Indian Journal of Agronomy **59** (4): 575–580 (December 2014)

Research Paper

Tillage and irrigation management in chickpea (*Cicer arietinum*)–fodder sorghum (*Sorghum bicolor*) cropping system under semi-arid conditions of India

A.K. DIXIT[1], SUNIL KUMAR[2], ARVIND K. RAI[3] AND T. KIRAN KUMAR[4]

ICAR - Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh 284 003

Received : January 2014; Revised accepted : September 2014

ABSTRACT

A field experiment was conducted at Jhansi during the winter season (*rabi*) of 2009–10 to rainy season (*kharif*) of 2012 to study the impact of tillage practices and irrigation management on chickpea (*Cicer arietinum* L.) and their carry-over effects on succeeding fodder sorghum [*Sorghum bicolour* (L.) Moench]. Reduced tillage recorded 1.74 t/ha grain yield of chickpea and was on a par with conventional tillage. However, reduced tillage (57.7%) and zero tillage (57.4%) recorded significantly higher harvest index than conventional tillage (55.2%). Similarly, application of 2 irrigations to chickpea recorded higher grain yield (1.90 t/ha) and system productivity in terms of chickpea-equivalent yield (4.00 t/ha) but application of only 1 irrigation recorded higher irrigation water-use efficiency (295 kg grain /ha-cm). Significantly higher plant height, plant population, grains per pod, 100-seed weight, weeds count and weed dry matter were also recorded in irrigated plots than unirrigated control. Higher system productivity in terms of chickpea-equivalent yield (CEY) was recorded under reduced tillage (3.85 t/ha) and conventional tillage (3.90 t/ha) than zero tillage. Reduced tillage and 2 irrigations in chickpea recorded higher net returns i.e. ₹ 33.1×10^3 and 34.6×10^3/ha and benefit: cost ratio i.e. ₹0.85 and 0.87, from whole system. After 3 years, the bulk density of 15–30 cm soil depths was lower in zero tillage (1.34 Mg/m^3) than conventional (1.40 Mg/m^3) and reduced tillage (1.37 Mg/m^3). Similarly, significantly higher values of total organic carbon (10.31 g/kg), electrical conductivity (0.20 dS/m), available N (260.1 kg/ha) and available K (197.7 kg/ha) were recorded under zero tillage. Application of 2 irrigations recorded lower electrical conductivity (0.152 dS/m) and available N (237.0 kg/ha) and higher available K (189.8 kg/ha) status.

Key words : Chickpea, Fodder sorghum, Irrigation, Soil health, System productivity, Tillage

In semi-arid region of India, fodder sorghum–chickpea is an age-old cropping system. But the productivity of chickpea is low due to a number of biotic and abiotic stresses. Moisture stress has been identified as one of most important factors limiting chickpea yield (Angadi *et al.,* 2008) in different chickpea-growing regions on India. It is mainly grown under rainfed situation and hence crop often experiences moisture stress at critical growth stages. To achieve high yield level of chickpea, the crop needs completion of all the development stages before occurrence of water and temperature stress (Singh *et al.,* 1989). Among other constraints, optimum tillage is another factor determining productivity and profitability of chickpea under rainfed systems owing to its impact on residual soil moisture availability. Tillage also contributes a major share to total energy requirement of the cropping system.

[1]**Corresponding author Email:** dixitak21@yahoo.com

[1]Senior Scientist (Agronomy), [2]Head, and [4]Scientist (Agronomy), Division of Crop Production, ICAR-IGFRI Jansi - 284003, [3]Principal Scientist, ICAR-CSSRI, Karnal, Haryana 125 004

To improve the overall productivity and stability of chickpea-based food–fodder cropping system, proper management of these 2 critical inputs, viz. energy and water, is essential. In different agricultural operations, energy is mainly consumed during land preparation and irrigation. Several research results showed that yield of different crops can be increased up to 30% by using optimal level of energy input (Chaudhary *et al*., 2006). Zero tillage technology has enabled farmers to reduce the cultivation by ₹2,500/ha and save 50–60 litres diesel/ha in the Indo-Gangetic plains. The major advantage of conservation tillage is that they can increase soil organic matter (SOM) content and helps in improving factor productivity. Therefore, for efficient use of energy, optimum tillage requirement needs to be standardized for proper seed-bed preparation depending on the crops and cropping system. Zero and reduced tillage combined with proper irrigation management can help mitigate the adverse effects of conventional farming practices by increasing soil organic carbon, increased soil moisture availability and sustainability of the production system in a long run. Thus, the present work was undertaken to find out suitable tillage and irrigation management practice for enhanced productivity and profitability of chickpea–fodder sorghum cropping system and its effect on soil fertility in semi-arid region of central India.

MATERIALS AND METHODS

A field experiment was conducted for consecutive 3 years from (2009 to 2012) at the Central Research Farm of Indian Grassland and Fodder Research Institute, Jhansi, which is 25°27' N Latitude, 78°35' E, 271 m above mean sea-level. Composite top soil samples representing the whole field were taken before sowing and plot-wise samples were collected after completion of 3 years cropping cycle for analysis of physical and chemical properties. The soil samples were analysed for pH (in 1:2 soil: water suspension using glass electrode), organic carbon and electrical conductivity (by EC meter). The bulk density (BD) of 0–15 cm and 15–30 cm soil depth was determined by using core sampler. The available N, P and K were determined by $KMnO_4$-oxidizable N, Olsen method and extraction with 1 N ammonium acetate (NH_4OAC solution at pH 7.0) respectively (Singh *et al*., 1999). The experimental soil was clay loam with pH 7.1, electrical conductivity 0.114 dS/m and bulk density 1.23 Mg/m^3 in 0–15 cm and 1.38 Mg/m^3 in 15–30 cm soil depth. The initial total organic carbon, available nitrogen, available phosphorus and available potassium status of soil were 8.51 g/kg, 243.0 kg/ha, 19.3 kg/ha and 179.9 kg/ha respectively.

The experiment was laid out in split-plot design with 4 replications, comprising 3 tillage practices, viz. conventional tillage (2 harrowing followed by planking in the last pass), reduced tillage (1 harrowing followed by planking) and zero tillage (without any tillage and drilling of seeds by zero till seed drill), in main plot and 3 irrigation levels, viz. no irrigation (without any irrigation), 1 irrigation (at branching stage) and 2 irrigations (1 each at branching and podding stage), in subplot during the winter season of experimentation. The mean depth of irrigation water was 6 cm per irrigation. Chickpea (cv. 'Avarodhi') was sown at the seed rate of 75 kg/ha and spacing 30 cm × 10 cm. The crop was fertilized with recommended dose of nutrients, i.e. 20 kg N, 40 kg P_2O_5, 20 kg K_2O and 20 kg S/ha. The residual effect of tillage and irrigation management in chickpea was studied in succeeding fodder sorghum (cv. 'PC 6') which was sown in undisturbed plots of preceding chickpea crop with recommended package of practices.

The plant biometric and yield-attributing parameters were recorded as per standard procedures. Observations on weeds were recorded only during the winter season at 1 week after first irrigation stage. The soil-moisture content was recorded from 0–15 cm and 15–30 cm soil depth at the time of sowing and harvesting of chickpea. Total irrigation water applied was calculated by adding the depth of water applied in irrigation for the respective treatments. Irrigation water-use efficiency was calculated as the grain yield of chickpea (kg) divided by the irrigation water (ha-cm) applied (Ibagimov *et al*., 2011). Data recorded for different parameters were analysed using analysis of variance (ANOVA) technique for split-plot design and means were separated at 5% level of significance.

RESULTS AND DISCUSSION

Weeds population

Tillage practices had marked effect on weed density and weed dry-matter accumulation in chickpea plots (Table 1). The pooled data of 3 winter seasons showed that among different tillage management practices, zero tillage recorded significantly lower weed density being 19.5 and 14.5% lower than conventional tillage and reduced tillage respectively Similarly, dry-matter accumulation by weeds was also significantly lower under zero tillage than conventional tillage practice and was statistically similar to reduced tillage. This might be attributed to least disturbance of soil under zero tillage system which does not favour emergence and proper establishment of weeds. The contrast to this weed seeds which were in deeper soil layer comes to upper soil layer due to conventional and reduced tillage and gets germinated in conducive environment. Mishra *et al.* (2012) also studied the effect of tillage practices in chickpea and found that zero tillage and conventional tillage showed statistically at par weed density and weed dry weight. Contrary to above findings lesser weed biomass in conventional tillage was reported by Rathore *et al*. (1998) than in no tillage. Among different irrigation levels, chickpea without irrigation application recorded statistically lower weed density by 33.0% and 35.0% and weed dry-matter accumulation by 35.7% and 36.2% than application of one irrigation and 2 irrigations respectively.

Plant height and yield attributes

Data on plant height of chickpea at harvest indicated no variation due to application of different tillage practices (Table 1). Although the plants of conventional tillage (47.5 cm) and reduced tillage (44.5 cm) plots were taller than plants of zero tillage (43.7 cm) plots, differences were statistically non-significant. The pooled data on yield attributes of chickpea showed that tillage practices fail to show any significant variation among them although superior yield attributes were recorded with conventionally tilled plots. In case of irrigation treatments, significant influence on plant height, plant stand, grains/pod and 100-seed weight of chickpea was observed, but these were statistically at par with application of 1 irrigation and 2 irrigations in chickpea. One irrigation and 2 irrigations recorded 46.2 and 48.3 cm plant height, 30.1 and 30.0 plants/m^2, 1.70 and 1.73 grains/pod and 17.12 and 17.21 g 100-seed weight, respectively, which were significantly higher than without irrigation application. Availability of irrigation water at 2 important critical growth stages of moisture stress in chickpea obviously contributed to increase in growth attributes (Naresh *et al.,* 1985; Singh *et al.,* 2004).

Soil moisture and irrigation water-use efficiency

The soil-moisture content at the time of sowing and harvesting of chickpea in 0–15 cm soil depth and 15–30 cm soil depth was not influenced significantly by tillage management and irrigation water application except at harvest (Table 1). At harvest, application of 2 irrigations resulted in 6.64% soil moisture in 0–15 cm soil depth and 9.82% soil moisture in 15–30 cm soil depth which was significantly higher than application of 1 irrigation and without irrigation water application. This might be due to the second irrigation which was applied at the time of podding. Irrigation water-use efficiency (IWUE) with tillage practices was 302, 290 and 255 kg grain/ha-cm under conventional tillage, reduced tillage and zero tillage respectively (Table 2). In case of irrigation management, 1 irrigation recorded higher IWUE (295 kg grain/ha-cm), whereas 2 irrigations recorded 158 kg grain/ha-cm. These findings are in accordance with the findings of Angadi *et al.,* (2008).

Effect on yield

Grain and straw yields of chickpea were influenced significantly by tillage and irrigation-management practices. The lowest grain and straw yields were recorded under zero tillage and without application of irrigation to chickpea (Table 2). Pooled data of 3 years revealed that conventional tillage and reduced tillage gave significantly higher grain yield to the tune of 18.3 and 13.7%, respectively, than zero tillage (1.53 t/ha). Conventional tillage and reduced tillage practices showed 30.2 and 12.2% higher straw yield than zero tillage (1.14 t/ha), respectively which was significantly superior. Harvest index (HI) was significantly lower under conventional tillage (55.2%) than reduced tillage (57.7%) and zero tillage (57.4%), whereas under reduced tillage and zero tillage it was statistically at par. Higher grain and straw yields of chickpea resulted in superior yield attributes associated with conventional tillage and reduced tillage. Barzegar *et al.* (2003) and Tripathi *et al.* (2004) reported that chickpea yield was significantly affected by various tillage systems and direct drilling resulted in lower yield. Veronica Munoz-Romero *et al*. (2012) also reported that conventional tillage gave higher grain and straw yields.

Among different irrigation treatments, 2 irrigations recorded significantly higher grain yield (1.90 t/ha) and straw yield (1.46 t/ha) than rest of the treatments (Table 2). The pooled data showed that application of 2 irrigations gave 7.3 and 35.4 % higher grain yield than single irrigation and unirrigated control respectively. Harvest index remained unaffected due to irrigation treatments. This may be as a result of better yield-contributing character with the application of 2 irrigations. Kaushik and Chaubey

Table 1. Influence of tillage and irrigation management in chickpea on weed, plant height, yield attributes and soil-moisture content during the winter season under food–fodder cropping system (pooled data of 3 years)

Treatment	Weed study		Plant height at harvest (cm)	Yield attributes				Soil moisture (%) in different soil depths			
								At sowing		At harvesting	
	Density (number/ m^2)	Dry matter weight (g/ m^2)		Plant stand/ m^2	Branches/ plant	Grains/ pod	100-seed weight (g)	0–15 cm	15–30 cm	0–15 cm	15–30 cm
Tillage practices chickpea											
Conventional tillage	109.2	8.16	47.5	30.1	5.4	1.70	16.88	11.5	14.5	5.71	8.79
Reduced tillage	102.8	7.31	44.5	29.6	5.2	1.67	16.80	11.7	15.1	5.89	8.87
Zero tillage	87.9	6.76	43.7	28.0	5.1	1.66	16.86	11.9	15.1	5.89	8.64
SEm±	1.31	0.25	1.12	0.7	0.14	0.02	0.24	0.2	0.2	0.06	0.18
CD (P=0.05)	4.55	0.86	NS	NS	NS	NS	NS	NS	NS	NS	NS
Irrigation levels chickpea											
No irrigation	74.4	5.39	41.3	27.6	5.1	1.59	16.21	11.6	14.7	4.92	7.54
1 irrigation	111.1	8.38	46.2	30.1	5.3	1.70	17.12	11.8	14.9	5.93	8.95
2 irrigations	114.5	8.45	48.3	30.0	5.3	1.73	17.21	11.8	15.0	6.64	9.82
SEm±	2.19	0.15	0.85	0.6	0.13	0.03	0.21	0.2	0.2	0.08	0.13
CD (P=0.05)	6.50	0.46	2.53	1.8	NS	0.08	0.62	NS	NS	0.24	0.39

Table 2. Influence of tillage and irrigation management on yield, harvest index and irrigation water-use efficiency (IWUE) of chickpea in fodder–food cropping system (pooled data of 3 years)

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)	Irrigation water applied (ha-cm)	IWUE (kg grain/ ha-cm)
Tillage practices - chickpea					
Conventional tillage	1.81	1.49	55.2	6.0	302
Reduced tillage	1.74	1.28	57.7	6.0	290
Zero tillage	1.53	1.14	57.4	6.0	255
SEm±	0.03	0.02	0.4	-	-
CD (P=0.05)	0.10	0.07	1.4	-	-
Irrigation levels - chickpea					
No irrigation	1.40	1.08	56.7	-	-
1 irrigation	1.77	1.36	56.8	6.0	295
2 irrigations	1.90	1.46	56.8	12.0	158
SEm±	0.02	0.03	0.6	-	-
CD (P=0.05)	0.06	0.09	NS	-	-

(1999) and Singh *et al.* (2004) also reported similar findings.

The carry-over effect of application of tillage and irrigation-management practices in chickpea was studied in succeeding fodder sorghum and pooled data showed that although green fodder yield and dry-matter yield were higher under zero tillage and reduced tillage treated plots, all the treatments were statistically at par among themselves (Table 3).

System productivity

System productivity in terms of chickpea-equivalent yield (CEY) of conventional tillage and reduced tillage was significantly higher than the zero tillage (Table 3). Pooled data showed that CEY of system was 3.9 t/ha under conventional tillage and 3.8 under reduced tillage whereas it was only 3.6 t/ha under zero tillage treatment. The application of irrigation in chickpea had significant effect on system productivity in terms of CEY (Table 3). The CEY obtained by 2 irrigations (4.0 t/ha) was 14.6 and 3.4% higher than unirrigated control and 1 irrigation respectively.

Table 3. Effect of tillage and irrigation management in chickpea on yield of succeeding fodder sorghum and system productivity in terms of chickpea-equivalent yield (pooled data of 3 years)

Treatment	Green fodder yield (t/ha)	Dry-matter yield (t/ha)	System productivity in terms of CEY (t/ha)
Tillage practices - chickpea			
Conventional tillage	37.1	10.2	3.9
Reduced tillage	38.2	10.4	3.8
Zero tillage	37.9	10.4	3.6
SEm±	0.5	0.2	0.04
CD (P=0.05)	NS	NS	0.1
Irrigation levels - chickpea			
No irrigation	38.0	10.4	3.5
1 irrigation	37.6	10.3	3.9
2 irrigations	37.6	10.3	4.0
SEm±	0.5	0.2	0.03
CD (P=0.05)	NS	NS	0.09

MSP of chickpea ₹17,300, 17,600 and 21,000/tonne, local market price of chickpea stover ₹1,000, 1,500 and 2,000/tonne and green fodder ₹750, 1,000 and 1,200/tonne for the year 2010, 2011 and 2012, respectively

Soil fertility

Influence of tillage and irrigation-management practices in chickpea after 3 years chickpea–fodder sorghum cropping system, exhibited significant variation in different soil properties. There was no perceptible change in bulk density of 0–15 cm soil layer, soil pH and available P status due to different tillage and irrigation-management practices in chickpea (Table 4). However, other parameters like bulk density at 15–30 cm soil depth, electrical conductivity (EC), total organic carbon, available N and available K status of soil were affected significantly due to tillage practices and electrical conductivity (EC), available N and available K due to irrigation practices.

Bulk density is also an important parameter describing the soil's physical condition that affects root growth, soil compaction, infiltration rate, number of macro and micro pores in soil, *etc.* Top soil (0–15 cm) bulk density was almost same before at the start and completion of experiment. However, over a period of 3 years bulk density of 15–30 cm soil depth under zero-tilled plots reduced from its initial value and it was 1.34 Mg/m^3 which was significantly lower than conventionally tilled plots (1.41 Mg/m^3) and remained on a par with reduced tillage (1.37 Mg/m^3). The soil of zero-tilled plots was significantly higher in electrical conductivity, EC (0.200 dS/m), total organic

Table 4. Change in soil properties due to tillage and irrigation management in chickpea under food–fodder cropping system after 3 years of experimentation

Treatment	Bulk density (Mg/m^3) 0–15 cm	Bulk density (Mg/m^3) 15–30 cm	pH	Electrical conductivity (dS/m)	Total organic carbon (g/kg)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
Tillage practices - chickpea								
Conventional tillage	1.24	1.40	6.93	0.156	8.78	234.8	20.34	174.2
Reduced tillage	1.25	1.37	6.93	0.164	9.73	248.6	19.76	186.4
Zero tillage	1.25	1.34	6.22	0.200	10.31	260.1	20.29	197.7
SEm±	0.014	0.008	0.03	0.002	0.047	1.92	0.34	1.82
CD (P=0.05)	NS	0.030	NS	0.007	0.186	6.64	NS	6.29
Irrigation levels - chickpea								
No irrigation	1.24	1.36	6.93	0.197	9.52	255.2	20.35	181.2
1 irrigation	1.25	1.37	6.93	0.171	9.63	251.5	19.96	187.3
2 irrigations	1.25	1.38	6.92	0.152	9.66	237.0	20.09	189.8
SEm±	0.009	0.015	0.02	0.002	0.042	1.38	0.24	1.99
CD (P=0.05)	NS	NS	NS	0.007	NS	4.11	NS	5.92

Table 5. Effect of tillage practices and irrigation management in chickpea on economic return (mean of 3 years data)

Treatment	Cost of cultivation (× 10^3 ₹/ha)			Gross returns from whole system (×10^3 ₹/ha)	Net returns (×10^3 ₹/ha)			Benefit: cost ratio		
	Chickpea	Fodder sorghum	System		Chickpea	Fodder sorghum	System	Chickpea	Fodder sorghum	System
Tillage practices - chickpea										
Conventional tillage	22.8	17.2	40.0	72.4	13.2	19.2	32.4	0.58	1.11	0.81
Reduced tillage	21.7	17.2	38.9	72.0	12.9	20.2	33.1	0.59	1.17	0.85
Zero tillage	20.5	17.2	37.8	67.8	10.0	20.1	30.1	0.49	1.16	0.80
Irrigation levels - chickpea										
No irrigation	20.5	17.2	37.8	65.4	7.6	20.0	27.6	0.37	1.16	0.73
1 irrigation	21.6	17.2	38.9	72.2	13.5	19.8	33.3	0.62	1.15	0.86
2 irrigations	22.7	17.2	40.0	74.6	14.9	19.7	34.6	0.66	1.14	0.87

carbon (10.31 g/kg), available N (260.1 kg/ha) and available K (197.7 kg/ha) than conventional tillage and reduced tillage treatments. Reduced tillage also recorded significantly higher total organic carbon (9.73 g/kg), available N (248.6 kg/ha) and available K (186.4 kg/ha) than conventional tillage. Analysis of large global data set also showed that total organic carbon was generally increased by no-tillage practices, but had a delayed response, with peaks in years 5–10 (West and Post, 2002). Application of 2 irrigation water resulted in significantly higher available K (189.8 kg/ha) and lower electrical conductivity EC (0.152 dS/m) and available N (237.0 kg/ha) than without irrigation application. These findings confirm the results of Barzegar *et al.* (2003).

Economics

Cost of cultivation and gross returns showed that among different tillage practices, conventional tillage required higher cost of cultivation, i.e. ₹22,786 and 40,037/ha with higher gross returns ₹35,989 and 72,408/ha in chickpea as well as from whole system respectively (Table 5). In case of net returns and benefit: cost ratio, reduced tillage gave higher net return (₹33,129/ha) and benefit: cost ratio (0.85) than conventional tillage and zero tillage. This is mainly owing to lower cost of cultivation in reduced tillage. In case of irrigation management, higher cost of cultivation, gross returns, net returns and benefit: cost ratio were recorded owing to application of 2 irrigations in chickpea. Application of 2 irrigations at branching stage and podding stage incurred higher cost of cultivation of whole system (₹40,008/ha) but gave 14.1 and 25.4% higher gross return and net returns, respectively over no irrigation. Application of 2 irrigations to chickpea also gave higher benefit: cost ratio (0.87). This may be because of lower cost of cultivation under reduced tillage and higher economic yield with the application of 2 irrigations in chickpea.

It can be concluded that the biological and grain yields of the cropping system in zero tillage was less than the reduced tillage. Reduced tillage gave higher net return and benefit: cost ratio as compared with conventional and zero tillage. Hence, reducing the tillage intensity from 2 harrowing (conventional tillage) to 1 harrowing (reduced tillage) in chickpea is more productive and economical. Application of 2 irrigations (one each at branching and podding stage) in chickpea is beneficial in fodder sorghum – chickpea cropping system under semi arid conditions of India.

REFERENCES

Angadi, S.V., McConkey, B.G., Cutforth, H.W., Miller, P.R., Ulrich, D., Selles, F., Volkmar, K.M., Entz, M.H. and Brandt, S.A. 2008. Adaptation of alternative pulse and oilseed crops to semi arid Canadian pairie: seed yield and water use efficiency. *Canadian Journal of Plant Science* **88:** 425–38.

Barzegar, A.R., Asoodar, M.A., Khadish, A., Hashemi, A.M. and Herbert, S.J. 2003. Soil physical characteristics and chickpea yield responses to tillage treatments. *Soil and Tillage Research* **71**(1): 49–57.

Chaudhary V.P., Gangwar, B. and Pandey, D.K. 2006. Auditing of energy use and output of different cropping systems in India. *Agricultural Engineering International: CIGR Journal* **8**: 652–58.

Ibagimov, N., Evett, S., Esenbecov, Y., Khasanova, F., Karabaev, I., Mirzaev, L. and Lamers, J. 2011. Permanent beds vs. conventional tillage in irrigated arid central Asia. *Agronomy Journal* **103**(4): 1002–11.

Kaushik, M.K. and Chaubey, A.K. 1999. Studies on irrigation requirement of chickpea (*Cicer arietinum*). *Indian Journal of Agronomy* **44**(2): 367–69.

Mishra, J.S., Singh, V.P., Bhanu, C. and Subrahmanyam, D. 2012. Crop establishment, tillage and weed management techniques on weed dynamics and productivity of rice (*Oryza sativa*) – chickpea (*Cicer arietinum*) cropping system. *Indian Journal of Agricultural Sciences* **82**(1): 15–20.

Naresh, R.K., Singh, O.P. and Gupta, R.K. 1985. Growth and yield attributing parameters in relation to different irrigations in chickpea. *Indian Journal of Plant Physiology* **28**(4): 323–30.

Rathore, A.L., Pal, A.R. and Sahu, K.K. 1998. Tillage and mulching effect on water use, root growth and yield of rainfed mustard and chickpea grown after lowland rice. *Journal of the Science of Food and Agriculture* **78:** 149–61.

Singh, D., Chhonkar, P.K. and Pandey, R.N. 1999. *Soil Plant Water Analysis: A Methods Manual*, pp. 160. Indian Agricultural Research Institute, New Delhi.

Singh, K.B., Malhotra, R.S. and Saxena, M.C. 1989. Chickpea evaluation for cold tolerance under field condition. *Crop Science* **29**: 282–85.

Singh, S., Saini, S.S. and Singh, B.P. 2004. Effect of irrigation, sulphur and seed inoculation on growth, yield and sulphur uptake of chickpea (*Cicer arietinum*) under late sown conditions. *Indian Journal of Agronomy* **49**(1): 57–59.

Tripathi, R.S., Kumar, M., Pandey, N., Sonboir, H.L. and Pandey, D. 2004. Establishment, yield and water use efficiency of on-farm rainfed chickpea (*Cicer arietinum* L.) as influenced by tillage practices. *Annals of Agricultural Research* **25**(1): 35–37.

Veronica, Munoz-Romero, V., Lopez-Bellido, L. and Lopez-Bellido, R.J. 2012. The effects of the tillage system on chickpea root growth. *Field Crops Research* **128**: 76–81.

West, T.O. and Post, W.M. 2002. Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis. *Soil Science Society of America Journal* **66**: 1930–46.