Chapter 4
Nutrient Management Perspectives in Conservation Agriculture

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Abstract Conservation agriculture (CA) has been promoted as a major way forward to make agriculture sustainable by protecting soils from degradation processes. The focus of this chapter is on nutrient management in CA. Special attention is given to crop management and its effect on nutrient management with particular emphasis on the three major principles of CA—tillage, crop rotation, and residue management. Nutrient management has received little attention in CA despite the fact that it has a direct effect not only on crop yield but also on the tolerance of crop plants to pests. Further research on nutrient management could increase the adoption of CA worldwide. In this chapter, nutrient management in CA is discussed and proposed as the fourth principle of CA. Breeding genotypes for better nutrient-use efficiency in CA is also important, as is the control of weeds, insect pests, and diseases. In addition, the appropriate use of fertilizer and nutrients is essential to increase crop productivity and to produce sufficient crop residues in the different climates that CA is practiced.

Keywords Nitrogen · Phosphorus · Potassium · Nutrient-use efficiency · Fertilizers · Mulch · Crop rotation · Tillage

4.1 Introduction

Sustainability is a term that has been used extensively in modern agriculture in recent years because of the effect that certain crop production methods have on the environment (Atkinson and McKinlay 1997; Hanson et al. 2007). Sustainable agriculture is the management and utilization of the agricultural ecosystem in a way that maintains its biological diversity, productivity, regeneration capacity, vitality, and ability to function, so that it can fulfill—today and in the future—significant

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M. Farooq, K. H. M. Siddique (eds.), *Conservation Agriculture,*
DOI 10.1007/978-3-319-11620-4_4

ecological, economic, and social functions at local, national, and global levels that does not harm other ecosystems (Lewandowski et al. 1999).

The sustainability of agriculture has faced significant challenges in recent years (Oborn et al. 2003; Hanson et al. 2007) including: (1) increased food demand for the ever-increasing human population, (2) overdependence on fossil energy and the increased monetary and environmental costs of nonrenewable resources, (3) global climate change (Diamond 2005; Brown 2006), and (4) globalization (Hanson et al. 2007). These dominant issues are challenging agriculturists to develop more sustainable management systems. To meet the food and nutritional needs of a growing population, agriculture needs to move beyond the past emphasis on productivity to encompass improved public health, social well-being, and a sound environment (Hanson et al. 2007).

Conservation agriculture (CA) is an important aspect of agriculture that contributes to sustainability. CA is based on the integrated management of different agricultural resources such as soil, water, and other resources to create an economically, ecologically, and socially sustainable agricultural production system. It relies on three major principles:

a. Minimal soil disturbance by direct planting through the soil cover without seedbed preparation.
b. Maintenance of a permanent vegetative soil cover or mulch to protect the soil surface.
c. Diversified crop rotations in the case of annual crops or plant associations in the case of perennial crops.

Nutrient management has received little attention in CA despite its direct effect on crop yield. Further research on nutrient management should increase the adoption of CA worldwide. In this chapter, nutrient management in CA is discussed and proposed as the fourth principle of CA (Vanlauwe et al. 2014).

4.2 Nutrient Management Perspectives

Nutrient management is an important aspect of CA for crop productivity and for the adoption of CA by farmers (Vanlauwe et al. 2014). CA improves nutrient-use efficiency (NUE) as it reduces soil erosion and prevents nutrient loss from the field. Nutrient loss may be minimized due to reduced runoff and the appropriate use of deep-rooting cover crops that recycle nutrients leached from the topsoil (FAO 2001). This leads to the greater availability of both native and applied nutrients to crop plants which can have a significant effect on fertilizer efficiency. It was found that in a rice–wheat system, fertilizer efficiency increased by 10–15 % due to better placement of fertilizer with the seed drill compared with broadcasting in the traditional system (Hobbs and Gupta 2004). There are reports of lower N fertilizer efficiency when soil microorganisms immobilized mineral N in the crop residues (Verhulst et al. 2010). Nonetheless, long-term experiments have indicated an increased release of nutrients owing to microbial activity and nutrient recycling (Carpenter-Boggs et al. 2003). In addition, increased soil organic matter (SOM) at the soil surface may increase NUE and water-use efficiency (Franzluebbers 2002). Similarly, crop residues can increase plant availability of phosphorus and its efficiency in no-tillage systems (Iyamuremye and Dick 1996; Sanchez et al. 1997).

A few studies have evaluated the effects of cover crops combined with different tillage systems on N mineralization and release, as well as P sorption (Fontes et al. 1992; Afif et al. 1995; Bhatti et al. 1998). Adsorption sites of goethite can be blocked by organic matter (OM) components, e.g., humic acids, and other organic compounds, such as oxalate and malate, which decreases P sorption in the soil (Fontes et al. 1992; Afif et al. 1995; Bhatti et al. 1998). In addition, it is not clear whether this positive effect of organic compounds on decreasing P sorption by soils exists in the field as most studies have been conducted under controlled environments (Ziadi et al. 2013).

Legume-based crop rotations in CA significantly improve nutrient availability for crop plants (Burle et al. 1997; Govaerts et al. 2007b). Higher levels of exchangeable calcium (Ca), potassium (K), and magnesium (Mg) were found when pigeon pea (*Cajanus cajan* L.) and lablab (*Lablab purpureus* L.) were used compared with when white clover (*Trifolium repens* L.; Burle et al. 1997). In addition, others found higher C, N, K, and lower sodium (Na) concentration when the crop residue remained in the field compared to residue removal (Govaerts et al. 2007b). The effect of CA practices on nutrients can be due to decreased infiltration, which can decrease deep drainage and the leaching of mobile nutrients, and most of the applied N is retained in the topsoil (Erenstein 2002; Scopel et al. 2004).

4.2.1 Nutrient-Use Efficiency

Fertilizers and especially N fertilizers are an important input for many crops and account for approximately half of the energy inputs in cereal production worldwide (Raun and Johnson 1999). In addition, cereal crops are quite inefficient in using N and other nutrients as only 33 % of the applied N as fertilizer can be recovered in the grain (Raun and Johnson 1999). The term NUE has been used extensively to describe nutrient use by a crop and is defined as grain yield divided by the supply of available nutrient from the soil and added fertilizer (Moll et al. 1982; Fageria et al. 2008). NUE is an important index that can be used in CA in order to quantify the different nutrient management practices and to determine which is better for increasing the NUE. NUE has two components: (1) nutrient uptake efficiency (crop nutrient uptake per unit of nutrient available from the soil and fertilizer) and (2) nutrient utilization efficiency (which is grain dry matter (DM) yield per unit crop nutrient uptake at harvest; Moll et al. 1982; Fageria et al. 2008). However, "nutrient efficiency" has many different meanings in crop production and several definitions within the literature (Fageria et al. 2008). In short, there are two primary efficiencies to consider, one is fertilizer efficiency and the other is crop efficiency. Fertilizer efficiency is the fraction of freshly applied fertilizer that is recovered in the current crop.

Fertilizer efficiency can be measured in CA in several ways:

1. The fertilizer is labeled with a stable isotope, e.g., ^{15}N for nitrogen to differentiate fertilizer N from indigenous soil N. In winter wheat, the crop recovered 68 % of the N applied, of which 18 % was retained in the topsoil (as nitrate and ammonium ions in the soil solution, as exchangeable ammonium ions on clays, and as organic N incorporated into microbes), and 14 % was lost by leaching and denitrification (Powlson and Jenkinson 1981).
2. The "apparent fertilizer recovery efficiency" is less accurate but more easily measured. It is the total nutrient uptake (in aboveground parts of the crop at maturity) at a given fertilizer rate minus the uptake at zero fertilizer rate, divided by the amount of the nutrient applied. It is called "apparent" because part of the total uptake will be from mineralized soil organic nutrient and the amount that was mineralized varies with the amount of fertilizer that has been applied.
3. Fertilizer efficiency can be calculated by dividing the total nutrients removed in grain by the nutrients applied as fertilizer. Raun and Johnson (1999) calculated that only 33 % of the fertilizer applied to cereals is removed by the harvested grain, resulting in 67 % either lost from the soil or remaining in the soil.

4.2.2 Strategies for Improving NUE

An important target of modern crop production is to improve NUE as this will increase profitability through increased yields or reduced fertilizer costs, and environmental protection through reduced greenhouse gas emissions (Hirel et al. 2007).

NUE can be increased by adopting appropriate nutrient management strategies and through crop breeding. NUE is affected by soil conditions particularly leaching, denitrification, volatilization, and immobilization of nutrients in the soil; fertilizer rates; source, placement, and timing of fertilizer application; climatic conditions; plant type which can affect absorption, translocation, assimilation, and retranslocation of the nutrient; and plant characteristics such as tissue nutrient concentration, size, and number of reproductive sinks.

Management strategies involve manipulation of soil, plant, climatic, and fertilizer variables. These strategies involve soil sampling and analysis, crop monitoring and sampling, crop rotation, tillage practices, form of fertilizer and time of application, irrigation, and precision agriculture. Adopting these strategies could lead to increased crop yield and enhanced NUE. Ways to increase NUE include:

1. Crop rotations, especially when legumes are used, can significantly improve NUE (Raun and Johnson 1999).
2. Forage production systems which have lower plant gaseous losses due to leaf senescence and higher NUEs as they tend not to flower (when N losses are

greater) and the biomass is harvested and removed from the field, e.g., wheat forage has N-use efficiency of 77 % compared with grain at 33 % and corn forage has N-use efficiency at 70 % (Raun and Johnson 1999).

3. Improved cultivars with higher NUE. Wheat cultivars were produced by genetic selection under low nutrient inputs to increase NUE. These wheat cultivars have high harvest index, low nutrient loss, and increased NUE. In addition, high NUE has also been observed in rice varieties with high harvest index (Raun and Johnson 1999).
4. Conservation tillage can improve NUE. In addition, erosion control and subsurface placement of fertilizers such as N has the potential to significantly improve N availability and NUE (Raun and Johnson 1999).
5. Fertilizer form. In many cases, the form of fertilizer can affect NUE, e.g., N as NH_4-N is more efficient as plants require more energy to assimilate NO_3 compared with NH_4 form. N uptake is higher at 35 % (NH_4), assimilation of N (NO_3 20 mol ATP/mol NO_3^-, NH_4 5 mol ATP/mol NH_4^+; Raun and Johnson 1999)
6. Fertilizer application should be in season; foliar application is more effective (pre-plant N reduces NUE, late-season N increases grain protein and NUE, foliar applied N (at flowering) and increases protein content and NUE; Raun and Johnson 1999).
7. Irrigation can increase NUE as maximum NUE obtained with low N rates, which were applied in season together with irrigation (Raun and Johnson 1999).
8. Precision agriculture practices can improve NUE. These practices include timely and precise application to meet plant needs; exact implementation of all management operations uniformly applied to a single field; site-specific management within a field to account for spatial variation in soil and pests; crop management: variety/hybrid selection, tillage, planting date, density and row spacing, nutrient amount, formulation, and placement; integrated pest management; and amount of irrigation and timing (Raun and Johnson 1999).

4.2.3 Management of N, P, and K in CA

CA practices, especially tillage, residue management, and crop rotation have a significant impact on nutrient distribution and transformation in soils (Etana et al. 1999; Galantini et al. 2000), and the effects of these practices are related to soil organic matter content (SOC). The distribution of nutrients in a soil under zero tillage differs from that in tilled soil as enhanced conservation increases the stratification of nutrients and their availability near the soil surface compared to conventional tillage (Follett and Peterson 1988; Franzluebbers and Hons 1996; Duiker and Beegle 2006; Table 4.1). The altered nutrient availability under zero tillage is probably due to the surface placement of crop residues as opposed to the incorporation of crop residues with conventional tillage (Blevins et al. 1977; Unger 1991; Ismail et al. 1994). Slower decomposition of crop residues left on the soil surface (Kushwaha et al. 2000; Balota et al. 2004) can prevent rapid

Table 4.1 Soil organic carbon, total nitrogen and phosphorus content under conventional and zero tillage from different studies

Organic C (g kg^{-1})		Total N (g kg^{-1})		P (mg g^{-1})		Reference
CT	ZT	CT	ZT	CT	ZT	
49.00	50.00	3.60	3.80	6	12.2	Astier et al. (2006)
27.4	33.40	–	–	11.13	19.6	Lal et al. (1990)
9.80	8.80	1.18	0.99	–	–	Kushwaha et al. (2000)
22.60	28.20	–	–	0.031	0.058	Duiker and Beegle (2006)
10.75	11.30	–	–	12.00	11.5	Roldan et al. (2007)
50.00	67.60	4.40	5.80	21.9	23.8	Borie et al. (2006)
27.10	29.20	2.85	3.03	–	–	Larney et al. (1997)

CT conventional tillage, *ZT* zero tillage

leaching of nutrients through the soil profile, which is more likely when residues are incorporated into the soil. However, the possible development of continuous pores between the surface and subsurface under zero tillage (Kay 1990) may lead to more rapid passage of soluble nutrients deeper into the soil profile than when soil is tilled (Franzluebbers and Hons 1996). Furthermore, the response of soil chemical properties to tillage practices in site-specific management depends on soil type, cropping systems, climate, fertilizer application, and management practices (Rahman et al. 2008). The density of crop roots is usually greater near the soil surface under zero tillage compared to conventional tillage (Qin et al. 2004), as more nutrients are taken up from near the soil surface as illustrated by a significantly higher P uptake by corn from the 0–7.5 cm soil layer under zero tillage than under conventional tillage (Mackay et al. 1987).

4.2.3.1 Nitrogen

Nitrogen is the most important nutrient for plant growth, yield, quality and the environment, with extensive literature on the effect of N on crop yields (Marschner 1995; Fageria et al. 2008). The efficient use of N fertilizer is important for crop yield, the environment, and the adoption of CA and depends on the level of available N in the rooting zone. Applied N fertilizer rates should consider the available N in soils and other factors that affect crop response to N fertilization. Despite the importance of soil tests for N application, the adjustment of fertilizer rates as a result of soil tests is rare, together with calculations for N agronomic efficiency and the profit that can be gained by N fertilization. This is because these studies require trials on farmers' fields for several years. In addition, apart from inorganic N, organic soil N mineralized during crop growth can provide N for the crop (Mengel et al. 2001). A number of different extraction methods have been proposed to determine soil N levels (Sparks et al. 1996; Mengel et al. 2001).

In addition to soil N status measurements, several other diagnostic tools have been developed to determine N deficiency, which is used to improve N management and decrease the risk of N loss to ground and surface waters (Fageria and Baligar 2005; Lemaire et al. 2008). The plant-based diagnostic methods such as chlorophyll meters provide a valuable estimation of the N status of the crop (Piekielek and Fox 1992; Dordas and Sioulas 2008; Dordas et al. 2008; Lemaire et al. 2008; Ziadi et al. 2008; Lemaire and Gastal 2009; Ziadi et al. 2010). Other diagnostic tools such as the nitrogen nutrition index (NNI) may be used to determine the level of plant N nutrition (Debaeke et al. 2006; Prost and Jeuffroy 2007; Dordas 2011) and is calculated by dividing the actual N concentration by the critical N concentration (N_c). N_c is defined as the minimum N concentration in shoot biomass required for maximum growth. The NNI is considered as a reference tool for assessing plant N status, but has limitations at the farm level as the actual crop biomass and its N concentration need to be determined at different growth stages which can be difficult. A more simplified method to evaluate crop N status and estimate NNI is needed.

During the first few years of CA, N is mainly found in organic forms (immobilized) and is not available for plants (Verhulst et al. 2010) because the mineralization process in the first years is quite slow and there is a need for application of N fertilizer which can speed up the mineralization process. In the years following the adoption of CA, soil microorganisms will significantly increase and essential plant nutrients will be efficiently recycled leading to less need for fertilizers. Therefore, N needs to be managed carefully to avoid N deficiency due to slow mineralization, immobilization, and volatilization, and to avoid excess N fertilization. There are several options that allow sufficient time for SOM to decompose before sowing the crop. Application of N fertilizer (25–70 kg ha^{-1}) before sowing will speed up mineralization. During sowing, N can be applied in bands to prevent immobilization and provide young seedlings with adequate N. The use of nitrate fertilizers is preferred over ammonium fertilizers as nitrate dissolves easier and is more mobile in soil.

Soil mineral N available for plant uptake depends on the rate of C mineralization. There is no clear trend on the effect of reduced tillage on residue retention and N mineralization as zero tillage is generally associated with lower N availability due to increased immobilization by residues left on the soil surface (Rice and Smith 1984; Bradford and Peterson 2000; Table 4.1). The net immobilization phase, when zero tillage is adopted, is transitory and immobilization of N under zero tillage systems in the longer term reduces the opportunity for leaching and denitrification losses of soil mineral N (Rice et al. 1986; Follet and Schimel 1989). Higher immobilization in CA systems can increase the conservation of soil and fertilizer N in the long run, and the higher initial N fertilizer requirements decrease over time because of reduced losses by erosion and the buildup of a larger pool of readily mineralizable organic N (Schoenau and Campbell 1996). In addition, the efficiency of chemical fertilizers can be increased by applying them to mulch rather than to soil (Verhulst et al. 2010).

CA affects total N content, which is closely related to total SOC, as the N cycle is closely linked to the C cycle (Bradford and Peterson 2000; Table 4.1). A higher total N content under both zero tillage and permanent raised beds compared to conventional tillage has been reported (Borie et al. 2006; Astier et al. 2006; Govaerts et al. 2007b). However, no influence of tillage or cropping system on SOC and total N contents has been observed in some experiments (Sainju et al. 2008). Zero tillage affects mineralizable N and the light fraction of soil N more than total N

(Larney et al. 1997). Significant increases in total N have been measured with increasing additions of crop residue (Graham et al. 2002) and the amount of straw retained under permanent raised beds (Govaerts et al. 2007b).

Tillage practices also affect N mineralization as tillage increases aggregate disruption, and the SOC is more accessible to soil microorganisms (Beare et al. 1994; Six et al. 2002); thereby increasing mineral N released from active and physically protected N pools (Kristensen et al. 2000). In permanent raised beds, residue retention caused more stable macroaggregates and increased the protection of C and N in the microaggregates within the macroaggregates compared to conventionally tilled raised beds (Lichter et al. 2008). In addition, there is increased susceptibility to leaching or denitrification if the growing crop does not take advantage of these nutrients at the time of their release (Doran 1980; Christensen et al. 1994; Randall and Iragavarapu 1995). In corn, NO_3-N losses were about 5 % higher with conventional tillage compared to zero tillage (Randall and Iragavarapu 1995). In the initial years after switching to zero tillage, there was no effect on N availability (Jowkin and Schoenau 1998). However, the N mineralization rate increased as tillage decreased (Larney et al. 1997). Similarly, Wienhold and Halvorson (1999) reported that N mineralization generally increased in the 0–5 cm soil layer as the intensity of tillage decreased. Govaerts et al. (2006) observed that after 26 cropping seasons in a high-yielding, high-input irrigated production system, the N mineralization rate was higher in permanent raised beds with residue retention than in conventionally tilled raised beds with all residues incorporated, and that it increased with increasing rate of inorganic N fertilizer application. The tillage system determines the placement of residues. In a conventional tillage system, crop residues are incorporated, while in the case of zero tillage, residues are left on the soil surface. These placement differences contribute to the effect of tillage on N dynamics. Incorporated crop residues decomposed 1.5 times faster than surface-placed residues (Kushwaha et al. 2000; Balota et al. 2004). However, the type of residues and the interactions with N management practices may also affect C and N mineralization (Verachtert et al. 2009).

The composition of crop residues left on the field can affect their decomposition (Trinsoutrot et al. 2000). The C/N ratio of crop residues is used as a criterion for residue quality (Vanlauwe et al. 1996; Nicolardot et al. 2001; Hadas et al. 2004) together with initial residue N, lignin, polyphenols, and soluble C concentrations (Thomas and Asakawa 1993; Trinsoutrot et al. 2000; Moretto et al. 2001). Inorganic N can be immobilized during decomposition of SOM especially when organic material with a large C/N ratio is added to the soil (Zagal and Persson 1994). Total soil N mineralization has been significantly correlated with the C/N ratio of crop residues (Kumar and Goh 2002). Some plant species used as cover crops (such as *Tithonia diversifolia*) have relatively high N and P contents, while their crop residues have very low N (ca. 1 %) and P contents (ca. 0.1 %; Palm et al. 2001). However, these residues are more important in contributing to SOM buildup than as inorganic nutrient sources for plant growth because of their lignin and polyphenol contents (Palm et al. 2001). N immobilization can be significant when cereal residues are incorporated during the first years of implementation (Erenstein 2002). Kandeler et al. (1999) found that after a 4-year period, N mineralization in a conventionally tilled treatment was significantly higher than that in minimum and reduced tillage plots due to buried organic materials. In contrast, others observed that in soil with retention of maize residues, N immobilization still occurred after 13 years in an irrigated maize–wheat rotation system (Govaerts et al. 2006).

In conclusion, CA affects N soil levels especially during the first years of application as mineralization is quite slow which can lead to N deficiency. However, this can be corrected with N application to speed up the N mineralization process and with careful N management to ensure the availability of N for the crop plants. In addition, in the following years after adoption of CA, soil microorganisms increase and the essential nutrients are efficiently recycled leading to lower need for chemical fertilizers.

4.2.3.2 Phosphorus

Phosphorus (P) is the second most common nutrient applied to crops, is a part of many organic molecules of the cell (deoxyribonucleic acid (DNA), ribonucleic acid (RNA), adenosine triphosphate (ATP), and phospholipids) and is involved in many metabolic processes making it an important plant nutrient. Conservation tillage in most cases improves the availability of surface phosphorus by converting it into organic phosphorus. Plants take up P from below, “mining” and depositing it on the surface. In conventional tillage systems, P is remixed into the soil profile, whereas in conservation tillage P accumulates at the soil surface (Robbins and Voss 1991; Zibilske et al. 2002). Therefore, conservation of P may be a potential benefit of conservation tillage, improving P availability.

Several studies found higher extractable P levels in zero tillage compared with tilled soil (e.g., Follett and Peterson 1988; Franzluebbers and Hons 1996; Du Preez et al. 2001; Duiker and Beegle 2006; Table 4.1). This is because reduced mixing of fertilizer P with the soil leads to lower P-fixation. This is an important benefit when P is limiting, but may be a threat when there is excess P due to the possibility of soluble P losses in runoff water (Duiker and Beegle 2006). After 20 years of zero tillage, extractable P was 42 % greater at 0–5 cm, but 8–18 % lower at 5–30 cm depth compared with conventional tillage treatments in a silt loam soil (Ismail et al. 1994). Others found higher extractable P levels in zero tillage compared to tilled soil in the topsoil (Unger 1991). Therefore, accumulation of P at the soil surface under continuous zero tillage is commonly observed (e.g., Eckert and Johnson 1985; Follett and Peterson 1988; Franzluebbers and Hons 1996; Table 4.1). Concentrations of P are higher in the surface layers of all tillage systems compared to deeper layers, but are most striking in zero tillage (Duiker and Beegle 2006). When P fertilizers are used on the soil surface, a part of P will be directly fixed by soil particles making it unavailable for the crop plants. However, when P was banded as a starter application below the soil surface, there was P stratification which was taken up by the crop plants (Eckert and Johnson 1985; Duiker and Beegle 2006). This suggests that there may be less need for P starter fertilizer in long-term zero tillage because of high available P levels in the topsoil where the seed is placed (Duiker and Beegle 2006). Placement of P in zero tillage deeper in the soil may be beneficial if the surface soil dries out frequently during the growing season. However, if mulch is present on the soil surface in zero tillage, the surface soil is likely to be moister than conventionally tilled soils and the need for deep P placement is unlikely, especially in humid areas. Extractable P is redistributed in zero tillage compared with conventional tillage which is likely a direct result of surface placement of crop residues leading to accumulation of SOM and microbial biomass near the surface (Duiker and Beegle 2006). However, others found higher extractable P levels below the tillage zone, probably due to accumulation of P in senescent roots and the higher SOC content of the soil (Franzluebbers and Hons 1996). In contrast, in other studies available P was not affected by tillage system, soil depth, and crop type (Roldan et al. 2007).

4.2.3.3 Potassium

After nitrogen and phosphorus, potassium (K) is the nutrient most likely to limit plant production. In conservation tillage systems, K stays at the surface because it is not remixed by tillage (Robbins and Voss 1991). This redistribution of K can limit its availability to deeper-rooting crops or increase salinity problems. Cover cropping and conservation tillage may conserve K by taking up and redistributing it to the soil surface. Zero tillage conserves and increases the availability of K and other nutrients near the soil surface where crop roots proliferate (Franzluebbers and Hons 1996). Govaerts et al. (2007b) reported 1.65 and 1.43 times higher K concentrations in the 0–5 cm and 5–20 cm layers, respectively, on permanent raised beds than conventionally tilled raised beds, both with crop residue retention. A higher extractable K levels at the soil surface with decreased tillage intensity has also been reported (Lal et al. 1990; Unger 1991; Ismail et al. 1994). Du Preez et al. (2001) found higher levels of K in zero tillage compared to conventional tillage, and this effect declined with depth. However, others found surface accumulation of available K irrespective of tillage practice (Hulugalle and Entwistle 1997; Duiker and Beegle 2006). There is no clear trend with regard to soil extractable K as some authors reported either higher or similar extractable K levels in zero tillage compared to mouldboard tillage (Follett and Peterson 1988), while others reported no effect of tillage or depth on available K concentrations (Roldan et al. 2007). In contrast, Standley et al. (1990) observed higher exchangeable K in the topsoil (0–2 cm) when sorghum stubble was retained rather than removed. The increased K concentration was more pronounced for wheat than for maize because wheat takes up large amounts of K, and most of this remains in harvest residues (Du Preez et al. 2001). K accumulated in the rows of the previous crop, probably because it leached from the crop residue that accumulated there (Duiker and Beegle 2006). Higher concentrations of K were observed in crop rows of the zero tillage treatment but not the mouldboard tillage (Mackay et al. 1987).

4.3 Crop Management and its Effect on Nutrient Management

Sustainable agriculture approaches provide balanced plant nutrition and help to increase the availability of certain elements (Oborn et al. 2003). Approaches such as crop rotation, green manuring, manure application, residue retention, and tillage can affect nutrient availability and also plant growth and crop yield.

4.3.1 Soil Organic Matter

SOM content and quality affects many soil functions which are related to soil health such as moisture retention, infiltration, release, and plant health. Field-applied organic residues (crop residues, cover crops, and organic wastes) can affect soil microorganisms and thus the availability of nutrients (Stone et al. 2004). Practices such as addition of sphagnum peat, green manures, and animal manures have produced suppressive soils on which plant pathogens do not establish or persist and do not affect crop plants. Suggested mechanisms involved in biological and organic material-mediated disease suppression include microbiostasis, microbial colonization of pathogen propagulates, destruction of pathogen propagulates, antibiosis, competition for substrate colonization, competition for root infection sites, and induced system resistance (or systemic acquired resistance (SAR); Dordas 2008; Huber and Graham 1999). SOM quantity and quality can affect plant nutrient status and impact not only total soil nutrient content but also nutrient availability through the activity of soil microorganisms (Dordas 2008; Huber and Graham 1999).

4.3.2 Crop Rotations and Residue Management

Crop rotation is the practice of growing a sequence of different crops on the same field. Long-term experiments (more than 100 years) have shown that crop rotation together with other fertility management practices is fundamental to long-term agricultural productivity and sustainability (Reid et al. 2001; Stone et al. 2004). The most straightforward principle underlying crop rotation is disease and pest control as plant pathogen propagules have a lifetime in soils and by rotating with nonhost crops, starves them (Reid et al. 2001). Crop rotation can increase N levels and affect the availability of other nutrients which can then affect growth and yield of crop plants (Huber and Graham 1999; Reid et al. 2001). Crop rotation also affects the survival of pathogens and has been used extensively to reduce the severity of many diseases, pest and weed infestations.

Soil cover and residue management can change soil chemical, physical, and biological properties including the composition of the soil microbial community, and can affect the availability of nutrients (Dordas 2008). The extent of the effect depends on the plant species and cultivars. Cover crops can increase the active OM content in the soil, microbial biomass, and microbial activity and contribute to the suppression of pathogens and better crop growth. Cover crops affect the rhizosphere and indirectly can affect plant nutrient status (Huber and Graham 1999).

Green manure can affect the availability of N and other nutrients such as P and K. Most green manure species can fix N with N-fixing bacteria and increase soil N levels by 459 kg N ha^{-1} (Cherr et al. 2006). This can have a significant effect on disease and pest development. Green manures can also affect the availability of other nutrients such as P, Mn, Zn, which can affect disease and pest tolerance and crop growth and yield (Graham and Webb 1991; Huber and Graham 1999).

4.3.3 Tillage, Pest and Nutrient Management

Reduced-tillage systems or zero tillage can increase SOM content in many agricultural systems. Reduced tillage has the advantage that it conserves SOM and reduces erosion, energy consumption, and production costs (Carter 1994; Fernandez et al. 1998). It can also alter the soil environment and these changes can result in an increase, decrease, or no change in disease and pest incidence or severity depending on the cropping system and disease/pest (Dordas 2008; Ziadi et al. 2013). Minimum tillage concentrates residues at the soil surface and therefore concentrates pathogen propagule numbers at the soil surface; this may or may not impact disease incidence. Minimum and zero tillage do not disrupt plant residues on the soil surface as much as conventional tillage (i.e., since they tend not to bury them), thereby leaving more stubble on the soil surface. The adoption of conservation tillage by farmers has led to an increase in the incidence and severity of many stubble-borne diseases. Stand residues or residues lying on the soil surface are colonized by soil organisms much more slowly, and pathogen survival and growth in undisturbed residues is favored in these systems. Residue-colonizing pathogens are therefore favored over the reduced-tillage system and can generate significant yield reductions (Bockus and Shroyer 1998). Conservation tillage systems concentrate plant residues in the surface soil layer and microbial biomass and activity are higher in that layer (Dick 1992).

4.3.4 Impact of CA on Soil Microorganisms

Several microorganisms such as *Actinomycetes*, bacteria, fungi, protozoa, and algae exist in the rhizosphere. *Actinomycetes* play an important role in the soil especially in the decomposition of plant material as they produce bioactive metabolites that can be used to produce antibiotics and synthesize enzymes such as cellulase or lignin-degrading enzymes (McCarthy 1987; Wellington and Toth 1994). Filamentous fungi are decomposing OM such as lignin and play an important role in nutrient cycling (Parkinson 1994; van Elsas et al. 1997). Arbuscular mycorrhizal fungi are important for agriculture and are ubiquitous symbionts of most of the higher plants, including crops. Arbuscular mycorrhizal fungi act as an extension of host plant roots and absorb nutrients from the soil, especially those with low mobility such as P, Cu, and Zn (Li et al. 1991; Burkert and Robson 1994). In addition, arbuscular mycorrhizae interact with pathogens and other rhizosphere inhabitants affecting plant health and nutrition. Fungi are also important in soil conservation as they are involved in soil aggregation (Roldán et al. 2007).

Crop residues can serve as a continuous energy source for soil microorganisms when retained in the soil. Crop residues can increase microbial abundance as conditions are ideal for reproduction (Carter and Mele 1992; Salinas-Garcia et al. 2002). Govaerts et al. (2008) found increased populations of *Actinomycetes*, total bacteria, and fluorescent *Pseudomonas* under both zero and conventional tillage when crop residue was retained which indicates a clear interaction between tillage and residue management on microflora populations. Others found that reduced tillage stimulated rhizosphere bacteria, particularly *Agrobacterium* spp. and *Pseudomonas* spp., in different soil layers in different crop species, e.g., winter wheat, winter barley, winter rye, and maize (Höflich et al. 1999). The combination of zero tillage and residue retention seems to increase microflora and not zero tillage per se.

Crop residues that remain at the soil surface under no-tillage conditions have increased populations of fungi (Hendrix et al. 1986). Under zero tillage, parameters which indicate the size of the mycorrhizal population such as arbuscular mycorrhizal spore number, active hyphal length, and glomalin concentration are higher in the topsoil (0–10 cm) compared with those in the tillage treatments (Borie et al. 2006; Roldan et al. 2007). Under zero tillage systems, fungi generally dominate while under conventional tillage systems the bacterial population increases depending on whether the measurements are made near the soil surface or deeper in the soil profile (Kladivko 2001).

Under conventional tillage, root colonization by arbuscular mycorrhiza may decrease due to disruption of the mycorrhizal hyphae network. In addition, tillage transports hyphae and colonized root fragments to the upper soil layer, reducing and diluting their activity as viable propagules for the following crops (Borie et al. 2006). The differences in fungal populations between zero and conventional tillage systems are due to the ability of an ecosystem to withstand disturbance, where bacterial-dominated systems are more resilient than fungal-dominated systems due to the different energy pathways (Bardgett and Cook 1998; Simmons and Coleman 2008). Fungi are characterized as slow energy microorganisms while bacteria breakdown quicker via a “fast” energy channel (Coleman et al. 1983; Hendrix et al. 1986; de Ruiter et al. 1998). An increased population of fungal feeding nematodes in the 0–5 cm layer under zero tillage, reportedly showed decomposition processes occurring predominantly through the slower, fungal-based channel instead of the bacterial-based energy channel (Bell et al. 2006).

CA can affect soil microorganisms and especially biological N fixation (N_2) by legumes, an important biological phenomenon that adds N to agricultural systems reducing the need for chemical fertilizers. Crop rotation with legumes can maintain productivity of the land for many years (Papastylianou 1999; Cherr et al. 2006). More than 60% of the N inputs to natural plant communities have a biological origin (Postgate and Hills 1979). The amount of N fixed by legumes depends on the soil–plant environment and can be around 70 kg N year^{-1} ha^{-1} (Larue and Patterson 1981). Better crop management can increase N fixation in cropping systems, e.g., in the case of acid soils where N_2 fixation is low and increasing the pH of soil through liming improves N_2 fixation significantly (Correa et al. 2001). Organisms living free in the soil and not directly associated with higher plants are capable of nonsymbiotic N fixation. Many bacteria were studied for N fixation including *Beijerinckia, Azotobacter,* and *Clostridium* (Davis et al. 2003). *Azospirillum* is a bacterium that lives in the rhizosphere of tropical grass roots. There are photosynthetic bacteria and cyanobacteria (blue-green algae) that live near the soil surface which can fix N nonsymbiotically (Davis et al. 2003). The contribution of nonsymbiotic N_2 fixation from microorganisms to arable soils is quite small and can be around 5 kg N ha^{-1} year^{-1} (Steyn and Delwiche 1970).

4.4 Breeding for Better NUE in CA

Plant breeding may contribute to increasing productivity of CA by investigating and exploiting genetic variability under CA conditions. Studies have shown significant differences among cultivar performance when evaluated under different agronomic systems (O’Leary and Smith 1999). Thus, in order to identify suitable genotypes for CA, it may not be enough to merely evaluate genetic material developed for CA under high inputs with conventional tillage and without crop rotation, and with no residue retention. Selection for system yield under CA revealed adaptation to the CA environment that was not matched by selection for crop yield in conventional agriculture (O’Leary and Smith 2004). This suggests the need for further research on the value of separate breeding programs to develop varieties adapted to CA conditions and cultural methods.

As previously mentioned, for a CA system to be biologically advantageous, the genotypes need to be chosen with care. Unfortunately, the interactions among plants, animals, and microorganisms in a crop are so subtle and specific to particular locations that present knowledge only provides a rough guide as to what crops and varieties should be tried. Consequently, if the advantages of CA are to be exploited, then local experimentation will be needed using different crop species and cultivars over several seasons. However, in reality, it is not usually the biological but the economic advantage which decides which cropping systems are actually used.

Breeding and selection for nutrient-efficient species or genotypes within a species is important to reduce fertilizer input costs and contamination of soil, air, and water resources (Fageria et al. 2008). Significant efforts improved the yield potential in wheat, maize, soybean, and peanuts (Gifford et al. 1984; Ho 1988). In addition, several studies found genetic variability for macro- and micronutrient use or requirement in several species (Clark and Duncan 1991; Baligar and Fageria 1999;

Baligar et al. 2001; Fageria and Baligar 2005; Hillel and Rosenzweig 2005). Since micronutrients are required in small amounts by crop plants, the use of efficient genotypes can meet their requirements. In addition, important research has identified crop species and genotypes within a species which are efficient in nutrient use and tolerate elemental toxicity (Graham 1983; Foy 1984, 1992; Maas 1986; Clark and Duncan 1991; Marschner 1995; Baligar et al. 2001; Blamey 2001; Okada and Fischer 2001; Fageria et al. 2003; Yang et al. 2004; Epstein and Bloom 2005; Fageria and Baligar 2005; Fageria et al. 2006). Despite the published studies on breeding for nutrient efficiency, the release of new crop cultivars with improved nutrient efficiency is limited. Iron deficiency selection for iron-efficient genotypes in maize, sorghum, rice, and soybean lead to increased yields in calcareous soils (Graham 1983). Iron deficiency is widespread and a major problem for crop plants grown on calcareous or alkaline soils; the use of efficient genotypes is the best solution for correcting this problem (Welch et al. 1991; Marschner 1995; Fageria et al. 2003). Iron efficiency ranges from monogenic to polygenic control and the gene action can be additive or dominant (Duncan 1994; Duncan and Carrow 1999). Efforts to find efficient genotypes for major nutrients, e.g., N, P, and K concluded that under nutrient deficiency, grain yield is very low, so efficient genotypes need an appropriate amount of fertilizer. The genetic basis for the plant responses to N, P, and K are not well understood and appear complex (Clark and Duncan 1991). The heritability of some N-efficiency traits was relatively high, however, the heritability of other traits was low (Clark and Duncan 1991). In addition, P efficiency is heritable and can be used to improve germplasm (Clark and Duncan 1991). Yield of crop plants is a quantitative trait affected by many gene and yield improvements; nutrient efficiency deserves special attention in relation to identifying physiological components causing differences among cultivars. Soil P uptake can be increased by increasing the area of the root system (Lynch 1995). Biotechnology offers the opportunity to manipulate the structure and function of plant roots for improved acquisition of soil P (Richardson 2001). Technologies developed by molecular biology can help to isolate, identify, localize, and characterize gene(s) carrying desirable nutrient efficiency traits (Clark and Duncan 1991). Genetic engineering techniques have not been used in nutrient efficiency studies. There is potential to improve nutrient efficiency in crop plants by transferring the identified genes into other species or using them as molecular markers in breeding programs for CA.

There are several traits that can affect NUE (Fig. 4.1) such as demand at a cellular level (compartmentation, binding form), utilization within the shoot (e.g., retranslocation) and from seed reserves. In addition, the transport of nutrients a short distance (within the root) or long distance (root–shoot transport), and the compartmentation/binding form within the root can affect plant nutrient use (Marschner 1995). It is also important that the acquisition of nutrients by plants, is affected by root geometry/morphology (such as decreasing root radius, increasing mean root density, increasing root length and depth, increasing lateral spreading, branching, and number of root hairs). In addition, root physiology and biochemistry can affect nutrient uptake through the higher affinity of the uptake system (K_m), the threshold concentration (C_{min}), and modification of the rhizosphere (pH, oxidation

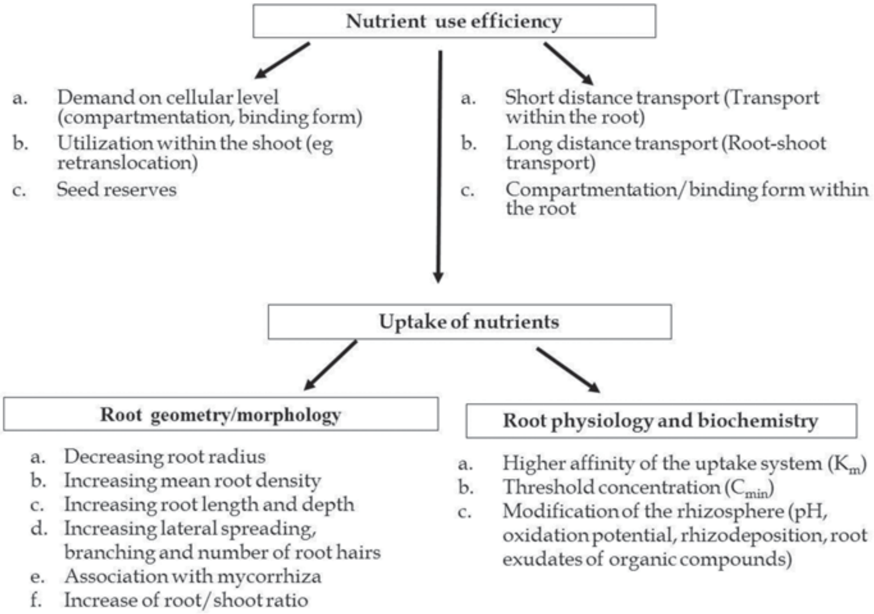

Fig. 4.1 Mechanisms of nutrient efficiency in plants. (Marschner 1995; Fageria et al. 2008)

potential, rhizodeposition, root exudates of organic compounds; Marschner 1995; Fageria et al. 2008).

Genetic variation in NUE and its components is important for improving NUE under low and high nutrient levels. Improvements in NUE (especially N) in wheat under low N supply occurred by improving N uptake efficiency (NUpE; Ortiz-Monasterio et al. 1997; Muurinen et al. 2006; LeGouis et al. 2000) or N utilization efficiency (NUtE; Foulkes et al. 1998; Barraclough et al. 2010). Under high N supply, improved NUE was explained approximately equally by NUpE and NUtE (Foulkes et al. 1998; Ortiz-Monasterio et al. 1997; Muurinen et al. 2006). In contrast, others reported that NUpE was the most important component of NUE under both low and high N supply (Dhugga and Waines 1989). From these studies, it is clear that there is an interaction between N supply and genotype which affects NUE and its components. In addition, grain yield was closely correlated with either NUpE or NUtE at low N supply depending on location, whereas at high N supply grain yield was correlated more with NUtE than with NUpE (Ortiz-Monasterio et al. 1997; LeGouis et al. 2000).

4.5 Effect of Nutrient Management on Weed Dynamics in CA

CA can affect the weed population. Certain practices can control weeds, such as crop rotation, mulching, nutrient management, and the efficient and reduced use of herbicides (Mousques and Friedrich 2007). These practices significantly affect nutrient levels, so it is possible that better weed control can be due to the nutrient effect. Use of CA for a long time can reduce weed infestations and weed pressure even after 1 year. Mulching can have positive effects on reducing the number and weight of weeds (Mousques and Friedrich 2007). Crop residues inhibit weed seed germination, and growth leads to reduced weed seed viability and therefore reduced weed numbers (Nurbekov 2008). Seed germination of weeds was lower under CA in rice–wheat systems due to less soil disturbance as was found for littleseed canary grass (*Phalaris minor* L.; Hobbs 2007). The residues from certain crop species such as cereals can have an allelopathic effect on inhibiting weed seed germination (Steinsiek et al. 1982; Lodhi and Malik 1987; Jung et al. 2004). Certain crop management techniques can affect weeds, such as when the cover crop is cut, rolled flat or killed by herbicides. Zero tillage increases the perennial weed population more than conservation tillage because tillage destroys the weeds and prevents them from setting seeds (Carter et al. 2002).

The use of mulch residue can reduce the weed population due to light exclusion (Ross and Lembi 1985). Under zero tillage systems, germination of some weeds such as littleseed canary grass decreased as a result of less soil disturbance in the wheat crop (Hobbs and Gupta 2003). The use of herbicide-tolerant crops (soybeans, maize, cotton, canola) reduced weed problems associated with zero tillage in many countries where CA is used. Moreover, crop rotation is important in CA and leads to diversification of cropping practices which can significantly affect the weed population (Hobbs and Govaerts 2010). In addition, soil microorganisms and microbial activity increases under CA which can suppress the weed population (Kennedy 1999). However, the net effect of crop residues maintained in CA on weed control is sometimes contradictory. In some cases, the maintenance of crop residue reduced herbicide efficacy (Erbach and Lovely 1975; Forcella et al. 1994) while in other cases, rainfall washed intercepted herbicides into the soil and efficacy remained high (Johnson et al. 1989) or the crop residue suppressed weed seed germination and/or seedling growth, thereby complementing the effects of herbicides (Crutchfield et al. 1986). All these CA practices have a direct effect on nutrient availability, yet there are no studies on the effect of nutrient availability under CA conditions on the weed population and dynamics. Therefore, research is needed on the interaction between CA, nutrient management, and weed population and infection.

4.6 Effect of Nutrient Management on Insect Pests and Disease Infestation in CA

Nutrients are important for growth and development of plants. They are also important factors in insect pest and disease control (Agrios 2005; Dordas 2008). The essential nutrients can affect the infestation of crop plants by pests and the disease severity (Huber and Graham 1999). There is no general rule of thumb as one nutrient can decrease the severity of a pest and at the same time increase the severity of other pests, and could have the opposite effect in a different environment (Huber 1980; Graham and Webb 1991; Marschner 1995). Despite the importance of nutrients on pest and disease control, nutrient management to control pests and diseases in CA has received little attention (Huber and Graham 1999; Dordas 2008).

Nutrients can affect pest and disease resistance or tolerance (Graham and Webb 1991). Resistance of the host is its ability to limit the penetration, development, and reproduction of attacking pests (Graham and Webb 1991). Tolerance of the host is measured in terms of its ability to maintain its own growth or yield in spite of the infection. Resistance depends on the genotype of the two organisms, plant age, and with changes in the environment. Although plant pest and disease resistance and tolerance are genetically controlled (Agrios 2005), they are affected by the environment, particularly by nutrient deficiencies and toxicities (Marschner 1995; Krauss 1999). The physiological functions of plant nutrients are generally well understood, but there are still unanswered questions regarding the dynamic interaction between nutrients and the plant–pathogen system. A number of studies have shown the importance of the correct nutrient management to control diseases in order to obtain higher yield (Marschner 1995; Huber and Graham 1999; Graham and Webb 1991; Dordas 2008 and references therein). However, there is no enough information regarding appropriate crop management practices in CA to reduce yield losses from pests and diseases. Many factors can affect the severity of plant disease, such as seeding date, crop rotation, mulching and mineral nutrients, organic amendments (manures and green manures), liming for pH adjustment, tillage and seedbed preparation, and irrigation (Huber and Graham 1999). Many of these practices are used in CA and can affect the level of nutrients available for both plant and pathogen which affects disease severity.

It is important to manage nutrient availability through fertilizer or change the soil environment to influence nutrient availability; in that way, plant disease is controlled in an integrated pest management system (Huber and Graham 1999; Graham and Webb 1991). The use of fertilizers produces a more direct means of using nutrients to reduce the severity of many diseases and, together with cultural practices, can affect the control of diseases (Marschner 1995; Atkinson and McKinlay 1997; Oborn et al. 2003).

Nutrients can affect the development of a pest or disease by affecting plant physiology or by affecting the pest, the pathogen, or both. The level of nutrients can influence plant growth which can affect the microclimate and therefore the infection, growth, and development of the pathogen (Marschner 1995). The level of nutrients can affect the physiology and biochemistry of crop plants, especially the integrity of cell walls, the membrane leakage, and the chemical composition of the host, e.g., the concentration of phenolics can be affected by B deficiency and therefore the infection by fungi (Graham and Webb 1991). Nutrients can affect the growth rate of the host which enables seedlings to escape/avoid infection at the most susceptible stages. In addition, fertilizers and especially organic fertilizers can influence the soil environment by altering the microorganism population and species and the development of pathogens and pests.

Fertilizer application affects the development of pests under field conditions directly through the nutritional status of the plant and indirectly by affecting the conditions which influence the development of pests, such as dense stands and changes in light interception and humidity within the crop stand. It is important to provide balanced nutrition at the critical time when the nutrient is most effective for pest control and higher crop yields. It is not only fertilizer application that affects disease development but other factors also affect the soil environment, such as pH modification through lime application, tillage, seedbed firmness, moisture control (irrigation or drainage), crop rotation, cover crops, green manures, manures, and mulch.

There are several studies on insect-pest dynamics under CA with different results. Reduced tillage generally increases the number of insect pests (Musick and Beasley 1978) and increases the diversity of predators and parasites of crop-damaging insects (Stinner and House 1990). Crop rotations used in CA can reduce the insect pest population by breaking the cycles of insect pests, diseases, and weeds. During the transition from conventional agriculture to CA, there may be more crop loss due to insect pests when the population of predators/parasites is low. It is possible that a diversified double-cropping system can be effective in solving the problems associated with insect pests, diseases, weeds, and herbicide resistance (Mousques and Friedrich 2007). Reduced soil tillage and soil cover can protect the biological components of the soil and keep pests and diseases under control while increasing biological diversity (Hobbs and Govaerts 2010). When the diversity of microorganisms has increased, it is possible to have integrated pest control under CA and, together with better nutrient management, the effects will be better. Moreover, conservation practices which enhance biological activity and diversity and predators/competitors can improve pest management. In addition, nematodes can increase as SOM increases which stimulates the action of several fungi-attacking nematodes and their eggs (Forcella et al. 1994). Reduced tillage can affect the various pathogens differently depending on their survival strategies and life cycle (Bockus and Shroyer 1998) and soil moisture and temperature (Krupinsky et al. 2002).

Crop rotation is important under zero tillage as it decreases pathogen numbers and reduces pathogen carryover from one season to another (Reid et al. 2001; Stone et al. 2004). This environment can be more antagonistic to pathogens due to competition (Cook 1990) and to cooler temperatures (Knudsen et al. 1995). Residue management can affect the balance of beneficial and detrimental microorganisms in the soil (Cook 1990). Zero tillage over the long term creates favorable conditions for the development of predators, by creating a new ecological stability. In addition, some crop residues reduce the damage to crops which can be due to inhibitory chemicals, stimulatory chemicals that promote beneficial microbial control agents, high C/N ratios which increase the populations of competitive pathogenic species, and higher soil water contents that increase crop vigor making them less susceptible to diseases (Huber and Graham 1999; Graham and Webb 1991). Crop residues are sources of food for bacteria, fungi, nematodes, earthworms, and arthropods which can cause major changes in disease pressure in CA (Hobbs and Govaerts 2010). Increased soil microbial biomass suppresses pathogens as increased numbers of microorganisms compete for resources or cause inhibition through antagonism or the release of antibiotic (Cook 1990; Sturz et al. 1997; Weller et al. 2002). Better disease control occurred in zero tillage and conservation tillage compared with conventional tillage (Govaerts et al. 2007a).

4.7 Challenges and Future Outlook

More research is needed to find the effect of different CA practices on crop yield and nutrient dynamics especially in long-term experiments. Best integrated management approaches should be optimized with new varieties which can be combined with specific cultural management techniques and CA. The influence of different management practices on nutrient dynamics should also be explored. Despite the fact that each nutrient has several functions, mild deficiency can usually be linked to one or more sensitive processes which are linked to secondary metabolism and not immediately necessary for the survival of the organism. Secondary metabolism is involved in the defense against pests and weeds; some of the roles are well understood while others remain to be determined.

The reduction in crop production costs, conservation of beneficial biological enemies of pests, preservation of environmental quality, and slowing the rate of development of pesticide-resistant strains are some of the benefits that fertilizer use can have on integrated pest management and sustainable agriculture. Increases in NUE under CA should be studied, especially the use of more efficient genotypes. Breeding programs should be developed under CA conditions in different environments.

4.8 Conclusions

CA is a sustainable and eco-friendly crop production technique which is practiced in many countries of the world. Although slight yield reductions have been reported during the initial years of adoption, the reduction in cultivation costs due to reduced tillage and higher input-use efficiency has resulted in minimal effects on economic returns for farmers. In addition, CA has important benefits such as soil conservation with improved soil health, higher rain-water-use efficiency, climate change mitigation and adaptation, improved biodiversity, resilience to climate shocks, higher economic returns, and more leisure time for farmers. It is important that medium to long-term studies on CA and nutrient management are conducted in different environments to better guide farmers to successful adoption. In sustainable agriculture, balanced nutrition is an essential component of any integrative crop protection program because in most cases it is more cost-effective and environmental friendly to control plant disease with adequate amounts of nutrients and no pesticides. Nutrients can reduce disease to an acceptable level or at least to a level where further control by other cultural practices or conventional organic biocides are more successful and less expensive.

Many CA practices affect soil processes such as increased SOM content and soil porosity, increased biological nitrogen fixation by legumes in rotation, or exploitation of deeper soil layers by crops with deep and dense root systems, all of which have a significant bearing on nutrient management. In addition, the nutrient requirements of CA systems are lower than conventional agriculture, as nutrient efficiencies are higher and the risk of polluting water systems with mineral nutrients is lower. Moreover, nutrients are a necessary production input but not a sufficient condition for sustainable production intensification. In CA systems, the emphasis is on managing soil health and productive capacity simultaneously, which depends on many complex cropping system relationships in space and time, and biodiversity and OM within soil systems when enlisted for agricultural production. The management of nutrient input–output relationships in CA systems must balance the nutrient accounts. The output levels of biological products will dictate the levels of inputs, and ongoing nutrient balances must remain positive. The major difference with CA systems is the management of multiple sources of nutrients and the processes by which they are acquired, stored, and made available to crops are more biologically mediated. More research is needed on different aspects of soil health and nutrient management in CA systems, as more countries begin to adopt and integrate CA concepts and practices into commercial production activities at both small and large scales for future sustainable production. In many countries, there is a growing interest in applying CA technologies and practices, and as attempts are made to move farming towards CA, policy and institutional support must be provided to accelerate the transformation of these agricultural practices. This transformation must be backed up by new scientific thinking and research, including in the area of nutrient management, to fill the knowledge gap that currently exists about CA in different environments and countries.

Acknowledgments The author wishes to thank Professor A. Gagianas, Faculty of Agriculture, Forestry and Natural Environment Aristotle University of Thessaloniki, and also the editors of the book for their critical review and constructive comments of this book chapter.

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