J. Agric. Sci. Technol. (2008) Vol. 10: 295-306

REVIEW ARTICLE

Crop Nutrients for Sustainable Agricultural Production in the Drought-Stressed Mediterranean Region

J. Ryan[1]

ABSTRACT

Most areas of the world where rainfall is limiting are characterized by low agricultural output and, ironically, high population growth rates that generate increased food demand. Arid and semi-arid regions permit a range of vegetative biomass production, from rainfed crops to native pasture, and sparse steppe shrubs to true desert. Given the harsh climatic conditions in areas such as West Asia-North Africa, where less than 10% of the land area is amenable to rainfed cropping, soil resources are fragile and cropping conditions precarious. Yet with appropriate manipulation of soil fertility and crop management within a systems context, including breeding of improved cultivars, conservation tillage, and rotations, substantial production increases can occur at the farmer's level. While irrigation has increased considerably in the past few decades, having a major impact on crop yields, surface and ground water sources remain limited. Applied research specific to the region has shown that crop output can be considerably enhanced with adequate nutrition, most of which has to be added as commercial fertilizer. The substantial yield increases that have taken place in several countries of the region have been attributed to three factors: water, fertilizers, and improved varieties. Technologies that potentially produce such high yield increases include identification of nutrient stresses and taking corrective action, and, where appropriate, adapting the plant to the soil conditions. If managed properly, innovative cropping systems to overcome these constraints can improve rather than degrade soil conditions. Regardless of the advances in biotechnology, crop adaptation, and integrated cropping systems, chemical fertilizers will, in future, play an even greater role in the nutrition of both rainfed and irrigated crops in Mediterranean agriculture. Crop nutrition research will have to keep pace with agronomic developments. The future challenge in soil fertility-crop nutrition lies as much in overcoming obstacles to technology transfer as in the generation of new knowledge. This selective review is based mainly on the author's research experiences in the field of soil fertility and crop nutrition in the WANA region for the past 32 years. It seeks to highlight research developments within the context of the region's crop production constraints, culminating in a perspective on future research challenges within the framework of cooperation between international institutions and the region's national research and development programs.

Keywords: Irrigated cropping, Mediterranean agriculture, Micronutrients, Nutrient dynamics, Nitrogen fertilizer use, phosphorus.

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 (Borlaug, 2003). In some countries the specter 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 low rainfall arid to semi-arid regions. The

[1] International Center for Agricultural Research in the Dry Area (ICARDA), P. O. Box: 5466, Aleppo, Syria. email: j.ryan@cgiar.org

[DOR: 20.1001.1.16807073.2008.10.4.6.4]

International Center for Agricultural Research in the Dry Areas (ICARDA), based in Aleppo, Syria, focuses primarily on a major rainfed area of the world, i.e., the Mediterranean area, where settled agriculture began and where several of the world's major food crops such as cereals and legumes have evolved (Damania *et al*.,1998). The Center works in conjunction with the national agricultural systems in the various countries in its mandate region of West Asia-North Africa (WANA), merging into Central Asia, with linkages in other dryland areas of the world. A concise overview of the WANA region with respect to food security and sustainable development is to be found in a keynote address given at a recent conference in Tehran, Iran, on “Sustainable Development and Management of Drylands in the Twenty-first Century” (Roozitalab, 2005)

ICARDA's research is aimed at germplasm enhancement, production systems management, natural resources conservation and development, socioeconomic policy, and institutional strengthening of national agricultural research systems. Despite the potential of irrigation to increase yields, crop output is limited by water availability from surface or groundwater sources. Therefore, for the Mediterranean region and other semi-arid areas of the world, dryland cropping, which depends on limited rainfall, will continue to be important for the lives of many and to merit research attention in order to meet the goal of self-sufficiency and contribute to poverty alleviation.

Notwithstanding the controlling influence of limited moisture- from rainfall or residual in the soil- an adequate supply of nutrients can have a major impact on yield in most years (Cooper *et al*., 1987; Ryan, 2002). Given the impoverished natural state of most soils, as a result of exploitive farming ("nutrient mining") for millennia since the beginning of settled agriculture, nutrients must invariably be added in the form of commercial chemical fertilizers. The extent to which manures and other organic sources of nutrients (Ryan *et al*., 1985a), or indeed "miracle" alternatives (Ryan *et al*., 1982) can contribute to crop production is limited- and will continue to be so.

In keeping with arid to semi-arid soils throughout the world, the soils of the Mediterranean area are deficient in major and essential elements such as nitrogen (N) and phosphorus (P) and several micronutrients, but are generally well supplied with potassium (K) and both calcium and magnesium. The purpose of this paper is to reflect a cross-section of the author's work on soil fertility and crop nutrition in the Middle East region; it is not intended as an exhaustive review, rather to capture the major issues related to crop nutrition. As a background to an exposition of the role of nutrients in the region's agriculture, a brief description of its environment, soil resources, and cropping systems is pertinent - all influence in one way or another how efficiently nutrients are used.

Weather, Cropping Systems, and Soil

Despite the common features of limited rainfall and harsh production environments, considerable variation exists in the WANA region (Kassam, 1981). Much of the area is desert and scrubland. Where rainfall ranges from 200 to 600 mm year^{-1} rainfed cropping is generally practiced, but there is much inter-annual and seasonal variation (Harris, 1995). Within Syria, a range of rainfall zones exist, thus reflecting weather conditions in most of the Mediterranean region. Complete crop failure is common, especially in the low rainfall areas, i.e. less than 200 mm, and drought is a chronic threat. However, crop growth conditions and evaporative demand are influenced by elevation and landmass. Highland areas are cold, often with snow and severe frost, as are inland areas which tend to have a continental climate.

Strategies for crop improvement have to consider the variation in agroecological zones (Ryan *et al*., 2006). In addition to weather-induced biophysical constraints, i.e. drought, cold, heat, other limitations include salinity and shallow soils with low moisture-retention capacity. Furthermore, as a result of the low organic matter (Ryan, 1998), most soils are inherently low in N and invariably deficient for crops.

The farming systems that have evolved in the region are based on cool-season, winter rainfall (Cooper *et al*., 1987). Cereals predominate with barley in the drier areas, bread wheat in the more favorable zones, and durum wheat in the intermediate rainfall zones. Forage and food legumes, notably chickpea and lentil, are grown extensively and in rotation with cereals. The area of fallow land is rapidly diminishing due to land-use pressure, with continuous cereal cropping becoming more common. Livestock production, mainly sheep, is usually associated with cereal growing, with grazed stubble and straw a feed source (Harris, 1995). While the area of irrigated land is increasing, it is small by comparison with the rainfed area; with limited surface water sources and rapidly depleting groundwater, rainfed farming will continue to be dominant.

Several socioeconomic factors compound the biophysical constraints, i.e., small and fragmented land holdings, a weak agricultural educational and technology infrastructure, poor credit facilities, and low inputs of fertilizers and other farm chemicals (Gibbon, 1981). While some farms are modern, many are traditional with low output, and are more prone to the vagaries of nature.

Soil properties are related to climatic conditions, past and present. At least six of the world's major soil orders are represented in the region, ranging from deep fertile Vertisols to shallow Inceptisols and true desert Aridisols (Matar *et al*., 1992). Despite such variability in soil types, the soils have several common features; most have considerable amounts of calcium carbonate, reflecting the calcareous parent rocks and the weak weathering environment. This, in turn, induces deficiencies of P and micronutrients (Matar *et al*., 1992). Most soils are low in organic matter (Ryan, 1998), reflecting low root biomass, grazing of residues, and high soil temperatures which promote organic matter mineralization. Thus, in most soils, the reserve of N is low, as is mineral N, i.e. nitrate and ammonium.

Given the low soil reserves of the major elements and the crop demand, most countries in WANA have experienced substantial increases in fertilizer use, especially N and P. As most soils are relatively well supplied with K (Ryan *et al*., 1997), fertilizer K input has been low or moderate, especially for the dominant cereal crops (Ryan and Mazid, 2003). For example, in Syria, from the low base in the 1970s to 25 years later, N fertilizer use increased by 15 to 20-fold; the figure for P was about 10- to 15-fold (IFA, 2006). Iran was no exception to the general use pattern, with N currently at about 1,400 thousand tons, P about half that amount at 800 thousand, and K less than 400 thousand tons, i.e. a nutrient use ratio of 1.0: 0.43:0.17. The implications of such ratios for balanced fertilization were raised by Malakouti (1997a). That fertilizer nutrient has leveled out in the past decade poses additional concerns for fertilizer management (Malakouti, 1997b).

Nitrogen: The Dominant Element

For crop nutrition, N is the element which is needed most; with increasing cropping intensification, it is indispensable in today's agriculture. Given its economic and, indeed, environmental importance, N has been the focus of intense study, both in developing and developed countries. In the context of WANA's dryland region, some background generalizations from Harmsen (1984) are worthy of mention and are still relevant and reflected in later publications (Ryan and Matar, 1992; Ryan, 1997; Ryan, 2004)

The crucial question for the early research was to determine the nutritional needs of the crop for N and how much and how effectively fertilizer should be applied. The many factors involved include; costs and availability, expected yields and economic benefit, crop variety and its requirement system, and soil N mineralization/immobilization. Well established facts show that ammonium (NH_4) is subject to biological transformation, nitrate ($N0_3$) is mobile downward with the wetting front and upward with capillary rise, and the crop $N0_3$ uptake is correlated with soil $N0_3$. Nitrogen-use efficiency is influenced by source, application rate, method and timing. Possible losses from the system include volatilization induced by high soil pH with urea or ammonium fertilizers, denitrification and leaching, the latter processes being of little significance due to the low rainfall environment.

From its early days, ICARDA's research focused on N efficiency, a consideration still valid today. The goal of good N management is to increase N-use efficiency; currently, values in the WANA dryland area range from 20 to 70%. With these generalizations, it is relevant to examine the course of N research at ICARDA. While the concerns were mainly in Syria, there were parallel situations in other WANA countries (Ryan and Matar, 1992; Ryan, 1997). This brief review does not purport to do justice to the full literature on N research from the region.

Dryland Nitrogen Research

Most of the early priorities on N research emerged from a workshop at Tel Hadya (Monteith and Webb, 1981). The issues identified were: the role of soil moisture in relation to N; fluxes and transformations of N in soil; biological N fixation and rhizobial inoculation; native fertility levels, tillage systems, fallowing, and rotations in relation to N; as well as the need for baseline soil data in field trials and identification of agro-ecological zones to facilitate technology or information transfer. Thus, the scene was set for a wide range of N-related studies involving most field crops.

The initial field trials at ICARDA's main station, Tel Hadya, and at sub-stations in higher and lower rainfall zones showed clear responses to fertilizer N for barley and wheat in all but the driest areas. Fertilization also increased water-use sufficiency (Matar *et al.*, 1992). There was a yield relationship with seasonal rainfall which was modified by available soil nutrients. In other agronomic studies with cereals, high N application exacerbated drought stress during the grain-filling period and thus increased the proportion of shriveled grain. Nitrogen response was related to variety, while the effect of splitting N application depended on rainfall conditions. Nitrogen application was related to percent vitreousness in durum wheat, which enhanced quality as well as yield (Mahdi *et al.*, 1996).

Apparent N uptake efficiency was related to rainfall, being 30 to 40% at the drier sites (<300 mm), about 60% at Tel Hadya (330 mm), and greater than 80% at the wetter (>400 mm) sites. Actual N recoveries, using N-15, were 94% at Tel-Hadya (48% plant, 46% soil), and 80% at the drier Breda site. Most of the recovered soil N was in the top 0 to 20 cm layer. In an analysis of N and crop response data, Harmsen (1984) showed agronomic efficiencies of 52.5 to 96.8 kg grain per kg N uptake, apparent recovery fractions of 0.10 to 0.36, and N harvest index of 0.33 to 0.66. Clearly, there was room to improve efficiency.

Sampling after a year's fallow revealed more mineral N per hectare than in cropped plots, presumably from mineralization. Seasonal differences were observed for mineral N, with flushes occurring in late fall after the initial rains; a decrease in NH_4-N over time was attributed to immobilization biomass, and not to nitrification. The ratio of NH_4/NO_3 was apparently related to rainfall. Soil N loss by volatilization is also a potential concern in calcareous soils due to enzymatic hydrolysis or urea to ammonia gas (Ryan *et al.*, 1981). However, under cool-season, field conditions, volatile losses were relatively low (11 to 18%) and decreased with increased rainfall and clay content (Abdel Monem *et al.*, 1999).

Considerable attention was given to cool-season legumes, which are grown alternately with cereals. A key question was how much N crops such as chickpea and lentil fix, and how much is left over for the succeeding cereal crop? Improved cultural practices increased biological N fixation (BNF) from 55 to 69%, but the figure was less as rainfall decreased; legumes contributed at least 10 kg N to the next cereal crop. Using nonnodulating chickpea and barley as reference crops, Beck *et al*. (1991) estimated % Ndfa (% N derived from the atmosphere) at 70% for pea and lentil across all stations. Marked differences in Ndfa existed for winter (72%) compared to spring chickpea (26%). Inoculation with appropriate strains of rhizobia increased Ndfa from 52 to 72%. Despite the contribution of BNF for chickpea, there was a net loss of N from the soil when all the biomass was removed from the field.

After the initial trials at ICARDA's stations, a logical progression was to conduct on-farm trials, in collaboration with the Syrian Soils Directorate, across the rainfall zones and soil types in the cereal-growing area of northern Syria. The 4-year series with wheat and barley showed clearer trends (Pala *et al*., 1996). Where no other factor is limiting, yields were related to seasonal rainfall, especially on flat, deep soils. In other soils, this relationship would be modified by soil properties, such as slope and texture, which influence soil moisture. Responses to N increased with rainfall, i.e., 3% at>250 mm, 24% at 250 to 400 mm, and 32% at >400 mm. However, there was rarely any residual effect of applied N, in contrast to P, which tends to accumulate with time. Over the range of 40 sites, $N0_3$-N in the top 0-60 cm was highly correlated with yield. A critical soil $N0_3$-N level was considered as 8 mg kg^{-1} following a legume or a low-yielding cereal yield, and 15 mg kg^{-1} after a summer crop or a high-yielding cereal yield.

Nitrogen in Long-Term Rotation Trials

Following the findings from the early on-station and on-farm trials, it was essential to take a wider longer-term assessment of farming systems. Thus, the "systems" approach spawned several long-term trials which were established in the mid-1980s. While ICARDA had a comparative advantage in conducting such trials, a few others were already in existence in the WANA region, and several similar ones were to follow in other countries (Ryan, 1997; Ryan and Abdel Monem, 1998). While the initial years of the rotations were production-oriented, this gave way to the notion of sustainability and indicators of soil quality.

The main trial, "Cropping Systems Productivity", involved durum wheat alternated with legumes, fallow or continuous wheat (Harris, 1995). Sub-treatments included N application rates (0, 30, 60, 90 kg ha^{-1}) and grazing intensities (no grazing, medium, and heavy). The trial involved several parameters: biomass and grain yield; economics, soil physical, chemical and biological properties; water relations; and diseases.

Conclusions regarding the role of N are as follows (Harris, 1995). Yields consistently increased with added N in the cereal phase; responses were low, only 30 kg N ha^{-1}, in dry years, and up to 90 kg ha^{-1} in favorable years. Responses also were conditioned by the preceding crop, and the extent to which it influences soil moisture, being highest after fallow. Significantly, N influenced soil properties and was, in turn, influenced by the rotation. Thus, with increasing application rates of fertilizer N, there was a consistent increase in soil organic matter, largely due to the increased root biomas associated with the higher yields; this in turn would increase the soil content or reserves of organic N (Ryan, 1998).

The legume-based rotations produced more soil N than either continuous cereal or fallow. In concomitant laboratory studies, soil from medic rotations produced higher mineralization rates (Ryan *et al*., 2003). Measurements *in situ* revealed the same trend. Associated with added N and indeed the rotation was a positive effect on soil physical properties (Masri and Ryan, 2006), i.e., reduced dispersion and increased aggregate stability.

In addition to on-going sampling of all plots in this 23-ha trial on a yearly basis, we are currently examining N mineralization from each rotation (unfertilized, un-grazed), using bare (2×3 m) micro-plots. Periodic sampling of the profile to 1 m revealed the net outcome of mineralization. Temperature and moisture data were recorded. Several times during the growing season, mineralization was measured by dilution of N-15 over an 8-day period. Samples were measured in the laboratory for biomass and labile N and C, reputedly more sensitive indicators of soil organic matter changes.

So far, seasonality has a strong influence on soil data. Total mineral N only began to increase with increasing soil temperature; it declined again as the soil dried out. The highest amount of N released, irrespective of these trends, come from medic and vetch rotations. Biomass N had a similar rotation effect, but was more sensitive to temperature and decreased when the soil dried out. Again, the effect of the medic and vetch rotation was large. Thus, the residues of these crops had higher sources of soil N and supported greater bacterial activity.

Nitrogen in Irrigated Systems

The past decade has seen a dramatic increase in the area of irrigation, not only in arid areas with insufficient rainfall to grow any crop, but has encroached onto traditional rainfed areas, especially for wheat-crops such as cotton, potatoes, and sugar beet are only grown under irrigation. As the main water source is groundwater, and as water tables are showing a consistent decline, the sustainability of groundwater irrigation is in question. In view of water scarcity, research has focused on improving efficiency of use, especially with supplemental irrigation and trickle or drip irrigation (Ryan, 2000a).

Several field studies have shown that water use in terms of crop production could only be optimized when combined with adequate N fertilizer use (Oweis *et al*., 1998; Garabet *et al*., 1998). More recent work (Ryan *et al*., 2006) has shown that, where untreated urban wastewater was used for irrigation, the amount of N and P needed as fertilizer could be reduced or eliminated as this water source is rich in nutrients; wastewater is the only source of water that is increasing in the Middle East, where all other sources are diminishing.

Phosphorus

Second to N in importance for crop production, P is one of the most complex elements in soils. As the soils of the WANA region are mainly calcareous, the chemistry of P is dominated by calcium carbonate. Thus, in their natural state, soils of the region are inherently low in available P, though not necessarily in total quantities of the element (Ryan, 1983). The chemical reactions of P in soils covers volumes; the most recent review was that of Matar *et al*. (1992) for the Mediterranean region and that of Ryan (2003) specifically for Syria.

Earlier work from the region showed that iron oxides, although recurring in small amounts, have a disproportionate influence on the initial reactions of soluble or fertilizer P in soils (Ryan *et al*., 1985b) as well as the longer-term reversal reactions (Ryan *et al*., 1985c). These reactions dictate the efficiency of fertilizer use as well as the changes that take place with continued fertilization. Thus, P research was another major thrust in ICARDA's research agenda.

Much of the early work in Syria (Matar *et al*., 1992) and throughout the region (Ryan and Matar, 1992) showed the ubiquity of crop response to applied P fertilizer in the field. The soil test calibration program at ICARDA identified the Olsen $NaHC0_3$ test as most suitable for the region's soils and critical levels as a guide to fertilization (Ryan and Matar, 1992). In contrast to N, fertilizer P was shown to be relatively more effective in drier areas; fertilizer P also promoted greater water-use efficiency (Matar *et al*., 1992); in addition soil organic matter was shown to enhance its availability (Habib *et al*., 1994). While mycorrhizae were shown favorably to influence crop P uptake, the effect was minor and was not a substitute for fertilizer (Ibrikci *et al*., 2004). Consequently, fertilizer use dramatically increased in most countries of the region. Indeed, work recently reported (Ryan and Matar, 1992; Ryan, 1997) indicates that due to P buildup from fertilization, many soils are now well supplied with P and need only maintenance levels of P, if at all.

In the past few decades, much has been learned in relation to P fertilizer use (Ryan,

[DOR: 20.1001.1.16807073.2008.10.4.6.4]

2002 and 2004): identification of soil test levels, responses to crops in different environments, most efficient methods of application, and long-term residual value of P fertilizers. In that context, the issue of providing laboratory facilities to provide reliable and valid analyses is paramount (Ryan, 2000b). The challenge now is to implement what we know and to transfer such technology to the end-user, the farmer. The focus of P research in the future will be in irrigated agriculture and the development of soil test criteria and overcoming obstacles to efficient use associated with fertigation (Ryan, 2000a).

Potassium

As one of the trilogy of major crop nutrients, potassium (K) is seen as of limited importance for dryland farming in the WANA region, and probably similar regions elsewhere. Indeed, a major conference held in Iran (Johnston, 1997) provided an overview of K in soils and crops of the region in the context of its implications for food security. The perception of general adequacy of K in soils of WANA largely stems from the fact that such soils are relatively rich in K, as the pedo-genetic environment does not favour weathering or significant leaching. Surveys of a range of dryland stations across northern Syria bear out this contention, with all being well above the critical level (Ryan *et al*., 1997). In addition, such soils have the capacity to release plant available K over a long period of time. This does not exclude the possibility of localized problems with K deficiency in sandy soils, while responses to K are probably with irrigation, especially for high K-demanding crops such as potatoes and sugar beet. Regardless of how rich the soil is, the supply of nutrients is finite; ultimately, what is removed by crops has to be replaced by added nutrients, mainly as chemical fertilizers. While K research will remain a low priority by comparison with N and P, it will need to be monitored by soil and plant analysis to ensure adequacy for crop growth.

Micronutrients

Given the low crop yields limited by water, and the dominance of N and P as crop growth constraints in the past, it is not surprising that there was little initial interest in micronutrients as limiting factors in the overall scheme of crop production. Nevertheless, there are several soil factors that promote micronutrient stresses- either deficiency or toxicity. The main factor inducing metal deficiencies is calcium carbonate, with its associated high pH and consequently reduced solubility of these metals, mainly iron and zinc, and, to a lesser extent, manganese and copper. Therefore, the perception of the importance of micronutrients has now changed as reflected in the current extensive review of micronutrients by Rashid and Ryan (2007) for the WANA region.

Extensive studies with cereals by Cakmak (2004) in Turkey showed that the problem of Zn deficiency was widespread, with serious implications not only for crop production, but also human health. Research on Zn in forage legumes, suggest that deficiency may also be common in Syria (Materon and Ryan, 1995). Low levels of soil organic matter can exacerbate the problem, as does the transition from superphosphate to more concentrated and forms, with less Zn as an incidental contaminant. Soil surveys and the use of soil information from existing data bases can help indicate areas where micronutrient deficiencies are likely to occur (Ryan *et al*., 1996).

While boron (B) is generally not deficient on such a large scale as Zn, it is widespread in some countries of the region such as Pakistan (Rashid and Ryan, 2004). However in contrast to Zn, the opposite to deficiency does occur in some locations- too much or, even toxic levels. This problem often goes undetected as it is characterized by subsurface accumulations (Ryan *et al*., 1998) and the fact that the range between too little and too much soluble B is narrow. Unfortunately, little can be done in terms of soil amelioration to solve this problem; adaptation of resistant cereal cultivars presents a possible solution (Yau *et al*., 1997). Fortu-

[DOR: 20.1001.1.16807073.2008.10.4.6.4]

nately, many cereal landraces are resistant to B toxicity to varying degrees and the process of transferring such resistance genes to improved cultivars is relatively simple.

With increasing cropping intensification and the elimination of other nutrients as crop growth-limiting factors, increasing attention will be given to micro-elements, especially under irrigated conditions. Indeed, given current trends in human nutrition, greater attention will be given to the role of micro-elements in the entire food chain, from the soil through the plant, and ultimately the human being, as indicated by an ameliorating effect of Zn on the neurotoxin endemic in grasspea, a legume crop of last resort in times of famine in countries such as Ethiopia and Bangladesh (El-Moneim *et al*., 2000). Indeed, the issue of Zn in relation to grain quality for human consumption was addressed at a recent international meeting on Zn (Malakouti *et al*., 2007). Future research will no doubt be focused and expanded on this area of relevance to human nutrition.

CONCLUSIONS

The past decades have witnessed major changes in the agriculture of the lands bordering the Mediterranean, mainly a transition from a traditional, centuries-old, dryland, cereal-livestock system to a more diverse one characterized by chemical inputs, especially fertilizers. The dramatic increases in crop production that have occurred in several countries of the region-Syria is now self-sufficient in cereal production for the first time-are attributed primarily to better nutrition through fertilizer use and more water through irrigation , and to a lesser extent, better varieties. While the issue of water will continue to be problematic due to the precarious nature of water sources, fertilizers will continue to increase in importance, to an extent that is controlled by water availability.

The soil fertility-crop nutrition research conducted over the past three decades, mainly at ICARDA, has contributed greatly to our scientific knowledge of the region's agriculture. This has come about through collaboration with the region's national programs, including close linkages with regional research stations and centers such as the Aridoculture Center in Settat, Morocco (Ryan, 1997), the Central Research Institute for Field Crops, Ankara, Turkey (Avci *et al*., 1997) and the Dryland Agricultural Research Institute (DARI), in Marageh, Iran (Haghighati, 1997). The regional workshops on the soil test calibration network in WANA (Ryan and Matar, 1992; Ryan, 1997) provide a forum for comparing research results from all countries of the network leading to common perceptions of problems and common solutions. Much of what has been achieved was due to the network approach to conducting research (Ryan *et al*., 1995).

The major areas of research accomplishment include identification of crop nutrient constraints and elucidation of various aspects of the soil–plant nutrient behavior. This accumulated knowledge has led to more efficient use of crop nutrients, such as band application of P fertilizers, more effective timing of application in relation to the crop's needs, and minimizing nutrient losses through leaching, runoff and volatilization. Similarly, developments in fertigation have led to more efficient fertilizer use. Soil testing, along with associated correlation and calibration have provided a more rational basis for efficient fertilizer use (Ryan and Matar, 1992), thus promoting better economic returns for the farmer and avoiding environmental damage due to excessive nutrient use. The benefits of integrated fertilizer use within rotational cropping were clearly shown, as was the potential of fertilizers to enhance soil quality and crop nutrient enhancement for human nutrition.

While much has been learned in the area of crop nutrition in Mediterranean agriculture, challenges will continue to emerge as agriculture changes and evolves in response to broader influences at the global level that impinge upon the region. The need for more integrated approaches to using nutrients at farm level will inevitably increase along with the need to use nutrient sources, whether organic or inorganic, in a more biologically and economically efficient manner. Further research is needed in reducing losses of nutrients to the environment, especially the role of crop production in greenhouse gas emission and in carbon sequestration. Increasingly, the implications for fertilization for food quality and human nutrition will require increasing research attention. Concerns about sustainable use of the soil resources will increase.

At the broad socio-economic level, one cannot ignore government policies that influence produce prices and fertilizer availability. As in the West, where society is becoming more urbanized and people are becoming more divorced from the process of food production, the challenge is to inform the public at large of the essential role of fertilizers in their lives and to dispel the unfortunate myths that indicate the contrary. The research conducted in the Mediterranean region, as reflected in this brief overview, provides compelling and convincing evidence of the indispensability of fertilizers for the region's agriculture and for society as a whole.

ACKNOWLEDGEMENTS

I wish to recognize the many scientists who have contributed to the knowledge base in soil fertility, agronomy, and crop nutrition. My sincere thanks to all the colleagues who assisted in the various publications cited here. I am particularly indebted to the late Samir Masri, who was of invaluable help to me during my years at ICARDA, and the exemplary collaboration of scientists from the national programs, in particular Abdul Rashid (Pakistan), Hayriye Ibrikci (Turkey), and S. K. Yau (Lebanon).

REFERENCES

1. Abdel Monem, M., Lindsay, W. and Ryan, J. 1999. Volatile Loss of Ammonia from Urea Applied to Syrian Soils Cropped to Wheat. Sixth Int. Meeting, *Soils with a Mediterranean–type Climate*, Barcelona, Spain, July 4-9, 1999. Abstracts. PP. 208-210.
2. Avci, M., Avcin, A., and Donnez, O. 1997. Nitrogen Uptake and Requirements of Wheat in Dryland Wheat/Chickpea Rotations in Central Anatolia. PP. 317-321. In: "*Accomplishements and Future Challenges in Dryland Soil Fertility Research in the Mediterranean Area*". Ryan, J. (Ed.) ICARDA, Aleppo, Syria.
3. Beck, D. P., Werry, J., Saxena, M. C. and Ayadi, A. 1991. Dinitrogen Fixation and Nitrogen Balance in Cool-season Legumes. *Agron. J.*, **83**: 334-341.
4. Borlaug, N. E. 2003. Feeding a World of 10 Billion People: The TVA Legacy. Travis, P., Hignett Memorial Lecture, March 14, Muscle Shoals, Alabama, USA.
5. Cakmak, I. 2004. Identification and Correction of Widespread Zinc Deficiency in Turkey: A Success Story. Proc. Fertilizer Soc., **552** , York, UK.
6. Cooper, P. J. M., Gregory, P. J., Tully, D. and Harris, H. C. 1987. Improving Water-use Efficiency of Annual Crops on the Rainfed Farming Systems of West Asia and North Africa. *Expl. Agric*., **23**:113-158.
7. Damania, A. B., Valkoun, J., Willcox, G. and Qualset, C. O. 1998. The Origins of Agriculture and Crop Domestication. The Harlan Symposium. ICADRA/ IPGRI/FAO/ GRCP. Aleppo, Syria.
8. El-Moneim, A. M., and Ryan, J. 2000. Nutritional Influences on Neurotoxin Concentrations in Grasspea (*Lathyrus sativus*). *Third International Crop Science Congress*, Hamburg, Germany. Abstracts, P. 39.
9. Feiziasl, V., Valizadeh, Gh. R., Pala, M., Ketata, H. and Siadat, H. 2005. Soil Fertility for Sustainable Ceraal-based Cropping Systems in the Dry Highlands of Western Iran. In: "*Sustainable Development and Management of Drylands in the Twenty-first Century*". El-Beltagy, A. and Saxena, M. C. (Ed.). ICARDA, Aleppo, Syria. PP. 93-107.
10. Garabet, S., Wood, M. and Ryan, J. 1998. Nitrogen and Water Effects on Wheat Yield in a Mediterranean-type Climate. 1. Dry Matter Yield and Nitrogen Accumulation. Field *Crops Res***. 57**: 309-328.
11. Gibbon, D. 1981. Rainfed Farming Systems in the Mediterranean Region. *Plant Soil*., **58**: 59-80.
12. Habib, L., Hayfa, S. and Ryan, J. 1994. Temporal Changes in Organically Amended Soil: Implications for Phosphorus Solubility and Adsorption-desorption. *Commun. Soil Sci. Plant Anal*., **25 (19&20):** 3281-3290.
13. Haghighati, A. 1997. Synthesis of Dryland Fertilizer Trials in Western Iran. In: Accomplishements and Future Challenges in Dry-

land Soil Fertility Research in the Mediterranean Area. Ryan, J. (Ed.), ICARDA, Aleppo, Syria. PP. 322-323.

14. Harmsen, K. 1984. Nitrogen Fertilizer Use in Rainfed Agriculture. *Fert. Res*., **5(4)**: 371-382.
15. Harris, H. 1995. Long-term Trials on Soil and Crop Management at ICARDA. *Adv. Soil Sci*. **19**: 447-469.
16. Ibrikci, H., Ryan, J., Yildiran, U., Gizel, N., Ulger, A. C., Buyuk, G., Karnez, E. and Kormaz, K. 2004. Phosphorus Fertilizer Efficiency and Mycorrhizal Infection of Corn Gernotypes. *Sust. Agric. Food Systems*., **19(20)**: 92-99.
17. IFA. 2006. IFADATA Statistics International Fertilizer Industry Association, Paris, France.
18. Johnston, A. E. 1997. (Ed.) *Food Security in The WANA Region, The Essential Need for Balanced Fertilization*. International Potash Institute, Basel, Switzerland.
19. Kassam, A. H. 1981. Climate, Soil and Land Resources in West Asia and North Africa. *Plant Soil*., **58**: 1-28.
20. Mahdi, L., Bell, C. J., and Ryan, J. 1996. Non-vitreousness ("Yellow Berry") in Durum Wheat as Affected by Both Soil Depth and Date of Planting. *Cereal Res. Commun*., **24 (3)**: 347-352.
21. Malakouti, M. J. 1997a. Potassium Status in Soils and Crops, Recommendations and Present Use. In: "*Food Security in the WANA Region, The Essential Need for Balanced Fertilization*". Johnston, A. E. (Ed.), International Potash Institute, Basel, Switzerland, PP. 66-70.
22. Malakouti, M. J. 1997b. Nutrient Balance and Chemical Fertilizer Control in Iran. In: "*Accomplishments and Future Challenges in Dryland Soil Fertility Research in the Mediterranean Area*". (Ed.) Ryan, J. ICARDA, Aleppo, Syria. P. 260-266.
23. Malakouti, M. J., Majidi, A. and Bybordi, A. 2007. The Role of Zinc on the Reduction of PA/Zn Molar Ratio in Wheat Grains and Human Nutrition. *ZINC CROPS 2007*, Istanbul, Turkey. May 24-26.
24. Masri, Z., and Ryan, J. 2006. Soil Organic Matter and Related Physical Properties in a Mediterranean Wheat-based Long-term Rotation Trial. *Soil Till. Res*., **87 (3)**: 146-154.
25. Matar, A., Torrent, J. and Ryan, J. 1992. Soil and Fertilizer Phosphorus and Crop Responses in the Dryland Mediterranean Zone. *Adv. Soil Sci*. **18**: 81-146.
26. Materon, L., and Ryan, J. 1995. Rhizobial Inoculation, and Phosphorus and Zinc Nutrition for Annual Medics (*Medicago spp*) Adapted to Mediterranean-type Environments. *Agron. J*. **87**: 692-698.
27. Monteith, J., and Webb, C. 1981. *Soil Water and Nitrogen in Mediterranean-type Environments. Developments in Plant and Soil Sciences*, Vol. 1. Martinus Nijhoff/Dr. Junk, W. Publ., The Hague, Holland.
28. Oweis, T., Pala, M. and Ryan, J. 1998. Stabilizing Rainfed Wheat Yields with Supplemental Irrigation in the Mediterranean Region. *Agron. J*., **90**: 672-681.
29. Pala, J., Matar, A. and Mazid, A. 1996. Assessment of the Effects of Environmental Factors on the Response of Wheat to Fertilizers in a Mediterranean Environment. *Expl. Agric*., **36**: 339-349.
30. Rashid, A. and Ryan, J. 2004. Micronutrient Constraints to Crop Production in Soils with a Mediterranean-type Climate. *J. Plant Nutr*., **27(6)**: 959-975.
31. Rashid, A. and Ryan, J. 2007. Micronutrient Constraints to Crop Production in the Near East; Potential Significance and Management Strategies. "*Micronutrients Deficiencies in Global Crop Production*". (Ed.), Alloway, B. A., International Fertilizer Industry Association, Paris, France. PP. 149-180.
32. Roozitalab, M. H. 2005. Global Food Security and Sustainable Agricultural Development in the Region of West Asia and North Africa. In: "*Sustainable development and management of drylands in the twenty-first century*". El-Beltagy and Saxena (Ed.) ICARDA, Aleppo, Syria.
33. Ryan, J. 1983. Phosphorus in Soils of Arid Regions. *Geoderma*., **19**: 341-354.
34. Ryan, J. (Ed.). 1997. *Accomplishments and Future Challenges in Dryland Soil Fertility Research in the Mediterranean Area*. Proceedings, International Soil Fertility Workshop, Nov. 19-23, 1995, ICARDA, Aleppo, Syria.
35. Ryan, J. 1998. Changes in Organic Carbon in Long-term Rotation and Tillage Trials in Northern Syria. "*Management of Carbon Sequestration in Soil* " P. 285-296.
36. Ryan, J. 2000. *Plant Nutrient Management under Pressurized Irrigation Systems*. Proceedings of an International Workshop,

April 25-27, 1999. ICARDA, Aleppo, Syria, and IMPHOS, Casablanca, Morocco.
37. Ryan, J. 2002. Available Soil Nutrients and Fertilizer use in Relation to Crop Production in the Mediterranean Area. PP. 123-246. In: "*Soil Fertility and Crop Production*". (Ed.) Khrisna, K. R. Science Publ., Enfield, New Hampshire, USA.
38. Ryan, J. 2003. Phosphorus use in Dryland Agriculture: the Perspective from Syria. P. 500-513. In: "*Innovative Soil-plant Systems for Sustainable Agricultural Practices*". (Ed.) Lynch, J. M., Sheppers, J. S. and Unver, I., OECD, Paris, France, and Tubitak, Ankara, Turkey.
39. Ryan, J. 2004. Soil Fertility Enhancement in Mediterranean Agriculture: a Perspective for Development. In: "*Challenges and Strategies of Dryland Agriculture*". (Ed.) Rao, S. and Ryan, J., *Crop Sci. Soc. Am.* Special Publ. No. 32, Madison, WI, USA. PP. 275-290.
40. Ryan, J., Curtin, D. and Safi, I. 1981. Ammonia Volatilization as Influenced by Calcium Carbonate Particle Size and Iron Oxides. *Soil Sci. Soc. Am. J.* **45**: 338-341.
41. Ryan, J., Saghir, A. R., Shaffyuddin, M. and Barsumian, A. 1982. Agronomic Evaluation of "Cytozyme" as a Crop Growth Regulator. *Agron. J*., **74**:144-146.
42. Ryan, J., Shwayri, R. and Hariq, S. N. 1985a. Short-term Evaluation of Non-conventional Organic Wastes. *Agric. Wastes*., **12**: 241-249.
43. Ryan, J., Curtin, D. and Cheema, M. A. 1985b. Significance of Iron Oxides and Calcium Carbonate Particle Size in Phosphorus Sorption and Desorption in Calcareous Soils. *Soil Sci. Soc. Am. J*., **49**: 74-76.
44. Ryan, J., and Matar, A. 1992. *Fertilizer Use Efficiency Worker Rainfed Agriculture in West Asia and North Africa*. Proceedeings, Fourth Regional Soil Test Calibration Workshop, 5-10 May, 1991, Agadir, Morocco. ICARDA, Aleppo, Syria.
45. Ryan, J. and Mazid, A. 2003. *Fertilizer Use in Syria*. Food and Agriculture Organization. Soil and Fertilizer Bulletin, Rome, Italy.
46. Ryan, J., Materon, L. and Christensen, S. 1995. The Networks for Research Collaboration in the Dryland West Asia-North Africa Region. *J. Nat.Res. Life Sci. Educ*., **24**: 155-160.
47. Ryan, J. and Abdel Monem, M. 1998. Soil Fertility for Sustained Production in the West Asia-North Africa Region: The Need for Long-term Research. In: "*Soil Quality and Agricultural Sustainability*". (Ed.) Lal, R., Ann Arbor Press, Chelsea, MI, USA.
48. Ryan, J., de Pauw, E., Gomez, H. and Mrabet. R. 2006. Drylands of the Mediterranean Zone: Biophysical Resources and Cropping Systems. In: "Agron. Monograph, "*Dryland Agriculture*". (Ed.) Peterson *et al*., G. A. Amer. Soc. Agron., Madison, WI, USA. PP. 577-624.
49. Ryan, J., Hasan, H., Bassiri, M. and Tabbara, H. S. 1985c. Availability and Transformation of Applied Phosphorous in Calcareous Lebanese Soils. *Soil Sci. Soc. Am. J*., **49**: 1215-1220.
50. Ryan, J., Singh, M. Yau, S. K. and Masri, S. 1998. Excess Boron in Syrian Soils and Implications for Plant Growth. *Soil Till. Res*., **45 (3/4)**: 407-417.
51. Ryan, J., Hasbany, R. and Atallah, T. 2003. Factors Affecting Nitrogen Mineralization under Laboratory Conditions with Soils from a Wheat-based Rotation Trial. *Lebanese Sci. J*., **2**: 3-12.
52. Ryan, J., Masri, S. and Qadir, M. 2006. Nutrient Monitoring of Sewage Water for Irrigation: Impacts on Soil Quality and Crop Nutrition. Commun. *Soil Sci. Plant Anal*. **37 (15-20)**: 2513-2522.
53. Ryan, J., Masri, S. and Garabet, S. 1996. Geographical Distribution of Micronutrient Soil Test Values in Syria and their Relationship to Crop Response. *Commun. Soil Sci. Plant Anal.* **27(5-8)**: 1579-1593.
54. Ryan, J., Masri, S. and Masri, Z. 1997. Potassium in Syrian Soils: Implications for Crop Growth and Fertilizer Needs. In: "*Food Security in the WANA Region: The Essential Need for Balanced Fertilization*". (Ed.) Johnstown, A. E., Bornova, Turkey, May 26-30, 1997. Int. Potash Inst., Basel, Switzerland. PP. 134-145.
55. Yau, S. K, Nachit, M. and Ryan, J. 1997. Varieties in Growth, Development and Yield of Durum wheat in Response to High Soil Boron. 2. Differences between Genotypes. *Aust. J. Agric. Res*., **48**: 951-957

J. Agric. Sci. Technol. (2008) Vol. 10: 295-306

عناصر غذایی گیاهان و تولید پایدار کشاورزی در مناطق مدیترانه‌ای با تنش خشکی

ج. ریان

چکیده

در بیشتر مناطق جهان با بارندگی محدود، تولید و بهره‌وری کشاورزی پایین می‌باشد و این در حالی است که نرخ رشد جمعیت بالا است ، در نتیجه تقاضا برای مواد غذایی بیشتر خواهد شد. در مناطق خشک و نیمه‌خشک جهان امکان تولید بیوماس گیاهی به صورت متنوع از زراعت دیم، مراتع طبیعی، بوته زارهای پراکنده و حتی در اراضی بیابانی وجود دارد. در شرایط اقلیمی سخت نظیر غرب‌آسیا و شمال آفریقا که کمتر از ۱۰ درصد مساحت اراضی مناسب زراعت دیم می‌باشد، شرایط منابع خاک شکننده و زراعت بسیار دشوار است. بنابراین با استفاده از مدیریت حاصلخیزی خاك و زراعت در چارچوب یک مجموعه فعالیتهای کشاورزی نظیر اصلاح نباتات، خاك‌ورزی حفاظتی و تناوب، افزایش تولید به میزان زیادی در سطح مزرعه امکانپذیر خواهد بود. علی‌رغم محدودیت آبهای سطحی و زیرزمینی، آبیاری در دهه‌های گذشته به میزان قابل توجهی افزایش پیدا کرده است که این امر تأثیر عمده‌ای در افزایش تولید محصولات زراعی داشته است. تحقیقات کاربردی در منطقه نشان داده است که امکان افزایش تولیدات کشاورزی به مقدار زیادی با استفاده از تغذیه مناسب گیاهان از طریق مصرف کودهای شیمیایی وجود دارد. افزایش قابل ملاحظه تولیدات زراعی در تعدادی از کشورهای منطقه به سه عامل آب، کود و ارقام پرمحصول نسبت داده می‌شود. فناوریهایی که امکان افزایش تولید محصول در سطح بالایی دارند شامل شناخت تنشهای تغذیه گیاهان و چگونگی اصلاح آن با توجه به شرایط گیاه و خاك می‌باشند. اگر مدیریت صحیح اعمال شود، سیستمهای زراعی نوین می‌تواند بر این محدودیتهای فایق شده و در عین حال موجب اصلاح شرایط خاکها شود. علی‌رغم پیشرفتهای بدست آمده در فناوری زیستی، تولید ارقام زراعی و سیستمهای تلفیقی زراعت، مصرف کودهای شیمیایی در آینده همچنان نقش مهمی در تغذیه گیاهان در زراعت آبی و دیم منطقه مدیترانه خواهند داشت. تحقیقات روی تغذیه گیاهان باید هماهنگ با توسعه زراعت پیشرفت حاصل کند. چالش آینده در حاصلخیزی خاك و تغذیه گیاه به همان اندازه که به مسائل مربوط به انتقال فناوری در سطح مزارع ارتباط دارد، به تولید دانش جدید نیز بستگی دارد. در این مقاله‌که براساس تجربیات ۳۲ ساله نویسنده در منطقه غرب آسیا و شمال آفریقا در زمینه حاصلخیزی خاك و تغذیه گیاه استوار است، تلاش می‌شود تا مروری بر تحقیقات انجام شده در چارچوب شناخت تنگناهای تولیدات کشاورزی انجام شود و دورنمای همکاری بین مؤسسات بین‌المللی و برنامه ملی تحقیقات کشاورزی بررسی شود.