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Research Articles

Ecosystem services of wheat (*Triticum aestivum*) production with conventional and conservation agricultural practices in the Indo-Gangetic Plains

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ABSTRACT

Agriculture has short and long-term impacts on the environment affecting the ecosystem services. Agriculture could also have some dis-services, i.e. negative impacts on the environment. An attempt was made to quantify these services and dis-services of conventionally tilled wheat and wheat grown under zero tillage as well as with zero tillage and residue applied treatment. Net as well as green income was calculated for these treatments. The data for quantification of ecosystem services was obtained from an on-farm study conducted at Taraori village of Karnal district of Haryana, India. Economic value of the ecosystem services obtained from conventionally cultivated wheat were ₹ 68381/ha while in zero tilled and residue applied wheat the value of ecosystem services was highest, i.e. ₹ 75253/ha. In conventionally tilled wheat, cost of ecosystem dis-services was ₹ 1072/ha, which reduced to ₹ 1015/ha and ₹ 1009/ha in zero tilled and zero tilled plus residue applied wheat. Green income from conventionally tilled wheat was ₹ 33358/ha, which increased to ₹ 52449/ha in zero tilled wheat and to ₹ 53493 ha in zero tilled and residue applied wheat. The study highlighted the importance of including the ecosystem services and environmental cost in assessing the sustainability of various agricultural practices.

Key words: Conservation agriculture, Economic valuation, Ecosystem services, Green income

Intensive agriculture contributes immensely towards enhancing agricultural production and food security. However, it adversely affects the environment through losses of nutrients, particularly nitrogen (N); emission of greenhouse gases (GHGs); biocide residue remaining in soil and depletion of groundwater. These, in-turn have short- and long-term adverse impacts on yield and quality of crop, animal and human health. Agriculture, however, also has certain positive impacts on the environment through various provisioning, regulating, supporting and cultural ecosystem services (ES). These services include food production; nutrient cycling; conservation of biodiversity and purification of water, soil and air. Food production, classified as provisioning services by the recent Millennium Ecosystem Assessment (MEA), is a crucial ecosystem service for the survival of humanity (Sandhu *et al.* 2012) and is dependent upon supporting and regulating services as inputs to production, e.g. soil fertility and pollination (Zhang *et al.* 2007). Although agriculture provides provisioning services but intensive agricultural practices have resulted in the degradation of other valuable ecosystem services such as soil fertility, soil formation, water purification, climate regulation and biodiversity conservation.

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There has been a recent trend of decline in ecosystem services globally with 60% of the ecosystem services degraded in the last 50 years (MEA 2005). The positive and negative impacts of agriculture on the environment can be assigned with some economic valuation, i.e. ecosystem services and ecosystem dis-services. Some global studies measured impacts of agriculture production on ecosystem services (Dale and Polasky 2007, Sandhu *et al.* 2008). According to Sandhu *et al.* (2012), agricultural sector in Australia has negative impacts on all regulating and supporting ecosystem services.

Indian agriculture faces the challenge of meeting food demand of a growing population without compromising the environment (Tilman *et al.* 2002). Use of high amount of inputs like nitrogenous fertilizers, irrigation water and farm machinery in the Indo-Gangetic Plains (IGP) has led to increased GHG emissions, lowering of ground water table and leaching of nitrates into the groundwater. Research on ecosystem services obtained from agro-ecosystems in India, however, has received relatively less importance. The objectives of the present study were to develop a methodology for quantification of ecosystem services and dis-services generated from agricultural activities and estimate the net and green income of conventional and zero-till wheat in north-west India.

MATERIALS AND METHODS

The study was conducted at Taraoi village in Karnal, Haryana where rice-wheat cropping system is followed in the village for last 40 years. The site is located at 29.7ºN and 76.97ºE. The climate is sub-tropical monsoon climate. Under average climatic conditions, the area receives 700 mm annual rainfall. The mean annual maximum temperature is 35°C while the mean annual minimum temperature is 18°C. The soil is sandy loam in texture. Conservation agricultural practices like zero tillage and zero tillage along with residue application were practiced in wheat crop.

In the present study four ecosystem services were quantified, e.g. soil formation, fertility enhancement, carbon sequestration and improvement in water holding capacity. Soil samples were collected from farmers' field growing wheat with three practices: (1) conventional tillage, (2) zero tillage and (3) zero tillage with crop residue retention. Soil samples were collected from the selected treatments in replicate for three consecutive years, air dried under shade, processed and sieved through 0.2 mm screen, for further analysis. The samples were analyzed for available N, P, K and total carbon contents using standard methodologies (Page *et al.* 1982). Soil moisture content was measured using gravimetric method and bulk density was measured using core-sampling method. Economic valuation of soil nutrients (N, P and K) was done using replacement cost approach (RCA). Monetary valuation of nutrient added or lost in 3 years time period was done by calculating the price of fertilizer equivalent to the amount of nutrient. Then cost of added or lost carbon was calculated based on the cost of farmyard manure (FYM) needed to replace that much amount of carbon in soil. Economic value of soil moisture conserved was quantified from the irrigation cost calculated based on price of diesel to irrigate one ha of land. Earthworm population was quantified to estimate the amount of soil formed per ha per year. Four 25-cm^3 soil samples were taken from each field using a spade (Martin 1978). The soil was spread on polythene sheet and earthworms were extracted by hand. Economic value of soil formation service was quantified on the basis of earthworm population.

The provisioning service, i.e. the price of the raw materials produced by wheat crop has been calculated using the methodology given by Sandhu *et al.* (2008).

Price of raw materials (₹/ha) = Grain yield (tonnes/ha) × Price of grain (₹/tonne) + Straw yield (tonnes/ha) × Price of straw (₹/tonne)

The minimum support price offered by the Government of India for wheat was taken as price of grain, and the local-market price of straw was taken as price of straw.

Price of C sequestration was estimated with the following formula (Kumar 2004).

Price of C sequestration (₹/ha) = Amount of C accumulated in soil (tonnes/ha) × Price of equivalent amount of FYM (₹/tonne)

Economic valuation of nutrient enrichment in soil was done using the replacement cost approach (Sreeja *et al.* 2009, Kiran and Kaur 2011).

Price of soil nutrient enrichment (₹/ha) = Amount of added soil nutrient (tonnes/ha) × Price of nutrient (₹/tonne)

Rate of soil formation is closely linked to the activities of earthworms and their population density. Economic value of earthworms in soil formation was calculated based on the assumption that the mean biomass of earthworm is 0.2 g (Fraser *et al.* 1996) and that 1000 kg of earthworms form 1000 kg of soil/ha/y (Pimentel *et al.* 1997).

Price of soil formation (₹/ha) = 0.2×10^{-3} × Number of earthworms/ha × Price of top soil (₹/kg).

Several researchers have assigned different prices of soil ranging from US$ 53.6 tonne in Denmark (Porter *et al.* 2009) to US$ 23.6 tonne in New Zealand (Sandhu *et al.* 2008). Kathuria and Balasubramaniam (2013) reported that price of 1 acre feet of soil is ₹ 54400 in Tamil Nadu state in India. In the present study price of top soil was taken as ₹ 130/tonne.

Value of water holding service was calculated using the following equation.

Price of water holding services (₹/ha) = Irrigation water saved (mm/ha) × Price of diesel to pump water (₹ mm^3/ha)

The cost due to negative impacts (i.e. losses of N, emission of GHGs, depletion of groundwater and impacts on animal and human health) was calculated as follows.

Losses of N through leaching and volatilization were calculated using the InfoRCT model (Pathak *et al.* 2011). The environmental cost of N loss was calculated as follows.

Cost of N loss (₹/ha) = Amount of N lost due to leaching and volatilization (kg/ha) × Price of N fertilizer (₹/kg)

The GHGs emission was calculated based on soil, weather and management data using the InfoRCT model (Pathak *et al.* 2011). Data on fertilizer use, irrigation practices, tillage practices, use of farm machinery, pesticide use and seed rate were collected by conducting a survey in farmers' field growing wheat crop. Weather data were collected from the weather station located in the district. The GHGs emission was converted into economic value based on the current market price of carbon. The environmental cost of GHG emission was calculated as follows.

Cost of GHGs emission (₹/ha) = Amount of GHGs emitted (kg CO_2 eq/ha) × market price of carbon mitigation (₹/kg CO_2 eq.)

Intensive pumping of ground water in the country, particularly in north-west India has resulted in depletion of groundwater level. Farmers are required to extract water from deeper layer by lowering down and using more powerful pump. This incurs into additional cost to the farmers for use of additional energy (e.g. diesel). A preliminary estimate suggested that with the conventional practices, the groundwater of north-west India is depleting at a rate of 25 cm/yr and farmers need to incur into additional cost of about ₹ 500/ha for lowering down and using more powerful pump.

Cost of groundwater depletion was calculated using the following equation (Sandhu *et al.* 2008).

Cost of groundwater depletion (₹/ha) = Depletion in groundwater (mm/ha) × Price of diesel to pump water (₹ mm^3/ha)

Data on impacts of ecosystem services on animal and human health is scarce. Cost for adverse impacts on animal and human health was taken as 10% of the sum of the cost of ecosystem dis-services, i.e. N loss, emission of GHGs and cost of groundwater depletion.

The cost of cultivation was calculated by taking into account the costs of seed, fertilizers, biocide, and the hiring charges of human labour and machines for land preparation, irrigation, fertilizer application, plant protection, harvesting, and threshing, and the time required per ha to complete an individual field operation. Cost of irrigation was calculated by multiplying time (hr) required to pump the calculated amount of irrigation water, consumption of diesel by the pump (l/ha) and cost of diesel. The prices of human and machine labour, and diesel ard their current prices in India collected by market survey. Net income of the farmers was calculated as the difference between gross income and total costs of inputs and labour.

Net income (₹/ha) = Price of raw materials (₹/ha) – Cost of production (₹/ha)

The following equation was used to estimate the green income of agriculture.

Green income (₹/ha) = Net income (₹/ha) + Price of C sequestration (₹/ha) + Price of soil nutrient enrichment (₹/ha) + Price of soil formation (₹/ha) + Price of water holding services (₹/ha) - Cost of N loss (₹/ha) - Cost of GHGs emission (₹/ha) - Cost of groundwater depletion (₹/ha) – Cost on animal and human health

RESULTS AND DISCUSSION

Impact of conservation agricultural practices on ecosystem services

Carbon sequestration – In the study the treatments showed significant difference in different soil parameters. Total soil carbon content increased in all the 3 treatments. But the rate of increase was maximum in zero tillage along with residue application. Conventionally tilled plots also recorded increase in soil carbon over the 3 years period. But the rate of increase was much less than the zero tilled plots. This was attributed to the fact that tillage operations lead to breaking of soil aggregates, increasing surface area exposure and oxygen supply resulting in higher decomposition of soil organic matter. In residue applied treatment crop residues degraded and contributed to enrichment of soil carbon. Higher C accumulation in soil resulted in higher economic value of added carbon in zero tillage and zero tillage plus residue applied plots. There are reports of conservation tillage causing organic carbon enrichment of soils (Lal 1999). Smith et al. (1998) reviewed long-term experiments comparing conventional tillage with zero tillage and concluded that with zero tillage soil carbon increases at 0.39 t C/ha/yr (0.18-0.60 t C/ha/yr). Several other workers also reported that crop management practices such as crop residue management, zero or minimum tillage or conservation agriculture could increase carbon accumulation in soils (Garcia-Torres et al. 2003, Magdoff and Weil 2004).

The economic value of the added soil carbon was estimated as ₹ 3770/ha in case of zero tillage plus residue applied treatment followed by zero tillage treatment where the value of added soil carbon was ₹ 2925/ha (Table 1). Similar estimates for UK suggest that carbon could bring arable and grassland farmers, an income between £18m (US$ 27m) and £147m (US$ 220m) per year representing significant additional income source (Pretty and Ball 2001).

Nutrient enrichment in soil

Available nitrogen and phosphorus (P) content of soil increased in all the 3 treatments during the study period. But available potassium (K) content of soil decreased in conventional as well as zero tilled system. In zero tillage plus residue applied treatment available soil K increased during the 3 years of study. Maximum increase in available N and P occurred in zero tilled plots. Soil available N increased from 330.5 to 342.3 kg/ha and available P from 19.5 to 20.2 kg/ha in this treatment. In zero tillage with residue applied treatment increase in available N and P was less as compared to the other 2 treatments. But available K content of soil increased from 241.5 to 265.9 kg/ha in residue-applied plot while decreased in the other 2 treatments. Increase in available potassium of soil in residue applied treatment is attributed to the fact that crop residues are rich in potassium and when they were retained in the field they were decomposed by microorganisms resulting into higher soil potassium levels.

Hence the value of soil macronutrients (N, P and K) was positive (₹ 34 and 162/ha) in zero tillage and zero tillage plus residue applied plots which shows that in these two treatments there was net gain in added soil macronutrients while in conventionally tilled plots, the value of those nutrients is negative which implied that there was net loss of macronutrients in economic terms (Table 1). In conventional and zero tilled plots economic value of soil available K was ₹165/ha and ₹104/ha while in zero tilled plus residue applied plots the value was ₹ 366/ha. Increased microbial biomass in soil under no-tillage treatment (Andrade De Souza *et al.* 2003) might have resulted in increased nutrient availability in soil. Sreeja *et al.* (2009) also used the RCA for valuation of soil nutrients and reported that the value of N, P and K in one ha of mangrove soil was ₹ 1.309/kg, ₹ 162.82/kg

Table 1 Ecosystem services from wheat under conventional and conservation agriculture systems.

Ecosystem service parameters	Conventional	Zero tillage	Zero tillage + residue
		₹/ha	
Value of raw materials	66771	70465	70465
Value of soil nutrients	-6	34	162
Value of soil carbon	936	2925	3770
Water holding service	675	777	837
Soil formation service	5.2	13	19.5
Ecosystem service	68381	74213	75253

and ₹ 2940/kg, respectively, while in non mangrove soil the value was ₹ 1.2/kg, 67.9/kg and 684/kg, respectively.

Water holding service

Higher soil moisture content in zero tillage and zero tillage plus residue applied treatments resulted in higher value of water holding service in these 2 treatments as compared to conventional treatment. Water holding service was quantified as ₹ 837/ha with zero tillage plus residue application and ₹ 777/ha with only zero tillage plots (Table 1). Minimum soil disturbance and covering of soil with crop residues resulted in less evaporation loss of soil water which resulted in increased soil moisture content in zero tillage with residue applied plots. Practicing zero tillage significantly improved soil water content (SWC). Soil moisture content on surface soil layer (0-10 cm) was 19.3% in conventionally tilled plots which increased to 21.3% and 23.8% in zero tillage and zero tillage plus residue applied treatments respectively. Ghosh *et al.* (2015) reported that soil moisture content up to 90 cm soil depth in conventional agriculture plots under rainfed conditions was 28.1 mm, compared to 58.5 mm soil moisture in conservation agriculture plots.

Soil formation

Soil formation service was quantified as ₹ 5.2/ha in conventionally tilled wheat, whereas in zero tilled wheat the value of soil formation service was ₹ 13/ha. In zero tilled plus residue applied treatment maximum earthworm population has led to maximum value of this service, i.e. ₹ 19.5/ha (Table 1). Absence of tillage in zero tilled plots might have reduced direct physical damage to earthworms, as well as damage to their habitat (Kladivko 2001, Lavelle *et al.* 2001). Higher earthworm population in residue-applied plots could be due to gradual accumulation of organic material in these plots, which might have served as major food source for most earthworm species (Lavelle *et al.* 2001).

Provisioning service

Provisioning service, i.e. the price of raw materials produced was quantified as ₹ 66771 in conventional tillage treatment while in the other 2 treatments, the value was ₹ 70465/ha (Table 4). Higher crop yield in zero tillage as well as zero tillage plus residue applied treatment (4.8 Mg/ ha) as compared to conventional tillage (4.5 Mg/ha) has led to higher value of provisioning service in those treatments.

Values of all the ecosystem services obtained from conventionally cultivated wheat were ₹ 68381/ha (Table 4). In zero tilled and residue applied wheat the total value of ecosystem services was highest, i.e. ₹ 75253/ha. Sandhu *et al.* (2008) quantified ecosystem services of conventional and organic croplands based on experimental approach. Results from their study showed that value of ecosystem services in organic fields ranged from US$ 1610 to 19420 ha/yr while that of conventional fields ranged from US$ 1270 to 14570/ha/yr.

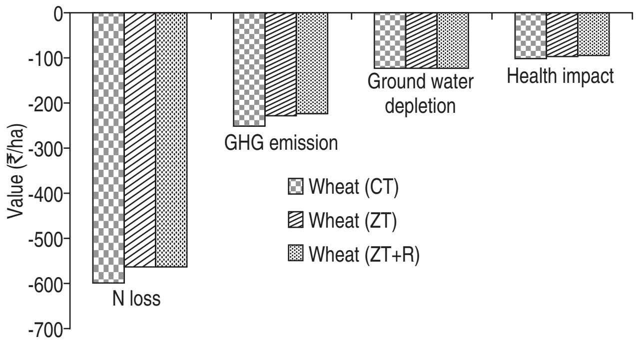

Fig 1 Environmental cost of conventionally tilled and zero tilled wheat in Karnal, Haryana

Impact of conservation agricultural practices on ecosystem dis-services

Cultivation of wheat also led to certain ecosystem dis-services by release of GHG, loss of N as leaching and volatilization and also groundwater depletion. Less use of farm machinery in zero tillage treatments has led to lower GHG emission.

The environmental cost in conventionally tilled wheat was estimated to be ₹ 1072/ha, whereas in the zero tilled wheat and zero tilled plus residue applied wheat it was ₹ 1015 and 1009/ha, respectively. Cost of nitrogen lost through leaching contributed maximum to the environmental cost, followed by cost of GHG emission and ground water depletion (Fig 1). Cost of groundwater depletion was at par in all 3 treatments, but cost of GHG emission was higher (₹ 248/ha) in conventionally tilled wheat. In the present study health cost was quantified as ₹ 100/ha in conventional treatment while it was ₹ 98/ha and ₹ 97/ha in zero tilled and zero tilled plus residue applied treatments respectively (Fig 1).

Impact of conservation agricultural net and green income in wheat

Net income from conventionally tilled wheat was ₹ 32823/ha, which was increased to ₹ 49716/ha in both zero tilled wheat and zero tilled plus residue applied wheat (Fig 2). Higher net return obtained in zero tilled plots was due to the higher wheat yield and lower input cost incurred in those treatments. Less use of tractor has reduced the cost of machinery as well as the cost of diesel required to run

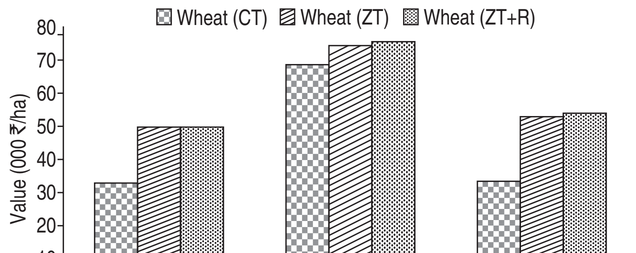

Fig. 2 Net and green income of conventionally tilled and zero tilled wheat in Karnal, Haryana

those tractors. Green income from conventionally tilled wheat was ₹ 33358/ha, which was increased to ₹ 52449/ha in zero tilled wheat and to ₹ 53493/ha in zero tilled plus residue applied wheat (Fig 2). Higher green income in the conservation agriculture treatments was due to the higher value of ecosystem services along with lower pollution cost and lower input cost.

The present study highlighted the importance of including the price of ecosystem services and cost of ecosystem dis-services in calculating the green income from agriculture to assess the sustainability of various agricultural practices in the long-run. The ecosystem service values can be used to assess the impact of land use and management practices, across an agricultural field, as planning tool for farmers, policy makers and extension workers. Hence, the quantification and valuation of ecosystem services can be used as quantitative tools for decision making at local, regional and national scales.

REFERENCES

Andrade De Souza D, Colozzi-Filho A, Balota E Land Hungria M. 2003. Long-term effects of agricultural practices on microbial community. (*In) Conservation Agriculture,* pp 301–6.Garcia-Torres L, Benites J, Martinez-Vilela A and Holgado-Cabera A (Eds.).

Dale V H and Polasky S. 2007. Measures of the effects of agricultural practices on ecosystem services. *Ecological Economics* **64**: 286–96.

Fraser P M, Williams P H and Haynes R J. 1996. Earthworm species, population size and biomass under different cropping systems across the Canterbury Plains, New Zealand. *Applied Soil Ecology* **3**: 49–57.

Garcia-Torres L, Benites J, Martinez-Vilela A and Holgado-Cabera A (Eds). 2003. *Conservation Agriculture*. Kluwer Academic Publishers, Dordrecht.

Ghosh B N, Dograa P, Sharma N K, Bhattacharyya R and Mishra P K. 2015. Conservation agriculture impact for soil conservation in maize–wheat cropping system in the Indian sub-Himalayas. *International Soil and Water Conservation Research* **3**: 112–8.

Kiran G S and Kaur M R M. 2011. Economic valuation of forest soils. *Current Science* **100**(3): 396–9.

Kathuria V and Balasubramanian R. 2013. Environmental cost of using top-soil for brick-making. *Review of Market Integration* **5**: 171–201.

Kladivko E J. 2001.Tillage systems and soil ecology. *Soil and Tillage Research* **61**: 61–76.

Kumar P. 2004. Economics of Soil Erosion: Issues and Imperatives from India. Concept Publishing Company, New Delhi.

Lal R.1999. Soil management and restoration for carbon sequestration to mitigate the accelerated greenhouse effect. *Progressive Environmental Science* **1**: 307–26.

Lavelle P, Barros E, Blanchart E, Brown G, Desjardins T, Mariani L and Rossi J P. 2001. SOM management in the tropics: Why feeding the soil macrofauna? *Nutrient Cycling in Agroecosystems* **61**: 53–61.

Magdoff F and Weil R R. (Eds.) 2004. *Soil Organic Matter in Sustainable Agriculture*. CRC Press, Florida.

Martin N A. 1978. Earthworms in New Zealand agriculture. *Proceedings of the 31st New Zealand Weed and Pest Control Conference,* pp 176–80. New Zealand Plant Protection Press, New Plymouth.

MEA. 2005. *Millennium Ecosystem Assessment Synthesis Report*. Island Press,Washington DC.

Page A L, Miller R H and Keeney D R. 1982. *Methods of Soil Analysis: Chemical and Microbiological Properties,* Part 2, Second Edition. American Society of Agronomy, Madison, Wisconsin, USA.

Pathak H, Saharawat Y S, Gathala M and Ladha J K.2011.Impact of resource-conserving technologies on productivity and greenhouse gas emission in rice-wheat system. *Greenhouse Gas Science and Technology* **1**: 261–77.

Pimentel D, Wilson C, McCullum C, Huang R, Dwen P, Flack J, Tran Q, Saltman T and Cliff B.1997.Economic and environmental benefits of biodiversity. *Bio Science* **47**(11): 747–57.

Porter J, Costanza R, Sandhu H, Sigsgaard L and Wratten S. 2009. The value of producing food, energy, and ecosystem services within an agro-ecosystem. *Royal Swedish Academy of Sciences* **38**(4): 186–93.

Pretty Jand Ball A. 2001.Agricultural influences on carbon emissions and sequestration: A review of evidence and the emerging trading options. Centre for Environment and Society Occasional Paper, University of Essex, UK.

Sandhu H S, Crossman N D and Smith F P. 2012. Ecosystem services and Australian agricultural enterprises. *Ecological Economics* **74**: 19–26.

Sandhu H S, Wratten S D, Ross C and Case B. 2008. The future of farming: The value of ecosystem services in conventional and organic arable land. An experimental approach. *Ecological Economics* **64**: 835–48.

Sreeja P, Gilna V V and Khaleel K M. 2009. Economic valuation of soil nutrients from the mangrove rich wetlands of Kannur District. *Botanical Research International* **2**(1): 27–9.

Smith P, Powlson D S, Glendenning M J and Smith J U. 1998. Preliminary estimates of the potential for carbon mitigation in European soils through no-till farming. *Global Change Biology* **4**: 679–85.

Tilman D, Cassman G, Matson P A, Naylor R and Polasky S. 2002. Agricultural sustainability and intensive production practices. *Nature* **418**: 671–7.

Zhang W, Ricketts T H, Kremen C, Carney K and Swinton S M. 2007. Ecosystem services and dis-services to agriculture. *Ecological Economics* **64**: 253–60.