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Irrigation, tillage and mulching effects on soybean yield and water productivity in relation to soil texture

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ABSTRACT

Depleting groundwater resources in Indian Punjab call for diversifying from rice to crops with low evapotranspiration needs and adopting water-saving technologies. Soybean offers a diversification option in coarse- to medium-textured soils. However, its productivity in these soils is constrained by high soil mechanical resistance and high soil temperature during early part of the growing season. These constraints can be alleviated through irrigation, deep tillage and straw mulching. This 3-years field study examines the individual and combined effects of irrigation, deep tillage, and straw mulching regimes on soybean yield and water productivity (WP) in relation to soil texture. Combinations of two irrigation regimes viz., full irrigation (I_f), and partial irrigation (I_p) in the main plot; two tillage regimes viz., conventional-till (CT)-soil stirring to 0.10 m depth, and deep tillage (DT)-chiseling down to 0.35 m depth followed by CT in the subplot; and two mulch rates viz., 0 (M_0) and 6 t ha^{-1} (M) in the sub-subplot on two soils differing in available water capacity were evaluated.

Seed yield was greater in the sandy loam than in the loamy sand reflecting the effects of available water capacity. Irrigation effects were greater on loamy sand (40%) than on sandy loam (5%) soil. Deep tillage benefits were also more on loamy sand (14%) compared to sandy loam (5%) soil. Yield gains with mulching were comparable on the two soils (19%). An evaluation of interaction effects showed that mulching response was slightly more in I_p (20%) than in I_f regimes (17%) in the sandy loam; while in the loamy sand, mulching gains were comparable (18-19%) in both irrigation regimes. Benefits of deep tillage in the loamy sand soil were more in I_p (20%) than in I_f regimes (17%). Deep tillage and straw mulching enhanced WP (ratio of seed yield/water use) from 1.39 to 1.97 kg ha^{-1} mm^{-1} in I_p regime, and from 1.87 to 2.33 kg ha^{-1} mm^{-1} in I_f regime in the loamy sand soil. These effects on WP were less in the sandy loam soil with greater available water capacity. Yield and WP gains are ascribed to deeper and denser rooting due to moderation of soil temperature and water conservation with straw mulching and tillage-induced reduction in soil mechanical resistance. Root mass in CTM$_0$, CTM, DTM$_0$ and DTM was 2.79, 5.88, 5.34 and 5.58 mg cm^{-2} at pod-filling in the loamy sand soil. Comparable yield responses to deep tillage or mulching in the loamy sand soil suggest that either of the options, depending on their cost and availability considerations, can be employed for improving soybean yield and water productivity.

1. Introduction

In irrigated alluvial tract of the Indo-Gangetic plains in South Asia, rice cropping is dominant due to high productivity and profitability. However, large water input in rice due to high evapotranspiration (ET) needs and percolation loss has led to over-use of groundwater. In Punjab state of north-west India, where irrigated rice has been grown in alluvial soils since 1970s, there has been an alarming depletion of groundwater. In central Punjab having good quality groundwater, area having water table below 10 m depth increased from 3% in 1973 to over 90% in 2004 (Singh, 2006) thereby threatening the sustainability of rice culture. It calls for measures like partial diversifying to crops with low ET needs and adopting water-saving soil and agronomic interventions. Soybean offers a diversification option to rice in coarse- to medium-textured soils of the region. However, mean productivity of soybean in these soils in farmer fields varies within a range of 1.2–1.8 t ha^{-1}. The low crop yields are generally caused by high soil temperature during the early part of growing season (Sekhon et al., 2005) and high soil mechanical resistance, more so in coarser (non-plastic) soils (Gajri et al., 2002). These constraints can be alleviated through practices of irrigation, deep tillage and straw mulching.

Numerous reports indicate that use of crop residues as straw mulching affects hydro-thermal regime of soils by moderating soil temperature and reducing soil water evaporation (E) component of ET, and control weeds by their smothering action. This has led

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Table 1
Physical and chemical characteristics of experimental soils.

Soil depth, m	% sand (2000–20 μm)	% clay (<2 μm)	pH	EC	Water retention, vol.%	
					FC[a]	−1.5 MPa
Loamy sand						
0–0.30	88	5	7.8	0.32	20.0	7.5
0.30–0.60	87	6	7.7	–	20.0	8.0
0.60–0.90	87	7	7.8	–	20.0	7.8
0.90–1.20	90	6	8.0	–	18.0	6.3
1.20–1.50	91	5	8.1	–	16.0	6.2
Sandy loam						
0–0.30	75	10	8.0	0.35	25.0	9.0
0.30–0.60	70	12	8.1	–	27.0	10.5
0.60–0.90	68	14	7.9	–	29.0	10.1
0.90–1.20	65	16	7.9	–	29.0	9.8
1.20–1.50	64	17	7.9	–	29.0	10.3

[a]Determined in situ 24 h after a thorough wetting.

to improvements in crop yields in arid and semi-arid environments of tropical and sub-tropical regions (Lal, 1974; Prihar and Arora, 1980) and economized use of irrigation water (Sandhu et al., 1980; Gajri et al., 1997). Similarly, there is strong evidence that deep tillage or sub-soiling of non-plastic soils provides a continuous low soil strength slit for root proliferation that provides an interim relief to crops. It caused substantial gain in yield of field crops viz., soybean (Batchelor and Keisling, 1982; Busscher et al., 2000), maize (Chaudhary et al., 1985; Arora et al., 1991), wheat (Gajri et al., 1991), mustard (Arora et al., 1993) and sunflower (Gajri et al., 1997). Deep tillage benefits have been reported to vary with seasonal rainfall (Unger, 1979); irrigation regimes and soil texture (Gajri et al., 2002). There are few reports on the interactive effects of straw mulching and deep tillage in relation to irrigation regimes on crop yields. Information on water productivity (WP) of soybean (Scott et al., 1987; Payero et al., 2005; Garcia et al., 2010) indicates strong dependence of WP on irrigation. In a review, Molden et al. (2010) observed that in water-limited conditions, influence of non-water factors (soil fertility, tillage and crop residues) on crop WP assumes greater importance through their effects on reducing *E* component. This study examined the combined effects of irrigation, deep tillage and straw mulching on soil physical properties, yield and WP of soybean in relation to soil texture in a semi-arid sub-tropical environment of Punjab in northwest India.

2. Materials and methods

2.1. Site characteristics

A field experiment was conducted for three cropping seasons (2005–2007) at Punjab Agricultural University Research Farm, Ludhiana, India (30°54′N, 75°48′E, 247 m above mean sea level). The soils were deep alluvial loamy sand and sandy loam developed under hyper-thermic regime. These soils are present in the same site at a distance of 200 m, and had same cropping history and management. Soybean was grown in the same plots in the three seasons. Important physical and chemical characteristics in different layers of the soils are given in Table 1. The surface 0.15 m deep soil layer had 0.25 and 0.35% organic carbon, 35 and 47 kg ha^{-1} available P, and 105 and 110 kg ha^{-1} available K in the loamy sand and sandy loam soil, respectively. The groundwater was more than 15 m deep. Weather information during the experimental period is given in Table 2.

2.2. Treatments

During the three cropping seasons, combinations of irrigation, deep tillage and straw mulching regimes were evaluated in a split-split-plot design with irrigation in the main plot, tillage in the subplot, and mulching in the sub-subplot with three replications. Each sub-subplot measured 7 m by 3m with a bund height of 0.15 m to minimize run-off loss or run-on gain. Irrigation regimes included: full irrigation (I_f), and partial irrigation (I_p) by withholding irrigations during pod-filling; tillage regimes included: conventional-till (CT)-soil manipulation to 0.10 m depth by two runs of a disc harrow, two runs of a tine cultivator followed by a planking, and deep tillage (DT)-sub-soiling with a chisel 0.35 deep and 0.40 m apart followed by CT; and mulching included: no mulching (M_0) and 6 t ha^{-1} wheat residue (M) spread between soybean rows.

2.3. Crop management

After the harvest of preceding wheat, the fields were irrigated in the last week of April. For the DT treatment, the plots were sub-soiled in the last week of May by which time the sub-soil had dried enough to permit maximum shattering. The plots were irrigated again before seedbed preparation by CT as described. Soybean (cv. SL 295) was planted @ 75 kg ha^{-1} in rows spaced 0.45 m apart (with population of 44 plants m^{-2}) and at a depth of 0.03 m in the first week of June after inoculating seed with *Rhizobium* culture. All plots were fertilized with 30 kg N and 80 kg P_2O_5 ha^{-1} (through

Table 2
Monthly mean of daily mean air temperature (AT, °C), sunshine hours (SS, h) and monthly cumulative pan evaporation (E_p, mm) and rainfall (RF, mm) in different cropping seasons.

Month	2005				2006				2007			
	AT	SS	E_p	RF	AT	SS	E_p	RF	AT	SS	E_p	RF
June	32.9	9.9	302.8	48.1	31.5	8.0	251.5	40.9	32.3	8.1	261.5	89.2
July	30.0	5.9	139.6	183.5	30.7	6.0	162.3	209.2	30.8	7.1	151.8	150.7
August	30.2	9.0	141.6	197.6	30.0	7.2	147.6	142.7	30.4	6.5	141.3	110.6
September	28.5	8.0	121.4	166.5	28.1	8.0	126.7	103.6	28.4	6.5	105.5	56.8
October	24.6	8.4	102.2	–	25.3	7.4	113.7	6.8	23.9	8.9	115.7	–
Total	–	–	807.6	595.7	–	–	801.8	503.2	–	–	775.8	407.3