NUTRIENT MANAGEMENT

Perspectives on Nutrient Management in Conservation Agriculture*

AMIR KASSAM[1] and THEODOR FRIEDRICH[2]
Plant Production and Protection Division
Food and Agriculture Organization of the United Nations
Viale delle Terme di Caracalla
00153 Rome, Italy

Abstract

Conservation Agriculture (CA) systems aim at enhancing soil health and function as a precursor to sustainable production intensification. Nutrient management in CA must be formulated within this framework of soil health. Thus, nutrient management strategies in CA systems would need to attend to the following four general aspects, namely that:

> (i) the *biological processes* of the soil are enhanced and protected so that all the soil biota and microorganisms are privileged and that soil organic matter and soil porosity are built up and maintained;
> (ii) there is adequate *biomass production and biological nitrogen fixation* for keeping soil energy and nutrient stocks sufficient to support higher levels of biological activity, and for covering the soil;
> (iii) there is an adequate *access to all nutrients* by plant roots in the soil, from natural and synthetic sources, to meet crop needs; and
> (iv) the *soil acidity* is kept within acceptable range for all key soil chemical and biological processes to function effectively.

The paper discusses in general terms the above four aspects of nutrient management in CA systems.

Key words: Conservation Agriculture, Soil Health, Nutrient Management

INTRODUCTION

Fundamentally, CA is underpinned by biologically-framed management practices, the so called ‘second-paradigm approaches’ as enunciated by Sanchez (1994). As such, soil organic matter and soil biota are essential components in the complex system of interactions related to soil health and crop productivity. They provide a basis for optimizing the use of inorganic soil amendments

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[1] kassamamir@aol.com

[2] Theodor.Friedrich@fao.org

and plant nutrients so that there is a positive-sum effect on agricultural productivity and the environment. Since the second-paradigm approaches are relatively new, little systematic research has been done on how to harness the potentials of biologically-framed agricultural production systems. However, an exciting glimpse of the scientific foundations of this emerging biological paradigm for agricultural production systems and its empirical accomplishments can be obtained from the work of a number of scientists presented in a single volume by Uphoff *et al.* (2006).

Conservation Agriculture (CA) systems are defined by three key elements, namely: no or minimal mechanical soil disturbance, permanent organic soil cover specially by crop residues and cover crops, and diversified crop rotations in the case of annual crops or crop associations in case of perennial crops, including legumes. These elements in various combinations aim at establishing and sustaining healthy soil systems that can offer the best crop and livestock productivities and environmental services within the prevailing ecological and socio-economic conditions while optimizing the use of agrochemicals with biological interventions. CA system principles cannot be applied in a standardized prescriptive manner, and therefore in many ways they do represent a radical departure from the prevailing tillage-based mono-cropped production systems that depend dominantly on external inputs of mineral fertilizer and pesticides to maintain crop productivity and output.

Soil health is the capacity of the soil to function as a living system in which soil biological processes or the endogenous inputs are utilised alongside any exogenous inputs required to achieve the desired level of agricultural production that is economically and environmentally sustainable. Thus, with CA systems, the establishment and maintenance of healthy soil condition is inextricably linked to the achievement of effective nutrient management.

This paper elaborates on the notion of soil health in CA system as a precondition for effective nutrient management, and discusses in general terms four broad elements that need to be considered in nutrient management strategies for CA systems.

SOIL HEALTH AND CONSERVATION AGRICULTURE

For a soil to be productive for agricultural use, it must *inter alia* have the space for plant roots to grow, to hold and make water and nutrients available to plant roots, and provide a conducive biotic and chemical environment for soil microorganisms to function to maintain soil porosity, fix atmospheric nitrogen, hold and mineralize nutrients. All these dimensions must operate together and form the basis of soil health as defined below (Derived by combining Doran and Zeiss; Wolfe; and Trutmann, quoted together on http://ppathw3.cals.cornell.edu/mba_project/moist/TropSCORE.html.)

"Soil health is the capacity of soil to function as a living system, with ecosystem and land use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health. It emphasises a unique property of biological systems, since inert components cannot be sick or healthy.

Healthy soils maintain a diverse community of soil organisms that help to control plant disease, insect and weed pests, form beneficial symbiotic associations with plant roots (e.g., nitrogen-fixing bacteria and mycorrhizal fungi); recycle essential plant nutrients; improve soil structure (e.g., aggregate stability) with positive repercussions for soil water and nutrient holding capacity, and ultimately improve crop production.

Examples of management practices for maximizing soil health would include maintaining vegetative cover on the land year-round to increase organic matter input and minimize soil erosion, more reliance on biological as opposed to chemical approaches to maintain crop productivity (e.g., rotations with legume and disease-suppressive cover crops), and avoiding physical (mechanical) interventions which might compact, alter or destroy the biologically-created porous structural arrangements of soil components."

In many parts of the world soils are acknowledged to be sick, in poor health, and falling in potential for self-sustaining productivity. While there is much talk of 'soil quality' as if it were a static and sufficient characteristic, there is less-frequent mention of 'soil health', referring particularly to the biological dynamics of soil quality. (A relevant definition of Soil Health has been given above).

If plants we see above-ground don't thrive because soil is in poor condition, then probably the life below ground doesn't thrive either (= is 'sick'), for the same reasons, jeopardizing the effectiveness of the mutual interdependence of the above-and below-ground parts of the soil/plant system. It is easy to see the symptoms above-ground, but more difficult (as yet) to discern and characterize them below the surface.

Soil in ‘good condition’ (static) or ‘good health’ (dynamic) benefits from the following key components of CA (Shaxson *et al.* 2008):

Minimum disturbance of optimum porous soil architecture, which provides/maintains:

(a) Optimum proportions of respiration gases in the rooting-zone
(b) Moderates organic-matter oxidation;
(c) Porosity to water movement, retention and release at all scales
(d) Limits re-exposure of weed seeds and their germination.

A permanent covering of sufficient organic matter (esp. crop residues) over the soil surface, which provides:

(a) Buffering against severe impact of solar radiation and rainfall;
(b) A substrate for soil organisms’ activity;
(c) Raised cation-exchange capacity for nutrient capture, retention and slow-release;
(d) Smothering of weeds

Cropping sequences and rotations which include legumes, providing:

(a) Minimal rates of build-up of populations of pest species, through life-cycle disruption;
(b) Biological N-fixation in appropriate conditions, limiting external costs;
(c) Prolonged slow-release of such N from complex organic molecules derived from soil organisms;
(d) Range of species, for direct harvest and/or fodder;
(e) Soil improvement by organic-matter addition at all depths reached.

In light of the above elaboration of soil health and CA, it is clear that scope of the topic of nutrient management in CA systems is extremely wide and complex. Nor do we believe that enough scientific research has been done on nutrient management aspects to explain most of the productivity-related ecological process at work. Instead, the following sections offer some general perspectives on four elements of nutrient management in CA.

ELEMENTS OF A NUTRIENT MANAGEMENT STRATEGY IN CA

Being a biologically-based practice with an agro-ecological perspective, CA does not focus on a single commodity or species. Instead, it addresses the complex interactions of several crops to particular local conditions capitalizing on the complex systems of interactions involved when managing soil systems productively and sustainably. An illustration of soil system dynamics under CA developed from the work of Lucien Séguy and CIRAD researchers in several countries is given in Uphoff *et al.* (2006).

Therefore nutrient management practices in CA systems cannot be reduced to simple physical input-output model. While there is much new work that needs to be done to formulate nutrient management strategies in CA systems, it would seem to us that all such strategies would need to ensure that soil health as elaborated above becomes the means of meeting crop nutrient needs in an optimum and cost-effective way within the prevailing ecological and socio-economic conditions.

Nutrient management strategies in CA systems would need to attend to the following four general aspects, namely that:

(i) the *biological processes* of the soil are enhanced and protected so that all the soil biota are microorganisms are privileged and that soil organic matter and soil porosity are built up and maintained;
(ii) there is adequate *biomass production and biological nitrogen fixation* for keeping soil energy and nutrient stocks sufficient to support higher levels of biological activity, and for covering the soil;
(iii) there is an adequate *access to all nutrients* by plant roots in the soil, from natural and synthetic sources, to meet crop needs; and
(iv) the *soil acidity* is kept within acceptable range for all key soil chemical and biological processes to function effectively.

The above four elements are elaborated below but without engaging in a comprehensive discussion regarding how they are affected by the level of production, climate and seasonality, water supply, soil type, clay content and type etc, or by farm size and resources, or type of farm power and mechanization, etc. Based on our assessment of the situation, it would be true to say that not enough is known about these four elements to formulate a comprehensive framework for nutrient management in CA systems.

Managing Soil Biological Processes – Soil as a Living System

From many physical landscapes, we expect the three-dimensional catchments which are clothed in soil to yield sufficient crops and other vegetation of various types and, simultaneously, volumes of clean water from streams and boreholes regularly on a repeated annual basis.

Plants, rivers and groundwater depend on water penetrating into soil which is porous from the surface downwards. Insufficiency of water for plants hinders the interacting functioning of the other components of soil productivity: biological, physical, and chemical. The rate of entry of water into and through and its movement within the soil is governed by soil's porosity, both micro and macro, which in turn is governed by the volume and inter-connectedness of pores able to transmit water. The volume and availability of water which plants can use is determined by the proportion of soil pores which can retain water against the force of gravity and yet can release that water in response to 'suction' exerted through roots as dictated by the plants' physiology and atmospheric demand. Water management in soil is intrinsically linked to nutrient management.

Insufficiency of water and/or of various nutrients required by plants for growth processes diminish the derived productivity of the soil in which they are growing, inhibiting full interactions in the plant-soil system. Inadequacy of plant nutrients hinders plant growth and development; severe water-stress stops the whole system.

Soil porosity is damaged or destroyed by compaction, pulverization, and/or collapse due to degradation and loss of organic matter. Net loss of organic matter is caused by tillage of the soil, which results in accelerated oxidation of the carbon in the materials to carbon dioxide gas and its loss to the atmosphere. Following such damages, appropriate soil porosity is regained and maintained chiefly through biotic transformation of the non-living fraction of organic matter by its living fraction - soil-inhabiting fauna and flora - from micro-organisms such as bacteria to macro-organisms such as worms, termites and plants themselves. Their metabolic activity contributes glue-like substances, fungal hyphae etc. to the formation of irregular aggregates of soil particles, within and between which are the all-important pore-spaces in which water, oxygen and carbon dioxide flow and roots grow. These substances also contribute markedly to the soil's capacity to capture and retain nutrient ions on organic complexes, and provide a slow-release mechanism for their liberation back into the moisture in the soil. For this activity and its effects to be maintained, a sufficient supply of new organic matter needs always to be available as a source of energy and nutrients to the soil organisms – not just to the plants alone.

If the conditions are kept favourable for biotic activity in the soil, this dynamic process of formation and re-formation of the porous soil architecture will continue from year to year, maintaining the capacities of landscapes thus treated to continue yielding vegetation and water on a recurrent basis, contributing to sustainability of such production processes. Here lies the significance of maintaining 'soil health'. For the purposes of deciding how best to manage the land and nutrients to maintain its productivity, it is more appropriate to think of the soil primarily as a living porous biological entity interpenetrating the non-living components, and forming from the top downwards, rather than as a geological entity forming from the bottom upwards with living things in it at the top (Shaxson *et al.* 2008).

Managing Biomass Production and Biological Nitrogen Fixation

CA systems require higher levels of biomass production within the rotation to develop and maintain an adequate mulch cover, to raise soil organic matter level, to enhance soil biodiversity and their functions, to raise moisture and nutrient holding capacities, to enhance nutrient supplies, to enrich the soil with nitrogen in the case of legumes, and to protect the soil surface.

Practices that enhance soil organic matter are built into CA principles and include one or more of the following, including: minimal or no-till; diversifying cropping systems; planting trees;

mulching; using cover crops and green manures, using crop rotations; and using nitrogen fixing crops.

Nitrogen is fixed from the atmosphere by all kinds of free living organisms in undisturbed soils, and also by rhizobia in root nodules in legume crops as well as in herbaceous and woody legumes. Soil organisms including protozoa and nematodes in the root rhizosphere also fix atmospheric nitrogen, and so the nitrogen cycle has multiple pathways to restore nitrogen to the soil and supply to crops. For crop growth and for soil microorganisms to function, and for soil organic matter to build up, adequate nitrogen supply is needed. No-till and planted fallows and pastures in the rotation can preserve soil integrity and soil organic matter, and various herbaceous and tree legumes can make a contribution to maintaining a positive nitrogen balance for the cropping system (Boddey *et al.* 2006). Equally, failure to compensate for any net nutrient outputs can lead to losses in soil organic matter and soil nutrient reserves in the short run, and to soil erosion and soil system degradation in the long term.

Farmer and research experience have demonstrated the long-term benefits of a CA system. Research in Canada has shown, that after 20 years of continuous no-till with full stubble retention, higher yields can be obtained compared with a short-term (2-year) no-till system. Major increase in soil organic matter content is assumed to be responsible for these benefits (Derpsch 2007a). The evolution of a long-term CA system is described by Sá (2004) and is quoted by Derspsch 2007a as follows:

“In the initial phase (0-5 years) the soil starts rebuilding aggregates and measurable changes in the carbon content of the soil are not expected. Crop residues are low and nitrogen needs to be added to the system. In the transition phase (5-10 years) an increase in soil density is observed. The amounts of crop residues as well as carbon and phosphorus contents start to increase. In the consolidation phase (10-20 years) higher amounts of crop residues as well as higher carbon contents are achieved, a higher cation exchange capacity and water holding capacity is measured. Greater amount of nutrient cycling is observed. It is only in the maintenance phase (>20 years) that the ideal situation with the maximum benefits for the soil is achieved and less fertilizer is needed.”

A constraint that can be critical for many of these biologically-driven innovations is the availability of biomass. We are reminded in Uphoff et al. (2006), that little thought and little investment have been devoted to reducing biomass production and biological nitrogen as a constraint.

Managing Access to a Balanced Nutrient Supply

The more common notion regarding crop nutrition is based on maintaining overall quantities or concentrations of nutrients in the soil. At the practical level, this is reduced to a simple output-input nutrient balance equation so that what is taken out by the crop is or must be replaced by application of nutrients from inorganic fertilizer or other sources. Invariably, this approach is combined with intensive soil tillage that reduces, over time, soil organic matter and porosity, and therefore also its water and nutrient holding capacity as well as all the beneficial soil biological processes.

Neal's Kinsey's book "Hands-on Agronomy" (Kinsey and Walters 2006) clearly shows from direct field experience across many years and many countries, that what is important is that not only is each element necessary individually, but a balance of all soil elements is necessary collectively. If there is too much of a given nutrient, it is going to tie up something else that is needed, e.g. too much potassium ties up boron, too much phosphorus ties up zinc, too much nitrogen ties up copper, too much calcium could tie up all the other nutrients, depending on their availability. Also, imbalances in nutrients can lead to unbalanced plant metabolism making plants vulnerable to all kinds of pathogens as elaborated by Chaboussou (2004).

In a CA system there is no compact subsoil plough layer. Instead there is another type layer, a surface layer of mulch enriched with organic plant residues and nutrients, and altering the dynamics of the organic matter of the soil and the cycling and flows of nutrients (Séguy *et al.* 2006). In a sense, in CA systems, forest floor conditions are emulated and nutrient cycling through cover crops act as 'nutrient pumps' to enhance and conserve pools of nutrients from which plant roots feed. Nutrients are returned to the system via mulch mineralization, regulated by C:N ratio and lignin content of the aboveground and root parts of the crops. Much of the system's nutrients are held in the biomass in a semi-closed manner rather than in the soil.

The continuous increase in surface and soil biomass and in soil biological processes in CA facilitate the formation and existence of a nutrient balance as proposed by Kinsey and which leads to crop plants that are healthier. At least 18 mineral nutrients are necessary for plant growth, and maintaining access to a balanced supply of nutrients to crops in CA system is clearly helped by the biologically-oriented processes in the system that has a higher level of biomass and soil organic matter. Organic soil amendments have the advantage of providing more or less a full range of nutrients in contrast to mineral fertilizers. Where there are likely to be serious deficiencies of mineral nutrients, these have to be corrected from the start to avoid disrupting the development of the soil biological processes.

In a fully established CA system the aim of fertilizer nutrient management is to maintain soil nutrient levels, replacing the losses resulting from the nutrients exported by the crops. Because CA systems have diverse crop mix including legumes, and nutrients are stored in the soil organic matter, nutrients and their cycles must be managed more at the system or crop mix level. Thus, fertilization would not anymore be strictly crop specific, with the exception of nitrogen top dressing (if required at all), but will be given to the soil system at the most convenient time during the crop rotation. With the management of legume crops, either as previous crop in the rotation or as component in a cover crop before the next cash crop "top" dressing with nitrogen can be replaced by the N captured by the legumes and released during the following cropping cycle at the required time (more legume content – earlier release, more grass content in cover crop, later release). Additionally, undisturbed soils are habitats for free living nitrogen fixing bacteria and there is rhizospheric fixation of nitrogen (Sprent and Sprent 1990).

Conventional soil analysis data are not necessarily valid as a basis of fertilizer recommendations for CA, since the available soil volume and the mobility of nutrients through soil biological activities tend to be higher than in tillage-based systems against which the existing recommendations have been calibrated. In established CA systems, most nutrients are concentrated and maintained in the top 0-10 cm. For example, phosphorus often identified as a key constraint to crop production, is actually abundant in most soils, with much less that 10% of the total supply "available" at any one time (Uphoff *et al.* 2006). In CA systems, soils show a higher concentration of available phosphorus in the upper soil layer, and roots will grow right to the soil surface under the mulch. There is much potential for phosphorus solubilization and mobilization through biological processes as influenced by soil moisture changes. Also, the role of mycorrhizas, which are obligate symbioants, in foraging, absorption and translocation to the roots of associated plants of a range of nutrients, and imparting resistances and tolerances against soil pathogens, drought and salinity, aluminum and heavy metals is extensively documented and so is their ability to induce changes in root morphology. Mycorrhiza associations therefore allow larger volume of soil to be exploited for nutrients, particularly those which do not move readily through mass flow or are in relatively immobile form particularly phosphorus, ammonium nitrogen, copper and zinc (Habte 2006). However, micorrhiza diversity and activity is severely curtained by soil tillage and intensive use of agrochemicals, and soil tillage destroys the hyphal networks of micorrhiza fungi thus affecting nutrient mobilization and uptake. Similar to the way rhizobia are linked with leguminous plants, so are symbiotic micorrhizas related to plant nutrition and development in general (Rivera and Fernadez 2006), and these relationships need to be incorporated into nutrient management strategies in CA systems as elaborated in Turner *et al.* (2006).

Managing Soil Acidity

Soil pH is critical for several reasons. It has a major influence on the availability of elements, including primary nutrients like nitrogen, phosphorus and potassium, as well as secondary nutrients, micronutrients and potentially toxic elements like aluminum. Most soil microorganisms are sensitive to soil acidity, which has an influence on nutrient availability (especially nitrogen), soil organic matter and general soil health. The most beneficial soil fungi, for instance, do not like a high pH, and soil bacteria have problems at lower pH. One of the main reasons for managing soil pH by application of lime is to reduce such toxic effects. However, soil acidity becomes self-adjusting at 6.2 or 6.3 when all four cations -- calcium, magnesium, potassium and sodium -- are in proper equilibrium (Kinsey and Walters 2006). Any one of them in excess can push pH up, and any one of them in lower amounts can take pH down.

CA systems are based on building and breaking down organic matter to maintain soil health and productivity. As microorganisms decompose soil organic matter, organic acids are continuously being formed. If these acids are not neutralized by free bases, then soil acidity will increase. There are other reasons why soil can be acidic, due to leaching of basic cations by rainfall, or to soil being formed from acid parent materials, or to biological nitrogen fixation. Where soils are acidic particularly in humid and sub-humid soils and may have toxic levels of aluminum, the effectiveness of broadcast lime application without incorporation has been long proven in CA systems, as lime moves into deeper soil layers, especially when applied in small quantities each year in combination with green manure cover crops (Derpsch 2007b). Experience Brazil shows that aluminum toxicity tends to disappear over time under CA systems.

TOWARDS CA-BASED NUTRIENT MANAGEMENT PRACTICES

Integrated Soil Fertility Management (ISFM) and Integrated Natural resources Management (INRM) approaches of various types and nomenclature have been in vogue in recent years in certain sections of the scientific community. Generally, such approaches are focused more on meeting crop nutrient needs rather than managing soil health and land productivity as is the case with CA systems. Also, most of the work that is couched under the rubric of ISFM or INRM over the past 15 years or so has been geared towards tillage-based systems which have many unsustainable elements, regardless of farm size or the level of agricultural development. Unless the concepts of soil health and function are explicitly incorporated into ISFM or INRM approaches, sustainability goals and means will remain only accidentally connected, and sustainable crop intensification will be difficult to achieve particularly by resource poor farmers.

We believe that CA systems have within them their own particular sets of ISFM or INRM processes and concepts that combine and optimize the use of organic with inorganic inputs integrating temporal and spatial dimensions with soil, nutrient, water, soil biota, biomass dimension, all geared to enhancing crop and system outputs and productivities but in environmentally responsible manner. There is empirical evidence to show that CA-based ISFM or INRM processes can work because of the underpinnings of soil health and function.

Focusing on soil fertility but without defining the tillage and cropping system, as often proposed by ISFM or INRM approaches, is only a partial answer to enhancing and maintaining soil health and productivity in support of sustainable production intensification, livelihood and the environment. Over the past two decades or so, empirical evidence from the field has clearly shown that healthy agricultural soils constitute biologically active *soil systems within landscapes* in which both the soil resources and the landscape must operate with plants in an integrated manner to support the various desired goods and services (e.g., food, feed, feedstock, biological raw material for industry, livelihood, environmental services, etc) provided by agricultural land use.

Consequently, successful nutrient management strategies as part of any ISFM or INRM approach must pay close attention to issues of soil health management which means managing the microscopic integrity of the soil-plant system particularly as mediated by soil living biota, soil organic matter, soil physico-chemical properties, available soil nutrients, adapted germplasm as well as to managing the macroscopic dimensions of landscapes, socioeconomics and policy. Given that CA principles and practices offer substantial benefits to all types of farmers in most agro-ecological and socio-economic situations, CA-based IFSM and INRM approaches to nutrient management and production intensification would be more effective for farmer-based innovation systems and learning processes such as those promoted through Farmer Field School networks.

Adopting a CA-Based Nutrient Management Framework

CA has now emerged as a major “breakthrough” systems approach to crop and agriculture production with its change in paradigm that challenges the status quo. However, as a multi-principled concept, CA translates into knowledge-intensive practices whose exact form and adoption requires that farmers become intellectually engaged in the testing, learning and fine tuning possible practices to meet their specific ecological and socio-economic conditions (Friedrich and Kassam 2009).

In essence, CA approach represents a highly biologically and biogeophysically-integrated system of soil health and nutrient management for production that generates a high level of “internal” ecosystem services which reduces the levels of “external” subsidies and inputs needed. CA provides the means to work with natural ecological processes to harness greater biological productivities by combining the potentials of the endogenous biological processes with those of exogenous inputs. The evidence for the universal applicability of CA principles is now available across a range of ecologies and socio-economic situations covering large and small farm sizes worldwide, including resource poor farmers (Goddard et al. 2007, FAO 2008).

There are many different ecological and socio-economic starting situations in which CA has been and is being introduced. They all impose their particular constraints as to how fast the transformation towards CA systems can occur. In the seasonally dry tropical and sub-tropical ecologies, particularly with resource poor small farmer in drought prone zones, CA systems will take longer to establish, and step-wise approaches to the introduction of CA practices seem to show promise (Mazvimavi and Twomlow 2006). These involve two components: the application of planting 'Zai-type' basins which concentrate limited nutrients and water resources to the plant, and the precision application of small or micro doses of nitrogen-based fertilizer. In the case of degraded land in wet or dry ecologies, special soil amendments and nutrient management practices are required to establish the initial conditions for soil health improvement and efficient nutrient management for agricultural production (Landers 2007). What seems to be important is that whichever pathway is followed to introduce CA practices, there is a need for a clear understanding of how the production systems concerned should operate as CA systems to sustain soil health and productivity, and how nutrient management interventions that may be proposed can contribute to the system effectiveness as a whole both in the short- and long-term.

CONCLUDING REMARKS

Many of the CA related soil processes, e.g. increased soil organic matter content and soil porosity, or increased biological nitrogen fixation by legumes in rotation, or exploitation of the deeper soil layers through crops with deep and dense root systems, have a significant bearing on nutrient management. Evidence shows that in CA systems, nutrient requirements are lower, nutrient efficiencies are higher and risks of polluting water systems with mineral nutrients lower.

However, systematic research into CA systems and their nutrient management requirements are of relatively recent origin as can be seen from the research work reported in Uphoff *et al.* (2006) or in the Goddard *et al.* (2007) compendium. Both these volumes imply that nutrients as a production input are a necessary condition but not a sufficient condition for sustainable production intensification. In CA systems, the focus is on managing soil health and productivity simultaneously and which depends on many complex cropping system relationships in space and time and on biodiversity and organic matter within soil systems when they are enlisted on behalf of agricultural production.

Ultimately, the management of nutrient input-output relationships in CA systems must balance the nutrient accounts which means that the levels of outputs of biological products that are aimed at will dictate the levels of inputs, and ongoing nutrient balances must remain positive. The major difference with CA systems is that the management of the multiple sources of nutrients and the processes by which they are acquired, stored and made available to crops are more biologically mediated. Much more research needs to be done on the different aspects of soil health and nutrient management in CA-system as is now beginning to occur as more countries begin to adopt and integrate CA concepts and practices into commercial production activities at both small and large scale as a basis for future sustainable production intensification strategies.

As an appropriate ending to this paper we would like to quote Derpsch 2007b:

"Experience has shown that most things learned at university about fertilization and liming should be revised, and new concepts of fertility management for no-till systems need to be developed and applied. The main principle to keep in mind is that farmers should fertilize their soils rather than their crops."

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