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***Balanced Fertilization in the Mediterranean Region: A Perspective from the International Center for Agricultural Research in the Dry Areas***

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Balanced Fertilization in the Mediterranean Region: A Perspective from the International Center for Agricultural Research in the Dry Areas

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## ABSTRACT

In the past century, there has been a dramatic increase in the world's population, now over 6 billion people. Notwithstanding the fact that poverty, malnutrition still affect many, especially in developing countries, the world has been able to sustain its population by advances in agricultural sciences that have enabled more food to be produced, and medical sciences that have enabled people to live longer and healthier lives. The achievements in enhanced agricultural output at the global level, especially in the developed world, are attributed to three main factors: *expansion of irrigation, development of improved higher-yielding, disease -resistant crop cultivars,* and *chemical fertilizers*.

It is estimated by Nobel Laureate and "Father of the Green Revolution", Norman Borlaug, that *over half of the world's crop output is attributed to chemical fertilizers*, and that future increases will even be more dependent on fertilizers since the possibility of expansion of arable land is limited. Thus, fertilizers will be fundamental to producing more crop output from existing land in cultivation. Along with increased fertilizer use will come greater concern about the environment in view of the potential for pollution arising from excess and inappropriate fertilizer use. Agricultural technologies that underpin cropping intensification will call for greater demands on the scientific and educational communities as well as farmers and the commercial fertilizer sector.

The past half century has seen 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 Middle East or the wider 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. The low level of K fertilizer use is attributed to the fact that the region's soils are weakly weathered and have high reserves of K that are plant-available. Fertilizer use of this order has occurred in the region's cereal-based dryland agriculture, and especially with irrigation. Indeed, it is not possible to envision viable agricultural production in the Middle East without chemical fertilizer use.

As research has shown the benefits of the major elements, and their requirements for maximum economic production of the major crops, 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 raises the issue of "balanced fertilization", in essence a

concept that implies tailoring individual nutrient needs of crops according to their physiological requirements and expected yields.

As P fertilizer use is universal and is influenced by soil and climatic factors, in addition to crops, and indeed interacts with other nutrient elements in the soil and the plant, the issue of nutrient balance is particularly relevant. In this presentation, the author 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.

## 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 reside 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 starved 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 (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 fertilizer, 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 came 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 nitrogen (N) and phosphorus (P), the two main fertilizer nutrients required by crops.

Despite the global resources available to produce food and fiber, 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. 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 North Africa and West Asia (Ryan et al., 2006). The region today is generally a food-deficit one, with only a few countries approaching anywhere near self-sufficiency. 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 center-of-origin of many of the world's crops, e.g., cereals, pulses, 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 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 inpetus 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 briefly describe the general agricultural sector of the region along with the climate and soil resources that dictate the region's particular farming system. Subsequently, brief discussion hinges around ICARDA's efforts in agricultural research, particularly in dry land agriculture (El-Beltagy et al., 2004), in collaboration with the national agricultural research and development programs of the various government of the WANA mandate region. (**Fig. 1).** This then leads to the central issue of the paper: concept of balanced fertilization, fertilizer use trends in some countries of the region and implications for balanced crop nutrition, and culminating in ways to achieve fertilizer use efficiency through balanced fertilization in the interest of economic and environmental protection.

## WEST ASIA-NORTH AFRICA

This vast region of the world 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, in addition to high population growth rates and poorly developed agriculture and rural infrastructure. The following is a brief overview of its agriculture, climate, soil resources, and farming systems.


**Fig. 1. The West Asia-North Africa region.**

## The Agricultural Sector

Agriculture in WANA is largely subsistence farming, and rainfed production is low; it is labour-intensive with relative 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. 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. 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.

## Climate

The WANA region is mainly characterized by a Mediterranean climate, with cool to cold, wet winters and warm to hot, arid summers (Kassam, 1981). However, local conditions are modified by topography and nearness to the sea. Thus, the countries of North Africa are milder due to maritime influences and low elevation, and are typically Mediterranean, while those of West Asia and higher elevations, and in larger land masses, are characterized by a Mediterranean climate merging to a continental climate.

Rainfall, though generally low, is highly variable in space and time. Variability over space is illustrated across a short transect from 150-600 mm in north western Syria. Similarly, a sharp variation in rainfall occurs in Morocco with favourable conditions in the north (<600 mm) to more stressed conditions (<300 mm) in the barley-growing south. The range of rainfall in most countries is about 100-600 mm, the extremes being 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. 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). The pattern changes a bit towards the east, i.e., Turkey and Iran, where the peak of rainfall is later (May), and rain can extend in June and July.

Not only does the total seasonal rainfall vary from year to year, but so also does its distribution. Rain is often delayed by a few months, it may finish much earlier than usual, or it may be dry for long spells during the season. Severe droughts which result in partial or complete crop future are common. For instance, in the early 1980's Morocco experienced the worst drought in history and again another one of comparable magnitude in 1995. Similarly, Syria was badly hit by drought in 1988-90.

Topography and maritime conditions similarly influence temperatures, especially in winter (Harris, 1995). Thus, winters are milder in the lowland areas of West Asia and in North Africa and severe in highlands areas of West Asia. Typical climatic parameters for the Mediterranean region are illustrated for Tel Hadya near Aleppo in a moderate rainfall belt, i.e., 330 mm $yr^{-1}$. There, the inverse pattern between rainfall and maximum and minimum rainfall and the relationship with 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 invariable suffer some degree of moisture stress during the grain-filling stage. What limited rainfall that does occur is not always used by the crop, depending on the pattern of rainfall.

**Soil Resources**

While the agriculture of the Middle East region is dominated by climate, specifically limited water, the quality of the regions soils is also of vital concern. Historically, civilizations have flourished in areas of the Mediterranean basin where both soil conditions were favourable and where water was adequate. The soil resources of the region are as variable as in other parts of the world, reflecting variation in climate and topography. Although soils of arid regions have unique features, about half of the world's soil orders are found in such areas. Entisols, Mollisols, Vertisols, Inceptisols and Aridisols in extremely dry areas. Kassam (1981) indicated that semi-arid cropland in North Africa is dominated by Inceptisols (20%), Lithosols or shallow soils (15.5%), Entisols (11%), and Aridsols (16.2%).

In West Asia, the landscape is dominated by Lithosols and Aridisols. Mollisols, with relatively high levels of organic matter in the soil profile, are not widespread, but are important locally in countries such as Morocco. No single soil map covers the WANA region; the only common one is the generalized map of FAO-UNESCO (1974) which depicts the region is several sheets for Africa and Asia. While the FAO classification used by Kassam (1981) does not correspond exactly to the US Soil Taxonomy, it is apparent that wide diversity exists at lower levels of classification.

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. For instance, experimental sites in northern Syria varied at the order level, ranging from Calciorthids in the drier end of the 200 mm rainfall spectrum to Calcixerollic Xerochrepts at Tel Hadya and Breda, and Chromoxerets in the wetter Jindiress station; a close a relationship exists between rainfall and organic matter and soil nutrients, but it is modified by the extents of cultivation. Even more extreme variation was noted in Morocco where, around Settat (380 mm), one can find Petrocalic Palexerolls, Typic Chromoxererts, and Vertic Calcixerolls (Shroyer et al., 1990).

While soils of rainfed regions in general are not as intensively studied as temperate areas, reviews of such areas permit some broad generalization about dryland areas such as the Mediterranean. According to Matar et al. 1(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. Also, shallow soils are particularly vulnerable to soil erosion. While clay soils, i.e., Vertisols are deep and inherently productive with high water-holding capacity of the soil- a major factor, since with infrequent rains most rainfed crops survive on residual soil moisture. Shallow soils are particularly vulnerable to soil erosion.

While clay soils, i.e., Vertisols, are deep and inherently productive with good water-holding capacity, the range at which they can be tilled is limited. Frequently, they are either too wet or too dry to cultivate. Extensive areas of Vertisols are found from Morocco to Syria. Crop yields from these soils are usually more than double those of shallower soils in the same rainfall zone. In North Africa, 1.2 million ha is under cultivation, while 4.1 million ha is cultivated in West Asia. Vertisols are difficult to hand cultivate, and are usually worked mechanically.

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%. Organic matter serves as a nutrient reserve, particularly for N, and P to a lesser extent.. 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 P in soils. As a result, most dryland soils that have not been fertilized are P-deficient.

Thus, inherent soil properties dictate nutrient behaviour and fertilizer use as a consequence, N is invariably deficient (Ryan and Matar, 1992). 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 to the ground. 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, 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**

Agriculture as we know it evolved in the Middle East; the soil of the "cradle of civilization" has been tilled for millennia, and its landscape and vegetation have been ravished in the process. The overview of the region's agriculture indicates that it is still very much traditional, having evolved over centuries. Detailed descriptions of rainfed farming in the Middle East are provided by Gibbon (1981) and Cooper et al., (1987), but immense changes have occurred in the last 10-15 years. Today, there is evidence of change, but much of the traditional character remains. The more obvious change is the inexorable shift from animal traction to mechanical cultivation and from hand broadcasting of seed to drilling. Similarly, the change from hand-harvesting to combine harvesting is nearly complete in some countries--the harvesting of lentils is still the exception.

The last few decades have witnessed increased use of chemical inputs, i.e., fertilizers and, to a lesser extent, pestcides (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 Attaturk 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, i.e., wheat (*Triticum* spp) and barley (*Hordeum vulgare* L.); cereal production and livestock and combined enterprises. The relative importance of breadwheat (T. *aestivum* L.) and durum wheat (T. *turgidum* var *durum* L.) depends on rainfall and the particular to 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 Medicago for grazing. Oilseed crops such as sunflower (*Helianthus annuus*), safflower (*Carthamus tinctorius*), 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: APPLIED RESEARCH IN WEST ASIA-NORTH AFRICA

As one of the International Agricultural Research Centers under the auspices of Consultative Group for International Agricultural Research (CGIAR), the International Center for Agricultural Research in the Dry Areas (ICARDA) was established in Aleppo in 1977, Syria, to primarily address dryland agriculture in the

West Asia –North Africa 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 three main areas: *natural resource management crop genetic improvement, and institutions and poli*cy.

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, as well as assessing crop growth responses in a range of rainfall and soil environments (Harmsen, 1984). This effort was supported by laboratory and greenhouse studies of nutrient interactions with soils and water. Later, the emphasis shifted to micronutrients (Materon and Ryan 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 of trials gradually gave way to a series of long-term rotation trials that evaluated fertilization and nutrient dynamics within a cropping system. A major effort involved a region-wide program 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 to improve quality analytical central and laboratory efficiency (Ryan and Garabet, 1994; Ryan et al., 1999).

A number of clear, but simple, concepts emerged from ICARDA's soil fertility work. (Ryan, 2004). The well-known Liebig's "Law of the Minimum" was 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

### Fertilizer Use Trends

As a background to "*balanced fertilization*" it is pertinent to make a brief examination of fertilizer use in the past 50 years, or the era of chemical fertilization. Globally, levels of total fertilizer consumption have remained static in the two decades or so, and in fact have declined in "developed" and "transition" economies; the only increase have been in developing countries. 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.

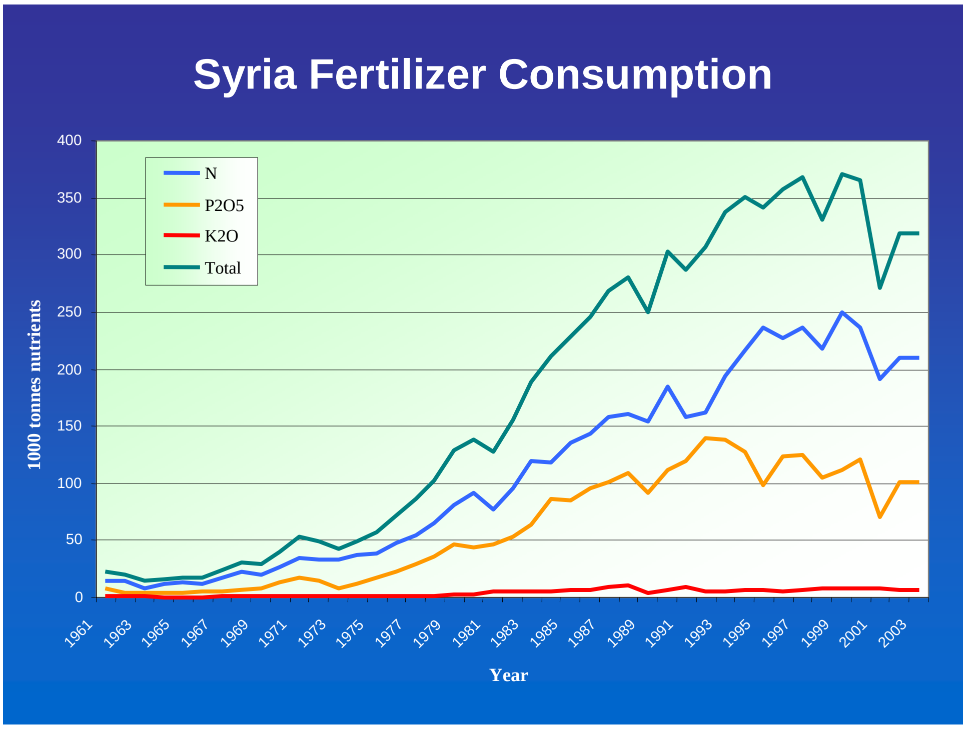


**Fig. 2. Pattern of fertilizer nutrient use in the past four decades.**

Data from Syria, Morocco, Turkey, and Egypt reveal broad similarities. Prior to 1970, little fertilizer was used in these countries. This was followed by a rapid increase in use of N and P (see Fig.2 for Syria), 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. While various circumstances such as internal production, importation and marketing, can influence the amount of fertilizer nutrient used in any one year, the variability in N and P use, 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.

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 are illustrated in the wide variation in the amount of fertilizer nutrients used as well as fertilizer nutrient ratios for many countries of the WANA region (Table 1)

| Nutrient use (000 tons) and ratio | | | | |
|---|---|---|---|---|
| Consumption 2003/04 - 2003 | N | P2O5 | K2O | NPK Ratio |
| China | 24,745.0 | 9,827.0 | 4,663.0 | 1.0 : 0.40 : 0.19 |
| United States | 11,882.0 | 4,364.4 | 4,988.0 | 1.0 : 0.37 : 0.42 |
| Pakistan | 2,527.0 | 637.7 | 27.7 | 1.0 : 0.25 : 0.01 |
| Cyprus | 8.1 | 4.2 | 3.1 | 1.0 : 0.52 : 0.38 |
| Turkey | 1,340.8 | 547.5 | 83.7 | 1.0 : 0.41 : 0.06 |
| Egypt | 1,190.8 | 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 |
| 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 |
| 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 |
| Azerbaijan | 16.6 | - | - | 1.0 : 0.00 : 0.00 |
| Kyrgyzstan | 7.0 | 0.2 | - | 1.0 : 0.03 : 0.00 |

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**Table 1. Fertilizer use and nutrient ratios in Middle East countries, and China and USA for comparison.**

## Efficient Fertilization

Despite the fact that balanced fertilization has gained considerable currency in the literature, the concept is an old and dating back to the 1840's and Liebig who expanded on "limiting nutrients" in his famous "Law of 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 two varying definition of balanced fertilization (Johnston, 1997a)); one 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 amount 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:

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, b, etc, 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.

There is no fixed recipe for balanced fertilization it is soil and crop-specific.
Any deficiency of one nutrient will severely limit the efficiency of others.
Imbalanced nutrition results in "mining" of soil nutrient reserves.
Luxury consumption is often a consequence of nutrients supplied in excess.
Imbalanced fertilization is *inefficient*, *uneconomic* and *wasteful*.

Balanced fertilization depends on soil test values and crop removal.
If a soil is rich in one nutrient, fertilization should be directed towards the deficient nutrients or those in least supply.
Crop nutrient requirements are related to yield level.
Fertilization with time can cause a buildup of P and K, thus reducing their fertilizer requirements.
The concept of balanced fertilization has expanded to integrated plant nutrition, embracing *all* sources of nutrients.
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). Though the meeting focused mainly on potassium, the need to recognize the implications of a buildup in P and K in the soil for nutrient ratios and budgets was recognised. The need to apply sound scientific principles to ensure *environmentally begin 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. 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.

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. More reliable is analysis of the plant tissue itself for a particular nutrient. Excellent guidelines have been developed for sampling, handling and analyzing the tissues, along with criteria for deficiency to adequacy. Quick tests designed to give results in the field without delay are based on qualitative nutrient determination in the expressed fresh plant sap.

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 Program to promote the awareness of the basic element in the agriculture of WANA, particularly with soil analysis (Ryan & Matar, 1990, 1992; Ryan, 1997). The likelihood is that soil analysis will be adopted as a tool in fertility-crop nutrient management 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.

## THE CHALLENGE AHEAD

*In theory, balanced fertilization leading to balanced crop nutrition cannot be argued with. However, many of the necessary conditions to respond to much to such concerns 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. The research that has taken place has clearly shows the value of chemical fertilizer application in terms of crop quality, economics, and environment what is needed at government level is adoption of policies that guarantee the timely and economic 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 section in such ventures. In order to provide an economic outlet for food supplies generated by increased fertilizer use and irrigation markets in transportation facilities and the overall rural infrastructure.*

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