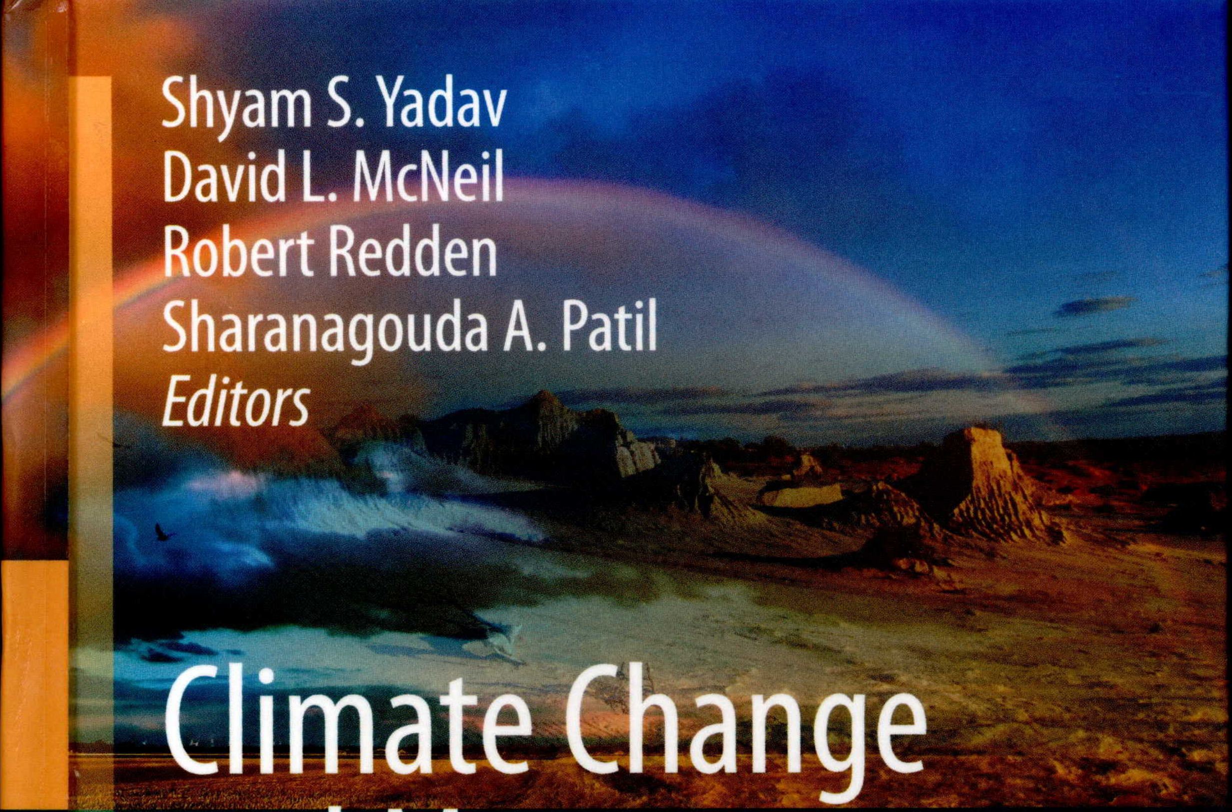

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Chapter 11
Nutrients Use Efficiency in Legume Crops to Climatic Changes

José L. García-Hernández, Ignacio Orona-Castillo, Pablo Preciado-Rangel, Arnoldo Flores-Hernández, Bernardo Murillo-Amador, and Enrique Troyo-Diéguez

11.1 Introduction

Increased intensity and frequency of storms, drought and flooding, altered hydrological cycles and precipitation variance, increased CO_2 and increased temperatures have implications for future food availability (IWGCC, 2007) and hence legume availability as a major global food source. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) dismissed many uncertainties about climate change. Warming of the climate system is now unequivocal and according to IPCC the increase in global temperatures observed since the mid-twentieth century is predominantly due to human activities such as fossil fuel burning and land use changes. Projections for the twenty-first century show that global warming will accelerate with predictions of the average increase in global temperature ranging from 1.8 to 4°C. The primary greenhouse gases associated with agriculture are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_20). Climate change is a global problem, affecting every nation and every living thing including cool season legumes as covered in this book.

These changes have implications for food production, food security and food safety. It is widely understood that the risks of global climate change occurring as a consequence of human behavior are inequitably distributed, since most of the actions causing climate change originate from the developed world, but the less developed world is likely to bear the brunt of the public health burden (Campbell-Lendrum et al., 2007).

The 670–750 genera and 18,000–19,000 species of legumes (Polhill et al., 1981) include important grain, pasture, and agro-forestry species (Graham and Vance, 2003), and they are going to play a very important role in the possible alterations in nutrient use efficiency under climatic change. Crop nutrients, particularly nitrogen, are intimately involved with the soil's exchange of gases involved in warming the

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global climate (Bruulsema and Griffith, 1997). Improving of nutrient use in agriculture, carbon sequestration and reductions in greenhouse gas emissions can occur through a variety of agriculture practices (Schahczenski and Hill, 2009). This work provides an overview of the relationship between agriculture, climate change, and nutrient use efficiency, and also suggests possible options for farmers and ranchers to have a positive impact on the changing climate and presents opportunities around incorporation of legumes and sustainable practices in cropping systems to improve nutrient use efficiency.

11.1.1 Environmental Degradation and Accelerated Desertification

Agriculture soil and water contamination and variation on levels of contaminants have been associated with alternate periods of floods and droughts. The frequency of these seasonal periods will be increased due to increased climate variability and changes. Impacts of climate change in physical systems or processes are exacerbated in areas where the environment has been damaged by humans for agriculture, mining or industrial purposes (Abberton et al., 2008).

These impacts may lead to very highly contaminated regions and therefore contamination and effects on local food supply. An illustrative example is the Aral Sea in Central Asia, which was once the fourth-largest lake in the world and has been one of the world's largest environmental disasters during the last 20 years. In the Aral Sea area, agriculture mis-management and accelerated desertification due to both environmental degradation and climate change, have resulted in serious contamination of soil, water and local foods with high levels of POPs and dioxins, leading to critical health and socio-economic impacts to local populations (Muntean et al., 2003).

11.1.2 Interactions with Soil Processes

Soil is one of the most influenced resources by climate change both directly through elevated CO_2 and indirectly through other environmental changes. That is very relevant for microbial infestation and activity in the soils, which affect the nitrogen fixation by bacteria associated with legumes (Zahran, 1999); a competitive and persistent rhizobial strain is not expected to express its full capacity for nitrogen fixation if limiting factors (e.g., salinity, unfavorable soil pH, nutrient deficiency, mineral toxicity, temperature extremes, insufficient or excessive soil moisture, inadequate photosynthesis, plant diseases, and grazing) impose limitations on the vigor of the host legume (Brockwell et al., 1995; Zahran, 1999). Kimball et al. (2002) have thoroughly reviewed the direct effects of elevated CO_2 on soil microbiology (as well as plant parameters) and indicate published changes in soil biodegradation of residues, mycorrhiza content, microbial N mineralization and gas outputs, disease infections, total microbial activity, soil respiration and importantly rhizobial numbers and infection rates.

Climate change can also potentially alter the transfer and the bioavailability of trace elements from the soil to the plant. Deficiency of nutrients or excess of toxic elements may results in lower resistance to insect, pests and plant diseases including the attack of toxigenic fungi and the consequent biosynthesis of mycotoxins. Fertilizer regimes may affect fungal incidence and severity of colonization either by altering the rate of residue decomposition, by creating a physiological stress on the host plant or by altering the crop structure (Yohe et al., 2007).

11.1.3 Legumes

Grain and forage legumes are grown on some 180 million ha, or 12 to 15% of the Earth's arable surface. They account for 27% of the world's primary crop production, with grain legumes alone contributing 33% of the dietary protein nitrogen needs of humans. Under subsistence conditions, the percentage of legume protein N in the diet can reach twice this figure. In rank order, bean (*Phaseolus vulgaris*), pea (*Pisum sativum*), chickpea (*Cicer arietinum*), broad bean (*Vicia faba*), pigeon pea (*Cajanus cajan*), cowpea (*Vigna unguiculata*), and lentil constitute the primary dietary legumes. Legumes (predominantly soybean and peanut [*Arachis hypogeae*]) also provide more than 35% of the world's processed vegetable oil (Vance et al., 2000; Graham and Vance, 2003).

11.2 Factors Associated with Changing Nutrient Use Efficiency

11.2.1 N-Fixation

A property trait of legumes is their ability to develop root nodules and to fix N_2 in symbiosis with compatible rhizobia. Crop, pasture and tree legumes are very important both ecologically and agriculturally because they are responsible for a substantial part of the global flux of nitrogen from atmospheric N_2 to fixed forms such as ammonia, nitrate, and organic nitrogen. Some 40–60 million metric tons (Mt) of N_2 are fixed by agriculturally important legumes annually, with another 3–5 million Mt fixed by legumes in natural ecosystems (Smil, 1999). This is amazing efficiency given the miniscule quantities of nitrogenase involved (Bruulsema and Griffith, 1997). In addition to its role as a source of protein N in the diet, N from legume fixation is essentially "free" N for use by the host plant or by associated or subsequent crops. Replacing it with fertilizer N would cost $7–10 billion annually, whereas even modest use of alfalfa in rotation with corn could save farmers in the U.S. $200–300 million (Peterson and Russelle, 1991). Furthermore, fertilizer N is frequently unavailable to subsistence farmers, leaving them dependent on N_2 fixation by legumes or other N_2-fixing organisms.

One of the driving forces behind agricultural sustainability is effective management of N in the environment (Graham and Vance, 2000). Application of fertilizer N increased approximately tenfold to 90 million Mt between 1950 and 1995 (Frink et al., 1999) up to 101 million Mt in 2007/8 (Heffer and Prud'homme, 2009) with significant energy consumption for N fertilizer synthesis and application. Further increases in N needs for agriculture are projected for the future (111 million Mt in 2012/2013, Heffer and Prud'homme, 2009) with much of this increased N application aimed at overcoming limitations due to other factors. Limitations which will certainly increase in some regions due to climate change. Legume fixation is seen as a major mechanism to overcome "Progressive Nitrogen Limitation" (PNL) in a world of increasing CO_2 (Luo et al., 2004). PNL results from increasing levels of CO_2 unbalancing C/N ratios and preventing the benefits of the fertilization effects of the CO_2 being realized. There are constraints to N_2 fixation which may reduce the ability of N fixing legumes to overcome PNL. These include drought, soil acidity, N fertilization, and nutrient limitations. Maximum benefits from N_2 fixation depend on soil P availability, while reserves of rock phosphate could be depleted in only 60–90 years (Abelson, 1999).

The ability of legumes to sequester C has also been seen as a means to offset increases in atmospheric CO_2 levels while enhancing soil quality and tilth. Resh et al. (2002) found that soils under N_2-fixing trees sequestered 0.11 kg m^2 $year^{-1}$ of soil organic carbon.

The common bean *Phaseolus vulgaris* is the most important food legume for human consumption worldwide, especially in Latin America and Africa, where its cultivation as a staple food extends into marginal areas. Symbiotic nitrogen-fixation potential in common bean is considered to be low (Pereira and Bliss, 1987) in comparison with other legumes. Nitrogen fixation in common bean is more affected by P deficiency than in other legume crops such as soybean. P is one of the most limiting nutrients for plant growth in the tropics, and it is estimated that over 50% of common bean production in tropical soils is limited by phosphate deficiency (CIAT, 1992; Olivera et al., 2004). Thus future potential benefits of increased fixation and C sequestration by legumes may not be fully realized.

11.2.2 Elevated CO_2, Photosynthesis and Soil Nutrients

CO_2 is one of the greenhouse gases which is rapidly increasing. Recent reviews confirm and extend previous observations that elevated CO_2 concentrations stimulate photosynthesis, leading to increased plant productivity and modified water and nutrient cycles (Kimball et al., 2002; Nowak et al., 2004). Experiments under optimal conditions show that doubling the atmospheric CO_2 concentration increases leaf photosynthesis by 0.30–0.50 in C_3-plant species (including legumes such as soybeans and clover) and by 0.10–0.25 in C_4-species, despite a small but significant down-regulation of leaf photosynthesis by elevated atmospheric CO_2 concentrations at some sites (Ellsworth et al., 2004; Ainsworth and Long, 2005).

A number of studies have found that plants grown in conditions of high nutrient supply respond more strongly to elevated atmospheric CO_2 concentrations than nutrient-stressed plants (Poorter, 1998). Some experiments confirm that high N soil contents increase the relative response to elevated atmospheric CO_2 concentrations

(Nowak et al., 2004). Under elevated atmospheric CO_2 concentrations, *Lolium perenne* showed a significant reduction in the concentration of shoot N (Soussana et al., 1996; Zanetti et al., 1996). With a non-limiting N fertilizer supply, the concentration of leaf N (N, mg g^{-1} dry matter) declined with the dry matter (DM) yield of shoots (DM, g) according to highly significant power models in ambient ($n = 49$ $DM^{-0.38}$) and in elevated ($n = 53$ $DM^{-0.52}$) atmospheric CO_2 concentrations.

When other nutrients are not strongly limiting, a decline in N availability may be prevented by an increase in biological N_2-fixation under elevated atmospheric CO_2 concentrations (Gifford, 1994). Indeed, in fertile grasslands, legumes benefit more from elevated atmospheric CO_2 concentrations than non-fixing species (Hebeisen et al., 1997; Lüscher et al., 1998) resulting in significant increases in symbiotic N_2 fixation and avoidance of PNL. Other nutrients, such as phosphorus, may act as the main limiting factor restricting growth and responses in yield in legumes to atmospheric CO_2 concentrations. Elevated CO_2-induced changes in C and N cycling below-ground. Plants grown under elevated atmospheric CO_2 concentrations generally increase the partitioning of photosynthates to roots which increases the capacity and/or activity of below-ground C sinks.

Studies (Newton et al., 1996; Cardon et al., 2001) have suggested a higher C turnover rather than a substantial net increase in soil C under elevated atmospheric CO_2 concentrations. Elevated atmospheric CO_2 concentrations reduced to a greater extent the harvested N derived from soil than that derived from fertilizer, and significantly increased the recovery of fertilizer-N in the roots and in the particulate soil organic matter fractions (Loiseau and Soussana, 1999). The increase in the immobilization of fertilizer-N in the soil fractions was associated with a decline in fertilizer-N uptake by the grass sward, which supported the hypothesis of a negative feedback of elevated atmospheric CO_2 concentrations on the N yield and uptake of swards. The actual impact of elevated atmospheric CO_2 concentrations on yields in farmers' fields could be less than earlier estimates which did not take into account limitations in availability of nutrients and plant–soil interaction.

Elevated CO_2 concentrations tend to reduce the sensitivity of grassland ecosystems to low levels of precipitation but induce progressive nitrogen (N) limitation on plant growth which can be alleviated by supplying a significant external input of N in the form of mineral fertilizer or through the increased use of N-fixing legumes. Other nutrients, such as phosphorus, can act as the main limiting factor restricting the growth response in legumes to atmospheric CO_2 concentration (Soussana and Lüscher, 2007).

11.2.3 Temperature, Photosynthesis and Soil Nutrients

Warmer temperatures are likely to enhance the growth response of most C_3-dominated grasslands and cropping systems to higher CO_2 and hence their productivity and demand for nutrients, particularly where water is not limiting, as in North and North West Europe (Hopkins and Del Prado, 2006). In high- and mid-latitude rangelands, currently subject to severe cold-temperature restriction on growth rate and duration, warmer temperatures alone are likely to enhance production (Polley et al., 2000). According to Baron and Bélanger (2007), effects in continental America include (a) a limited northward shift in production areas in US and Canada arising from higher temperatures and the frost-free season extending by 1–9 weeks, and (b) subtropical conditions extending further north with changes in relative distribution of C_3 and C_4 species (Abberton et al., 2008). However, in arid and semi-arid zones of Central and South America, Africa, Middle east, Asia and Australia, positive effects of temperature may be lessened or negated by accompanying increases in evapotranspiration and water deficit, leading to reductions in photosynthesis. In a European context, the vulnerability of grassland to negative temperature-related impacts of climate change is likely to be greatest in Mediterranean and southern Europe (Schroter et al., 2005), due to summer heat and drought, and also at the highest latitudes where natural ecosystems are threatened. While demand for nutrients may increase due to temperature induced changes it is not as clear with respect to availability. Soil nutrient mineralization rates may also be affected by increasing temperatures. C and N mineralization generally increases with increasing temperature as does, however, potential losses to the environment. P mineralization may also increase but soil availability may decrease due to more rapid binding or uptake by soil organisms (Nadelhoffer et al., 1991).

11.2.4 Drought, pH, Salinity, and Crop Nutrient Efficiency

Drought problems for legumes are likely to worsen with the projected rapid expansion of water-stressed areas of the world from 28 to 30 countries today to 50 countries encompassing 3 billion people by 2030 (Postel, 2000). There is a crucial need to increase drought tolerance in legumes; increasing salinity tolerance is a parallel requirement in many areas. The more drought-tolerant legumes, such as cowpea, are deeply rooted and may have reduced leaf size with thickened cuticles to reduce water loss. Deep rooting may enhance ability to extract nutrients (and toxic elements) from deep in the profile but drier soils may reduce availability of nutrients in the top of the soil profile. Less tolerant legumes such as beans can be selected for early maturity, efficiency in the partitioning of nutrients toward reproductive structures, and phenotypic plasticity (Beaver et al., 2003). Pinto Villa, now grown over 90% of the pinto bean area in Mexico, has these characteristics. Irrespective of demands from changing climates nutrient depletion of soil is a particular problem for small landholders in developing countries, where much grain-legume production occurs, and many farmers cannot afford to use fertilizers. Sanchez (2002) suggests average annual nutrient depletion rates across 37 African countries of 22 kg N ha^{-1}, 2.5 kg P ha^{-1}, and 15 kg K ha^{-1}. Sardans and Penuelas (2007) indicated in a Mediterranean environment drought increased total soil soluble organic P and reduced both P and K uptake by plants. Thus increased drought due to climate change may have negative effects on NUE.

Soil acidity affects more than 1.5 billion ha worldwide, with acid soil constraints to legume production likely to increase as the result of acid rain, long-term N fertilization, and natural weathering (Graham and Vance, 2000). H ion concentration per se, Al and Mn toxicity, and P, Mo, or Ca deficiency all contribute to the problem (Graham, 1992). Nodulation and N fixation and survival of rhizobia in soil are particularly affected under low P, acid soil conditions. Soil acidity may also interact with drought to increase its negative effects on crops and reduce nutrient uptake under drought conditions. Barszczak and Barszczak (1994) showing negative interactions in yield and N use efficiency when drought and soil acidity in oilseed rape. Thus where acid soils exist (eg the Wheat belt of Australia which produces large amounts of lentils, peas and chickpeas) greater negative effects on yield and NUE may result under climate change conditions.

Nitrogen-fixing is a process particularly sensitive to water stress or drought which is likely to increase regionally in response to climate change. The reduction of atmospheric nitrogen to ammonia can only be carried out by rhizobia. The plant benefits from the micro-organism that takes on the task of capturing nitrogen from the air and converting it into ammonia in such a way that the plant can use it. However, under drought conditions, a reduction in nodule sacarose synthesis activity has been observed. This drop occurred simultaneously with a decrease in nitrogen-fixing, enabling the establishment of a high correlation between both processes in adverse conditions. As a consequence of the inhibition of sacarose synthesis activity, a drop in the concentration of phosphate sugars and organic acids was also observed, indicating a decrease in carbon flow in the nodules, a drop which, in turn, limits the supply of carbon to the bacteroid and the capacity of the bacteroid to fix nitrogen thus affected (Galvez, 2005). Similarly under high temperature and drought conditions soil rhizobial survival and nodulation may be reduced adversely affecting fixation (McNeil and Materne, 2007).

Other problem that is increasing as the clime changes is the salinity. The response of legumes to salt stress is complex since it varies with salt concentration, ion type, other environmental factors and the stage of plant development. Some of the structural changes in plants subjected to salinity stress include fewer leaves, but information on the underlying mechanism for these structural changes is inadequate. Salinity can also interfere with root uptake capacity for essential ions such as potassium, nitrate or phosphate. Root growth and function may be restricted by high Na+/Ca++ (Esechie and Rodriguez, 1999).

11.3 Mechanisms to Overcome Reductions in Nutrient Use Efficiency

11.3.1 Sustainable Fertilizing Practices for Improving Crop Nutrient Efficiency and CO_2 Sequestration

Intensive high-yield agriculture is dependent on addition of fertilizers, especially industrially produced NH_4 and NO_3. Between 1960 and 1995, global use of nitrogen fertilizer increased sevenfold, and phosphorus use increased 3.5-fold (Tilman et al., 2002); both are expected to increase another threefold by 2050 unless there is a substantial increase in fertilizer efficiency (Cassman and Pingali, 1995; Tilman et al., 2002).

Fertilizer use and legume crops have almost doubled total annual nitrogen inputs to global terrestrial ecosystems (Vitousek and Matson, 1993; Galloway et al., 1994). Similarly, phosphorus fertilizers have contributed to a doubling of annual terrestrial phosphorus mobilization globally (Carpenter et al., 1998). Today, only 30–50% of applied nitrogen fertilizer (Smil, 1999) and 45% of phosphorus fertilizer (Smil, 2000) is taken up by crops. A significant amount of the applied nitrogen and a smaller portion of the applied phosphorus is lost from agricultural fields. This nitrogen contributes to riverine input into the North Atlantic that is 2- to 20-fold larger than in pre-industrial times (Howarth et al., 1996). Such non-point nutrient losses harm off-site ecosystems, water quality and aquatic ecosystems, and contribute to changes in atmospheric composition (Tilman et al., 2001; 2002).

Climate change adaptation for agricultural cropping systems requires a higher resilience against both excess of water (due to high intensity rainfall) and lack of water (due to extended drought periods). A key element to respond to both problems is soil organic matter, which improves and stabilizes the soil structure so that the soils can absorb higher amounts of water without causing surface run off, which could result in soil erosion and, further downstream, in flooding. Soil organic matter also improves the water absorption capacity of the soil for during extended drought (IWGCC, 2007). Innovative farming practices such as conservation tillage, organic production, improved cropping systems, land restoration, land use change and irrigation and water management, are ways that farmers can address climate change.

The development and preferential planting of crops and crop strains that have higher nutrient-use efficiency are clearly essential. Cover crops or reduced tillage can reduce leaching, volatilization and erosional losses of nutrients and increase nutrient-use efficiency. Closing the nitrogen and phosphorus cycles, such as by appropriately applying livestock and human wastes, increases legumes and in general crop production per unit of synthetic fertilizer applied (Tilman et al., 2002). These practices are having promising results in Baja California Sur, México, one of the driest regions in the world. Principal actions there include: application of green manure using legume as cowpea and *Lablab purpureus* (Fig. 11.1) and conservation tillage (Fig. 11.2) for vegetable production (Beltran-Morales et al., 2006). With both activities, it has been achieved to increase the levels of organic matter and microbial activity in desert, arid soils. Good management practices have multiple benefits that may also enhance profitability, improve farm energy efficiency and boost air and soil quality (Schahczenski and Hill, 2009); however, more research on improving efficiency and minimizing loses from both inorganic and organic nutrient sources is needed to determine costs, benefits and optimal practices (Tilman et al., 2002). Conservation agriculture and organic agriculture that combine zero or low tillage and permanent soil cover (mainly using legumes) are promising adaptation options promoted by FAO for their ability to increase soil organic carbon, reduce mineral fertilizers use and reduce on-farm energy costs (IWGCC, 2007).

Fig. 11.1 *Lablab purpureus* grown in arid soil in order to be used as green manure. Baja California Sur, México

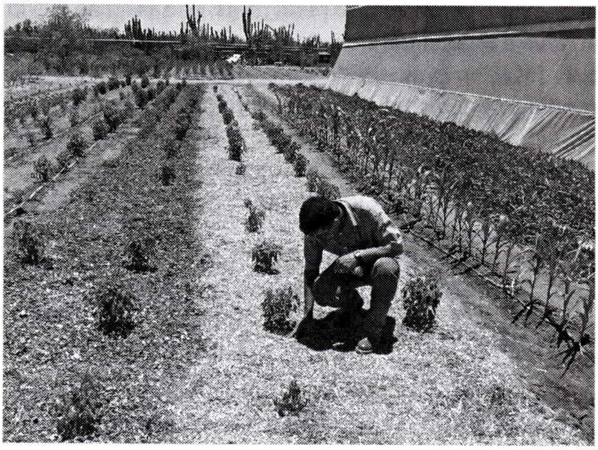

Fig. 11.2 Test of hot-wild-pepper grown under conservation tillage (using cowpea as mulch) in arid soils. Baja California Sur, México

Carbon sequestration and reductions in greenhouse gas emissions can occur through a variety of agriculture practices. Carbon sequestration in the agriculture sector refers to the capacity of agriculture lands and forests to remove carbon dioxide from the atmosphere. Carbon dioxide is absorbed by trees, plants and crops through photosynthesis and stored as carbon in biomass in tree trunks, branches, foliage and roots and soils (EPA, 2008). Conservation tillage refers to a number of strategies and techniques for establishing crops in the residue of previous crops, which are purposely left on the soil surface. Reducing tillage reduces soil disturbance and helps mitigate the release of soil carbon into the atmosphere. Conservation tillage also improves the carbon sequestration capacity of the soil.

Some of the most important strategies to improve the N efficiency include the use of cover crops and manures (both green and animal); nitrogen-fixing crop rotations; composting and compost teas. Low fertilizer nitrogen-use efficiency in agricultural systems is primarily caused by large nitrogen losses due to leaching and gaseous emissions (ammonia, nitrous oxide, nitric oxide, nitrogen). It is axiomatic then that most strategies that increase the efficiency use of fertilizer nitrogen will reduce emissions of N_2O (Schahczenski and Hill, 2009).

While N fertilizer is one of the direct contributors to N_2O emission, it also plays a positive role in the stabilization of soil C, and can help to mitigate CO_2 emissions. There are extensive reports from long-term trials indicating that wherever N enhances the yields of crops, the accumulation of C in the soil is increased. In addition, there is evidence that N itself is chemically involved in stabilizing soil C (Bruulsema and Griffith, 1997).

In other hand, nutrient-use efficiency is increased by better matching temporal and spatial nutrient supply with plant demand. Applying fertilizers during periods of greatest crop demand, at or near the plant roots, and in smaller and more frequent applications all have the potential to reduce losses while maintaining or improving yields and quality (Matson et al., 1996; Tilman et al., 2002).

Multiple cropping systems using crop rotations or intercropping (two or more crops grown simultaneously) may increase nutrient- and water-use efficiency (Tilman et al., 2002). Agroforestry, in which trees are included in a cropping system, may improve nutrient availability and efficiency of use and may reduce erosion, provide firewood and store carbon.

11.3.2 Genetic Adaptations

Biodiversity in all its components (e.g. genes, species, ecosystems) increases resilience to changing environmental conditions and stresses which are likely to occur due to climate change. Genetically-diverse populations and species-rich ecosystems have greater potential to adapt to climate change. FAO promotes use of indigenous and locally-adapted plants and animals as well as the selection and multiplication of crop varieties and autochthonous races adapted or resistant to adverse conditions. The selection of crops and cultivars with tolerance to abiotic stresses (e.g. high temperature, drought, flooding, high salt content in soil, pest and disease resistance) allows harnessing genetic variability in new crop varieties if national programs have the required capacity and long-term support to use them. To strengthen capacity of developing countries to implement plant breeding programmes and develop locally-adapted crops, FAO and other like-minded institutions are planning the Global Initiative on Plant Breeding Capacity Build (GIPB) initiative, to be launched at the governing body meeting of the International Treaty on Plant Genetic Resources for Food and Agriculture (Abberton et al, 2008).

11.4 Conclusions

Climatic change constitutes a challenge to be solved in the near future. Food production is being threatened by increased intensity and frequency of storms, drought and flooding, altered hydrological cycles and precipitation variance. As a consequence of these changes there is a marked potential to alter nutrient demand, availability and consequently plant nutrient use efficiency from soil, fertilizer and biologically fixed nutrients. Legumes are going to play a very important role in maintaining high N availability in part through enhamced N fixation overcoming Progressive Nitrogen Limitation under elevated CO_2 conditions. This review recognizes the role of legumes and their association with rhizobia to improve soil fertility and nutrients use efficiency, compared to other ways, such as increased use of fertilizer-N. However, it also recognizes the susceptibility of legumes to drought and temperature stresses which may both increase and decrease regionally as a result of climate change. Several symbiotic systems of legumes which are tolerant to extreme conditions of salinity, alkalinity, acidity, drought, fertilizer, metal toxicity, etc. must be exploited. These associations might have sufficient traits necessary to establish successful growth and N_2 fixation under the conditions prevailing in unfavorable regions. The use of legume as source of organic matter, combined with conservational tillage practices is another of the very important roles of this group of species as a mechanism to reduce adverse effects of climate change on nutrient use efficiency.

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