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Mini Review

Nitrogen and Water Use Efficiency in Conservation Agriculture

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Abstract

Conservation agriculture is resource conserving strategy for improving productivity and profitability of farming through efficient utilization of available resources with minimum foot print to the environment. Conservation Agriculture helps in carbon sequestration, soil erosion control, ground water recharge and moisture conservation. Conservation agriculture has been found to improve physical, chemical and biological properties of soil compared to conventional practices and ultimately helps in increasing nutrient and water use efficiency. Optimizing soil fertility and soil moisture simultaneously is possible through CA practice which ultimately increases resource use efficiency.

Keywords: Conservation agriculture; nitrogen use efficiency; water use efficiency

Introduction

The undesirable consequences of modern agriculture expand well beyond agricultural landscapes themselves. Biogeochemical cycles have been extremely altered at multiple scales and the rate of soil loss still exceeds soil formation Nitrogen (N) and phosphorus (P) are the two most important nutrients limiting biological production (Chapin et al., 1986; Tyrrell, 1999) and are the most extensively applied nutrients in managed terrestrial systems, mainly as soluble inorganic fertilizers.

Introduction of high yielding varieties (HYVs) coupled with expansion of irrigation facilities, and increased use of chemical fertilizers and other agro-chemicals have brought about spectacular increases in the yield of crops. About half of the total increase in food grain has been attributed to the use of fertilizers and more than one-third of this increase is due to N fertilizes alone. Harvesting high yields by applying only N is at best a short-lived phenomenon, as was shown in the early years of the green revolution. Clearly "N-driven systems" are not sustainable, as N becomes a 'shovel' to mine the soil of other nutrients, with the result that soils initially well supplied in other nutrients become deficient in them and productivity declines.

Conservation agriculture (CA) has been found to change physical, chemical and biological soil quality components compared to conventional practices involving tillage and thus affects N cycling in the soil and better moisture conservation. Therefore, an intensive reviews on role of conservation agriculture in sustainable crop production with efficient resource utilization has been carried out with following objectives; i) To know about the roles of CA practices on nitrogen use efficiency and ii) To know about the subsequent effect of improved soil properties on water use efficiency.

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Global Scenario of Nitrogen and Water Use

Projected 38% increase in global cereal demand by 2025 can be met by a 30% increase in N use and 20% yield response. But declining cereal harvest area at the rate of 0.33% per year and 60% increase in global N use on cereals would be required to meet cereal demand (Doberman, 2007).

One of the critical constraints to higher crop productivity is the low efficiency of applied nutrients especially N and P. In fifty years global scenario, total nitrogen input (Kg) and yield (Kg) per hectare per year are increasing but nitrogen use efficiency is in decreasing trend making farming system unprofitable. Fifty years of study reveal that there is decreasing NUE in India, Egypt and China, nearly constant in Brazil, USA and Bangladesh and increasing in Greece, France and Netherlands (Lassaletta et al., 2014).

Agriculture is the predominant user (75-80%) of the available freshwater resource in many parts of the world. At present most of the water used to grow crops is derived from rainfed soil moisture, with non-irrigated agriculture accounting for some 60% of production in developing countries. Although irrigation provides only 10% of agricultural water use and covers just around 20% of the cropland, it can vastly increase crop yields, improve food security and contribute 40% of total food production since the productivity of irrigated land is three times higher than that of rainfed land. The Food and Agriculture Organization (FAO) predicts that agricultural water withdrawals will increase by approximately 14% during 2000-2030 to meet food demand. For a variety of reasons, feasible expansion of irrigated agriculture will be able to accommodate only a portion of this increased demand, and the rest must come from an increase in the productivity of rainfed agriculture through possible interventions. Improving WUE by 40% on rainfed and irrigated lands would be needed to counterbalance the need for additional withdrawals for irrigation over the next 25 years from additional demand for food. However, this is a big challenge for many countries.

Role of Conservation Agriculture on Carbon Sequestration

Conservation agriculture practices increases residue biomass for succeeding crop. Total amount of residue biomass inputs (t/ha) of preceding crop for succeeding crop grown in maize-wheat- mung bean (MWMb) system during four different years of experiment conducted in India was 27.05, 30.80 and 31.01 t/ha in conventional tillage (CT), zero tillage (ZT) and permanent bed planting (PBP) respectively (Parihar, 2016). The higher biomass yields in ZT is due to the compound effects of additional nutrients , due to lesser weed population, improved soil physical health, better water regimes and improved nutrient use efficiency over CT (Unger 1998). Additional biomass yield benefits over time from the legume (due to N-accumulation through biological N2 fixation and leaf litter) were also observed. Result of 4 years long study also revealed that the amount of water use (Evapo-transpiration) in CT was more than the CA (ZT and PB) practiced plots (Parihar, 2016). Conservation agriculture trail conducted for more than five year in Nepal on maize reveal more organic matter on conservation agriculture plot (12.87 t/ha) compared to traditional agriculture plot (10.93 t/ha) after 5 months growing period of maize (Karki and Shrestha, 2015).

The Encouragement of Moisture Conservation and Groundwater Recharge

Mulching is an important component of conservation agriculture. Mulching influences soil evaporation, transpiration, grain yield and water use efficiency of cereal production. There is 23 and 45 mm less evaporation from mulched winter wheat and maize respectively compared to non mulched. 42, 43, and 68 mm less soil evaporation from mulched winter wheat field, maize field and summer fallow were observed respectively compared to non mulched as reported by Zhang et al., (2002) and Jaubo et al., (1996). Conservation agriculture trail on maize crop in Nepal demonstrated saving of 150 mm soil moisture from evaporation loss and 35 mm saving from transpiration loss on CA practice compared to traditional agriculture practice. Ground water recharge due to increased infiltration was observed on CA (2.7mm/ minute) compared to traditional agriculture practice (0.8mm/minute) (Karki and Shrestha, 2015). Conservation agriculture focuses on crop diversification and continuous covering of soil surface discouraging fallow field. Mulching on summer fallow saved 68 mm soil moisture from evaporation loss, contributing soil moisture conservation (Zhang et al., 2002 and Jaubo et al., 1996).

Nitrogen Use Efficiency in Conservation Agriculture

Use efficiency of applied N as estimated by the difference in N uptake of the above-ground portions of N fertilized and unfertilized plots, and expressed as percentage of N fertilizer applied to the crop is only about 30-40 per cent. CA practice increases nutrient use efficiency of the crop by 15- 25 % (Karki and Shrestha, 2015). Permanent bed planting is a special type of conservation agriculture practice that helps in increasing N use. Permanent bed–all straw left as stubble and PB–all straw burned had the highest N use efficiency (28.2 and 29.1 kg grain kg^{-1} of N supply, respectively) compared to straw removed(Limon et al., 2000). Agronomic N use efficiency (kg/kg) in maize under permanently raised beds (PRB) and conventional tillage (CT) method were found 28% and 16% respectively in an experiment conducted in Uzbekistan. Similarly, Apparent N recovery efficiency in maize crop was found higher in BRB (80%) than in CT (44%) (Devkota et al., 2015). CA practices increases the soil organic matter

(SOM) due to residue retention and cover cropping. An experiment conducted in Portugal reveal that increasing SOM from 1 %to 2 % will increase nitrogen-use efficiency from 19.1 to 36.6 kg of wheat per kg of applied nitrogen under Portugal's condition (Carvalho & Lourenço, 2014).

Water Use Efficiency in Conservation Agriculture

Low water use efficiency (WUE) has been the concern as the availability of water for agriculture is decreasing day by day. For saving and effective utilization of this vital resource, proper management strategies involving agro-techniques should be developed. Many promising strategies for raising WUE are available and CA and conservation tillage is one that increases water infiltration, reduces runoff and improves soil moisture storage.

In regions with pronounced seasonal water scarcity or low and erratic rainfall water use efficiency can be dramatically improved by the practice of CA. Higher and more stable crop yields have frequently been observed under CA, in dryland areas and in drought affected years (Peterson & Westfall, 2004; Cantero-Martinez et al., 2007). This improved water use efficiency may reduce water requirements for a crop by about 30 %, regardless of whether crops are under irrigation or rain fed (Bot & Benites, 2005). Similarly, there is improved nutrient use efficiency under CA which is known to reduce nitrogen application by 30-50% (Cantero-Martinez et al., 2007).

CA practices allow to increase water infiltration and to reduce evaporation and erosion. No tillage and residue retention gives positive control of surface water (Bachmann and Friedrich 2003) and increase water availability to plants in arid and semi-arid rainfed agriculture, and may lead to enhanced water use efficiency (WUE) by crops. CA based on no tillage system alters the partitioning of the water balance, decreasing soil evaporation and increasing infiltration and deep percolation, leading to increased yields and WUE (Wang et al. 2004). Water use efficiency is increased and save water by 15-50% through the adoption of CA technologies. It reduces water runoff, better water infiltration and more water in the soil profile throughout the crop growing period. It has potential to increase water application efficiency by over 50 % (Karki and Shrestha, 2015).

Experimental results and farmers experience disclose that considerable saving in water (up to 20% – 30%) and nutrients are achieved with zero-till planting and particularly in laser leveled and bed planted crops. They also found that across growing seasons, soil water content under no-till was about 20% greater than under conventional tillage (De Vita et al., 2007). Studies have shown that cultivating crops on relatively permanent raised beds with residue retention, potentially saves 12-23% irrigation water in wheat and maize. Compared with conventional agriculture practices, raised bed systems saved up to 70% of irrigation water in rice (Devkota et al., 2015). Crop water productivity (kg/m3) of crops grown under cotton- wheat-maize and rice-wheat rotation system in Uzbekistan was found higher in permanent raised bed (PRB) system compared to conventional system. Water productivity of wheat and maize grown on PRB was 1.73 and 0.88 kg/m3 while that under conventional system was 1.36 and 0.48 kg/m3 respectively. Similarly, under rice-wheat system water productivity was higher for rice (0.27 kg/m3) and wheat (1.48 kg/m3) than on conventional system (Devkota et al., 2015). WUE was observed higher under mulched winter wheat (1.94 kg/m3) and mulched maize (1.84 kg/m3) compared to non mulched field (Zhang et al., 2002; Jaubo et al., 1996). Four years average WUE (US $ net returns per ha per mm) in MWMb system was higher in both PB (1.131) and ZT (1.019) compared to CT (0.680) (Parihar et al., 2016). The significantly higher WUE of MWMb system under CA practices compared to CT was also due to lesser water use in CA plots compared to CT plots. Das et al. (2016) reported 30% higher WUE in the pigeon pea-wheat system in PB plots with 84% decreased water use in a sandy loam soil of India.

Higher overall irrigation water productivity (kg grain m^{-3}) of wheat during five year experiment (2009-2014) was found higher (1.57) in scenario of full CA (ZT: rice-wheat-mungbean system) compared to conventional agriculture (1.37). Similarly, water productivity of system was found higher (1.94) in scenario of full CA (ZT: maize-wheat-mungbean) compared to conventional agriculture (0.47) (Parihar et al., 2016). Increase in total biomass (t/ha) is more in CA practices (PB and ZT) compared to conventional practices. The added biomass contributes to improved soil properties, which also increases WUE (Parihar et al., 2016). WUE is also positively correlated with soil fertility status. Fertile soil resulted from CA practices will also have higher WUE compared to less fertile (Deng et al., 2006). Further, NUE can be successfully increased by supplying irrigation water (Gajri et al., 1993). But it is not always possible to provide irrigation facilities everywhere. So, conserving moisture through CA can be an alternative strategy.

Conclusion

Conservation agriculture is one of the alternatives to cope up with the recent scenario of inefficient resource consuming scenario created by modern agriculture. Low nitrogen and water use efficiency in global context is challenging for profitability and sustainability of farming. More than half the nitrogen used for crop fertilization is currently lost into the environment. Increase in yield with simultaneous increase in water and N is considered possible through various researches. Even though a significant improvement in NUE occurred in some countries, the present results suggest that a further increase of nitrogen fertilization would result in a disproportionately low increase of crop production with further environmental alterations, unless cropping systems improve their efficiency substantially. In that respect, CA could be a suitable strategy to increase nutrient and water use efficiency in profitable manner with minimum environmental foot print.

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