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Conservation agriculture in cereal systems of south Asia: Nutrient management perspectives

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Abstract: In past, green revolution has paid dividends through impressive agricultural growth, which helped to keep balance between demand and supply in the past four decades. But, the real challenges have surfaced in the recent years with ever-increasing food demand due to burgeoning populations, degradation of natural resources and changing climatic conditions. The current food crisis witnessed a dramatic increase in world food prices, causing political and economical instability and social unrest in both poor and developed nations. Further, cereal crops (rice, wheat and maize) grown in different sequences, contribute bulk of the food in south Asia wherein production growth both in terms of grain and residue has slowed. Annual yield growth rates in rice and wheat were two to three times higher during 1966-94 than during 1995-2005. The challenges are further exacerbated with the sharp rise in the cost of food and energy, depleting water resources, vulnerability of soil to degradation and desertification & loss of biodiversity. In the last five decades in India nutrient use has increased by 1573%, total food grain production by 145% with an increase in area of just 3.5% and average yield increase of 125%. Therefore, the input use efficiency is decreasing at a fast pace, posing a threat of food insecurity and rapidly engulfing poor and under-privileged population. Conservation agriculture based management practices has proved to produce more at less costs, reduce environmental pollution, promote conjunctive use of organics (avoids residue burning), improve soil health and promotes timely planting of crops to address issues of terminal heat stresses in the region. Thus, for addressing the issues of resource fatigue and bridging 'management yield gaps', Conservation agriculture based management solutions are cornerstone. However, shift from conventional plow based farming practices to crop management practices based on key elements of conservation agriculture (minimal soil disturbance, surface retention of crop residues & efficient crop rotations) have varied nutrient dynamics and hence, the nutrient management perspectives. In this paper, we have made efforts to synthesize the information available in relation to nutrient management perspectives in conservation agriculture.

Key words: Conservation agriculture, cropping systems, soil, organic, carbon, tillage

Introduction

Global food supply has kept pace with demand in the past four decades due to impressive economic growth and linking global markets. During the second half of the 21st century, achievements of agriculture in South Asia in general and India in particular are among major global success stories. But, the real challenges have surfaced in the recent years with ever-increasing food demand due to burgeoning populations, degradation of land and natural resources and changing climatic conditions. To compound the challenges further, global climate change is likely to impact crop and livestock production, hydrologic balances, input supplies and other components of agricultural systems, making production much more variable than at present. Climate change is contributing to shift in growing seasons for major crops such as rice, production of which could fall by 40% and decrease the acreage of favorable wheat growing areas in the country. The current food crisis witnessed a dramatic increase in world food prices, causing political and economical instability and social unrest in both poor and developed nations. Therefore for food and livelihood security, agricultural think tanks and United Nations have prioritized four major areas i.e. natural resources, climate change, water and food.

Cereal crops (Rice, Wheat and Maize) grown in different sequences, contribute bulk of the food in South Asia. Cereal based systems greatly affect the livelihoods and health of the urban and rural poor. Impressive gains in yields of these systems were mainly due to introduction of superior germplasm, increased use of fertilizer inputs, expansion in irrigated areas and partly by interactions between inputs. However in recent years, cereal production growth both in terms of grain and residue has slowed. Annual yield growth rates in rice and wheat were two to three times higher during 1966-94 than during 1995-2005. In the 1970s and 1980s, the peak of the green revolution, agricultural research helped to reduce urban and rural poverty by making food more affordable. In the 1990s, however, yield growth stalled, setting the stage for the higher food prices now being observed. It is now generally agreed that easy gains from the original Green Revolution Technologies (GRTs) have for the most parts been realized. Therefore, new sources of productivity growth other than through increasing the crop acreage will have to be tapped for food production to keep pace with population growth. The slowdown in yield growth mainly affected wheat and rice, with annual growth rates falling below 1% in recent years and staying well below annual population growth for the past decade or more. Therefore, the South Asian agriculture is currently facing twin challenges of resource fatigue and decelerating productivity growth of cereal crops. Also, there exist large yield gaps more particularly *'management yield gaps'* ranging from 14-47%, 18 to 70% and 36 to 77% in wheat, rice and maize, respectively. In recent years, the challenges are further exacerbated with the sharp rise in the cost of food and energy, depleting water resources, vulnerability of soil to degradation and desertification & loss of biodiversity.

India alone need to produce additional 64 million tons (MT) of food over the next decade to achieve targeted 294 MT by 2020. The important question is where will the future productivity gains come from? Will germplasm improvement research repeat the progress achieved in last 4 decades? To us it seems that future growth in productivity in intensively cultivated systems will come increasingly from adoption of improved natural resource management practices designed to increase the efficiency of inputs in irrigated semi-arid, humid and sub-humid tropics and improving the productivity in rainfed agro-ecosystems. Incidentally the latter, are also the areas where seed-based technologies alone have not done so well in enhancing productivity. In the last five decades in India nutrient use has increased by 1573%, total food grain production by 145% with an increase in area of 3.5% and average yield increase of 125%. Therefore, the input use efficiency is decreasing at a fast pace, posing a threat of food insecurity and rapidly engulfing poor and under-privileged population leading to increased poverty; will be exacerbated further by the projected threats to agriculture due to consequences natural resource degradation and projected climate change effects.

Conservation agriculture based resource conservation technologies has proved to produce more at less costs, reduce environmental pollution, promote conjunctive use of organics (avoids residue burning), improve soil health and promotes timely planting of winter crops to address issues of terminal heat stresses in the region. Like any other tillage and crop establishment technology, it may not be a panacea for all present day ills, but has proven to bring out south American Agriculture out of its stagnant state almost 20 years ago, skyrocketing the cereals and oilseed production system. Thus, for addressing the issues of resource fatigue and bridging *'management yield gaps'*, Conservation Agriculture based management solutions are cornerstone.

In this paper we discuss the constraints of cereal production system of South Asia and their solutions through Conservation Agriculture based technologies and nutrient management perspectives in CA.

Cereal systems of south Asia

Rice, maize, and wheat are major cereals contributing to food security and income in south Asia. These crops are grown either as a monoculture or in rotations in tropical and sub-tropical environments of South Asia. In the irrigated and favorable rainfed lowland areas, rice-rice (R-R), rice-wheat (R-W), and rice-maize (R-M) are the predominant cropping systems. Rice-rice is common in tropical climate with distinct dry and wet seasons such as in South India, and in sub-tropical areas with mild cool winter climate such as in Bangladesh, Eastern India, and Eastern Nepal. Rice-wheat system is extensive in the sub-tropical areas of the Indo-Gangetic Plains of Bangladesh, India, Nepal, and Pakistan while R-M system is prevalent in tropical, sub tropical and warm temperate areas. Rice-maize system, however, is less extensive as compared to R-W or R-R if total area under these cereal systems is considered. There are mainly three cropping seasons in S. Asia: summer or *kharif* or *monsoon* (or called *kharif-II* or *aman* in Bangladesh) from June/July to Sept/Oct, *rabi* or winter from Oct/Nov to Feb/Mar, and spring or *pre-kharif* or *pre-monsoon* (or *kharif-1* in Bangladesh) from Mar/Apr to May/June. Rice (called transplanted aman or T. *aman* in Bangladesh) is the main crop in summer while a wide range of crops, including rice (called *Boro* in Bangladesh, eastern India and eastern Nepal), wheat, maize, winter pulses (chickpea, lentil, field peas), potatoes, and mustard are grown in *rabi* or winter season. In the *pre-kharif* or spring season, short-duration crops such as maize, pulses (mungbean, cowpea), and rice (called *aus* in Bangladesh) are grown. All the three major double-crop systems (R-R, R-W, R-M) often include an additional crop such as potato, lentil, chickpea, mustard, etc. in *rabi*, and jute, maize, rice, mungbean, cowpea, etc. during *pre-kharif-1* or *spring* season (Table 1).

Table 1. Area (Mha) under major cropping systems in four south Asian countries

Cropping system	Area (Mha)			
	Bangladesh	India	Nepal	Pakistan
Rice-rice	4.50	4.70	0.30	-
Rice-rice-rice	0.30	0.04	-	-
Rice-wheat	0.40	9.20	0.57	2.20
Rice-maize	0.35	0.53	0.43	NA
Maize-wheat	-	1.80	0.04	1.00
Rice-pulses	-	3.50	-	-
Rice-vegetable	-	1.40	-	-
Millet-wheat	-	2.44	-	-
Rice-potato	0.30	NA	-	-
Cotton-wheat	-	1.39	-	3.10

(Source: modified and updated from YS Saharawat, unpublished data, Mayee *et al.*, 2008; Timsina *et al.*, 2010)

Table 2. Total uptake of major nutrients by cereal crops (Kg/tone of produce)

Crop	Total uptake (kg/tone of main produce)					
	N	P_2O_5	K_2O	S	Ca	Mg
Rice	20.0	11.0	30.0	3.0	7.0	3.0
Wheat	25.0	9.0	33.0	4.7	5.3	4.7
Maize	29.9	13.5	32.8			

(Source: Fertilizer Statistics 2007-2008, FAI New Delhi)

In India the total nutrient uptake by these three major cereal crops is as given in table 2.

Conservation agriculture: Principles and practices

Conservation Agriculture (CA) is a concept for optimizing crop yields, and economic and environmental benefits. The key elements of CA include no-tillage, adequate retention of crop residues on the soil surface for mulching, innovative cropping systems and measure to reduce soil compaction through controlled traffic. Freewheeling of the farm machinery in moist fields creates ruts and compacts soil. This must be avoided if zero-till is to be practised for a longer time. These CA principles are not 'site-specific' but represent 'unvarying objectives' that are practised to extend CA technologies efficiently across all production conditions. Conservation Agriculture (CA) systems are not only about precision planting using seed drill or planters without tillage or significantly reduced tillage. But, is also about management practices (weed, water, nutrient and IPM etc) that make O-till technology successful and provide added advantage to the farmers. The way crop management is practised in different ecologies (e.g. plains and sloppy lands) may vary the importance of the "unvarying objectives' according to local situations, resource endowments of the farmers and farming systems. This only suggests that CA systems (zero-tillage) are 'divisible' in nature and 'flexible' in operation allowing farmers to benefit from them under diverse situations. Conservation agriculture based RCTs are an "open" approach, easier to mainstream. CA therefore, will be able to quickly address two critical needs that address concerns faced by South Asian agriculture today- farm economics and climate change.

Conservation agriculture based crop management - A paradigm shift

There has been a tremendous shift in the production variables of modern farming over traditional plow based farming (Table 3). Even then, the most agronomic works revolved around tillage and labor intensive farming. Declining soil organic carbon (SOC) status of soils has been main shift in agriculture from 'traditional animal based subsistence' to 'intensive chemical and tractor based' agriculture that multiplied problems associated with sustainability of natural resources. The SOC concentration in most cultivated soils of India is less than 5 g/kg compared with 15 to 20 g/kg in uncultivated virgin soils. Low SOC concentration is attributed to plowing, removal of crop residue and other bio-solids, and mining of soil fertility (Lal, 2004). Large

Table 3. Dynamism of production variables changing scenario

Sl. No.	Production variables	Traditional scenario	New/Changing scenario
1	Cropping systems	Less intensive	More intensive, Monotonous
2	Water table	High	Declining
3	Soil fertility	Medium to high fertility	Low, imbalances, multiple nutrient deficiencies surfaced
4	Land leveling	Traditional	Laser assisted
5	Tillage,	Repeated intensive tillage	No –till/drastically reduced tillage
6	Organic recycling	Animal based	Crop based
7	Cultivar choices	Limited	Wider
8	Climatic variability	Less	More extremes

acreage of cultivated lands shows fertility fatigue and deficiency of micro-nutrients in many intensively cropped areas. This adds to our challenge of making farming more profitable.

Globally, it took few decades for the farming community to shift away from the common belief that summer-fallow / ploughing was the only way to improve farm productivity to a belief that drastically reduced or minimum/zero tillage was more advantageous. Conservation agriculture (CA) is being widely accepted as an important component of the overall strategy for enhancing productivity, improving environmental quality and preserving natural resources for food security and poverty alleviation in such areas. The basic components of CA include drastic reduction in tillage, adequate retention of crop residues on the soil surface, use of economically feasible diversified crop rotations, avoidance of freewheeling and practice of controlled traffic, if possible (Kassam and Friedrich, 2009). These elements of CA are *not site-specific* but represent *unvarying objectives* that are practiced to extend CA technologies efficiently across all production conditions. No-till agriculture is considered as a revolutionary step in the direction of preventing land degradation and rehabilitation of the resilient but fragile lands. No-till agriculture together with other associated management practices such as *direct seeding* into loose *crop residues* to provide *soil cover and to conserve soil moisture*, judicious choice of *crop rotations* and agro-forestry tree species constitutes conservation agriculture (CA). CA is an innovation process of developing appropriate CA implements, crop cultivars etc. for iterative guidance and fine-tuning to modify crop production technologies. CA practices, many reduced till variants, have been widely adopted in tropics/subtropical and temperate regions of the world to grow rainfed cereals systems, cereals between rows of perennial crops, irrigated rice-wheat systems, and development of agriculture in hillsides sloping lands. CA has steadily increased worldwide to cover about 7% of the world arable land area.

It must be remembered that the conservation tillage (CT) and conservation agriculture (CA) are not synonymous. CT refers to reduced/minimum tillage with some residues left on the surface. In CA tillage is avoided or drastically reduced and adopt efficient crop rotations. Zero-till drill simply disturb the soil in a narrow slit just to place seed in the soil and hence minimal till system is very close to no-till system practiced in conservation agriculture. Soil conservation (SC), conservation tillage (CT) and resource conservation technologies (RCTs) are also not synonymous to conservation agriculture (CA). All RCTs may not form part of the CA. The CA requires a paradigm shift in our thinking and actions as indicated below:

·Uneven field levels	⇨	Precision land leveling
·Excessive tillage	⇨	No till / drastically reduced tillage
·Residue burning or incorporation	⇨	Surface retention of residues
·Use of ex-situ FYM/ composts	⇨	In-situ use of organics/ composting
·Green manuring (incorporated)	⇨	Brown manuring (surface drying)
·Free-wheeling of farm machinery	⇨	Controlled traffic
·Single or sole crops	⇨	Inter cropping / relay cropping
·Monotonous cropping system	⇨	Diversified cropping system
·Crop based management	⇨	Cropping system based Management

Experiences with conservation agriculture based technologies in south Asia

The growing realization that the agriculture of the post-Green Revolution era will be guided by the need to produce more quality food from the same land and water resources, besides sustaining environmental quality, only adds to the challenge. The zero-till wheat in rice-wheat cropping system has been addressing the several issues of sustainability and its success has encouraged the farmers to adopt the double no-till practice for long-term sustainability of the system. The major benefits (Gupta *et al.*, 2007a, 2007b, Saharawat *et al.*, 2010) of zero-till technology include (i) reduced costs due to savings in fuel and labor, (ii) timely planting of *kharif* and winter season (*rabi*) crops, resulting in higher yields, (iii) reduced weed density (iv) saving of irrigation water (up to 15-20%), (vi) improved input use efficiency because of better crop stands due to good seed and fertilizer nutrients placement, and (vii) build-up in soil organic carbon due to reduced burning of crop resides (Phillips *et al.*, 1980) & reduced oxidation of soil C. Presently we are at half way of conservation agriculture (CA) and evaluation and accelerating the adoption of double no-till is the immediate step towards CA. Several studies conducted across the production systems under varied ecologies of South Asia revealed potential benefits of CA based RCTs on resource conservation, use efficiency of external inputs, yield enhancement and adaptation to terminal heat effects (Gupta *et al.,* 2003; Malik *et al.,* 2005; Gupta & Seth, 2007, Gupta & Sayre, 2007, Gupta *et al.,* 2010, Jat *et al.,* 2010). Laser assisted land levelling being practiced over 1.5 m ha in south Asia saves on water by 25-30 %, improve yields by 5-15 % with other associated benefits (Jat *et al.,* 2009a, 2009b). Zero tillage in cereal systems have helped in saving in fuel, water, reduce cost of production, improve system productivity and soil health (Gupta *et al.,* 2003; Malik *et al.,* 2005; Gupta & Seth, 2007, Gupta & Sayre, 2007, Jat *et al.,* 2009 a; Saharawat *et al.,* 2009, 2010). The results across IGP suggests that double no-till with retention of crop residues produced higher system productivity over conventional and zero till without residues (Fig 1). Raised bed planting technology provides opportunity for diversification through intensification and saves on water (Jat *et al.,* 2005, 2006). Residue management in zero till systems (surface retention) helps in improving soil health (Sharma *et al.,* 2008) reducing GHG emission equivalent nearly 13 tonnes/ha

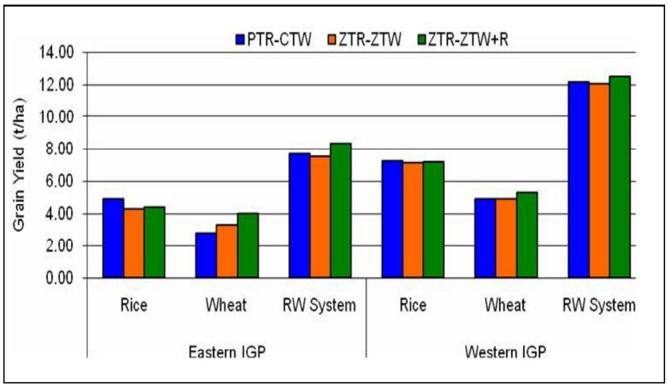

Figure 1. Yield performance of RWCS under CA and conventional tillage practices in western and eastern IGP *(Adopted from CIMMYT farmers participatory field trial data)*

(Mandal *et al.,* 2004) and also regulates canopy temperature at grain filling stage to mitigate the terminal heat effects in wheat (Jat *et al.,* 2009c, Gupta *et al.,* 2010).

Adoption of CA based practices in south Asia

CA practices have been widely adopted in tropics/subtropical and temperate regions of the world for rain-fed and irrigated systems. Acreage of Conservation Agriculture is increasing steadily worldwide to cover about 108 m ha (Derpsch and Friedrich, 2009) globally (7% of the world arable land area). Thus, CA is an innovation process of developing appropriate CA implements, crop cultivars, etc. for iterative guidance and fine-tuning to modify crop production technologies. Recent estimates revealed that CA based RCTs are being practiced over nearly 3.9 mha of South Asia (Anon., 2010).

Current nutrient availability and management scenario

On a macro-scale, N:P:K ratio of 4 : 2 : 1 has come to known as an ideal ratio, and a deviation in NPK consumption pattern, would suggest imbalanced fertilizers use- greater the departure , more the imbalance. In India, the average fertilizer consumption (Kg/ha) in paddy is 81.7 N, 24.3 P_2O_5, 13.1 K_20; whereas in wheat is 99.6 N, 30.2 P_2O_5, 6.9 K_20 and in maize is 41.7 N, 14.7 P_2O_5, 3.8 K_2O. This is not entirely true as there is hardly any basis for the suggested single valued ideal N:P: K ratio. The ratio will be further widening with mismatch in the demand and supply of major nutrients across Asia (Figure 2).

The NPK ratio is likely to vary with crops, cropping systems, CA practices, soils and their reactions. It appears that there is need to work out new N:P: K ratios for basing fertilizer allocations for different regions. In the demand and supply of fertilizer nutrients, use of organics in agriculture seems inevitable particularly for correcting the N: K imbalances. From plant nutrition point of view, the importance of the concept of balanced fertilizer use lies in adjusting the level of fertilizer use, taking into account available soil nutrients, crops requirement for targeted production levels under specific soil-water-crop management practices (Gupta and Jat, 2010). New information seem to strengthen our understanding that conservation agriculture has a distinct influence on soil quality and nutrient dynamics as compared with the traditional agriculture based on intensive tilled systems. The current nutrient prescriptions are (i) age old, (ii) area general- not site specific (iii) designed for the

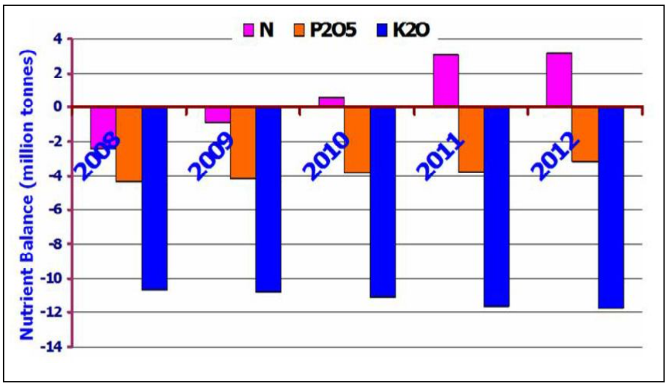

Figure 2. Nutrient balance in Asian agriculture (Source: FAO, 2008. www.fao.org)

component crops of the cropping system and (iv) better suited to tilled agriculture. Therefore, the focus should be *"feed the soil and let the soil feed the plant"*.

Nutrient management perspectives in conservation agriculture

Under the changing scenario of natural resources and management practices, the production variables are dynamic (Table 4). Hence, when everything is changing- How nutrient prescriptions designed for different situations will work under contrasting production environment. The key elements of CA have direct and indirect bearing on the nutrient supplying/ availability of soil which are described as below (Kassam and Friedrich, 2009).

1. *Minimum disturbance of optimum porous soil architecture*
- Optimum proportions of respiration gases in the rooting-zone
- Moderates organic-matter oxidation;
- Porosity to water movement, retention and release at all scales
- Limits re-exposure of weed seeds and their germination

2. *A permanent covering of sufficient organic matter over the soil surface*
- Buffering against severe impact of solar radiation and rainfall;
- A substrate for soil organisms' activity;
- Raised cation-exchange capacity for nutrient capture, retention and slow-release;
- Smothering of weeds

3. *Cropping sequences and rotations which include legumes*
- Minimal rates of build-up of populations of pest species, through life-cycle disruption;
- Biological N-fixation in appropriate conditions, limiting external costs;
- Prolonged slow-release of such N from complex organic molecules derived from soil organisms;
- Range of species, for direct harvest and/or fodder;
- Soil improvement by organic-matter addition at all depths reached.

Table 4. Dynamism of production variables in changing scenario

S. No	Production Variables	Dynamics
1	Cropping Systems	More intensive, Monotony
2	Water Table	Declined/increased
3	Soil nutrients	Deficiencies surfaced
4	Tillage, Land leveling	Contrasting
5	Organics	Different
6	Cultivar Choices	Wider
7	Climatic variability	Extremes
8	Policy	Changing

It is only prudent that new fertiliser recommendations should be able to mimic significant effects of residue retention vis-a-vis incorporation of organics having differential soil moisture and thermal regimes. Therefore, the paradigm shift from tilled to no-till CA systems require a serious thrust on nutrient management research to improve soil and crop productivity and environmental quality.

Conclusion

The key elements of CA including no-tillage, adequate retention of crop residues on the soil surface for mulching, innovative cropping systems are not 'site-specific' but represent 'unvarying objectives'. CA systems are 'divisible' in nature and 'flexible' in operation allowing farmers to benefit from them under diverse situations and also cope with climate change. Globally CA has been widely accepted as an important component of the overall strategy for enhancing productivity, improving environmental quality and preserving natural resources for food security and poverty alleviation in such areas. CA requires a paradigm shift in our thinking and actions. The zero-till wheat in rice-wheat cropping system has been addressing the several issues of sustainability also reduce costs in fuel and labor, help in timely, produce higher yields, reduce weed density, help in saving of irrigation water, improve input use efficiency because of better crop stands due to good seed and fertilizer nutrients placement, and also build-up in soil organic carbon due to reduced burning of crop resides. Double no-till with retention of crop residues also produce higher system productivity, improve soil health, reduce GHG emission equivalent nearly 13 tonnes/ha and also regulates canopy temperature at grain filling stage to mitigate the terminal heat effects in wheat. The NPK ratio is likely to vary with crops, cropping systems and there is a need to work out new N:P: K ratios for basing fertilizer allocations for different regions especially in the CA based systems as CA has a distinct influence on soil quality and nutrient dynamics as compared with the traditional agriculture based on intensive tilled systems. Therefore, the focus should be *"feed the soil and let the soil feed the plant"*. It is also prudent that new fertiliser recommendations should be able to mimic significant effects of residue retention vis-a-vis incorporation of organics having differential soil moisture and thermal regimes. Therefore, the paradigm shift from tilled to no-till CA systems require a serious thrust on nutrient management research to improve soil and crop productivity and environmental quality.

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