://www.ipipotash.org).

West Asia-North Africa

This vast region of the world surrounding the Mediterranean Sea (Figure 1) exhibits great diversity in its landscapes, climate, natural resources, and its people, but it has many common features, notably low rainfall and a dry climate (Kassam, 1981), in addition to high population growth rates and poorly developed agriculture and rural infrastructure.

The Agricultural Sector

Agriculture in WANA is largely subsistence farming, and rainfed production is low; it is labour-intensive with relatively low inputs to new technology (Gibbon, 1981); however, there has been a rapid increase in fertilizer use in the past 3 decades, albeit from a very low base. The farm holdings are small, often only a few hectares, and frequently in fragmented parcels (Shroyer et al., 1990). Effective change in land management is not always promoted by traditional inheritance laws, tribal and common lands, and nomadism. Most farmers have little formal education. Support services are less than satisfactory for most rural communities, i.e. limited credit, poor roads and distribution systems, weak marketing and research and structures, and, in most cases, ineffective extension services. The private commercial sector is poorly developed in most countries (Ryan, 2002). Such socio-economic constraints are often as insurmountable as the biophysical ones, but an understanding of the social context in which farmers operate is essential to exploiting the region's natural resources and improving people's lives. In contrast to many other areas of the world, the Mediterranean region has limited land area for agricultural production, with most of the area being too dry for cropping, with limited possibilities for increasing the area of land for cultivation (Figure 2). Increased productivity must largely depend on increased output from land already in cultivation and/or increased cropping intensity.

Climate

The WANA region is mainly characterized by a Mediterranean climate, with cool to cold, wet winters and warm to hot, arid summers merging into a continental one inland (Kassam, 1981). Rainfall, though generally low (200-600 mm), is highly variable in space and time, with extremes in desert areas and high mountains. Snow is common in high plateaus and mountainous areas, often lasting for several months of winter and early spring, as in Turkey and Iran. The winter rains normally commence in mid September to early October, reach a peak in January-February, and fall off rapidly in April (Harris, 1995). A typical seasonal rainfall distribution is illustrated for the area of northern Syria, which has an average

Figure 1. The Mediterranean region in a broad geographical context.

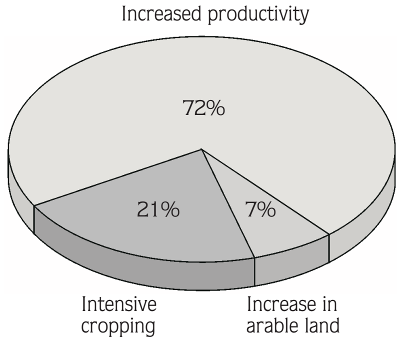

Figure 2. Options for increasing crop production in the West Asia-North Africa region.

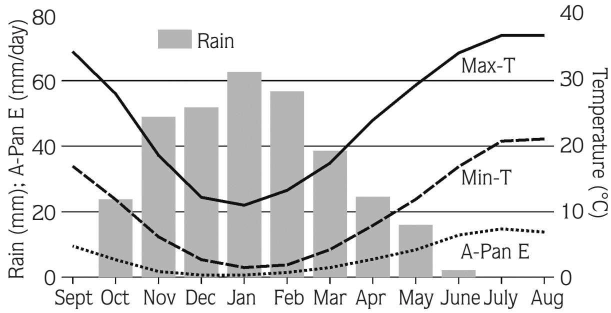

Figure 3. Typical weather conditions for the Mediterranean climate.

rainfall of 340 mm per year (Figure 3). Severe droughts that result in partial or complete crop failure are common. Topography and maritime conditions similarly influence temperatures, especially in winter (Harris, 1995).

Rainfall and temperatures dictate evapo-transpiration, which, in turn, influences crop water use. Both climatic variables dictate the extent to which rainfed cropping is possible for the region. Crops depend on stored soil water to complete their life cycle, and invariably suffer some degree of moisture stress during the grain-filling stage. In arid areas, where cropping is only possible with irrigation, or in low rainfall areas, where supplemental irrigation in increasing in normal rainfed areas where water sources are available (Oweis et al., 1998), the question of sustainability ultimately arises with declining water tables.

Soil Resources

While the agriculture of the Middle East region is dominated by climate, specifically limited rainfall, the quality of the region's soils is also crucial. The soil resources of the region are as variable as in other parts of the world, reflecting variation in climate and topography. While broad soil variation can be expected as a result of wide climatic variation in Syria (Ryan et al., 1997), a diversity of soils can occur over a small range. Although soils of rainfed regions in general are not as intensively studied as in temperate areas, reviews of such areas permit some broad generalization about dryland areas such as the Mediterranean. According to Matar et al. (1992), such soils range in texture from sands to clays; most are shallow and have serious inherent or external drawbacks. Limitation on depth, in turn, limits the water-holding capacity of the soil—a major factor—since with infrequent rains most rainfed crops survive on residual soil moisture. While deep clay soils are inherently productive, shallow soils are particularly vulnerable to soil erosion.

Dryland soils are usually low in organic matter (OM), which, in turn, limits soil structure and chemical fertility. Arid soils usually contain from 0.1% to 1% OM, while semiarid soils range from 1% to 3%. OM serves as a nutrient reserve, particularly for N, and P to a lesser extent, and is critical to maintaining soil aggregate stability (Masri and Ryan, 2006). With cultivation and intensification of agriculture, declines in OM invariably occur. As a consequence, P behaviour in dryland soils is dominated by inorganic soil compounds. As most dryland soils are calcareous, solubility relationships dictated by high pH and $CaCO_3$ combine to reduce available P in soils. As a result, most dryland soils that have not been fertilized are P-deficient (Matar et al., 1992).

Thus, inherent soil properties dictate nutrient behaviour and fertilizer use; as a consequence, N is invariably deficient (Ryan and Matar, 1992; Ryan, 1997). Prior to the advent of commercial fertilization, P deficiency was also widespread (Matar et al., 1992). These deficiencies reflected many centuries of exhaustive cropping, with little or no return of nutrients, since crop residues were usually grazed bare. While K is rarely deficient in the soils of Mediterranean region—a result of the parent materials and the low weathering intensity—increasingly there is evidence of other nutrient stresses being locally important, e.g., zinc deficiency (Materon and Ryan, 1995), and boron (B) toxicity (Yau et al., 1995).

The Soil Test Calibration Network, involving ICARDA and the national research systems (e.g., Turkey, Morocco, and Tunisia), did much to stimulate awareness of potential value of soil testing as a basis for fertilizer recommendations (Ryan and Matar, 1990, 1992) and to improve the performance standards in laboratories that conduct those tests (Ryan and Garabet, 1994). However, despite such developments, the impact at farm level is still far from satisfactory in terms of yield increases.

Farming Systems: Traditional and Current

The region's agriculture spans the range of arid deserts, native pastures and steppe, barley and wheat-based systems to favourable rainfall areas where a wide range of crops can be grown (Figure 4). While agriculture still has much of a traditional character that has evolved over the centuries (Gibbon, 1981; Cooper et al., 1987), immense changes have occurred in the past few decades, which have witnessed increased use of chemical inputs, i.e. fertilizers and, to a lesser extent, pesticides (Ryan, 2002). Although dryland farming dominates the WANA region, and will continue to do so, supplementary irrigation is being increasingly introduced in order to stabilize rainfed yields in areas where groundwater or surface water sources can be tapped (Oweis et al., 1998). In the arid zones of WANA, e.g., Egypt Nile Valley and the Tigris-Euphrates system in Iraq, cropping is totally dependent on irrigation. Developments such as the Atatürk Dam on the Euphrates will inevitably expand irrigation in former dryland areas of south-eastern Turkey. Similar developments, though on a smaller scale, occur elsewhere.

Dryland cropping in most cultivated areas with winter rainfall is dominated by cereals (Cooper et al., 1987), i.e. wheat (*Triticum* spp.) and barley (*Hordeum vulgare* L.). Cereal production and livestock are combined enterprises within the typical farming system. The relative importance of bread wheat (*T. aestivum* L.) and durum wheat (*T. turgidum* var *durum* L.) depends on rainfall and the particular country; bread wheat tends to occupy the more favourable rainfall areas. In general, barley and triticale (*Secale cereale*) are grown mainly in North Africa. A close relationship exists between crop yields in general and rainfall, the effectiveness of which is modified by the soil's water storage capacity and the evapo-transpiration rate.

Associated with cereal production are food legumes, i.e. chickpea (*Cicer arietinum*), lentil (*Lens culinaris*), faba bean (*Vicia faba*), and peas (*Pisum sativus*). Forage legumes are also common, i.e. vetch for hay and medic (*Medicago* spp.) for grazing. Oilseed crops such as sunflower (*Helianthus annuus*), safflower (*Carthamus tinctorius*), and rape (*Brassica rapa)* are of minor importance. As all rainfed crops in the WANA region are invariably limited by drought to some degree in most years (Pala et al., 2004), the cropping "strategy" that has evolved to mitigate this constraint is the use of rotations, i.e. growing of crops in a particular sequence.

ICARDA's Applied Agricultural Research

As the international agricultural research centre for the WANA region, the International Center for Agricultural Research in the Dry Areas (ICARDA) was

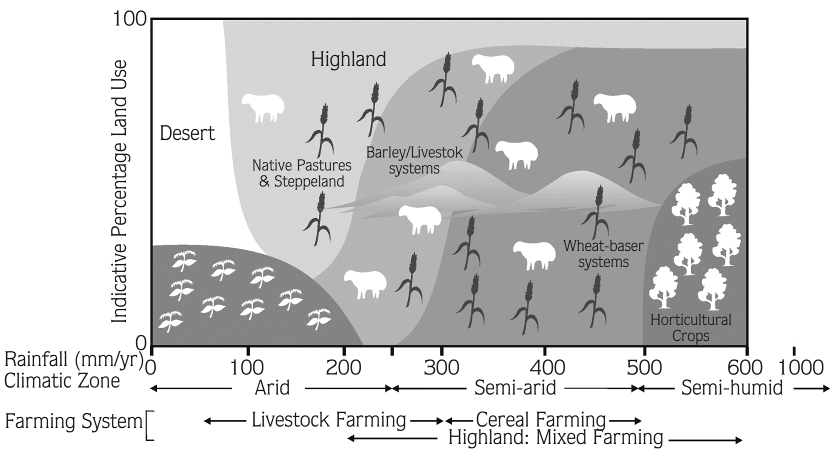

Figure 4. Schematic representation of the farming systems in the West Asia-North Africa region.

established in Aleppo in 1977, Syria, primarily to address dryland agriculture in the WANA region; it later embraced the newly independent countries in Central Asia. Its mission is to improve the livelihood of the region's poor though agricultural research, while preserving biodiversity and protecting the environment. The Center's research evolved with changes in its mandate environment, with a gradual shift towards irrigated agriculture and biotechnology. Currently, it has a global mandate for research on barley, lentil, faba bean, and water-use efficiency, and a regional mandate for chickpea, durum wheat, bread wheat, forage legumes, and rangeland and small ruminant nutrition. Most of the Center's research and development hinge around 3 main areas: *natural resource management, crop genetic improvement, and institutions and policy*.

Soils and soil fertility have played a major role in ICARDA's research (Ryan, 2004). Initial effort focused on identification of nutrient constraints in the field, mainly N and P (Cooper et al., 1987), as well as assessing crop growth responses in a range of rainfall and soil environments (Harmsen, 1984). Factors that dictate nutrient use efficiency in terms of crop management and fertilizer application were identified and quantified (Ryan, 1997, 2002). These studies showed that band application of P fertilizer was more efficient than broadcasting (Matar et al., 1992) and that moderate losses in terms of ammonia volatilization, and thus fertilizer use efficiency, can occur when urea is broadcasted (Abdel Monem, 1986). The field crop nutrition/soil fertility programme was supported by laboratory and greenhouse studies of nutrient interactions with soils and water. Later, the emphasis shifted to micronutrients such as zinc deficiency (Materon and Ryan, 1995) and boron toxicity (Yau et al., 1995), and organic matter (Ryan, 1998) as an index of soil quality, with implications for cropping systems on carbon sequestration in relation to greenhouse gasses and climate change.

Individual field-response trials gradually gave way to a series of long-term rotation trials that evaluated fertilization and nutrient dynamics within a cropping system (Harris, 1995; Ryan and Abdel Monem, 1998). Multi-year studies in Turkey (Ibrikci et al., 2005) and in Syria (Ryan et al., 2008) showed the extent to which P can build up in the soil and provide a residual effect for subsequent crops. A major effort involved a region-wide programme designed to provide a rationale basis for fertilizer use in the field, i.e. soil test correlation and calibration (Ryan and Matar, 1990, 1992; Ryan, 1997). These extensive studies sought to improve quality analytical control and laboratory efficiency (Ryan and Garabet, 1994; Ryan et al., 1999).

A number of clear, but simple, concepts emerged from ICARDA's soil fertility research work (Ryan, 2004). The well-known Liebig's "Law of the Minimum" was implicitly demonstrated; if one element such as P was deficient, adding another such as N has little or no effect. Crop responses in the field increased as limiting element or factors were supplied. Crop response patterns clearly showed that fertilization has a major effect if a nutrient is deficient in the soil, and thus the economic value of fertilizer use was related to the degree of efficiency. Indeed, adding too much fertilizer could have negative effects on crop yields. While these concepts were well known in the literature it was important to apply them in specific conditions of the Middle East region.

Balanced Fertilization

As a background to "*balanced fertilization*" in the overall context of efficient nutrient use from fertilizers and soil, it is pertinent to make a brief examination of fertilizer use in the past 50 years, or the era of chemical fertilization. Globally, fertilizer use patterns vary between developed and developing countries (Figure 5). Total fertilizer consumption has remained static in the past 2 decades or so, and in fact has declined in "developed" and "transition" economies; the only increase has been in developing countries (IFA, 2006). Similarly, only N use increased in this period, with actual declines in P and K consumption. In the longer term, growth in total consumption is estimated to be 2.2% per annum in developing countries, but only 0.2% in developed countries.

Data from Syria, Morocco, Turkey, and Egypt reveal broad similarities in fertilizer use trends, but of differing magnitude (Figure 6). Prior to 1970, little fertilizer was used in these countries. This was followed by a rapid increase in use of N and P, with limited amounts of K. Except in the case of Egypt, N use doubled that of P. While N and P use seem to be stable in the last decade, the increase was continuous for Egypt. Various circumstances such as internal production, importation, and marketing can influence the amount of fertilizer nutrients used in any one year.

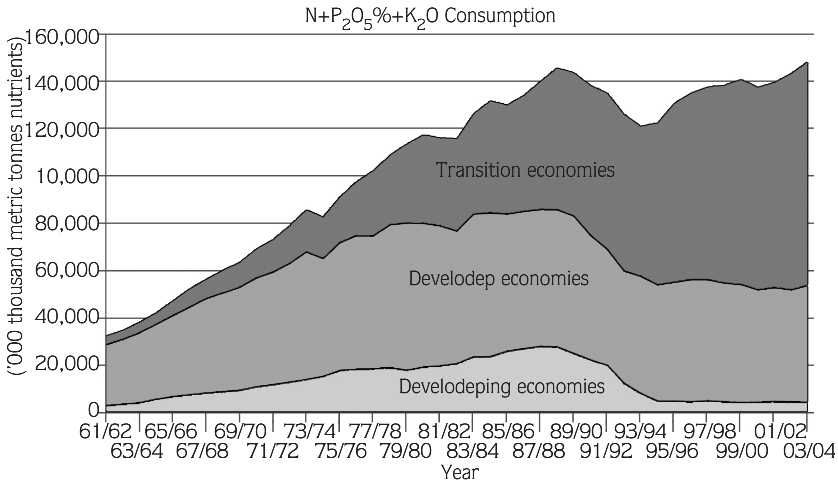

Figure 5. Total fertilizer nutrient use according to country-category economies (IFA, 2006).

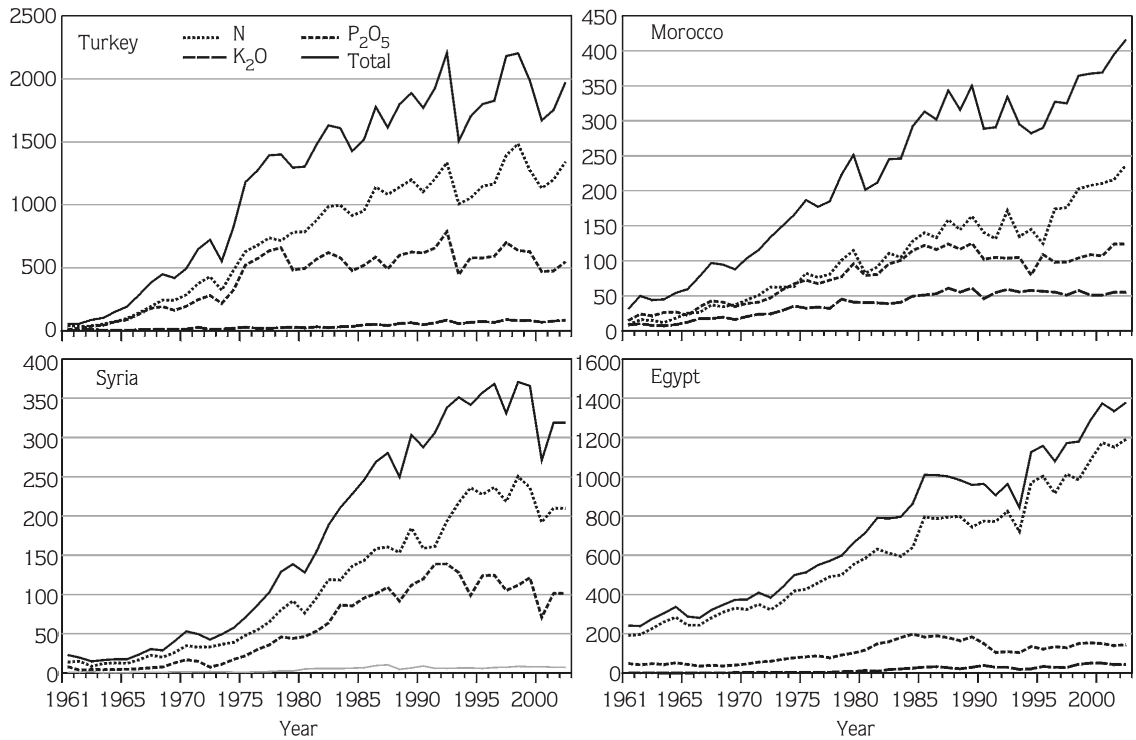

Figure 6. Pattern of fertilizer nutrient use in the past 4 decades in selected countries of the WANA region (IFA, 2006).

The variability in N and P use in the region, and the minimal amounts of K use, inevitably raise the issue of how appropriate are the ratios of nutrients applied to satisfy the specific crop's needs. As N is needed in greater quantities than other nutrients, the proportions of P and K are less than that of N (Table). For instance, ratios of applied NPK are 1.0, 0.30, and 0.30 in the UK and 1.0, 0.38, and 0.44 in the USA. Corresponding nutrient ratios are 1.0, 0.14, and 0.02 in Egypt; 1.0, 2.0, and 0.50 in Jordan; 1.0, 0.41, and 0.06 in Turkey; and 1.0, 0.83, Table. Fertilizer nutrient use (1000 tonnes) and ratios in some developed countries and the West Asia-North Africa region.

Consumption 2003/04	Nitrogen	Phosphorus	Potassium	NPK Ratio				
China	24,745.0	9827.0	4663.0	1.0	:	0.40	:	0.19
United States	11,882.0	4364.4	4988.0	1.0	:	0.37	:	0.42
Pakistan	2527.0	637.7	27.7	1.0	:	0.25	:	0.01
Cyprus	8.1	4.2	3.1	1.0	:	0.52	:	0.38
Turkey	1340.8	547.5	83.7	1.0	:	0.41	:	0.06
Egypt	1190.8	143.9	43.3	1.0	:	0.12	:	0.04
Iran	822.0	354.6	139.5	1.0	:	0.43	:	0.17
Morocco	237.0	124.0	55.0	1.0	:	0.52	:	0.23
Saudi Arabia	224.3	132.2	9.0	1.0	:	0.59	:	0.04
Syria	210.0	101.5	7.3	1.0	:	0.48	:	0.03
Iraq	83.2	106.8	0.7	1.0	:	1.28	:	0.01
Tunisia	56.0	41.0	5.0	1.0	:	0.73	:	0.09
Algeria	48.0	28.0	22.0	1.0	:	0.58	:	0.46
Libya	33.8	52.5	5.0	1.0	:	1.55	:	0.15
Sudan	41.9	1.8	2.7	1.0	:	0.04	:	0.06
Lebanon	22.1	10.0	8.8	1.0	:	0.45	:	0.40
Jordan	17.3	10.5	9.0	1.0	:	0.61	:	0.52
Uzbekistan	579.6	122.0	15.0	1.0	:	0.21	:	0.03
Turkmenistan	97.9	-	14.0	1.0	:	0.00	:	0.14
Kazakhstan	50.0	12.0	2.1	1.0	:	0.24	:	0.04
Tajikistan	26.0	-	-	1.0	:	0.00	:	0.00
Afghanistan	20.8	-	-	1.0	:	0.00	:	0.00
Azerbaijan	16.6	-	-	1.0	:	0.00	:	0.00
Kyrgyzstan	7.0	0.2	-	1.0	:	0.03	:	0.00

and 0.06 in Tunisia. Theoretically, the nutrient needs of any crop are dependent on the crop species and the actual yields. The nutrients that do not come from the soil have to be supplied in fertilizer form, allowing for losses that inevitably occur. These discrepancies at least suggest that there is an imbalance with respect to the fertilizer nutrients applied in many countries of the WANA region.

Despite the fact that balanced fertilization has gained considerable currency in the literature, the concept is an old one dating back to the 1840s and Liebig, who expanded on “limiting nutrients” in his famous “Law of the Minimum”. He erroneously implied that it was only necessary to replace nutrients in the exact amounts removed by the crop. The ideas developed by Liebig evolved to 2 varying definitions of balanced fertilization (Johnston, 1997a); one definition sees balanced nutrition as supplementation of nutrients so that they are in the correct physiological ratios for optimum growth of specific crops, while the other sees it as ensuring that the amounts of nutrient added do not exceed what the crop removes.

In a recent overview of optimizing plant nutrition for food security, Roy et al. (2006) expanded on *balanced fertilization*, which, in turn, creates *balanced plant nutrition*. Some of the points made are worthy of listing:

1. On many soils, application of N without addition of P and K made little sense.
2. Given the costs of crop production and the range of nutrients that can limit yields, fertilization with N, P, and K is counter-productive unless nutrients such as S, Zn, and B are also applied if they are deficient in the soil.
3. *Balanced fertilization* is the deliberate application of all nutrients that the soil cannot supply in adequate amounts for optimum crop yields.
4. There is no fixed recipe for balanced fertilization; it is soil and crop specific.
5. Any deficiency of one nutrient will severely limit the efficiency of others.
6. Imbalanced nutrition results in "mining" of soil nutrient reserves.
7. Luxury consumption is often a consequence of nutrients supplied in excess.
8. Imbalanced fertilization is *inefficient*, *uneconomic*, and *wasteful*.
9. Balanced fertilization depends on soil test values and crop removal.
10. If a soil is rich in one nutrient, fertilization should be directed towards the deficient nutrients or those in least supply.
11. Crop nutrient requirements are related to yield level.
12. Fertilization with time can cause a build-up of P and K, thus reducing their fertilizer requirements.
13. The concept of balanced fertilization has expanded to integrated plant nutrition, embracing *all* sources of nutrients.
14. Integrated plant nutrition seeks to improve nutrient-use efficiency, build up nutrient stocks in the soil, and to limit losses to the environment.

While much of the fertility research in the WANA region was at the level of individual nutrient deficiencies—and using fertilizer to overcome them—the concept of "balanced nutrition" was also in evidence. Indeed, a symposium in Bornova, Turkey, addressed the very issue "Food security in the WANA region: The essential need for balanced fertilization" (Johnston, 1997b). Although the meeting focused mainly on potassium, the need to recognize the implications of a build-up in P and K in the soil for nutrient ratios and budgets was recognized. The need to apply sound scientific principles to ensure *environmentally benign integrated plant nutrient management* was stressed.

Strategies for Balanced Fertilization

Both the soil itself and the growing crop can provide the basis for balanced fertilization and consequently balanced nutrition. The main approach is through soil analysis (Ryan and Matar, 1990, 1992). In essence, this involves the development and selection of appropriate tests (extractants and associated procedures) that established a relationship between the soil test value and plant uptake of the nutrient in question, i.e. *correlation*. The second phase of testing involves *calibration* or developing guidelines for fertilizer recommendations in the field; in this way, "*critical*" levels can be established below which a nutrient level is deficient, with the probability of a response to fertilizer, and a point beyond which there is no need to apply fertilizer. Other factors such as soil type, soil moisture or rainfall, and nutrient spatial variability have to be considered in practical field situations (Ryan, 2004).

A second but less reliable approach to assessing fertilizer needs involves the crop itself; in case of severe deficiency, plant symptoms can indicate the deficiency, but other factors such as drought or disease can mask the symptoms. Analysis of the plant tissue itself is more reliable for a particular nutrient. Excellent guidelines have been developed for sampling, handling, and analysing the tissues, along with criteria for deficiency to adequacy (Ryan et al., 1999). Quick tests designed to give results in the field without delay are based on qualitative nutrient determination in the expressed fresh plant sap. Similarly, colour meters are another cheap and easy way to quantify the need for N in a growing crop in the field based on the green colour intensity of the leaves.

While these approaches to assessing soil fertility are commonplace in developed countries, they are less frequently used in developing countries, and in some countries not at all. The major obstacles to such approaches include a *weak extension sector*, the absence of laboratory facilities for such analysis, and limited applied on farm research related to soil fertility and fertilizer use. Nevertheless, much has been done through the regional soil Test Calibration Programme to promote the awareness of the basic element in the agriculture of WANA, particularly with soil analysis (Ryan and Matar, 1990, 1992; Ryan, 1997). The likelihood is that soil analysis will be adopted as a tool in fertility-crop nutrient management and will be more widely accepted in view of increasing crop intensification, especially with irrigation, and the increasing use of farm chemicals. However, Middle Eastern farming is—and will remain—a long way from a situation where nutrient application is tailored to each crop and farm holding. Nevertheless, despite institutional constraints, the winds of change will affect the Mediterranean region. With pressure on land use, cropping intensity in the region will inevitably increase with fertilizers having a major influence.

The Challenge Ahead

In theory, balanced fertilization leading to balanced crop nutrition cannot be argued with. In its broadest interpretation, it is linked to concepts of fertilizer-use efficiency and efficient nutrient management. However, many of the necessary conditions for balanced fertilization do not exist in developing countries. The WANA region is one such area of the world. Nevertheless, science has inexorably moved agriculture forward in the past few decades, especially with the widespread adoption of chemical fertilizers in both irrigated and rainfed cropping conditions. As developments have taken place in fertilizer application that promote fertilizer use efficiency, it is inevitable that current thinking on fertilizer best management practices will impinge to varying degrees on the agriculture of the Mediterranean region.

The research that has taken place has clearly shows the value of chemical fertilizer nutrient application, particularly N and P, in terms of crop quality, economics, and environment. Similarly, micronutrient deficiencies were also shown to be serious constraints in addition to the major elements, and as was clear from the recent “Zinc Crops 2007” meeting in İstanbul, the importance of elements such as Zn is now widely appreciated, largely as a result of the work of Professor Çakmak and colleagues in central Anatolia. Consequently, the concept of balanced fertilization has to extend beyond NPK to micronutrients. In that context, the significance of soil OM is likely to increase in terms of soil quality, resource sustainability, environmental protection, and carbon sequestration to mitigate the effects of carbon dioxide on climate change. In short, fertilizer use has implications beyond the farmer’s field.

While new farming conditions such as conservation or no-till cultivation (Pala et al., 2000), crop rotations (Harris, 1995), and fertigation (Ryan, 2000) will pose new challenges to balanced efficient nutrient use, the issue is to apply at farm level what is already known. What is needed at government level is adoption of policies that guarantee the timely and economical availability of fertilizers, and the necessary support services that backstop modern agriculture; this includes increasing technical education for farmers and the rural community, including personnel from the fertilizer industry.

A key prerequisite is the provision of laboratories to perform soil, plant, fertilizer, and water analysis; efforts should be made to involve the private sector in such ventures. In order to provide an economic outlet for food supplies generated by increased fertilizer use and irrigation, there is an urgent need to develop markets and improve transportation and overall rural infrastructure.

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