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Water productivity of summer mungbean (*Vigna radiata*) in relation to irrigation, tillage and mulch in sandy loam and loamy sand soils

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ABSTRACT

There is a growing interest among the farmers of the state to take an additional crop, i.e. summer mungbean (*Vigna radiata* L.) in the window period of rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) system with a little emphasis on the water productivity of summer mungbean. The present study was aimed to assess the water productivity of summer mungbean under differential irrigation regimes, tillage and mulch in sandy loam and loamy sand soils. A field experiment was conducted during the summer 2021 and 2022 with three irrigation regimes (based on irrigation water to PAN-E ratio of 0.75 ($I_{0.75}$), 0.50 ($I_{0.50}$), 0.25 ($I_{0.25}$) in sandy loam and 0.8 ($I_{0.8}$), 0.6 ($I_{0.6}$) and 0.4 ($I_{0.4}$) in loamy sand soils, two tillage systems, viz. deep tillage and conventional tillage; and two mulch rates (no mulch and application of rice straw mulch @6 t/ha). Irrigation regime, $I_{0.75}$ and $I_{0.8}$ resulted in higher crop biomass, however the seed yield and water productivity were highest under $I_{0.50}$ and $I_{0.6}$. Deep tillage with mulch resulted in higher seed yield and water productivity in comparison to conventional tillage with no mulch. Medium irrigated regime ($I_{0.50}$ and $I_{0.6}$) coupled with deep tillage and rice straw mulch was found to be effective in improving the seed yield of mung bean in loamy sand soils in north-west India.

Keywords: Deep tillage**,** Mulch, Penetration resistance, Root proliferation, Water productivity

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system in Punjab state is being faced by issues of yield stagnation with decreased input factor productivity (Arora *et al.* 2011). High water demands of the cropping system have led to over-exploitation of ground water resources. In order to put a check on the same, the state government has banned the transplantation of rice before mid-June. However, it has provided a window for taking an additional short duration crop, i.e. summer mungbean (*Vigna radiata* L.) in between wheat and paddy. Apart from being a rich source of proteins to humans, it adds to the soil fertility also. Furthermore, hike in MSP of pulses; arrangement of procurement through government agencies and source of additional income, has increased the interest of farmers in summer mungbean cultivation (Bishnoi *et al.* 2020). But, little thought has been given to the water productivity of summer mungbean as during the crop season, relative humidity is lowest, wind speed is highest and temperature is maximum, thereby resulting in high evaporation losses.

In spite of its short duration, the crop demands 3–5 irrigations depending upon the weather conditions. So, for guaranteeing high water use efficiency, legitimate planning of the irrigation water system is essential through proper irrigation scheduling along with other interventions. As most of the soils in Punjab are coarse to medium in texture, deep tillage prior to sowing could provide an interim relief to the crop and enable the penetration of roots to fetch water and nutrients from deeper soil layers. This practice in the region has caused a substantial increase in yield of crops like soybean (Arora *et al.* 2011), spring maize (Kaur and Arora 2019), and direct seeded rice (Dhaliwal *et al.* 2021). Further, there are various reports indicating the positive effect of straw mulch application on water productivity. Straw mulch moderates the soil temperature, reduces surface evaporation, controls weeds and helps in yield gain (Arora *et al.* 2011). During high atmospheric temperature conditions, straw mulching has the potential for reducing water use in coarse-textured soils under deficit irrigation (Ambachew *et al.* 2014). It was hypothesised that during the hot dry summer months, reduction in evaporation by straw mulch and better root proliferation due to deep tillage will result in higher soil moisture use which ultimately will affect the yield and water productivity.

MATERIALS AND METHODS

Site characteristics: The present study was carried out at the research farm of Department of Soil Science, Punjab Agricultural University, Ludhiana, Punjab (30º 54' N, 75º 48' E and 247 m amsl) during the summer season of 2021 and 2022 on two different soil types, viz. sandy loam and

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loamy sand. The region has a subtropical and semi-arid type of climate. Mean annual rainfall in the region ranges from 650–750 mm out of which 80% is concentrated in the monsoon months. Mean maximum temperature during the crop growth season varied from 34.2–36.3°C during 2021 and 38.8–39.3°C during 2022. Mean minimum temperature varied from 17–25.4°C during 2021 and 20.5–27°C during 2022. Total rainfall in the month of April to June was 136.4 mm during 2021 and 96.2 mm during 2022. The soils of the experimental sites were non-saline and slightly alkaline in nature with low organic carbon content and medium content of phosphorus and potassium. The bulk density of sandy loam soil profile (0–90 cm) ranged from 1.48–1.65 g/cm^{3}and that of loamy sand soil profile ranged from 1.68–1.81 g/cm^3.

Treatments: The experiment was conducted in split-split plot design with three replications. Main plots consisted of three irrigation regimes, two tillage practices in subplots and two mulch rates in sub-subplots. The irrigation regimes were based on irrigation water to pan-evaporation (PAN-E) ratio of 0.8 ($I_{0.8}$), 0.6 ($I_{0.6}$), and 0.4 ($I_{0.4}$), for loamy sand and 0.75 ($I_{0.75}$), 0.5 ($I_{0.5}$), and 0.25 ($I_{0.25}$) for sandy loam soils. Number of irrigations were three in $I_{0.75}$ and $I_{0.8}$; two under $I_{0.5}$, $I_{0.25}$, $I_{0.6}$ and $I_{0.4}$. Tillage treatments included conventional tillage (CT) in which the seed bed was prepared by two passes of disc plough followed by two passes of cultivator and one pass of planking and in deep tillage (DT), the chiselling was done to a depth of 0.40 m at a distance of 0.50 m using a single tine chiseller followed by CT. Mulch rates included application of rice straw @6 t/ha (M_6) between the rows and no mulch (M_0).

After the harvesting of previous wheat crop, chiselling in the DT plots was done in the starting of April so that the subsoil had attained enough shattering and the respective plots were prepared as per the treatments. Cultivar SML 668 was raised by following the recommended practices of Punjab Agricultural University. After seedling establishment, rice straw mulch was applied in the selected plots. The harvesting was done manually at the end of June for both the soil types. The harvested biomass was kept in the respective plots for sun drying for a few days followed by manual threshing. The produce from each plot was expressed on t/ha basis.

Measurements: Soil penetration resistance was measured at the time of sowing at field capacity using digital cone, hand-held penetrometer (CP40II; Rimik Electronics, RFM Australia) and reported as cone index (MPa). Soil temperature in the mulched and no-mulched plot was measured daily at 7:00 am and 2:00 pm using mercury thermometer at a depth of 0.05 m. Root samples were collected at a podding stage up to a depth of 75 cm by taking four concentric soil cores of 0.05 m diameter at a depth interval of 0.15 m. Following cleaning, root samples were oven dried at 60°C and weighed. Root dry weight of the respective depth was expressed as root mass density (μg/cm^3). Seed yield was recorded from a net area of 12 m^2 and expressed on t/ha basis. Water productivity was calculated as the ratio of seed yield to the total water use (summation of difference in soil profile moisture content between the sowing and harvesting, irrigation and rainfall amount during the crop growth season).

Statistical analysis: The data were subjected to analysis of variance in split-split plot design using SAS software 9.3. The comparison of treatment means was made by the least significant difference (LSD) at a 5% confidence interval ($P<0.05$).

RESULTS AND DISCUSSION

Soil physical changes: Soil penetration resistance was higher in CT plots in comparison to DT plots in both the soil types. Mean cone index of 0–10 cm soil layer was 0.60 and 1.01 MPa in CT plots and 0.40 and 0.50 MPa in DT plots in sandy loam and loamy sand soils respectively during 2021 (Table 1). Reduced penetration resistance could be attributed to shattering and loosening of soil caused by deep tillage (Arora *et al.* 2018). Mean penetration resistance increased with depth and the increase being higher in CT plots; this could be attributed to depth of tillage as in case of conventional tillage the implements penetrate to a depth of 10–15 cm soil layer, however in deep tilled soils it was 40–45 cm (Dhaliwal *et al.* 2021). Mulch lowered the soil temperature during the early crop growth season. Mean maximum temperature was 10°C lower in M_6 plots (26.9–32.4°C) as compared to M_0 plots (26.8–41.9°C) in sandy loam soil (Fig 1a). Differences in maximum and minimum soil temperature were less in case of mulched plots in comparison to no-mulched plots as mulch moderates the soil temperature (Kaur and Arora 2019). However, there was no significant difference in the mean minimum temperature of M_6 (24.1–26.5°C) and M_0 plots (24.8– 26.8°C). As the crop growth advanced, the difference in soil temperature of M_0 and M_6 plots decreased due to the increased canopy cover (Fan *et al.* 2017). Similarly in loamy sand soils, mean maximum temperature varied between 26.8–32.4°C in M_6 plots and 26.9–41.5°C in M_0 plots (Fig 1b).

Root mass density: Deep tillage coupled with mulch (DT-M_6) resulted in higher root mass density up to 75 cm of the soil depth in sandy loam soils during 2021 (Fig 2a) and 2022 (Fig 2b). However, deep tillage without mulch (DT-M_0) had higher root mass density (RMD) up to 60 cm soil depth in 2021 (Fig 2a) and up to 45 cm soil depth in 2022 (Fig 2b). Under conventional tilled plots, the impact of mulch was significant only up to 30 cm soil depth, the

Table 1 Soil penetration resistance (MPa) of sandy loam and loamy sand soils at the time of sowing

	Sandy loam			Loamy sand		
Soil depth (cm)	CT	DT	LSD (0.05)	CT	DT	LSD (0.05)
0–10	0.60	0.40	0.18	1.01	0.50	0.30
10–20	2.01	1.50	0.46	2.60	1.70	0.51
20–30	2.60	1.60	0.60	2.90	1.70	0.73

CT, Conventional tillage and; DT, Deep tillage.

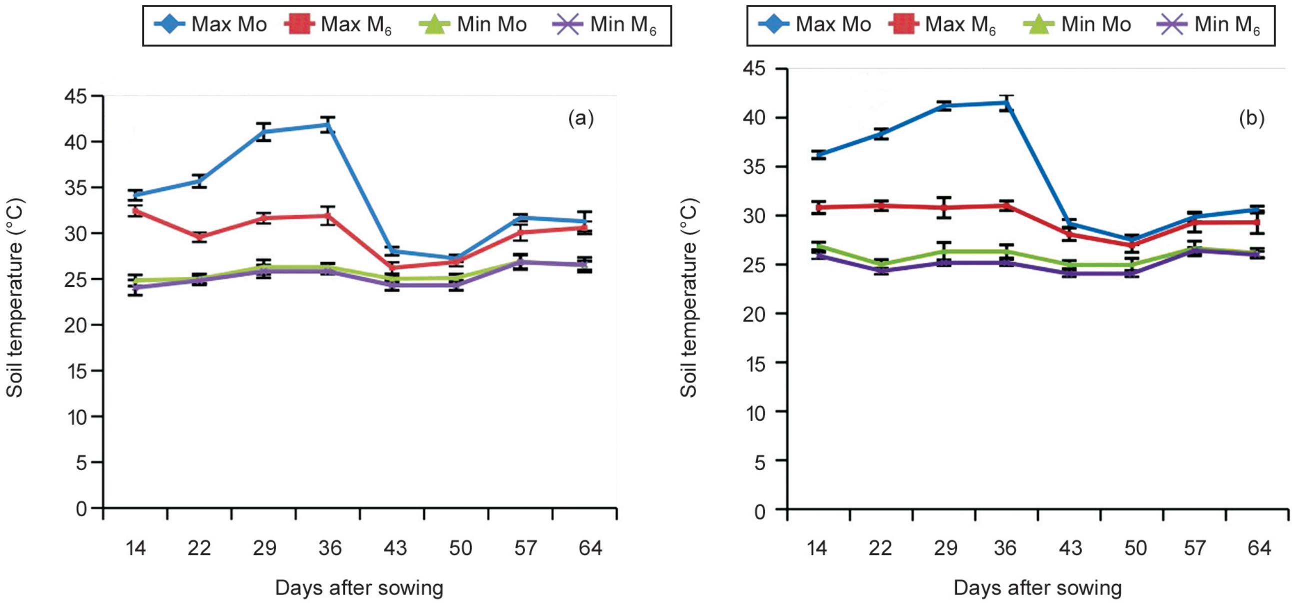

Fig 1 Periodic soil temperature in relation to mulch (a) sandy loam and (b) loamy sand soils during the crop growth season (2021). (*Vertical bars represent standard errors).

fndings are in corroboration with Mu *et al.* (2016). In loamy sand soils, the DT-M_6 plots had the highest RMD followed by DT-M_0 and CT-M_6 and lowest RMD was found in CT-M_0 in 0–15, 30–45 and 45–60 cm of the soil layer (Fig 2c). However in soil depth of 15-30 cm, highest RMD was observed in DT-M_6 followed by DT-M_0 followed by CT-M_6 and was lowest in CT-M_0 during both the years (Fig 2c and 2d). Lower penetration resistance in deep tilled plots reduces the impedance to the growing roots thereby promoting proliferation of the root system (Bandyopadhyay *et al.* 2010). On the other hand, higher penetration resistance under conventional tilled plots restricts the lateral root growth and penetration of roots to the deeper layers (Lin *et al.* 2016). Mulching reduces the soil temperature and surface soil evaporation and thereby improves the hydro-thermal regimes which promote root growth (Kader *et al.* 2019).

Crop biomass: Mean crop biomass was significantly highest under $I_{0.75}$ and $I_{0.8}$ followed by $I_{0.50}$ and $I_{0.6}$ and was lowest in $I_{0.25}$ and $I_{0.40}$ during 2021 and 2022 (Table 2). The higher irrigation water input in frequently irrigated regime resulted in higher vegetative growth. Crop biomass was significantly higher in plots with deep tillage as compared to conventional tilled plots in both soil types during both the years. Above-ground biomass

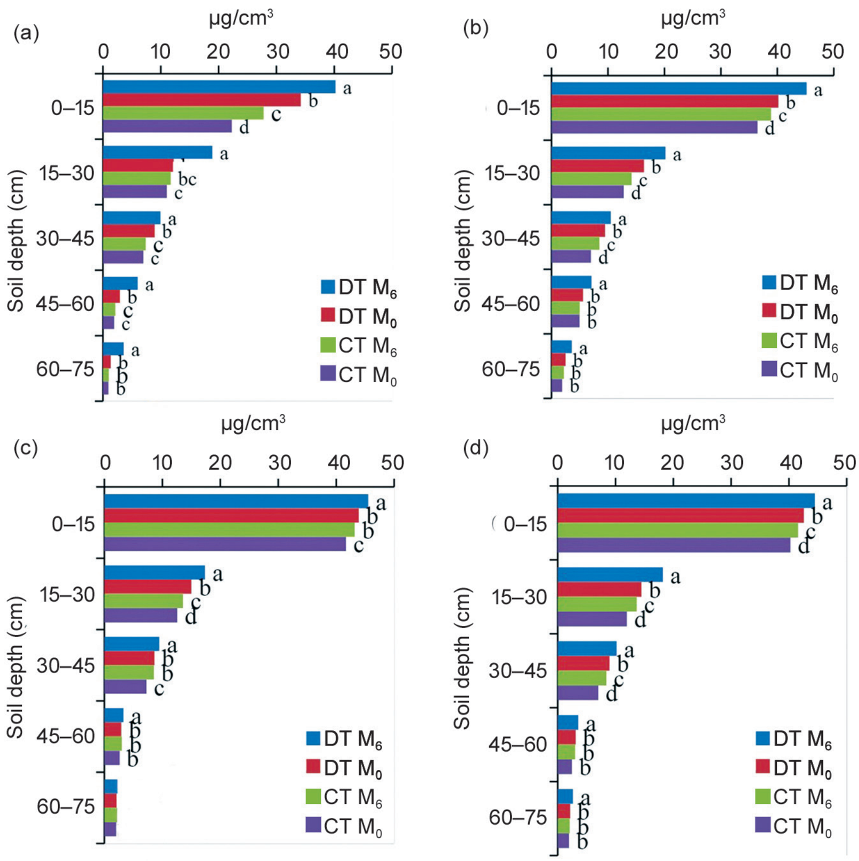

Fig 2 Root mass density (RMD) of mungbean in relation to tillage and mulch in sandy loam (a) 2021, (b) 2022 and loamy sand soils (c) 2021, (d) 2022.
*Different small letters indicate significant difference based on least significant difference (0.05).

Table 2 Effect of irrigation, tillage and residue mulch on crop biomass (t/ha) and seed yield (t/ha) of mungbean in sandy loam and loamy sand soils

		Crop biomass								Seed yield							
		2021								*2021*							
		Sandy loam				Loamy sand				Sandy loam				Loamy sand			
Treatment		$I_{0.25}$	$I_{0.50}$	$I_{0.75}$	Mean	$I_{0.4}$	$I_{0.6}$	$I_{0.8}$	Mean	$I_{0.25}$	$I_{0.50}$	$I_{0.75}$	Mean	$I_{0.4}$	$I_{0.6}$	$I_{0.8}$	Mean
CT	M_0	4.12	4.29	4.46	4.29	3.78	4.21	4.65	4.21	0.71	0.77	0.72	0.73	0.60	0.76	0.63	0.66
	M_6	4.32	4.79	5.51	4.87	3.64	4.81	4.78	4.41	0.80	0.90	0.89	0.86	0.69	0.95	0.85	0.83
	Mean	4.22	4.54	4.98		3.71	4.50	4.71		0.75	0.83	0.80		0.64	0.85	0.74	
DT	M_0	4.34	4.29	4.79	4.47	3.72	4.35	4.76	4.27	0.76	0.89	0.83	0.82	0.68	0.80	0.77	0.75
	M_6	4.79	5.98	5.66	5.47	3.89	4.87	4.95	4.57	0.86	0.96	0.90	0.90	0.87	0.98	0.87	0.91
	Mean	4.56	5.13	5.22		3.80	4.61	4.85		0.81	0.92	0.86		0.77	0.89	0.82	
Factor means		$I_{0.25}$ = 4.39, $I_{0.50}$ = 4.50, $I_{0.75}$ = 5.10 CT = 4.58, DT = 4.80 M_0 = 4.38, M_6 = 5.00				$I_{0.4}$ = 3.75, $I_{0.6}$ = 4.56, $I_{0.8}$ = 4.78 CT = 4.31, DT = 4.42 M_0 = 4.26, M_6 = 4.46				$I_{0.25}$ = 0.78, $I_{0.50}$ = 0.88, $I_{0.75}$ = 0.83 CT = 0.80, DT = 0.88 M_0 = 0.78, M_6 = 0.90				$I_{0.4}$ = 0.70, $I_{0.6}$ = 0.87, $I_{0.8}$ = 0.78 CT = 0.74, DT = 0.82 M_0 = 0.70, M_6 = 0.86			
LSD (0.05)		I=0.08, T=0.07, M=0.07, I×T=0.12, I×M=NS, T×M=NS, I×T×M=0.18				I=0.08, T=0.05, M=0.05, I×T=NS, I×M=NS, T×M=NS, I×T×M=NS				I=0.04, T=0.01, M=0.01, I×T=NS, I×M=NS, T×M=0.01, I×T×M=NS				I=0.02, T=0.01, M=0.01, I×T=0.02, I×M=NS, T×M=NS, I×T×M=0.02			
		2022								2022							
		$I_{0.25}$	$I_{0.50}$	$I_{0.75}$	Mean	$I_{0.4}$	$I_{0.6}$	$I_{0.8}$	Mean	$I_{0.25}$	$I_{0.50}$	$I_{0.75}$	Mean	$I_{0.4}$	$I_{0.6}$	$I_{0.8}$	Mean
CT	M_0	4.20	4.30	4.52	4.34	3.70	4.30	4.55	4.18	0.73	0.80	0.74	0.76	0.65	0.78	0.65	0.69
	M_6	4.35	4.83	5.00	4.73	3.82	4.80	4.88	4.48	0.82	0.91	0.89	0.87	0.69	0.90	0.88	0.82
	Mean	4.27	4.56	4.76		3.76	4.55	4.69		0.78	0.86	0.82		0.67	0.84	0.76	
DT	M_0	4.25	4.32	4.85	4.44	3.68	4.32	4.96	4.32	0.78	0.91	0.85	0.85	0.70	0.84	0.76	0.77
	M_6	4.69	4.75	5.20	4.88	3.90	4.68	5.10	4.56	0.89	1.00	0.92	0.94	0.86	0.99	0.89	0.91
	Mean	4.47	4.53	5.03		3.79	4.5	5.03		0.84	0.96	0.88		0.78	0.92	0.83	
Factor means		$I_{0.25}$ = 4.39, $I_{0.50}$ = 4.53, $I_{0.75}$ = 4.87 CT = 4.53, DT = 4.68 M_0 = 4.41, M_6 = 4.80				$I_{0.40}$ = 3.78, $I_{0.6}$ = 4.53, $I_{0.8}$ = 4.86 CT = 4.33, DT = 4.44 M_0 = 4.25, M_6 = 4.52				$I_{0.25}$ = 0.81, $I_{0.50}$ = 0.91, $I_{0.75}$ = 0.85 CT = 0.81, DT = 0.89 M_0 = 0.80, M_6 = 0.91				$I_{0.4}$ = 0.73, $I_{0.6}$ = 0.88, $I_{0.8}$ = 0.80 CT = 0.76, DT = 0.84 M_0 = 0.73, M_6 = 0.87			
LSD (0.05)		I=0.12, T=0.09, M=0.15, I×T=NS, I×M=NS, T×M=NS, I×T×M=NS				I=0.15, T=0.08, M=0.12, I×T=NS, I×M=NS, T×M=NS, I×T×M=NS				I=0.03, T=0.04, M=0.05, I×T=NS, I×M=NS, T×M=0.01, I×T×M=NS				I=0.05, T=0.06, M=0.05, I×T=0.04, I×M=NS, T×M=0.01, I×T×M=NS			

is the reflection of below-ground biomass, stronger root system resulting in better exploration of soil for water and nutrients, and hence their availability to the crop plant (Schneider *et al.* 2017). A significant interaction between the tillage and irrigation regimes in sandy loam soil (during 2021) was observed as the biomass in $I_{0.75}$ (5.22 t/ha) and $I_{0.5}$ (5.13 t/ha) irrigation regime coupled with deep tillage was significantly highest, followed by conventional tillage with $I_{0.75}$ (4.98 t/ha) followed by $I_{0.25}$-DT (4.56 t/ha) and $I_{0.50}$-CT (4.54 t/ha) and was lowest in $I_{0.25}$-CT (4.22 t/ha). Deep tillage improves the profile moisture usage under water stressed conditions (Guan *et al.* 2015). Irrigation regime, tillage and mulch interacted significantly in sandy loam soil, the biomass being highest in plots with $I_{0.50}$-DT-M_6 (5.98 t/ha) and lowest in $I_{0.25}$-CT-M_0 (4.12 t/ha). Higher root proliferation under deep tillage and improved hydrothermal regimes under mulched plots gives higher biomass even under low water input conditions.

Seed yield: Though the crop biomass was highest in frequently irrigated regimes, but the mean seed yield of mungbean was highest in plots with medium irrigated regime in comparison to least and most frequently irrigated regimes during both the years (Table 2). It was higher by 6.02 and 7.05% in $I_{0.5}$ irrigation regime in comparison to $I_{0.75}$ and was higher by 12.8 and 12.3% in comparison to $I_{0.25}$ during 2021 and 2022 respectively in sandy loam soil. Differences in seed yield were more prominent in loamy sand soil as the seed yield was higher by 11.5 and 10% in $I_{0.6}$ in comparison to $I_{0.8}$ and 24.3 and 20.5% in comparison to $I_{0.4}$ during 2021 and 2022 respectively. The high water input under frequently irrigated regime resulted in higher vegetative growth but the mass was not translated into seed yield, thereby resulting in lower seed yield in comparison to medium irrigated regime (Arora *et al.* 2018). Deep tillage resulted in a yield gain of 10% in sandy loam and 11% in loamy sand soils during both the years. Mulch application resulted in higher mean seed yield in loamy sand as well in sandy loam soils. This could be due to improved hydrothermal conditions (Arora *et al.* 2011), as it was evident from the results that mulch lowered the maximum soil temperature and increased the soil moisture content. In loamy sand soils (during 2021), the interaction between the irrigation regime and tillage was significant with highest seed yield in DT-$I_{0.6}$ (0.89 t/ha) followed by CT-$I_{0.6}$ (0.85 t/ha), DT-$I_{0.8}$ (0.82t/ha), DT-$I_{0.4}$ (0.77 t/ha), CT-$I_{0.8}$ (0.74t/ha) and lowest in CT-$I_{0.4}$ (0.64 t/ha). Deep tillage increases the water availability for crop plants by increasing soil water storage and helps in higher soil volume exploration by promoting root growth, the effect is more significant under water limited conditions (Lampurlanes *et al.* 2001). During 2021, tillage and mulch interacted significantly in both the soil types. In sandy

Table 3 Effect of irrigation, tillage and residue mulch on water productivity (kg/ha/mm) of mungbean in sandy loam and loamy sand soils

Treatment		Sandy loam				Loamy sand			
2021		$I_{0.25}$	$I_{0.50}$	$I_{0.75}$	Mean	$I_{0.4}$	$I_{0.6}$	$I_{0.8}$	Mean
CT	M_0	2.37	2.57	1.95	2.29	2.00	2.50	1.70	2.06
	M_6	2.69	3.02	2.43	2.71	2.32	3.15	2.32	2.59
	Mean	2.53	2.79	2.19		2.16	2.82	2.01	
DT	M_0	2.53	2.96	2.24	2.57	2.23	2.63	2.05	2.30
	M_6	2.88	3.21	2.44	2.84	2.88	3.25	2.34	2.82
	Mean	2.70	3.08	2.34		2.55	2.94	2.19	
Factor means		Irrigation (I) $I_{0.25}$ = 2.61, $I_{0.50}$ = 2.94, $I_{0.75}$ = 2.26; Tillage (T) CT = 2.50, DT = 2.71; Mulch (M) M_0 = 2.43, M_6 = 2.78				$I_{0.4}$ = 2.35, $I_{0.6}$ = 2.88, $I_{0.8}$ = 2.10; CT = 2.30, DT = 2.54; M_0 = 2.14, M_6 = 2.70			
LSD (0.05)		I=0.06, T=0.04, M=0.04, I×T=NS, I×M=NS, T×M=0.06, I×T×M=NS				I=0.08, T=0.04, M=0.04, I×T=NS, I×M=NS, T×M=NS, I×T×M=NS			
2022		$I_{0.25}$	$I_{0.50}$	$I_{0.75}$	Mean	$I_{0.4}$	$I_{0.6}$	$I_{0.8}$	Mean
CT	M_0	2.81	2.86	2.33	2.66	2.50	2.85	2.04	2.46
	M_6	3.25	3.43	2.76	3.15	2.74	3.06	2.96	2.84
	Mean	3.03	3.15	2.55		2.62	2.96	2.39	
DT	M_0	3.05	3.37	2.61	3.01	2.73	3.11	2.33	2.73
	M_6	3.48	3.64	2.80	3.31	3.36	3.40	2.71	3.16
	Mean	3.26	3.50	2.71		3.05	3.26	2.52	
Factor means		$I_{0.25}$ = 3.15, $I_{0.50}$ = 3.32, $I_{0.75}$ = 2.63; CT = 2.91, DT = 3.16; M_0 = 2.84, M_6 = 3.23				$I_{0.4}$ = 2.83, $I_{0.6}$ = 3.28, $I_{0.8}$ = 2.46; CT = 2.69, DT = 2.97; M_0 = 2.62, M_6 = 3.09			
LSD (0.05)		I=0.10, T=0.12, M=0.08, I×T=NS, I×M=NS, T×M=NS, I×T×M=NS				I=0.15, T=0.12, M=0.10, I×T=NS, I×M=NS, T×M=NS, I×T×M=NS			

loam soils, the mean seed yield was highest in deep tillage coupled with mulch (0.90 t/ha) followed by conventional tillage coupled with mulch (0.86 t/ha), deep tillage with no mulch (0.82 t/ha) and conventional tillage without mulch (0.73 t/ha). In loamy sand soils, the highest mean seed yield was in DT-M_6 (0.91 t/ha) followed by CT-M_6 (0.83 t/ha), DT-M_0 (0.75 t/ha) and was lowest in CT-M_0 (0.66 t/ha). Deep tillage reduces the soil penetration resistance thereby promotes root growth and increases the water availability to the crop plant coupled with mulch which decreases the soil temperature by decreasing the impact of incoming solar radiation, hence reduces the surface soil evaporation and increases the availability of water to the crop plant (Kader *et al.* 2019). Seed yield was highest in $I_{0.6}$-DT-M_6 (0.98 t/ha) and was lowest in $I_{0.4}$-CT-M_0 (0.60 t/ha) in loamy sand soils. Therefore, deep tillage and mulch through their impact on soil physical environment (Schneider *et al.* 2017) aid in higher moisture use by the crop, thus improving yield gain under less water input conditions.

Water productivity: Higher yield and comparatively low water input resulted in highest water productivity in plots with medium irrigation regime ($I_{0.50}$ and $I_{0.60}$) followed by least frequently irrigated ($I_{0.25}$ and $I_{0.40}$) and were lowest in most frequently irrigated regime ($I_{0.75}$ and $I_{0.80}$) in both types of soil during both the years (Table 3). The proportionate yield gain was less per unit of water used in frequently irrigated regime, hence had low water productivity (Dhaliwal *et al.* 2020). Deep tilled plots had higher water productivity than conventional tillage in sandy loam (8.5%) and loamy sand (10.4%) soils during both the years due to higher yield under deep tilled conditions. The difference in water productivity of mulched and no-mulched plots was more prominent in loamy sand soil (26.0%) in comparison to sandy loam soil (14.0%). Water productivity was significantly higher under M_6 plots than M_0 plots in sandy loam (14% during both the years) and loamy sand soils (26.0 and 17.9% during 2021 and 2022 respectively) due to higher yield under mulched plots. Tillage and mulch interacted significantly in sandy loam soils during 2021 with highest water productivity in DT-M_6 plots (2.84 kg/ha/mm) followed by CT-M_6 plots (2.71 kg/ha/mm) followed by DT-M_0 plots (2.57 kg/ha/mm) and was lowest in CT-M_0 (2.29 kg/ha/mm). Higher yield with deep tillage and mulch led to higher water productivity.

Deep tillage resulted in reduced mechanical resistance, thereby promoting root proliferation and resulting in higher crop yield and water productivity in sandy loam and loamy sand soils. Crop biomass was higher under most frequently irrigated regime but the yield and water productivity was higher under medium irrigation regime. Mulching resulted in reduced soil temperature and improved thermal regime of the soil, thereby resulting in higher yield and water productivity. Deep tillage, mulch and irrigation regimes interacted significantly to affect the crop yield in loamy sand soil.

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