Indian Journal of Agronomy **55** (4): 245–252 (December 2010)

Tillage and legume mulching effects on moisture conservation and productivity of rainfed maize (*Zea mays*)–wheat (*Triticum aestivum*) cropping system

A.R. SHARMA*[,1], RATAN SINGH, S.K. DHYANI[2] AND R.K. DUBE[3]

Central Soil and Water Conservation Research and Training Institute, Dehradun, Uttarakhand 248 195

Received: July, 2009

ABSTRACT

A field experiment was conducted at Selakui, Dehradun from 2001 to 2004 to study the effect of tillage, viz. conventional tillage (CT) and minimum tillage (MT); and weed-control practices, *viz.* chemical and mechanical weeding along with legume mulching, viz. *in situ* grown sunnhemp (*Crotalaria juncea* L.) and subabul [*Leucaena leucocephala* (Lam.) de Wit] on soil moisture conservation, crop productivity and soil health in maize (*Zea mays* L.)–wheat (*Triticum aestivum* L. emend Fiori & Paol.) cropping system. CT gave higher grain yield of maize (+0.11 to 0.17 t/ha), but wheat performed equally well under CT (2.48 t/ha) and MT conditions (2.36 t/ha). Chemical weeding with herbicides (alachlor in maize and isoproturon in wheat) resulted in 7.8 and 9.9% higher yield of maize and wheat, respectively over mechanical weeding. Beneficial effect of live mulching with sunnhemp or *Leucaena* was similar (12.3–14.7%), while their combined application increased the maize yield by 19.1% over no mulching. Further, enhanced soil moisture conservation due to mulching at maize harvest led to greater productivity of wheat by 16.1% with sunnhemp or *Leucaena*, and 27.0% with sunnhemp + *Leucaena*. Nitrogen uptake of maize and wheat increased significantly with chemical weeding and legume mulching, but tillage practices made no effect on wheat while in maize it was lower under MT. Wheat gave 4–5 times more net returns than maize, and the net B : C ratio of the system was > 1.0 with chemical weeding and legume mulching. Tillage and weed-control practices made no effect on organic C and total N status of soil but legume mulching improved these parameters and reduced bulk density associated with increased infiltration rate. It was concluded that CT along with legume mulching in maize and MT in wheat, and chemical weeding of both the crops was beneficial for improving moisture and nutrient conservation, and achieving higher productivity and profitability of maize–wheat cropping system under Doon valley conditions.

Key words: Economics, Grain, *Leucaena*, Minimum tillage, Moisture conservation, Nitrogen uptake, Sunnhemp, Weed growth, Yield

Maize (*Zea mays* L.)–wheat (*Triticum aestivum* L. emend Fiori & Paol.) is an important cropping system in the hills and foothills of North-Western India. Both crops are grown largely under rainfed conditions, experiencing moisture deficiency at different stages of growth. Deficiency of moisture is more acute during ripening stage of maize and at sowing of wheat due to early withdrawal of monsoons. Further, nutrient deficiency, particularly of N, and unchecked weed growth inflict considerable reduction in maize yield (Sharma *et al.,* 2000; Sharma *et al.*, 2010). The role of tillage and mulching practices in conserving soil moisture, with subsequent beneficial effect on crop productivity has long been recognized (Sharma *et al.*, 1990; Sharma and Acharya, 2000). Adequate tillage operations controlled weeds and resulted in higher crop productivity, but caused more soil loss and were more capital intensive (Dogra *et al.,* 2002). Mulching is a very useful practice in rainfed areas for controlling erosion, weed growth and conserving moisture as well as nutrients in the soil profile (Sharma *et al.*, 2004; Sharma *et al.*, 2010). Studies have shown that it is possible to conserve moisture by applying mulch of waste organic materials during maize-growing season (Sharma *et al.*, 1990). Further, mulching coupled with conservation tillage proved better than conventional tillage. Despite these beneficial effects of mulching, adoption of this practice is constrained due to non-availability of vegetative mulch material. There is a possibility of biomass production and nutrient cycling

***Corresponding author** (Email: sharma.ar@rediffmail.com)

Present address: [1]Division of Agronomy, Indian Agricultural Research Institute, New Delhi 110 012; [2]National Research Centre for Agroforestry, Jhansi, Uttar Pradesh 284 003; [3]Regional Centre, Central Soil and Water Conservation Research and Training Institute, Agra, Uttar Pradesh 282 006.

through live mulching of *in situ* grown annual legumes as well as perennial leguminous trees and shrubs as hedge rows along the field bunds. Live mulching with sunnhemp (*Crotalaria juncea* L.) intercropped with maize was beneficial in controlling soil erosion and weeds through quick canopy cover, and conserving moisture and nutrients (Narain and Singh, 1997). Further, mulching with prunings of Subabul [*Leucaena leucocephala* (Lam.) de Wit] improved productivity of wheat through enhanced moisture and nutrient conservation (Sharma *et al.*, 1998). This study was undertaken to evaluate and analyze the effects of *in situ* grown sunnhemp and hedge rows of *Leucaena*, and recycling their biomass for developing an integrated moisture and weed management strategy for optimizing productivity in rainfed maize–wheat cropping system.

MATERIALS AND METHODS

A field experiment was conducted between 2001 and 2004 at the Selakui research farm of the Central Soil and Water Conservation Research and Training Institute, Dehradun, Uttarakhand. The soil of the experimental site was silty loam in texture with bulk density 1.39 g/cc, infiltration rate 7.0 mm/hour, pH 5.4, organic C 0.57%, total N 0.064%, available P 35 kg/ha and available K 160 kg/ha. The soil moisture content at maximum water holding capacity, field capacity and permanent wilting point were 35.5, 24.8 and 11.2%, respectively. The climate of the area is sub-humid, and the rainfall during maize- and wheat-growing seasons was 1,203 and 245 mm, 841 and 186 mm, and 1,210 and 131 mm in 2001–02, 2002–03 and 2003–04, respectively.

Maize was grown during rainy season (June to October) with 4 treatment combinations involving two levels each of tillage, viz. conventional tillage (CT) and minimum tillage (MT), and weed control practices, viz. mechanical weeding and chemical weeding; and 4 treatments of mulching, viz. control (no mulching), *in situ* grown sunnhemp, brought-in mulch of *Leucaena*, and sunnhemp + *Leucaena*. After the harvest of maize, wheat was grown under the residual effect of mulching treatments. However, the tillage and weed control treatments were the same as applied to the respective plots in maize. A split-plot design with tillage and weed control treatments in main plot, and mulching in sub-plot, keeping 3 replications was followed both for maize and wheat. All crops were grown in fixed plots without changing the layout over 3 cropping cycles. The net plot size was 26.4 m^2.

Conventional tillage for maize involved ploughing of field with a disc plough in May, followed by two cultivations in June to prepare a fine seedbed. However, in case of MT, paraquat was sprayed @ 0.5 kg/ha to kill the previously-growing weeds and thereafter only one ploughing was given with a cultivator before sowing in June. Sowing of maize hybrid ‘Kanchan’ (90 days) was done in the third week of June with a seed drill at a row spacing of 60 cm, and 20–25 cm spacing between plants was maintained after thinning. Sunnhemp was sown on the same day using 60 kg seed/ha in between the rows of maize (2 rows at 20 cm spacing). The plants of sunnhemp along with associated weeds were cut and spread as mulch in between the maize rows at 33–35 days of growth. Mechanical weeding was done twice with a hand hoe at 20 and 35 days of growth, and the weed biomass was used as mulch, except in control plots. In chemical weeding, alachlor was applied as pre-emergence @ 1.5 kg/ha. A common basal dose of 45–17.5–33.3 kg N–P–K/ha was incorporated at final ploughing, and 45 kg N/ha was top-dressed at knee-high stage (30 days after sowing or after mulching).

Seedlings of *Leucaena* were planted during July 2001 in paired rows at 1.0 m × 0.5 m spacing and were maintained as hedge rows on one side along the length of plots in the respective treatments. Pruning of these hedges was done from second year onwards during mid-August at 1 m height and all the side branches were removed. The biomass so harvested was separated into woody branches and tender twigs with leaves. In the first year (2001), brought-in mulching of the biomass pruned from *Leucaena* trees growing elsewhere was applied @ 10 t/ha (fresh weight). However, in the subsequent years, only the pruned biomass from the hedge rows of *Leucaena* was used for mulching at 60–65 days of growth of maize. Pruning of these hedges was also done in winter (January) to avoid shading effect on wheat and this leafy biomass was used as fodder for cattle.

After maize harvest in early October, the field was ploughed within a week, incorporating surface-applied mulch biomass for conserving moisture and nutrients for the following wheat crop. Conventional tillage for wheat involved one discing followed by 2 cultivations; whereas in minimum tillage, only one discing was done before sowing with a seed drill. Wheat ‘PB 2341’ (160 days) was sown by October-end at 20 cm spacing using 100 kg seed/ha. Similarly, mechanical weeding with a hand hoe was done twice at 25 and 45 days of growth, and isoproturon was sprayed at 40 days of growth @ 1 kg/ha in the respective plots. A common basal dose of 40–17.5–33.3 kg N–P–K/ha was applied, while 40 kg N/ha was top-dressed after 1–2 months depending on rainfall.

The major weed species in maize were: Jungle rice (*Echinochloa colonum* L.) and pig weed (*Amaranthus viridis* L.), besides bill goat weed (*Ageratum conyzoides* L.) which appeared in the later stages. Wheat was infested with common lambsquarter (*Chenopodium album* L.), *Medicago sativa* Willd., wild oat (*Avena fatua* L.) and little seed canary grass (*Phalaris minor* Retz.). Observations were recorded on growth and yield performance of maize and wheat crops. Biomass production of *in situ* grown sunnhemp as well as *Leucaena* prunings was assessed. Nitrogen content in grain and straw of crops as well as sunnhemp and *Leucaena* prunings was determined to work out N accumulation. Soil moisture content at each maize harvest, and residual soil fertility (organic C and total N), and physical parameters (bulk density and infiltration rate) were also determined at the termination of study in May 2004. Economic analysis of the data was done based on the prevailing cost of inputs / operations and price of produce. Statistical analysis of data was done as per the standard analysis of variance technique for the design used, and the treatment means were compared at P=0.05 level of significance.

RESULTS AND DISCUSSION

Biomass and N addition through legume mulching

Dry matter accumulation through intercroppped sunnhemp at 33–35 days of growth varied from 0.75–1.05 t/ha, which added 21.6–30.6 kg N/ha in different years. There was no perceptible difference in biomass production of sunnhemp under conventional and minimum tillage conditions. The cut biomass provided a good cover on the soil surface at the knee-high stage of maize and checked further weed growth, conserved rainwater and might have supplied N to the maize plants after mineralization during grand growth period owing to its narrow C:N ratio (17:1) (Sharma and Behera, 2010). On the other hand, biomass of brought-in mulch of *Leucaena* applied at 65 days was 2.93 t/ha in 2001, whereas the production from hedge rows increased from 1.89 t in 2002 to 3.05 t/ha in 2003. Accordingly, the amount of N added through *Leucaena* was 117.5 kg N/ha in 2001 and varied from 75.2–161.0 kg N/ha in other years. *Leucaena* mulching at this late stage of growth conserved moisture and checked later flushes of weeds, particularly of *Ageratum* species.

Growth and yield of maize

Based on the mean data of 3 years, the plants of maize were significantly taller and had relatively better yield attributes under CT than MT (Table 1). Accordingly, the grain and stover yields of maize were significantly lower under MT, and the decrease over CT ranged from 5.2–6.8 and 4.6–7.4%, respectively in different years. This decrease in yield was also attributed to significantly higher weed dry weight under MT conditions. Dogra *et al.* (2002) reported that reducing tillage operations in maize checked erosion losses but caused more weed growth, thereby leading to decreased productivity and profitability. Pre-emergence application of alachlor was significantly superior to mechanical weeding for increasing the growth and yield attributes of maize. Chemical weeding increased the mean grain yield by 4.5–9.2%, and stover yield by 7.9–10.8%,

Table 1. Effect of tillage, weed control and legume mulching on growth, yield attributes (mean of 3 years) and productivity of maize (t/ha), and weed dry weight (t/ha)

Treatment	Plant height at maturity (cm)	Cobs/ plant	Cob length (cm)	Grains/ cob	1000-grain weight (g)	2001		2002		2003		Mean weed dry weight at 60 days
						Grain	Stover	Grain	Stover	Grain	Stover	
Tillage												
Conventional	212.4	0.96	17.0	319.3	175.9	2.11	6.71	2.36	5.16	2.57	5.16	1.45
Minimum	196.6	0.93	16.7	310.9	171.7	2.00	6.40	2.20	4.82	2.40	4.78	1.94
SEm±	2.3	0.01	0.2	5.5	1.6	0.03	0.08	0.04	0.10	0.04	0.11	0.04
CD (P=0.05)	7.4	NS	NS	NS	NS	0.10	0.24	0.12	0.32	0.12	0.36	0.14
Weed control												
Mechanical weeding	196.9	0.90	16.2	296.4	167.0	2.01	6.21	2.18	4.76	2.38	4.78	1.95
Chemical weeding	212.1	0.98	17.5	333.8	180.6	2.10	6.88	2.38	5.22	2.59	5.16	1.45
SEm±	2.3	0.01	0.2	5.5	1.6	0.03	0.08	0.04	0.10	0.04	0.11	0.04
CD (P=0.05)	7.4	0.05	0.7	17.5	5.1	NS	0.24	0.12	0.32	0.12	0.36	0.14
Legume mulching												
Control	199.5	0.90	16.3	293.8	159.8	1.96	6.28	2.01	4.45	2.14	4.41	1.55
Sunnhemp (S)	204.0	0.93	16.7	315.3	178.9	2.11	6.38	2.31	5.03	2.59	5.11	1.88
Leucaena	203.7	0.98	16.9	316.2	177.8	2.05	6.64	2.29	4.99	2.52	4.97	1.72
S. + *Leucaena*	210.5	0.97	17.5	335.1	178.7	2.10	6.89	2.50	5.48	2.69	5.40	1.64
SEm±	2.0	0.01	0.2	5.6	1.6	0.06	0.10	0.04	0.09	0.04	0.12	0.04
CD (P=0.05)	5.9	0.04	0.6	16.2	4.6	NS	0.30	0.10	0.27	0.10	0.34	0.12

the difference in grain yield in 2001 being non-significant. This was due to the fact that alachlor application provided effective control of weeds from early stages and maintained near weed-free conditions up to 30 days of growth. Subsequent flushes did not cause much harm as these were taken care by the rapidly developing canopy of maize plants and application of mulched biomass. Mechanical weeding was comparatively less effective as it did not result in complete removal of weeds and there was also poor growth of maize plants in early stages as the first weeding was done at 20 days of growth. Weed dry weight was significantly higher under mechanical weeding than chemical weeding. Interaction between tillage and weed control practices was not significant.

Legume mulching was beneficial for improving the growth and yield attributes of maize over no mulching. Live mulching with sunnhemp or *Leucaena* increased the yield significantly, and the combined effect of sunnhemp + *Leucaena* was even more pronounced than their individual effect in 2002 and 2003. The increase in yield of grain and stover with sunnhemp mulching alone was about the same as *Leucaena*, although the magnitude of increase varied in different years. In 2001, the mean increase was relatively less (6.5%) and increased up to 17.7% in 2002 and 21.5% in 2003. On the other hand, combined use sunnhemp and *Leucaena* mulching did not result in additional response over their single use in 2001 but in 2002 and 2003, the increase in yield was 24.4 and 25.7% over no mulching, and 8.7 and 5.3% over their individual mulching, respectively. These differences in crop response were due to variable rainfall pattern in different years. Beneficial effects of mulching in maize were largely due to enhanced moisture conservation and weed control, and through additional nutrient supply. Mulching decreased weed dry matter significantly and the effect was more pronounced when it was done twice during the growth season. In 2001 and 2003, *Leucaena* mulching along with sunnhemp did not provide additional benefit in grain yield, but in 2002 mulching twice was better than once alone due to greater conservation of moisture following unevenly distributed rainfall pattern. Mulched biomass also added large quantities of nutrients, and the additional nutrients over that applied through fertilizers might have contributed to the increased yield of maize (Sharma and Acharya, 2000; Sharma *et al.*, 2010).

Residual soil moisture

Soil moisture content at maize harvest was comparatively higher in 2002 and 2003 than in 2001 due to the variable rainfall pattern in the late monsoon season (Table 2). Although the total rainfall during maize-growing season was almost same in 2001 and 2003 (1,203–1,210 mm) compared with 2002 (841 mm), the monsoons withdrew early in 2001 as the monthly rainfall during September was only 38 mm compared with 300 mm in 2002 and 208 mm in 2003. In general, tillage practices did not make much change in soil moisture content at maize harvest. CT resulted in slightly more soil moisture than MT in both soil depths but the differences were not significant. The mean soil moisture content in absolute terms was marginally higher by +0.65% at 0–15 cm depth and +1.05% at 15–30 cm depth. This may be due to the fact that the effect of

Table 2. Effect of tillage, weed control and legume mulching on residual moisture content (%) in two soil depths at harvest of maize

Treatment	2001		2002		2003	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm
Tillage						
Conventional	8.33	11.85	15.04	17.75	13.55	15.95
Minimum	8.08	10.35	14.19	16.92	12.72	15.12
SEm±	0.18	0.29	0.33	0.44	0.30	0.34
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Weed control						
Mechanical weeding	8.55	10.93	14.74	17.75	13.24	15.63
Chemical weeding	7.86	11.28	14.49	17.22	13.03	15.43
SEm±	0.18	0.29	0.32	0.44	0.30	0.34
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Legume mulching						
Control	7.10	9.72	13.41	15.98	11.85	14.29
Sunnhemp(S)	8.49	11.50	14.87	17.71	13.51	15.92
Leucaena	7.98	11.09	15.57	17.44	13.14	15.48
S. + *Leucaena*	9.26	11.97	15.61	18.22	14.05	16.44
SEm±	0.19	0.15	0.34	0.44	0.23	0.30
CD (P=0.05)	0.55	0.43	0.99	1.27	0.66	0.87

more intensive pulverization under CT was limited to the early growth season when it checked weed growth and may have stored more moisture in the soil profile because of increased infiltration. However, no such beneficial effect was observed at the harvest stage. Weeding through chemical or mechanical means also did not influence soil moisture storage significantly at maize harvest.

Legume mulching brought about significant improvement in moisture conservation compared with no mulching. The beneficial effect was evident in both soil depths and in all years. There was no significant difference in soil moisture content between live mulching with sunnhemp and *Leucaena*, but combined use of both the materials resulted in significant improvement in moisture conservation over their single use. Sharma and Acharya (2000) reported that mulching was more effective in conserving rainwater *in situ* when applied in standing maize, and that applied at harvest or wheat sowing might be effective in conservation of water received from intermittent rains showers during this period.

Growth and yield of wheat

Growth and yield attributes of wheat were not influenced significantly due to MT when compared with CT (Table 3). The decrease in grain yield under MT over CT was marginal (3.8–5.5%) in all years, which was not significant. Weed dry weight was lower in wheat than in maize, and there was no significant difference due to tillage practices. This showed that elaborate tillage operations involving 3–4 ploughings may not be necessary in wheat, and equally good yields can be obtained with reduced tillage (1–2 ploughings). Similar results have also been reported in rice-wheat cropping system in North-Western India, where no-till wheat gave equal or even higher yield than CT (Chauhan *et al.*, 2003; Pandey *et al.*, 2003). Chemical weeding was significantly superior to mechanical weeding for increasing the growth and yield attributes, which led to an increase of 9.6–10.6% in grain yield and 7.7–8.2% in straw yield in different years. Application of isoproturon provided complete control of grassy as well as broad-leaved weeds, whereas mechanical weeding with hand hoe did not check the growth of weeds growing along the wheat rows. Therefore, weed dry weight was significantly higher under mechanical weeding than chemical weeding because hand weeding is rarely practised and several herbicides are now available for effective and economical weed management in wheat crop.

Legume mulching, which showed its favourable effect on maize, also proved beneficial for improving the growth and yield attributes of following wheat significantly. Grain and stover yield of wheat increased significantly due to sunnhemp or *Leucaena* mulching when compared with

Table 3. Effect of tillage, weed control and legume mulching on growth, yield attributes (mean of 3 years) and productivity of wheat (t/ha), and weed dry weight (t/ha)

Treatment	Plant height at maturity (cm)	Spikes/m row length	Spike length (cm)	Grains/spike	1000-grain weight (g)	2001–02		2002–03		2003–04		Mean weed dry weight at 90 days
						Grain	Straw	Grain	Straw	Grain	Straw	
Tillage												
Conventional	72.7	39.0	9.12	40.3	37.8	2.36	4.83	2.45	4.97	2.63	5.28	0.55
Minimum	71.1	37.5	8.95	38.3	36.9	2.23	4.57	2.33	4.63	2.53	4.99	0.65
SEm±	0.7	0.5	0.13	0.7	0.3	0.04	0.01	0.04	0.10	0.04	0.09	0.04
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Weed control												
Mechanical weeding	70.0	35.9	8.93	37.0	35.6	2.19	4.53	2.28	4.61	2.45	4.94	0.85
Chemical weeding	73.7	40.6	9.14	41.5	39.1	2.40	4.88	2.50	4.99	2.71	5.33	0.34
SEm±	0.7	0.5	0.13	0.7	0.3	0.03	0.08	0.04	0.09	0.04	0.09	0.04
CD (P=0.05)	2.1	1.5	0.42	2.2	1.0	0.11	0.25	0.13	0.27	0.11	0.28	0.12
Legume mulching												
Control	68.6	34.9	8.64	35.8	35.7	2.01	4.19	2.11	4.43	2.22	4.52	0.66
Sunnhemp(S)	72.2	38.9	8.78	39.7	36.8	2.33	4.72	2.43	4.81	2.60	5.12	0.58
Leucaena	71.9	37.7	9.13	39.2	37.7	2.31	4.84	2.40	4.78	2.61	5.28	0.59
S. + *Leucaena*	74.8	41.6	9.42	42.5	39.3	2.53	5.07	2.62	5.18	2.88	5.62	0.56
SEm±	0.7	0.5	0.11	0.6	0.3	0.04	0.09	0.05	0.09	0.04	0.11	0.03
CD (P=0.05)	1.9	1.4	0.31	1.8	1.0	0.11	0.20	0.14	0.26	0.13	0.31	NS

control in all years. The effect of these mulches was almost similar with each other, and the increase in grain yield ranged from 14.5–17.3%, and that in stover yield from 8.2–15.0%. Further, the beneficial effect of sunnhemp + *Leucaena* mulching was significantly better than their single application, and the increase in yield of grain and straw was 24.2–29.7% and 16.9–24.3%, respectively over no mulching. Evidently, these beneficial effects were due to enhanced moisture and nutrient availability in mulched plots which resulted in better germination and crop stand from initial stages. Further, nutrient contribution from the mineralized organic matter increased growth of plants, which led to higher crop productivity. Weed dry weight was not affected significantly due to mulching treatments in previous maize. Sharma and Acharya (2000) reported that wheat yields under rainfed conditions can be improved with conservation tillage and mulching, and the conserved moisture should be used for sowing of wheat as early as possible.

Nitrogen uptake

Based on the mean data of 3 years, tillage practices influenced N uptake of maize significantly but not of wheat (Table 4). Evidently, the differences in N uptake were related to yield performance of crops as there was no change in N content of grain and stover due to different treatments. The mean N uptake of maize decreased significantly by 8.6% under MT when compared with CT, but there was only a marginal decrease (1.9%) in wheat which was not significant. Chemical weeding resulted in significant improvement in N uptake of both maize and wheat crops over manual weeding. This increase was almost similar in case of maize (12.4%) as well as wheat (12.1%). Similarly, sunnhemp and *Leucaena* mulching increased N uptake of maize by 20.4 and 25.0%, and of wheat by 22.7 and 26.8%, respectively. The combined use of both these materials resulted in an increase of 33.9 and 44.8% over no mulching. The enhanced moisture and nutrient contribution due to the added mulch material led to increased biomass production, and hence higher N uptake.

Economics

Total system productivity in terms of maize-equivalent yield was the highest under CT–chemical weeding, followed by MT–chemical weeding (Table 5). The mean increase was 5.7% under CT over MT, and 8.8% under chemical weeding over mechanical weeding. Total cost of cultivation was relatively more for maize (+10.6%) than for wheat. Presumably, CT and mechanical weeding increased the cost of cultivation compared with MT and chemical weeding, while legume mulching in maize also added to the cost. The net returns from maize were small but were relatively higher with chemical than mechanical weeding under both tillage conditions. Legume mulching did not influence the net returns from maize due to small increase in yield compared with the cost involved. On the other hand, wheat gave 4–5 times more net returns than maize, and mulching with both sunnhemp and *Leucaena* was vastly superior to their individual application. Although absolute yields of wheat were only marginally higher (+6.4%) than maize, the higher value of wheat grain (1.6 times) and stover (2 times) caused greater in-

Table 4. Effect of tillage, weed control and legume mulching on N uptake of maize and wheat crops (mean of 3 cropping cycles), and physico-chemical properties of soil at the termination of study

Treatment	N uptake (kg/ha)		Organic C	Total N	Bulk density	Infiltration
	Maize	Wheat	(%)	(%)	(g/cc)	rate (mm/hour)
Tillage						
Conventional	67.5	74.1	0.65	0.080	1.38	7.90
Minimum	61.7	72.7	0.66	0.079	1.42	8.31
SEm±	1.2	1.2				
CD (P=0.05)	3.8	NS				
Weed control						
Mechanical weeding	61.3	69.2	0.64	0.079	1.41	7.91
Chemical weeding	68.0	77.6	0.67	0.080	1.38	8.28
SEm±	1.2	1.2				
CD (P=0.05)	3.8	3.9				
Legume mulching						
Control	53.9	59.4	0.56	0.074	1.44	7.50
Sunnhemp(S)	64.9	72.9	0.67	0.079	1.40	8.05
Leucaena	67.4	75.3	0.66	0.080	1.39	7.93
S. + *Leucaena*	72.2	86.0	0.72	0.084	1.36	8.90
SEm±	1.2	1.1				
CD (P=0.05)	3.4	3.3				

Table 5. System productivity and economic analysis as influenced by tillage, weed control and legume mulching (mean of 3 cropping cycles)

Treatment	Mean productivity (t/ha)			Total cost of cultivation (x 10^3 Rs/ha)		Net returns (x 10^3 Rs/ha)			Net benefit : cost ratio		
	Maize	Wheat	Total maize equivalent	Maize	Wheat	Maize	Wheat	System	Maize	Wheat	System
Tillage and weed control											
CT – mechanical weeding	2.29	2.41	6.15	12.50	11.40	4.40	17.66	22.06	0.352	1.549	0.923
CT – chemical weeding	2.41	2.55	6.49	12.00	10.80	5.96	19.94	25.90	0.497	1.846	1.136
MT – mechanical weeding	2.09	2.21	5.63	12.00	10.90	3.50	15.76	19.26	0.292	1.446	0.841
MT – chemical weeding	2.31	2.51	6.33	11.50	10.30	5.66	19.72	25.38	0.492	1.915	1.164
Legume mulching											
Control	2.04	2.11	5.42	10.50	10.85	4.75	14.79	19.54	0.452	1.363	0.915
Sunnhemp(S)	2.34	2.45	6.26	12.00	10.85	5.21	18.51	23.72	0.434	1.706	1.038
Leucaena	2.29	2.44	6.19	12.00	10.85	4.98	18.61	23.59	0.415	1.715	1.032
S. + *Leucaena*	2.43	2.68	6.72	13.50	10.85	4.58	21.17	25.75	0.339	1.951	1.057

Common cost of cultivation involving seed, sowing, fertilization, harvesting, threshing and rental value of land was: Rs 8,500/ha for maize and Rs 9,200/ha for wheat.
The cost of different treatments was: CT – Rs 1,500 and MT – Rs 500 for both maize and wheat; chemical weeding – Rs 1,000 for maize and Rs. 600 for wheat; mechanical weeding – Rs 1,500 for maize and Rs 1,200 for wheat; legume mulching – Rs 1,500 each for sunnhemp and *Leucaena*.
Price of produce (Rs/t): maize grain – 5,000, maize stover – 1,000; wheat grain – 8,000, wheat stover – 2,000.

crease in net returns. Accordingly, the net B:C ratio was >1.0 in wheat, while it was <0.50 in maize under all treatments. CT-chemical weeding in maize and MT-chemical weeding in wheat gave the highest net B : C ratio. Legume mulching was not so much beneficial in maize but it residual effect on wheat was pronounced, with sunnhemp + *Leucaena* resulting in the highest net B: C ratio.

Soil physico-chemical properties

Organic C and total N status of soil did not show a perceptible change due to tillage and weed control practices over the 3-years period (Table 4). Sharma and Acharya (2000) also reported no significant change in soil organic C, but opined that the effects of conservation tillage may be significant when practised over a long period of time. However, legume mulching brought about large increases in these parameters of soil fertility, and the effect was more pronounced when sunnhemp and *Leucaena* mulching was applied together. In these plots, more than 10 t/ha of mulch biomass was applied over the 3 years period, which led to an increase in organic C and N content. Several workers have reported significant build-up of organic C in the surface layer due to repeated application of mulching over 4-6 years period in different cropping systems (Sharma *et al.*, 1995; Sharma and Acharya, 2000). Conventional tillage decreased while manual weeding increased bulk density over minimum tillage and chemical weeding, respectively. Similarly, legume mulching brought about a decrease in bulk density and an increase in infiltration rate over control. There is often a negative correlation between soil organic C and bulk density due to increased earthworm activity in mulched plots. Further, build-up of soil organic C with continuous mulching leads to improvement in water transmission and soil aggregation.

It was concluded that conventional tillage along with legume mulching with both sunnhemp and *Leucaena* prunings in maize and minimum tillage in wheat, with chemical weeding of both the crops was beneficial for improving moisture and nutrient conservation, controlling weeds, and achieving higher productivity and profitability of maize–wheat cropping system under Doon valley conditions.

REFERENCES

Chauhan, D.S., Sharma, R.K. and Chhokar, R.S. 2003. Comparative performance of tillage operations in wheat (*Triticum aestivum*) productivity and weed management. *Indian Journal of Agricultural Sciences* **73**(7): 402–406.

Dogra, P., Joshi, B.P. and Sharma, N.K. 2002. Economic analysis of tillage practices for maize cultivation in the Himalayan humid subtropics. *Indian Journal of Soil Conservation* **30**(2): 172–178.

Narain, P. and Singh, R.K. 1997. Erosion control and productivity through sunnhemp mulching and green manuirng. Annual Report, Central Soil and Water Conservation Research and Training Institute, Dehradun, pp. 40–41.

Pandey, L.M., Pal, Suresh and Mruthyunjaya. 2003. Impact of zero–tillage technology in the rice (*Oryza sativa*)–wheat (*Triticum aestivum*) system of foothills of Utttaranchal state, India. *Indian Journal of Agricultural Sciences* **73**(8): 432–437.

Sharma, A.R. and Behera, U.K. 2010. Green leaf manuring with prunings of *Leucaena leucocephala* for nitrogen economy and improved productivity of maize (*Zea mays*)–wheat (*Triticum aestivum*) cropping system. *Nutrient Cycling in Agroecosystems* **86**: 39–52.

Sharma, A.R. Toor, A.S. and Sur, H.S. 2000. Effect of interculture operations and scheduling of atrazine application on weed control and productivity of rainfed maize (*Zea mays*) in Shiwalik foothills of Punjab. *Indian Journal of Agricultural Sciences* **70**(11): 757–761.

Sharma, A.R., Singh, R. and Dhyani, S.K. 2004. Conservation tillage for improving productivity of maize-wheat cropping system in the sub-mountaneous Himalayan region. *Indian Journal of Soil Conservation* **33**(1): 35–53.

Sharma, A.R., Singh, R., Dhyani, S.K. and Dube, R.K. 2010. Moisture conservation and nitrogen recycling through legume mulching in rainfed maize (*Zea mays*)–wheat (*Triticum aestivum*) cropping system. *Nutrient Cycling in Agroecosystems* **87**(2): 187–197.

Sharma, N.K., Singh, P.N., Tyagi, P.C. and Mohan, S.C. 1998. Effect of *Leucaena* mulch on soil-water use and wheat yield. *Agricultural Water Management* **35**(3): 191–200.

Sharma, P.K. and Acharya, C.L. 2000. Carry-over of residual soil moisture with mulching and conservation tillage practices for sowing of rainfed wheat (*Triticum aestivum* L.) in North-West India. *Soil and Tillage Research* **57**: 43–52.

Sharma, P.K., Kharwara, P.C. and Tewatia, R.K. 1990. Residual soil moisture and wheat yield in relation to mulching and tillage during preceding rainfed crop. *Soil and Tillage Research* **15**: 279–284.

Sharma, P.K., Verma, T.S. and Bhagat, R.M. 1995. Soil structural improvements with addition of *Lantana camara* biomass in rice–wheat cropping. *Soil Use and Management* **11**: 199–203.