Chapter 5
Plant Nutrient Management in Rainfed Farming Systems

With Particular Reference to the Soils and Climate of the Mediterranean Region

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Abstract Global population growth and land-use pressure are placing increasing emphasis on expanding crop and animal output in rainfed agriculture. Rainfed areas of the world have some common features, but some unique biophysical and socio-cultural conditions. Rainfed agriculture in the Mediterranean region is characterised by cropping systems that have evolved from antiquity. The limited and seasonally variable rainfall exerts a major influence on the farming systems, which include production of cereals (wheat and barley) in harmony with livestock (sheep and goats). The region’s soils have been ‘nutrient mined’ for millennia and degraded through erosion; this poses constraints to output that are compounded by adverse socio-economic factors. The challenge to increase agricultural output centres on the adoption of technologies such as improved crop cultivars and enhanced crop nutrition. Chemical fertilisers are fundamental to producing more crop output from existing land in cultivation. The use of N and P, particularly has changed a once traditional low-input system to a high-input, relatively intensive one over the past 30 years. This chapter briefly examines the interactions of climatic and soil conditions in terms of how they impinge on crop nutrient use within a systems context, with emphasis on productivity and sustainability. Reference is made to the maintenance of chemical and physical fertility in rainfed cropping systems, balanced fertilisation, efficient use of nutrients in relation to crop rotations and soil moisture, exploitation of biological N fixation, implications of spatial and temporal variability, and factors conditioning change in the region’s rainfed agricultural sector.

Keywords Efficient fertiliser use • Soil quality • Nutrient variability • Balanced fertilisation

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5.1 Introduction

Despite the advances that have been made in agricultural production through research and technology transfer in the past half century (see Chap. 7), many areas of the world still fail to meet the nutritional needs of their people. The food supply–demand equation has become unbalanced through excessive population growth while many of the world’s poorest countries lie in low rainfall regions. In fostering agricultural output, Nobel Laureate Norman Borlaug (2003) contended that substantial gains can be made with improved tillage, water use, fertilisation, weed and pest control, and harvesting, as well as by conventional breeding and biotechnology. Particular emphasis is placed on the use of commercial chemical fertiliser as a key element. Borlaug estimated that chemical fertiliser use would have to increase several fold in the coming decades and cautioned against the erroneous public perception that organic nutrient sources could replace chemical fertiliser.

A recent analysis of world fertiliser use concluded that at least 50% of crop yields are attributable to commercial fertiliser nutrient use (Stewart et al. 2005). The other crop nutrients come from organic sources, natural soil reserves, and biological nitrogen (N) fixation. As future increases in crop production will have to come from higher yields from land already in production, the contribution of added fertiliser nutrients will be proportionally greater in the future. However, efficient fertiliser use is required to produce adequate, high-quality food while containing costs and limiting environmental impact.

Great disparities exist between countries in terms of societal wealth, access to food and medicine, general wellbeing and living standards. This chapter will study the lands around the Mediterranean, i.e. West Asia and North Africa (WANA) to explore plant nutrient management. The region is mainly arid to semi-arid; there is generally a food deficit, with only a few countries, such as Turkey and Syria, approaching self-sufficiency (Ryan et al. 2006). As in many developing countries, climatic, socio-economic, political and biophysical constraints plague agriculture in the WANA region (Kassam 1981). This is ironic since the region is the centre of origin of many of the world’s crops and forage species – cereals, pulses, nuts – and where settled agriculture and civilisation began (Harlan 1992).

Recognition of the urgent needs of the region has underpinned efforts by the various national governments to promote agricultural development through applied research (Rao and Ryan 2004), in particular with the establishment of the International Center for Agricultural Research in the Dry Areas (ICARDA) in Aleppo, Syria, in 1977. The Center has a global mandate for the agronomy of some rainfed crops (lentil, barley, and faba bean) in developing countries, as well as water use efficiency, rangelands, and small ruminants in those countries. It has a regional mandate (Central and West Asia and North Africa) for wheat (bread and durum), chickpea, pasture and forage legumes, and farming systems. As in other areas of the world, improvements in food production in the mainly rainfed WANA region will depend on the application of new technologies and intensification of management of land already in cultivation. This can only occur by exploiting the synergies
between the various biophysical and human factors involved in food production within the context of global economic forces. The process of development of rainfed agriculture in the WANA region requires an understanding of both biophysical and socioeconomic constraints that impinge upon this sector.

In addressing rainfed farming systems across the entire region, ICARDA was aided by its location in northern Syria, where rainfall conditions from the very dry to the highly favourable occur within a short distance from its headquarters at Tel Hadya near Aleppo (Fig. 5.1). Consequently, many of the findings emanating from its field stations in Syria and Lebanon are applicable to the WANA region as a whole.

### 5.2 Climate, Soils, Cropping, and Socioeconomic Conditions

Agriculture in WANA has traditionally been subsistence rainfed farming, highly labour-intensive but with low production (Gibbon 1981, Chap. 15). The soils have been overused – perhaps for millennia – with few inputs and, in many cases, severely eroded. The addition of fertilisers and the rebuilding of soil fertility is
therefore of primary importance. Fertiliser use has increased considerably in the past few decades (Ryan 2002). Farm holdings are generally small (<10 ha) and often in fragmented parcels (Shroyer et al. 1990). Effective change in land management is often hindered by traditional inheritance laws, tribal and common lands, and nomadism, while most farmers have little formal education. Support services are less than satisfactory for most rural communities; there is limited credit, poor road and distribution systems, and weak marketing and research. The private commercial sector is generally poorly developed in most countries (Ryan 2002). Socio-economic constraints are often as insurmountable as the biophysical ones.

With increasing pressure on land use driven by high population, especially in rural areas, cropping has to be intensified as cultivable land cannot be expanded. Agriculture in the WANA region is described in detail in Chap. 15.

The vast WANA region exhibits great diversity in its landscapes, climate, natural resources and its people, but it has many common features – notably low rainfall (Kassam 1981) and a Mediterranean climate that merges into a continental climate inland. Winters are cool to cold and wet while summers are warm to hot and arid. Rainfall is generally low (200–600 mm) and variable, with periodic drought. However, rainfall concentration at the cooler time of the year (November–April) provides an opportunity for cropping (Harris 1995). Crops may depend on winter-stored soil water to complete their life cycle in spring. Invariably, there is some degree of moisture stress during the grain-filling stage (Pala et al. 2004).

Soil properties which dictate crop growth and yields include soil depth, which limits the water-holding capacity of the soil and thus its capacity to support rainfed crops; lighter soil texture restricts soil capacity to hold moisture for crop growth. While deep clay soils are inherently productive, shallow soils are particularly vulnerable to soil erosion. The low organic matter (OM) (<1%) in the region’s soils have implications for physical properties such as aggregate stability (Masri and Ryan 2006) and chemical fertility; low organic matter also implies low reserves of available soil nutrients, particularly nitrogen (Ryan and Matar 1992; Ryan 1997). Soil chemical properties such as pH (commonly alkaline in the region) also have a determining influence on nutrient dynamics and availability in soils.

The solubility relationships dictated by high pH and CaCO$_3$ combine to reduce available P in soils; and to reduce the availability of P added as a fertiliser. Consequently, the use efficiency of P is much lower than that of N, being in the order of 5–10% in the initial cropping year after fertiliser application. However, recent evidence from long-term field studies suggests that much, if not all, the P precipitated or immobilised in the soil may ultimately be taken up by the crop (Syers et al. 2008). Most soils that have not been fertilised are invariably P deficient, with severe limitation of the crop’s yield potential (Matar et al. 1992). High soil pH in the Mediterranean region also reduces the plant availability of micronutrients such as zinc. Various field studies in Turkey (Cakmak 1998) and Syria (Materon and Ryan 1995) have shown crop growth responses to added zinc.
5.3 Balanced Use of Nutrients in Rainfed Cropping Systems

The concept of ‘balanced fertilisation’ implies meeting the individual nutrient needs of crops according to their physiological requirements and expected yields. This means the deliberate application of all nutrients that the soil cannot supply in adequate amounts for optimum crop yields. It depends on soil test values and requires estimates of what crops remove. There is no fixed recipe as it is soil and crop-specific.

The concept is old and based on Liebig’s ‘Law of the minimum’, that is that any deficiency of one nutrient will severely limit the efficiency of others. It has been developed into two approaches to balanced fertilisation (Johnston 1997): (1) balanced nutrition by supplying nutrients in the correct physiological ratios for optimum growth of specific crops, and (2) adding nutrients in amounts that do not exceed what the crop removes. In a recent overview of optimising plant nutrition for food security, Roy et al. (2006) equated balanced fertilisation with balanced plant nutrition. The fertiliser requirements for a particular crop can be determined by the difference in the amount available (soil test) and the amount required by the crop. The ratio of individual nutrients will vary with the soil and the crop. In theory, fertiliser practices (such as providing specific crop needs, appropriate fertilisers and application methods) are developed by applied agricultural research and conveyed to farmers by extension personnel. The absence of an effective extension agency in most developing countries is a stumbling block to effective technology transfer in the area of crop fertilisation. Farmers have to depend on a variety of sources of information, including fertiliser dealers and other farmers.

The concept of balanced fertilisation has been influenced by trends in global fertiliser use. These have remained static over the past two decades or have even declined in ‘developed’ and ‘transition’ economies. The only increases have been in developing countries (IFA 2006). At the global level, only N use increased in this period, with a decline in both P and K consumption.

Data from major rainfed agriculture such as in Syria, Turkey, and Morocco are in line with global trends in fertiliser use, but are of differing magnitude (IFA 2006). Before 1970, little fertiliser was used in these countries, but this was followed by a rapid increase in use of N and P, with limited amounts of K. Both N and P use seem to be relatively stable in the last decade, although various circumstances such as internal fertiliser production, importation and marketing, can influence the amounts of fertiliser nutrients used in any 1 year.

The variability in N and P use in the region, and the minimal K use, raise the question of how appropriate are the ratios of nutrients applied to satisfy specific crop needs. In developed countries, examples of ratios of applied NPK are 1.0: 0.30: 0.30 in the UK and 1.0: 0.38: 0.44 in the USA; in the WANA region, corresponding nutrient ratios are 1.0: 0.52: 0.23 in Morocco, 1.0: 2.0: 0.50 in Jordan, 1.0: 0.41: 0.06 in Turkey, and 1.0: 0.83: 0.06 in Tunisia. Most of these countries are dominated by rainfed agriculture. These differences between countries suggest that there is an imbalance of fertiliser nutrients applied in many countries of the region.
Where use of K is minimal in intensive cropping, deficiencies of this nutrient are likely to occur and lead to ‘soil mining’. When the ratio of N to P is close to, or greater than 1, either too much P is used or not enough N is used. However, balanced fertilisation has to consider site-specific conditions, especially with respect to available soil nutrient status.

5.4 Sustaining Soil Fertility and Related Physical Properties

Crop production is limited directly by nutrient availability of the soils and indirectly by physical limitations. Nutrients may be immediately available for uptake and utilisation by the growing crop or may be slowly released from less soluble inorganic sources or from mineralisation of soil organic matter. While deficiencies in fertility may be rectified by fertiliser application, improvements in physical properties are less easily obtained.

5.4.1 Nutrients for Crop Production

Crop production strategies are based on diagnosing nutrient deficiencies and establishing a rational basis for chemical fertiliser application (Brown 1987). Significant contributions have been made to both areas by the Soil Test Calibration Network that has involved most countries of WANA with significant rainfed agriculture (Ryan and Matar 1990, 1992; Ryan 1997). Measurement of both the soil and the growing crop can provide the basis for efficient fertilisation and crop nutrition (Roy et al. 2006). The main approach is through soil analysis, the initial phase of which involves developing appropriate tests with values that correlate with plant nutrient uptake.

The Olsen test was adopted as suitable for the mainly calcareous soils of the Mediterranean region; the critical range is 5–7 mg P/kg of oven dry soil. The measurement of soil nitrate to indicate N sufficiency was less reliable due to changes from fertiliser use. The DTPA test of Lindsay and Norvell1 (1978) was deemed adequate for micronutrients and is widely used; a multi-nutrient extractant such as the ammonium bicarbonate or AB-DTPA test (Soltanpour 1985) is used in Pakistan.

The second phase of testing involves calibration or developing guidelines for fertiliser recommendations in the field; in this way, ‘critical’ levels can be established below which a nutrient level in soil is deficient, with a probable response to fertiliser, and a point beyond which there is no need to apply fertiliser. Other factors such as soil type, soil moisture or rainfall, and nutrient spatial variability have to be considered in practical field situations (Ryan 2004).

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1 A test for micronutrients using DPTA (diethylenetriaminepentaacetic acid).
A less reliable approach to assessing fertiliser needs involves the crop itself. Plant symptoms can indicate the severe deficiency, but other factors such as drought or disease can mask the symptoms. Analysis of the plant tissue is more reliable for a particular nutrient. Appropriate guidelines for sampling, handling and analysing the tissues, along with criteria for the range from deficiency to adequacy have been developed (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. 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 (including the WANA region) and, in some countries, not at all. The major obstacles to such approaches include a weak extension sector, the absence of laboratory facilities for analyses, and limited applied, on-farm research related to soil fertility and fertiliser use. Nevertheless, much has been done through the regional Soil Test Calibration Program to promote the awareness of the soil analysis in the agriculture of WANA (Ryan and Matar 1990, 1992; Ryan 1997). Soil analysis is likely to be adopted as a tool in fertility–crop nutrient management as crop intensification increases, especially with irrigation and the increasing use of fertilisers. However, farming in developing countries is, and will remain, a long way from a developed country situation where precision agriculture allows nutrient application to be tailored to specific parts of a field (see Chap. 34). With pressure on land use, cropping intensity in developing countries will inevitably increase, with fertilisers having a major influence.

How efficiently fertiliser is used over large areas depends on the variability of the nutrient in the field or paddock. Recognition of this spatial variability is the basic principle behind precision agriculture (Chap. 34).

Some fields are naturally flat and uniform. This tendency to uniformity may be enhanced by a history of uniform management of crops and fertiliser application rates. Small fragmented parcels of land so characteristic of developing world agriculture promote variability (Abdel Monem et al. 1989) which is compounded by grazing, hand application of fertilisers, and variable erosion. Applying a standard rate of fertiliser to a non-uniform field is inefficient; however the only solution is costly, variable rate technology.

### 5.4.2 Soil Physical Properties

In contrast to chemical fertility, some physical properties such as soil texture are fixed, while soil structure depends on soil and crop management. Soil aggregation is mainly influenced by the soil organic matter content. However, in typical red Mediterranean soils (Alfisols), iron oxides can be significant aggregating agents, particularly when the iron is in the amorphous state (Arshad et al. 1980). Poorly structured soils are prone to erosion. Despite the importance of soil organic matter
(SOM) in soils of the WANA region, efforts to document changes on SOM in response to management over time have been limited. SOM content in trials has been listed without elaborating its significance (Ryan 1998). Only where long-term trials have been conducted has it been possible to document the dynamic nature of soil organic matter in relation to cropping over time, as in studies of crop rotations in northern Syria (Ryan et al. 2008a). Legume-based rotations and N fertilisation can each increase total SOM as well as labile\textsuperscript{2} and biomass C forms (Ryan et al. 2002, 2008c). However, only one study (Masri and Ryan 2006) showed that these crop/fertiliser induced changes in SOM were accompanied by improvements in soil physical properties such as aggregate stability, water infiltration and permeability (See also Chap. 15).

It is reasonable to assume that any practice that enhances soil organic matter content would also improve aggregation and related physical properties. Such practices could include fertiliser use to increase crop growth, and consequently root biomass. The effectiveness of the increased root biomass in increasing SOM depends on the extent to which tillage could influence mineralisation of the OM from the root biomass. Where there is minimum disturbance as in conservation tillage compared to conventional tillage, SOM is likely to increase (Ryan and Pala 2006). Similarly, the addition of crop residues or compost materials, or minimising stubble grazing can lead to improvements in organic matter and soil structure.

5.5 Crop Nutrients as Influenced by Rainfall and Soil Moisture

The obvious determinant of crop yields in rainfed farming systems is the amount of rainfall and the water use efficiency (WUE) (Stewart and Steiner 1990; Smith and Harris 1981). Any crop or soil management intervention (weed control, fertilising, and tillage) that contributes to increased yield under any given rainfall conditions automatically increases WUE (Matar et al. 1992). WUE can also be influenced by the particular crop sequence (Harris 1995; Pala et al. 2007).

Responses to N application increase as rainfall increases (Harmsen 1984) but, under low rainfall conditions, the relative response to P may be higher than that to N due to a stimulating effect on root growth and therefore soil moisture uptake (Cooper et al. 1987b). Nutrient use efficiency is influenced by variation in rainfall and temperature. Seasonal variability in available N is related to variation in the extent of mineralisation of soil organic matter and by any immobilisation of those nutrients.

Case studies provide an illustration of the interaction of nutrient use with moisture availability. A 4-year study of researcher-managed, on-farm field trials across the

\textsuperscript{2}See Glossary.
rainfall zones in northern Syria showed that wheat yields were strongly correlated with seasonal rainfall (October–May), almost irrespective of soil fertility status, crop sequence or fertiliser application rate (Pala et al. 1996 See also Chap. 1, Fig. 1.9). However, there was an increase in response to applied N with increasing rainfall and with decreasing soil N. In contrast, responses to P tended to be more pronounced under lower rainfall conditions (Jones and Wahbi 1992).

Despite the more obvious interactions of fertiliser with environment (especially rainfall and temperature), there are others of a biological nature. For instance, in Morocco in the 1990s, much effort was expended on stimulating cereal output in the medium-rainfall zone with particular emphasis on control of the devastating pest, the Hessian fly (*Mayetiola destructor*). In trials with wheat cultivars of varying resistance to Hessian Fly, the application of fertiliser N was shown to enhance tolerance of the pest (Ryan et al. 1991). In contrast, the addition of N had variable effects of conferring resistance to the fungal disease, Tan Spot (Jones et al. 1990).

When considering the economics of nutrient application, a more complete analysis than simple cost-benefit is required, to take into account the complex interactions of cropping system components. For example in the W ANA region only one study has assessed rotations in this way (Rodriguez et al. 1999), despite the many bio-physical studies dealing with crops and soils (Ryan et al. 2008a).

### 5.6 Use of Legumes in Crop Sequences

Since the Mediterranean is the centre of origin of many legume species, it is likely that such crops had a significant influence in early settled agriculture (Harlan 1992). Indeed the written record from Grecian and Roman times mentions legumes in the context of rotations with cereals and the predominantly cereal–fallow systems which sustained cropping in such a water-stressed environment (Karlen et al. 1994). Both Greeks and Romans recognised that legumes benefited cereal crops without being aware that this was related to N. Despite the antiquity of legumes, their use had declined over the centuries. However, in the past century, legumes, particularly forages, have shown a resurgence in many areas of the world. In Australia forage and pasture legumes in a cereal-sheep ley farming system (Puckridge and French 1983) have supplied both fodder for livestock and mineralised N for the subsequent cereal crop (Hossain et al. 1996). Similarly, the benefits of legumes in rotation with cereals was clearly recognized in the USA for enhancing soil N (Carpenter-Boggs et al. 2000) and for providing crop diversification (Norwood 2000).

Only in more recent times has the potential of legumes in rainfed agriculture been recognized in developing countries. The rationale for the resurgence of interest in food and forage legumes was articulated by Harris (1995) in the context of the Mediterranean region, where population and land-use pressure contributed to decreasing fallow and led to continuous cereal cropping. Similarly, with increasing populations of small ruminants, increasing pressure for livestock feed was put on marginal areas with consequent risks of land degradation.
Various crop rotation studies by ICARDA (Ryan et al. 2008a) show a strong impact of rotation sequence not only on soil properties, especially SOM (Ryan et al. 2008c), but also on WUE (Pala et al. 2007) and nutrient use (discussed in detail for WANA in Chap. 15).

The inclusion of legumes, particularly forage legumes, in the cereal-based rotation leads to an increase in nitrogen rich SOM, and thus an increase in the reserve of potentially available N. Not surprisingly, these increases in total SOM are accompanied by parallel increases in total mineral N as well as both labile and biomass N forms (Ryan et al. 2008d). The outcome of the increased N in legume-based rotations is higher N availability to the alternative wheat crop, with a correspondingly lower response to and need for fertiliser N. An example of the cumulative effect of N fixation by a forage legume on cereal growth is illustrated in Fig. 5.2.

The nutrient status of a soil varies over time, partly due to nutrient removal in harvested crops. For example cereal–legume rotations require regular P application (demonstrated in a range of rainfall zones by Ryan et al. 2008b). However, in these situations, there is usually a gradual build-up in available P over time which will call for changes in the amounts of fertiliser required to maximise both economic and nutrient use efficiency.

The belief that legumes could contribute both to cropping sustainability and to relieving grazing pressure on marginal lands laid the foundation of the extensive research on N fixation and related areas from 1980 to 1995 (Harris 1995; Ryan et al. 2008a). The success of biological nitrogen fixation (BNF) by legumes depends on the correct match between the \textit{Rhizobium} strain, host legume variety and the environment (Beck 1992). All these factors must be considered when introducing new legumes into a rotation.

\textbf{Fig. 5.2} A comparison of wheat growth in the medic rotation—medic in the alternate year (right), with wheat in the fallow rotation without added N
Various surveys in cropped fields throughout the WANA region (Syria, Turkey, Jordan, and Egypt) involved characterisation of the rhizobia (Moawad and Beck 1991) for tolerance to high temperature and salt, as well as antibiotic resistance. Based on the variation in the environment, legumes were inoculated with superior *Rhizobium* strains in areas where these legumes had not been previously grown. The use of $^{15}$N methodology and non-nodulating chickpea\(^3\) and barley as reference crops allowed for accurate evaluation of $\text{N}_2$ fixation under a wide range of environmental conditions (Beck 1992); $\text{N}$ fixation was higher under more favourable rainfall environments than in drier areas. The goal of good crop management should be to maximise the contribution of BNF through legumes and reduce the contribution of $\text{N}$ from the soil (Beck et al. 1991). The $\text{N}$ from legumes contributes substantially to the subsequent crops.

The WANA region provides a wide range of naturally occurring legumes and associated rhizobial communities. This wide genetic diversity is of great potential importance to cereal–legume systems, not only for the region but around the world (Keatinge et al. 1995). For example, rhizobial cultures from Turkey and northern Africa have been selected on the basis of climatological parameters, such as average minimum and maximum temperatures in the coldest month (January).

Medic–rhizobial associations in forage and pasture have been sought for tolerance to the cold winter conditions. The pasture may grow in such cold conditions but the rhizobia should also be able to fix $\text{N}$ under the same conditions. While cold tolerance is a factor in effectiveness of rhizobial–medic associations, nutrient deficiencies limit the growth of medics and their BNF effectiveness. The early research related to BNF in food legumes laid a firm basis for the widespread adoption of these crops. Chickpea and lentil (and vetch for forage) are now well established in the agricultural system in the region but the story of forage legumes is more chequered. Provided that a legume and rhizobium combination adapted to the climate and soils can be found, it can largely replace the need for fertiliser $\text{N}$. The use of legumes in the WANA region is discussed in the section on rotations in Chap. 15.

### 5.7 Conclusions

Achieving the correct nutrient balance is one of the keys to achieving productive and sustainable farming systems. The complex rainfed farming systems of the Middle East are a prime example. Their components include crops, livestock and forages (Fig. 5.3). As with many parts of the world, the socio-economic factors intrude on all aspects of the region’s agriculture, which for many remains a way of life rather than purely an economic enterprise. As elsewhere, the region’s agricultural system is markedly affected by the rapidly expanding populations, especially in rural areas, combined with the limited off-farm economic opportunities for gainful employment.

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\(^3\)A strain of chickpea bred for trial purposes.
Having been farmed for millennia, the region has an element of resilience in its agricultural system. Nevertheless, the sub-optimal traditional practices are undergoing inexorable change.

Today’s agriculture is more concerned with both productivity and profitability of the crop and livestock sector since subsistence and self-reliance are being replaced, albeit slowly, by a market-driven system. The pressure, by urbanisation, to intensify more output from the same area of land leads to concerns about degradation of the soil and water resource base. To produce more from less land requires more nutrients from fertilisers, as well as the use of pesticides and mechanisation. In working with nature, the diversity with respect to biological nitrogen fixation can be exploited to sustain cropping and reducing the need for fertiliser N.

In rainfed farming systems, no component can be considered in isolation. Fertilisers are pivotal to improving agricultural output, but they must be used rationally, taking into consideration constraints imposed by the limited rainfall and inherent soil properties. Sustainability of the soil resource base can be indirectly enhanced by fertiliser use, especially when used in a systems context. Balanced fertiliser application can lead to its more efficient use for production as well as for minimising adverse environmental impacts. Awareness of differences between soil types and spatial variability within soils can lead to a more rational and more efficient use of fertilisers.

In addition to the changes that are occurring within the rainfed farming sector of the WANA region, a major development has been the use of supplemental irrigation to stabilise crop yields within traditionally rainfed areas. Inevitably, that trend will be slowed or halted by limitations on groundwater and surface water sources. As most semi-arid or rainfed areas of the world are likely to be negatively impacted by climate change, the challenges to rainfed cropping in the Mediterranean region are daunting.
References

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