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Conservation agriculture impact for soil conservation in maize–wheat cropping system in the Indian sub-Himalayas

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Abstract

Conservation agriculture (CA) is considered as a suitable technique for soil erosion control, productivity enhancement, and improved economic benefits. To investigate these issues, an experiment was conducted under rainfed conditions using grass vegetation strip (VS) with minimum tillage, organic amendments and weed mulch during June 2007–October 2011 at Dehradun, Uttarakhand in the Indian Himalayan region. Results showed that the mean wheat equivalent yield was ~47% higher in the plots under with CA compared with conventional agriculture in a maize–wheat crop rotation. Mean runoff coefficients and soil loss with CA plots were ~45% less and ~54% less than conventional agriculture plots. On average, after the harvest of maize, soil moisture conservation up to 90 cm soil depth for wheat crop was 108% higher under CA than conventional agriculture plots. The net return from the plots with CA was 85% higher, and when expressed net return per tonne of soil loss, it was four and half times higher than conventional practice. Results demonstrate that the suitable CA practice (a grass strip of Palmarosa with applied organic amendments (farmyard manure, vermicompost and poultry manure) along with weed mulching under conservation tillage) enhances system productivity, reduces runoff, soil loss and conserve soil moisture.

Keywords: Vegetation strips; Organic amendments; Weed mulch; Minimum tillage; Soil conservation

1. Introduction

Conservation agriculture (CA) is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with sustained production, while concurrently conserving the environment. Conservation agriculture is characterized by three interlinked principles, namely continuous minimum mechanical soil disturbance, permanent organic soil cover and diversification of crop species grown in sequence or associations (FAO, 2010). Productivity losses of 13.4 m tonnes of food grain, worth nearly 2 billion US dollars due to soil erosion have been reported in rainfed areas of India (Sharda, Dogra, & Prakash, 2011). Maize crop productivity losses of 8.0–10.30 kg ha^{-1} have been reported in the Indian Sub-Himalayas (Ghosh, Dogra, Sharma, & Dadhwal, 2012). Vegetation strips are effective for control of soil erosion. For example, in the Shivalik hills, in the east-west mountain chain of the Himalayas, silt is transported by

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runoff and deposited near natural vegetation strips (VS). This sediment deposition and later tillage leads to the formation of benches, ranging from 15–40 m in length and 3–5 m in width. Other advantages of VS are reduced sheet, rill and ephemeral gully erosion, improved water management, stabilized slopes and sediment entrapment. This also improves the potential for additional fodder and green manure.

Panicum maximum (Guinea grass), *Vetiveriazizanioides* (Khuskhus) and *Eulaliopsisbinata* (Bhabar) have been found suitable for vegetation strips in the Shivalik hills (Sur & Sandhu, 1994; Lal, Sharma, &, Mishra, 1996). These three species are used as barriers for effective erosion and sediment control because they form an erect, stiff and uniformly dense hedge so as to offer high resistance to overland water flow. Also, the dense rooting habits bind soil to prevent rilling and scouring near the barrier, and they are tolerant to moisture and nutrient stress, and quickly re-establish top growth after rain (Dewald et al., 1996; Grimshaw & Helfer, 1995). These vegetation strips result in minimal loss of crop yield, the species do not proliferate as weeds, they do not compete for moisture, nutrients and light, they are not hosts for pest and diseases, and they often provide some additional economic benefits to farmers (Bhardwasj, 1994; Bharad & Bhatkal, 1991). For example, Palmarosa (*Cymbopogon martini*) is a grass species that that yields oil of high economic value (0.04–0.05% oil), with potential for reducing slope erosion and capturing sediment. However, the efficiency of grass species such as *Cymbopogon martini* (Palmarosa), for reducing runoff and soil loss has not been tested.

Minimum and zero tillage are recommended for soils of the Indian Himalayan region due to reduced cost of cultivation, more retention of soil water, and physical protection of soil organic carbon (SOC) (Bhattacharyya, Ved-Prakash, Kundu, Srivastva, & Gupta, 2009, and Bhattacharyya, Tuti, Kundu, Bisht, and Bhatt, 2012a, 2012b). This combination of minimum till (MT), coupled with various organic amendments, farmyard manure, vermicompost, poultry manure, weed mulching and VS of grasses, prompted the testing of a novel soil management system with the potential for multiple economic and environmental benefits (Bhattacharyya, Fullen, Davies, & Booth, 2010). Our objective was to evaluate the effectiveness of CA (MT, VS, organic amendment and weed mulching) compared with conventional agriculture on runoff, soil loss, moisture conservation and yield for a maize–wheat cropping sequence under rainfed conditions for Entisols in the northwestern hills. The hypothesis was that VS with weed mulch and manure application under MT will reduce runoff and soil loss, conserve soil moisture, and enhance crop yields on gently sloping lands.

2. Materials and methods

2.1. Study area

A fixed plot field study was conducted from June 2007 to October 2011 at the Research Farm of the ICAR—Central Soil and Water Conservation Research and Training Institute, Selakui, Dehradun, India (30°20'40'N latitude, 77°52'12'E longitude) at 516.5 m above mean sea level on a 2% slope. The climate of the region is sub-temperate; with mean annual rainfall (1956–2011) of 1625 mm, 80% occurring during the rainy season (June–September). Climatic characteristics of the experimental site are given in Fig. 1.

2.2. Lay out and establishments of vegetation trips and treatments

The experiment was laid out on a 2% slope, with vegetation grass strips of Palmarosa (Fig. 2) in maize–wheat crop rotations.

The experiment was laid out in a randomized block design with three replications, each measuring 100 × 20 m (2000 m^2) with the following three treatments:

(1) Conventional agriculture
100:60:40 N: P_2O_5:K_2O + conventional tillage (CT) + chemical weeding
(2) Conservation agriculture
Farmyard manure (FYM5 t/ha) + vermicompost(1.0 t/ha) + poultry manure (2.5 t/ha) + minimum tillage (MT) + 3 weed mulch (20, 40 and 60 days after sowing) + Palmarosa (*Cymbopogon martini*) as vegetation strips.

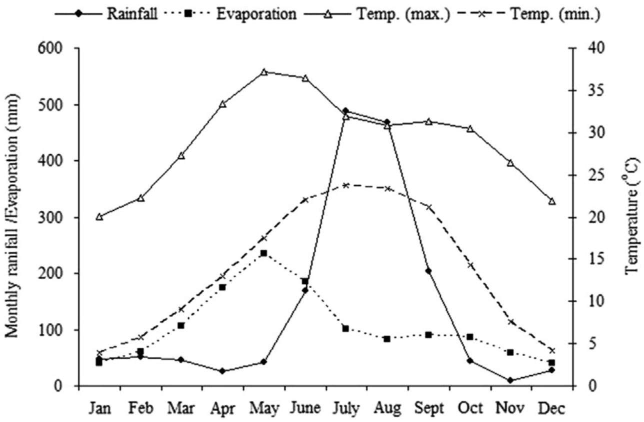

Fig. 1. Mean (1956–2011) rainfall, evaporation, maximum and minimum temperatures of the experimental site.

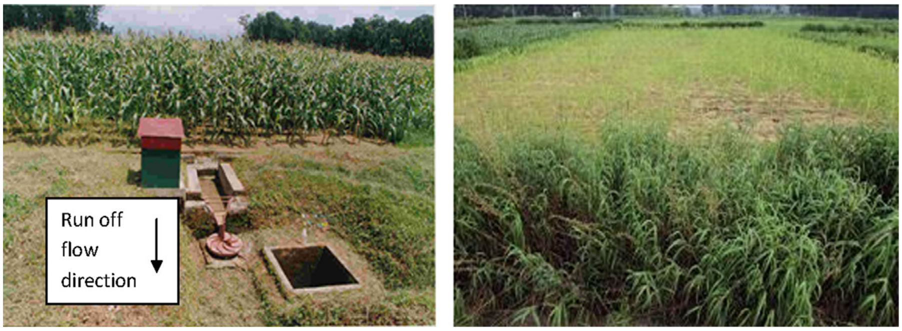

Fig. 2. Layout, gauging devices and establishment of vegetative strips (VS).

2.3. Soil and climate

Palmarosa can grow from sea level to 1800 m altitude, but thrives between 15 and 38 °C. The grasses are adapted to a wide range of soils, particularly on well-drained, light textured soil, preferably sandy loams or loams. They do not tolerate heavy clays, and continuous water logging should be avoided.

2.4. Field preparation

The VS were planted in the field of maize with two or three ploughings and one leveling. are sufficient. The planting strips were free of weeds, and fertilizer applications were the same as that for of the maize crop.

2.5. Planting materials

Seeds and slips were used as planting material. To obtain slips for planting, old clumps were uprooted and slips with roots were separated, with uprooting and planting of root slips completed in the same day. For quick establishment, root slips of grasses were preferred over seed. Root slips of grasses were collected from nearby, existing plant material or from authentic sources. About 1000–1500 root slips were required for a paired row (recommended planting row to row distance 75 cm and plant to plant 20 cm) for 100 m running length. This is comparable to about 4000–6000 root slips per ha for 2% slope.

2.6. Method of planting and time

Contour lines and slopes were confirmed and identified (1 m vertical interval over 50 m horizontal distance results in a 2% slope, respectively in a 100 m length plot). Furrows, 10 cm wide and 20 cm deep along contour line in a paired row at a distance of 75 cm were prepared using a country plough or with the help of small agricultural implements. Root slips containing 2–3 tillers were planted in the furrows in paired rows, in a staggered pattern. Planting was done during first to second week of July for all the grasses. The soil excavated from the contour furrows was heaped on the down slope side to form a bund. Watering was done with buckets to ensure better rooting. Data collection for runoff and soil loss

Runoff data were recorded from 15 June to 15 September in all years (2007–2011) at 0800 (local time) using a stage level recorder after each rainfall event with a hydrograph connected with a Coshocton wheel. A runoff coefficient was calculated as the percentage of daily runoff depth (mm) to daily rainfall (mm). The latter was recorded daily at 0800 using a rain gauge. The water from the runoff was collected and thoroughly stirred, and 1 L was taken from each tank to determine accumulated sediment from each plot. The resultant suspensions were filtered using Whatman 42 filter paper with a pore size of 2.5 μm. The sediment in the filter paper was oven-dried for 24 h at 105 °C and weighed to obtain soil loss. Grain yield of crops were determined at harvest from 2×8 m^2 areas with three replicates per plot. The wheat equivalent yield (WEY) of the maize crop was determined using the market price of maize and wheat crops.

2.7. Calculation of wheat equivalent yield

The yield of maize was converted into wheat equivalent yield (WEY) following Bhattacharyya et al. (2010) in order to isolate the overall impact of treatments in terms of comparable yield data, The converted maize yield per year was then added to the actual yield of wheat in that year. Therefore, WEY expresses total yield (productivity) for the maize–wheat crop sequence during 2007–08 to 2010–11 (four years). It is the yield of wheat plus yield of maize expressed in terms of wheat yield.

2.8. Cost of planting barrier

Total cost of different components of barrier was €41/ha, on a 2% slope (Table 1).

2.9. Protocol for maintenance of barriers

Gap filling is required after the first planting and until the complete barrier is established. All the grass species required at least two cuts a year, the first, just before the onset of monsoon in May/June and the second in October/November to encourage tillering. For an effective live barrier, trimming to the height of 15–30 cm annually along with hoeing in between rows with every cut is recommended. Other shrubs and grasses should be removed periodically.

2.10. Tillage, manuring and mulching

In conventional tillage plots, tillage operations were done four times with a tractor drawn cultivator, whereas in minimum tillage (MT) plots, two tillage operations were done with attempts to ensure 30% retention of surface maize and wheat crop residues. Recommended NPK doses (120:60:40 kg ha^{-1}) were applied with half the nitrogen and complete phosphorus and potassium applied at the time of sowing. The remaining nitrogen was top-dressed at tillering, panicle initiation and dough stages of the maize crop. In the Palmarosa + plots, the farmyard manure (FYM at 5 Mg ha^{-1}), vermi-compost (VC at 1.0 Mg ha^{-1}) and poultry manure (PM at 2.5 Mg ha^{-1}) were applied at the time of final land preparation before sowing of *kharif* (summer) crops. Weed mulching was done at 20, 40 and 60 days after sowing in Palmarosa + treatment. A maize–wheat crop rotation was followed where wheat was grown on residual fertility with one hand weeding in Palmarosa + treated

Table 1
Economics of planting barrier components.

Components	Cost (€/ha)
Cost of planting material @ €0.005–0.008/slip	33.61
Cost of labour for opening furrow and planting (lump sum)	4.03
Cost of gap filling and maintence (lump sum)	4.03
Total (€/ha)	41.68

Note based on €1 = 69.09 Indian Rupees (Rs.) on 15.11.2011.

plots. Atrazine weedicide for maize and isoputoron for wheat at 1.5 kg a.i L^{-1} were applied to control weeds in the treatment without VS. The maize cultivar Kanchan and wheat cultivar PBW4 were sown as *kharif* and *rabi* (winter) crops, respectively.

3. Results and discussion

3.1. Runoff and soil loss

Maximum runoff was recorded from plots under without CA (Table 2). Mean runoffs during the growing seasons were 39.8% from plots under conventional agriculture, whereas plots with CA recorded only 21.9% runoff. Approximately 45% less runoff was observed with CA plots compared with conventional agriculture. Mean data over five years of soil loss were 7.2 t/ha under conventional agriculture, whereas in CA plots, the soil loss was 3.5 t ha^{-1}(Table 2), a reduction of 51%. Over the five consecutive years, the CA treatment reduced runoff significantly compared to conventional agriculture; probably due to the dense vegetation VS resulting in reduced runoff and silt deposition (Sur & Sandhu, 1994). Retention of weed mulch on CA plots also contributed to a significant decline in soil loss and runoff as also noted by Lal et al. (1996). This indicates the effectiveness of the CA in terms of soil conservation (Bhattacharyya et al., 2012b).

Results from the study show that weed cut and mulch with MT, along with Palmarosa as a vegetation strip, maintained surface soil even during high intensity rainfall events. Standing maize, when provided with optimal nutrient supply, provided very good canopy cover and vertical mulching, resulting in greater water infiltration (4.24 mm/hr in the plots under CA as compared to plots under conventional agriculture. This protective mulching further reduced soil erosion (Gilley, Finkner, Spomer, &, Miclke, 1986). In addition to MT, the addition of organic amendments in CA plots improved soil structure, leading to enhanced infiltration and reduced runoff after each rainfall event. These results support the use of CA, including the oil yielding grass, Palmarosa, along with weed derived mulch, organic amendments and MT for maize to ensure soil and water conservation.

3.2. Maize, wheat yield biomass yield of vegetation strips

Mean maize yield was 1570 kg/ha with conventional agriculture compared to 2000 kg/ha in CA plots, an increase of about 27%. The succeeding mean yield of wheat was 950 kg/ha in the conventional agricultural plots, compared to 1700 kg/ha in CA plots, an increase of 79% (Table 2). Further, WEY increased by 47% because of conservation measures in CA plots by Palmarosa compared to conventional agriculture plots (without VS and conventional tillage). The mean dry biomass yields of grass (Palmarosa) was 610 kg/ha/yr, which yielded 4.0 kg oil/ha (Table 2). The mean weed biomass, which was used for three mulching in the CA treatments, was 2.18 t/ha (Table 2). Similar results have been observed by Bhardwasj (1994) for a maize–wheat cropping system.

3.3. Moisture conservation

Soil moisture data to 90 cm in conventional agriculture plots under rainfed conditions and before sowing the wheat crop was 28.1 mm moisture, compared to 58.5 mm soil moisture in CA plots, an increase of 108% (Table 2).

Table 2
Effect of conservation agriculture impact on crop productivity and conservation efficiency on a land with 2% slope at Dehradun, India.

Particulars	Conventional agriculture	Conservation agriculture
Water loss (% of rain)	39.8	21.9
Soil loss (t ha^{-1} yr^{-1})	7.2	3.5
Grain yield of maize (kg ha^{-1})	1570	2000
Grain yield of wheat after maize (kg ha^{-1})	950	1700
Wheat equivalent yield (kg ha^{-1}	2320	3407
Dry grass yield (kg ha^{-1} yr^{-1})	–	610
Oil yield (kg ha^{-1})	–	4.0
Weed biomass for mulching (kg $ha^{-1}yr^{-1}$)	–	2100
Moisture conservation for wheat (mm) compared to fallow	28.1	58.5

Table 3
Effect of conservation agriculture impact on net return.

Practice	Cost of cultivation (€ /ha)		Gross returns (€ /ha)		Net returns (€ /ha)		Net return per ton of soil loss (€ /ha)
	Maize	Wheat	Maize	Wheat	Maize	Wheat	
Conventional agriculture	162	165	191	239	29	74	14
Conservation agriculture	292	203	274	440	− 19	237	63

Conserved moisture not only helps in good germination of wheat crops, but also enhances production of biomass. Combined application of organic manure and weed mulch under minimum tillage helps in increasing the soil macro-aggregates.

3.4. Economics of the system

Cost of cultivation under conventional agriculture was less for both crops, while gross return for both the crops was higher with CA plots (Table 3). The net return for maize with CA was lower compared to conventional agriculture, but net return for wheat in CA plots was much higher. Comparing the maize–wheat system as a whole, the CA plots yielded a net return that was 110% higher than conventional agriculture plots (Table 3). Also, that the net return per tonne of soil loss was 350% higher under CA plots than conventional agricultural plots.

4. Conclusion

Results from experiments during five crop sequences demonstrate that a grass strip of Palmarosa with applied organic amendments (farmyard manure, vermicompost and poultry manure) along with weed mulching and minimum tillage enhances maize–wheat productivity and reduces runoff and soil loss. The reduction in runoff is due to enhanced temporary water storage and enhanced biomass beneath the vegetation strips, which in turn improves water infiltration, i.e. the vegetation strips retain water during the winter season, thus conserving soil moisture. Soil water retention also improved with applied weed biomass and the use of organic amendments in the minimum tillage system. The results demonstrate the potential of conservation agriculture (CA) system for increasing grain yield, reducing soil loss and runoff and conserving soil moisture. That said CA system is recommended for soil conservation as a long-term strategy.

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