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Research Article

Effect of Tillage Practices on Chickpea Productivity in Rotation with Wheat under Rainfed Semi-arid Environment

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Abstract: Chickpea is an important legume crop worldwide. We investigated effect of five different tillage practices on soil physical properties, water use efficiency by chickpea and chickpea productivity in chickpea-wheat rotation. The soil was a sandy clay loam and seasonal rainfall during the study period ranged from 198 to 543 mm. Chickpea was sown in October and harvested in April. Mean maximum crop yield was obtained with chisel plough once plus tine type cultivator twice (CPTC2) (1968 kg ha^{-1}) and mold board plough once plus tine type cultivator twice (MBTC2) (1736 kg ha^{-1}) with water use efficiency of 6.93 kg ha^{-1} mm^{-1}. Mean minimum yield was recorded in no-tillage (NT) (1695 kg ha^{-1}) with water use efficiency of 5.56 kg ha^{-1} mm^{-1}. Plots plowed with chisel plough once plus tine type cultivator twice (CPTC2) produced 16.28% and 17.66% more seed yield as compared to no-tillage (NT) and tine type cultivator three times (TC3, i.e., Farmer's practice). Chickpea root development was better in plots plowed by chisel plough once and tine type cultivator twice (CPTC2) as compared to other tillage treatments. However, chickpea seed yield was poorly related to biomass yield. Overall, chisel plough once and tine type cultivator twice (CPTC2) was the most effective tillage treatment and produced more seed yield and conserved more moisture as compared to other tillage treatments in this sandy clay loam soil in located in a semi-arid environment.

Keywords: Chickpea and wheat rotation, tillage, semi-arid environment, yield

1. INTRODUCTION

Chickpea (*Cicer arietinum* L.) is one of the most important pulses as well as vegetable crops in the world. Its world production was about 7.5 million tons in 2003. India and Pakistan are the major producers of chickpea [1]. There are two kinds of chickpea' desi and Kabuli; their adoptability depends on rainfall and climatic condition [2]. In Pakistan, during cropping season 2005-2006, the chickpea was sown on an area of 1.029 million ha and its production was 0.4795 million tons with an overall average yield of 466 kg ha^{-1}, while in Khyber Pakhtunkhwa Province of Pakistan its production was 513 kg ha^{-1} (Pakistan Statistics, 2007).Wheat and chickpea constitute the most important cropping system under rain-fed conditions in the Southern region of Khyber Pakhtunkhwa (KPK) of Pakistan. Average chickpea yields are very low as compared to other wheat and chickpea producing countries [3]. The major factors responsible for low crop productivity of wheat and chickpea in Khyber Pakhtunkhwa are: low organic matter, poor soil structure, deficiency of macro and micro nutrients, imbalance fertilizer use, soil erosion and improper use of tillage practices.

There is need for adoption of strategy on sound

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footings in respect of transfer of technology as the cultivation in the country on subsistence farms is still carried out with the help of conventional implements and tools [4]. Modern tillage practices should be aimed at maintaining the productivity of a given piece of land at an optimum level. In the past different researchers has investigated the effect of different tillage practices on crop production [5]. Deep tillage with mold board plough gave 52% (1.3 t/ha) and 36% (0.7 t/ha) more wheat yield than shallow cultivator in 1983-84 and 1984-85, respectively [6]. Straw yield was increased by average of 20% due to moldboard plowing during 1984-85. The increase was associated with improving rooting due to breaking of compact layer of the plow pan. Average seed yield of chisel plough was significantly higher as compared to moldboard plough and cultivator [7]. The increase in seed yield by chisel plough occurred due to deep root system, increased root spreading because of breaking sub-soil layer increased infiltration rate, decreased run-off and soil erosion, increase water efficiency and increase soil water storage [8, 9]. Tillage practices facilitate water penetration into the soil and enhance the quantity of water retained for crop use. Subsoil tillage improves water infiltration, decreases bulk density, penetration resistance and increase water-holding capacity as compared to no-tillage treatments on sandy loam and loam soil [10, 11].

Water use efficiency was improved by 20 - 25% with sub-soiler and chisel plow as compared to cultivator in loam soil [12]. The lowest value of soil strength and bulk density produced by deep tillage (moldboard plow) as compared to tine cultivator and no-tillage in a loamy and clay loam soils was reported by [13, 14]. Higher values of soil cone index decreased root elongation and growth [15]. The threshold level at which soil cone index affects the elongation and root growth ranges from 1800 to 3000 KPa [16] and also reported by [17], penetration resistance clearly reflected with the depth of primary tillage as compared to shallow tillage. The researcher [18] found that reduction in soil cone index from approximately 1000- 1500 KPa by deep tillage as compared to shallow tillage at 40 – 45 cm depth in a silty clay loam soil. A soil with a fine crumb structure is said to be in "good tilth". A soil in good tilth breaks up easily into crumbs or granules, which allow space in the soil for air and water [19]. In order to evaluate the impact of different tillage practices on topsoil properties; [20] reported that sub-soiling tillage produces a significant increase in the volume of larger pores (>50 m diameter). Sub soil was improved and a significant decreased in the volume of the smaller pores (<10 m diameter), resulted in an improvement of water transmission at high water content and in a decrease of water retention capacity at low water content. Another researcher [21] evaluated draft requirement of selected tillage implements in silty clay loam soil. Tillage implements cultivator, chisel plow, sub-soiler, disk plow and disk harrow were used at the field speed of 2.5 km ha^{-1} at 13.2% moisture content in the field. They reported that the draft consumed by tillage implement increased with increasing the depth of penetration. The subsoil compaction effects on physical properties of sandy clay loam soil and yield of wheat and sorghum. Subsoil compaction reduced both water and nutrient use efficiencies of wheat (24%); sorghum (18%) and fodder yield [22].

Root growth may be limited by high bulk density resulting in reduced aeration and increased penetration resistance. The higher soil resistance may inhibit root development in a silt loam soil [23]. The better root development was associated with breaking of plow pan to increase crop yield [24]. The better root development increased grain yield in silty loam and silty clay soil evaluated by [25], while the next study by [26] reported that chickpea yield and biomass with chisel plow was greater as compared to moldboard plow. Chisel plow was found the most appropriate tillage implement that improved the physical properties of soil. The highest precipitation use efficiency on a mass-produced basis for systems producing forage (14.5 kg ha^{-1} mm^{-1}) and lowest for rotations with a high frequency of oilseed crops (4.2 kg ha^{-1} mm^{-1}) or continuous small-grain production in the southern plains (2.8 kg ha^{-1} mm^{-1}) found by researchers [5, 10].

In Pakistan, in rain-fed area, in general tine type cultivator is more commonly used for tillage. Due to continuous use of tine type cultivator the yield of chickpea is relatively low because of its limited soil penetration ability. Very little information is available about the effects of different tillage practices on chickpea yield in rainfed semi-arid environment. Therefore, a detailed field study was conducted to find the effects of different tillage practices on soil physical properties, water use efficiency and crop root length of chickpea in southern region of Khyber Pakhtunkhwa (KPK) of Pakistan.

2. MATERIALS AND METHODS

2.1 Research Site and Experiments

Tillage experiments were conducted at Nangul Khel, District Karak and it is located at latitude of 33^{O}, 08'N, and longitude of 71^{O}, 06' E and altitude of 600 m. The experimental setup consisted of the following treatments, *i.e.*, NT for No-tillage, CPTC2 for Chisel Plough once and Tine Type Cultivator twice, MBTC2 for Mold board plough once and Tine Type Cultivator twice, DHTC2 for Disc Harrow once and Tine Type Cultivator twice and TC3 denoted the Tine Type Cultivator three times (Farmer's practices). All the treatments were replicated four times and a total of 40 plots of wheat and chickpea were used for the experiments with a plot size of 40 m x 8 m. Recommended doses of fertilizers and other inputs were applied uniformly to all treatments. Chickpea was sown in the last week of October through seed drill in all treatments and harvested at the end of April. Data were recorded in the following yield and yield components of wheat and chickpea.

2.2 Physical Properties of Soil

The soil texture, moisture content, bulk density [3] and soil penetration resistance [5] were determined at depths of 0-30, 31-60 and 61-100 cm during the chickpea-growing season. From the sieve analysis of soil samples, sand was 49.35%, silt 27.77% and clay of 22.88% and the dominant textural class was sandy clay loam. Soil aggregate data were collected once after primary tillage operation at both research sites. The aggregate were passed through set of sieve from >7 cm to 0.5 cm. Soil infiltration data were collected by using double ring infiltrometer before and after tillage treatments as well as during and after crop harvest at each research site.

2.3 Rainfall

A standard manual rain gauge was installed at the site and rainfall was recorded on daily basis. The rainfall data for the study period (2002-2005) are given in Table 1. As it can be seen from the table, a very scanty rainfall was received during the year 2003-2004 as compared to years 2002-2003 and 2004-2005. However, the rainfall during the fallow season for year 2004 was higher.

2.4 Yield and Yield Components

Six samples were randomly collected from each plot for assessment of yield components (plant height, number of pods per plant, 1000-seed weight) and seed yield. Seed yield recorded after threshing six samples from one m^2 area of each plot and then converted into kg ha^{-1}. Germination of seed data was determined after germination of seeds by counting the number of plants per m^2 in each plot at random at three locations.

2.5 Water Use Efficiency

Water use efficiency (WUE) was determined from the yield of the crop in kg. ha^{-1} and divided by the available water for crops during its growing season (water in the root zone up to one meter at the time of

Table 1. Rainfall during (2002-2005) the crops growing and fallow season at the site.

Month	**2002-2003**	**2003-2004**	**2004-2005**	**Month**	**2002**	**2003**	**2004**
	Crop Growing Season Rainfall (mm)				**Fallow Season Rainfall (mm)**		
October	12	0	6	May	0	28	26
November	0	0	0	June	53	35	0
December	23	6	39	July	105	192	109
January	20	22	36	August	12	188	59
February	48	44	88	September	37	40	92
March	78	0	70	**Total**	**207**	**98**	**286**
April	24	26	18				
Total	**205**	**98**	**257**				

sowing and the amount of rainfall received during the crop growing season).

2.6 Statistical Analysis and Regression Models

The data recorded for the above-mentioned parameters were individually subjected to the ANOVA technique by using MINITAB computer software and using Fisher's Protected LSD test for comparison of means. Regression models were developed to relate grain yield with bulk density, moisture contents, and root length and soil penetration resistance.

3. RESULTS

In this section, research findings of the field study conducted during 2002-2005 related to physical properties of soil, yield components and yield of chickpea in chickpea-wheat cropping system as influenced by different tillage treatments under rain-fed and semi-arid environment in district Karak (Pakistan) are reported, analyzed and discussed.

3.1 Bulk Density

The bulk densities were determined before and after tillage operations at depths of 0-30, 31-60 and 61-100 cm, during the study period 2002-2005 as shown in Table 2. Before tillage operation the bulk densities at different soil depths had a very little difference. However, after tillage operations maximum decrease in bulk density was observed at soil depth of 0-100 cm, and it ranged from 1.34 to 1.49 g cm^{-3}.

3.2 Soil Moisture

Before tillage operation the soil moisture at depths of 0-30, 31-60 and 61-100 cm ranged from 4.01 to 6.44% during June 2002. After the tillage operation, the soil moisture at depth of 0-100 cm varied from 5.26 to 11.2% during chickpea growing season 2002-05. Based on the three years, the overall mean minimum soil moisture was maintained by NT (7.51%), followed by TC3 (7.63%) and the maximum 9.43% was by CPTC2, followed by MBTC2 (9.38%) (Table 3).

3.3 Soil Penetration Resistance

Before tillage, soil penetration resistance at depths of 0-30, 31-60 and 61-100 cm was determined during June, 2002 and it ranged from 690 to 864 N cm^{-2} (Table 4). Soil penetration resistance determined after tillage operations at depth of 0-100 cm, ranged from 524 to 856 N cm^{-2}. The mean maximum soil penetration resistance was recorded in NT after the tillage operations as 827 N cm^{-2}, while the mean minimum was recorded for MBTC2 573 N cm^{-2}.

3.4 Soil Aggregates

The percent aggregates based on dry sieving from

Table 2. Effect of various tillage operations on the bulk density at 0-100 cm depth during chickpea growing seasons of 2002–2005.

Treatment	Soil Depth (cm)	Before Tillage	After Tillage Bulk Density (g cm^{-3})			
			2002-03	2003-04	2004-05	Mean
	0-30	1.49	**1.49**	1.48	1.47	**1.48 a***
NT	31-60	1.48	1.44	1.48	1.45	**1.46 a**
	61-100	1.49	1.47	1.49	1.43	1.46
	0-30	1.49	1.41	**1.34**	1.45	**1.40 c**
CPTC2	31-60	1.48	1.43	1.43	1.45	**1.44 b**
	61-100	1.49	1.39	1.48	1.41	1.43
	0-30	1.49	1.45	1.38	1.44	**1.42 bc**
MBTC2	31-60	1.48	1.40	1.46	1.45	**1.44 b**
	61-100	1.49	1.39	1.48	1.41	1.43
	0-30	1.49	1.44	1.41	1.47	**1.44 b**
DHTC2	31-60	1.48	1.38	1.46	1.47	**1.44 b**
	61-100	1.49	1.35	1.49	1.41	1.42
	0-30	1.49	1.44	1.41	1.45	**1.43 b**
TC3	31-60	1.48	1.46	1.47	1.47	**1.47 a**
	61-100	1.49	1.41	1.49	1.44	1.45

* Means followed by the same letter are not statistically different from one another ($P<0.05$)

Table 3. Effect of various tillage operations on soil moisture (on mass basis at 0-100 cm depth) during chickpea growing seasons of 2002-2005.

Treatment	Soil Depth (cm)	Before Tillage	Mean Soil Moisture on Mass Basis (%)			
			2002-03	2003-04	2004-05	Mean
	0-30	**4.01**	8.18	7.19	7.16	**7.51 c***
NT	31-60	5.62	5.76	5.84	8.19	6.60
	61-100	6.44	5.56	7.28	5.69	6.18
	0-30	4.01	11.02	9.22	8.06	**9.43 a**
CPTC2	31-60	5.62	**11.2**	8.04	8.36	9.20
	61-100	**6.44**	7.00	7.71	6.68	7.13
	0-30	4.01	11.00	8.96	8.19	**9.38 a**
MBTC2	31-60	5.62	6.42	8.68	9.60	8.23
	61-100	6.44	7.25	8.89	6.25	7.46
	0-30	4.01	10.73	7.46	7.34	**8.51 b**
DHTC2	31-60	5.62	6.68	7.01	8.72	7.47
	61-100	6.44	6.75	7.79	**5.26**	6.60
	0-30	4.01	8.88	6.98	7.02	**7.63 c**
TC3	31-60	5.62	6.23	7.49	8.69	7.47
	61-100	6.44	6.50	7.38	6.03	6.64

* Means followed by the same letter are not statistically different from one another ($P<0.05$)

Table 4. Effect of various tillage practices on the soil penetration resistance at 0-100 cm depth during chickpea during chickpea growing seasons of 2002-2005.

Treatment	Soil Depth (cm)	Before Tillage	After Tillage Soil Penetration Resistance (N cm^{-2})			
			2002-03	2003-04	2004-05	Mean
	0-30	**690**	678	670	595	648 a*
NT	31-60	793	752	727	721	733 a
	61-100	864	845	833	**856**	**827 a**
	0-30	690	649	562	573	595 c
CPTC2	31-60	793	700	624	665	663 c
	61-100	864	831	**792**	807	797 c
	0-30	690	663	531	**524**	**573 d**
MBTC2	31-60	793	702	628	709	680 bc
	61-100	**864**	828	798	808	798 bc
	0-30	690	660	628	563	617 b
DHTC2	31-60	793	727	646	715	696 b
	61-100	864	830	821	837	816 ab
	0-30	690	668	633	557	619 b
TC3	31-60	793	735	652	720	702 b
	61-100	864	832	823	810	808 b

* Means followed by the same letter are not statistically different from one another ($P<0.05$)

Table 5. An average percent of soil aggregates obtained from chickpea growing plots under different tillage treatments during 2002-05.

Treatment	Sieve size (cm)									
	>7	7-5.5	5.5-4.5	4.5-3	3-2.5	2.5-2	2-1.5	1.5-1	1-0.5	<0.5
	Soil Aggregate (%)									
CPTC2	0	1.04	1.68	2.12	3.13	3.28	4.95	3.58	7.79	72.38
MBTC2	0	0.00	2.78	1.87	4.74	4.71	5.28	4.43	6.44	**69.72**
DHTC2	0	0.00	0.86	0.55	3.67	3.15	5.88	3.76	7.83	74.27
TC3	0	1.08	0.00	0.16	2.10	2.99	4.46	3.80	7.83	**77.55**

Table 6. Effect of different tillage treatments on germination and plant height during the crop growing seasons of 2002-05.

Treatment	Germination (G) of Chickpea seeds m^{-2} and plant height (PH) in cm							
	2002-03		2003-04		2004-05		Mean	
	G	PH	G	PH	G	PH	G	PH
NT	69	69.71	63	64.20	67	65.14	**65 d**	**66.35 c***
CPTC2	79	73.93	62	69.87	73	66.91	**71 a**	70.24 a
MBTC2	76	73.94	60	68.11	72	69.53	69 b	**70.53 a**
DHTC2	74	67.32	59	65.35	71	69.13	68 c	67.27 bc
TC3	75	72.73	58	68.00	71	64.40	68 c	68.38 b

* Means followed by the same letter are not statistically different from one another (P<0.05)

Table 7. Effect of tillage treatments on length of primary root of chickpea during growing seasons of 2002-2005.

Treatment	Length of primary roots of Chickpea (cm)			
	2002-03	2003-04	2004-05	Mean
NT	**29.48**	40.00	37.24	**35.91 c***
CPTC2	36.74	42.00	44.52	**41.09 a**
MBTC2	33.30	37.50	40.40	37.07 bc
DHTC2	30.96	**47.50**	39.74	**39.40 ab**
TC3	29.81	41.25	39.98	37.01 bc

* Means followed by the same letter are not statistically different from one another (P<0.05)

Table 8. Effect of tillage treatments on No. of pods/plant and 1000 grain weight of chickpea.

Treatment	No of Pods per Plant (NPP) and 1000-Grain Weight (GW) in g							
	2002-03		2003-04		2004-05		Mean	
	NPP	1000-GW	NPP	1000-GW	NPP	1000-GW	NPP	1000-GW
NT	**24 d***	198 ab	33 e	184	45 c	182 bc	**34 d**	**188 b**
CPTC2	25 d	196 b	41 a	187	63 a	**180 c**	**43 a**	**188 b**
MBTC2	31 b	**200 a**	36 c	186	50 b	190 a	**39 b**	**192 a**
DHTC2	36 a	199 ab	35 d	190	37 d	186 abc	36 c	**192 a**
TC3	28 c	195 b	38 b	191	**51 b**	188 ab	**39 b**	**191 a**
LSD $_{0.05}$	2.67	3.17	0.85	NS	3.25	6.57	1.99	3.47

* Means followed by the same letter are not statistically different from one another (P<0.05)

Table 9. Effect of tillage treatments on the grain and biomass yield of chickpea during growing seasons of 2002-2005.

Treatment	Grain Yield (GY) and Bio-mass (BM) in kg ha^{-1}							
	2002-03		2003 04		2004-05		Mean	
	GY	BM	GY	BM	GY	BM	GY	BM
NT	**1549 e***	**1833 c**	1740 c	1880 d	1797c	3128 c	**1695 c**	**2371 d**
CPTC2	1634 b	1855 bc	2093 a	2048 b	**2177a**	3783 b	**1968 a**	2980 b
MBTC2	1594 c	2063 a	1559 d	2105 a	2054 b	**4185 a**	1736 b	**3303 a**
DHTC2	1678 a	1858 bc	1277 e	1945 c	2003 b	3738 b	1653 d	2778 c
TC3	1571d	1874 b	1798 b	1950 c	1593 d	3000	1654 d	2830 c
LSD $_{0.05}$	16.57	30.6	57.18	50.4	55.79	96.0	31.39	43.3

* Means followed by the same letter are not statistically different from one another (P<0.05)

different tillage treatments under chickpea are shown in Table 5. Major portions (69.72 to 77.55%) of the aggregates were smaller than 0.5 cm and only a small fraction was retained in large sieves.

3.5 Cumulative Infiltration

Based on the three years data (2002-2005), the mean maximum four hours cumulative infiltration rate was recorded in plots plowed with CPTC2 of 249 mm for a period of four hours, followed by MBTC2, while NT and TC3 resulted relatively the lowest infiltration (Fig. 1). All the tillage treatments generally increased infiltration rate as compared to NT during the chickpea growing season.

4. YIELD AND YIELD COMPONENTS OF CHICKPEA

4.1 Germination of Chickpea and Plant Height

The overall mean germination data ranged from 65 to 71 per m^2 and significant differences in plant heights were found in all the tillage treatments (Table 6). The overall mean plant height of chickpea ranged from 766.35 to 70.53 cm. The maximum chickpea plant height 70.53 cm was recorded for MBTC2, followed by CPTC2 (70.24 cm), while the minimum plant height 66.35 cm was recorded for NT. In general, deep tillage treatments created better root environment and enhanced the crop height as compared to shallow and NT.

4.2 Length of Primary Roots

During the growing season 2002-05, the primary roots lengths of chickpea ranged from 29.48 to 47.50 cm (Table 7). Based on the three years data, mean maximum primary roots length for chickpea was found in CPTC2 of 41.09 cm, followed by DHTC2 of 39.40 cm, while the mean minimum length of primary roots was recorded for NT of 35.91 cm.

4.3 No. of Pods/plant and 1000-Grain Weight

The number of pods per plant for the three years ranged from 24 to 51. On the overall mean basis the maximum number (43) pods per plant was recorded for CPTC2, followed by MBTC2 and TC3 (39), while the mean minimum was recorded for NT (34) pods per plant. The 1000-seed weight ranged from 180 to 200 g (Table 8). Based on the three years mean data, the mean maximum 1000-seed weight (192 g) for chickpea was obtained from DHTC2 and MBTC2, followed by TC3 (191 g), while the mean minimum (188 g) was obtained for CPTC2 and NT. There was no significant difference in all the tillage treatments of 1000-seed weight.

4.4 Seed Yield and Bio-mass Yield

A significant difference in seed yield of chickpea was found among all the tillage treatments. CPTC2 produced 18.98% and 16.12% higher seed yield as compared to the TC3 (farmer's practices) and NT. NT and TC3 almost produced the same chickpea seed yield, therefore NT is recommended for Chickpea under sandy clay loam soil condition. Significant differences were found in bio-mass yield of chickpea among various tillage treatments. The biomass yield for the three years ranged from 1833 to 4185 kg ha^{-1}. Overall mean basis the biomass yield varied from 2371 to 3303 kg ha^{-1}. The mean maximum bio-mass yield 3303 kg ha^{-1} was recorded for MBTC2, while the mean minimum 2371 kg ha^{-1} as recorded for NT (Table 9). MBTC2 produced 39.28 and 16.70% more biomass as compared to NT and TC3, respectively.

Response of chickpea yield to different tillage treatments and available water (an amount of rainfall received during the study period and available water in the soil up to a depth of one meter) is given in Fig. 2. It is obvious from the figure that the chickpea seed yield did not increase with rainfall, but it showed a declining trends but on the other hand the biomass of chickpea showed increasing trends with increasing rainfall. During the year 2003-2004 more rainfall occurred during the months of January to March, which increased the biomass. For better yield chickpea requires a relatively less rainfall during the flower formation. Heavy rainfall and cloudy condition is not a favorable environment during flower formation of chickpea. It was also clear from Fig. 3 that seed yield and biomass did not show significant correlation, although the yield was increased with increasing the biomass.

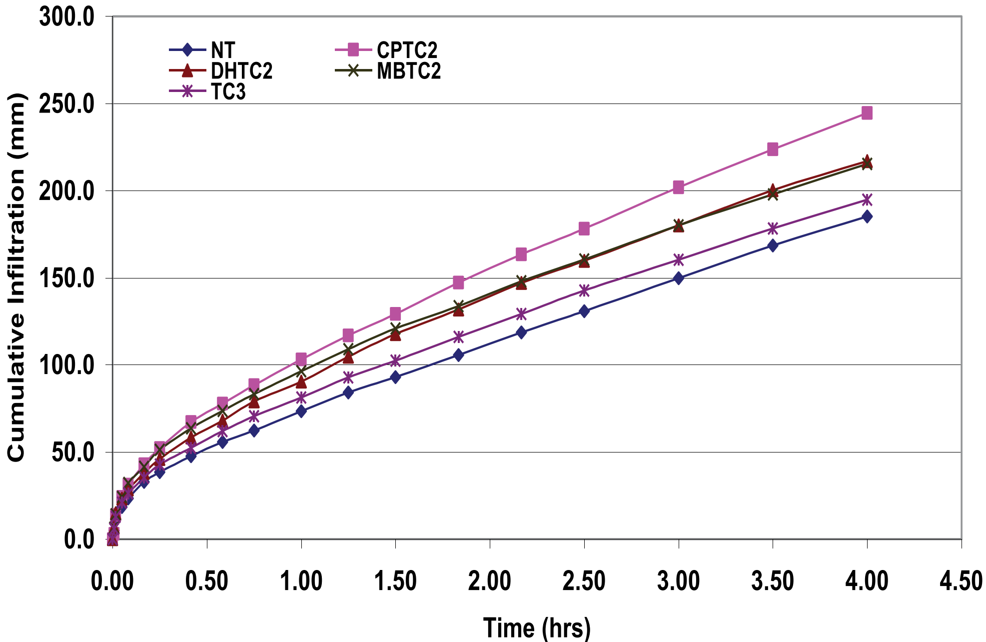

Fig. 1. Effect of different tillage treatments on cumulative infiltrations during the chickpea growing seasons of 2002-2005.

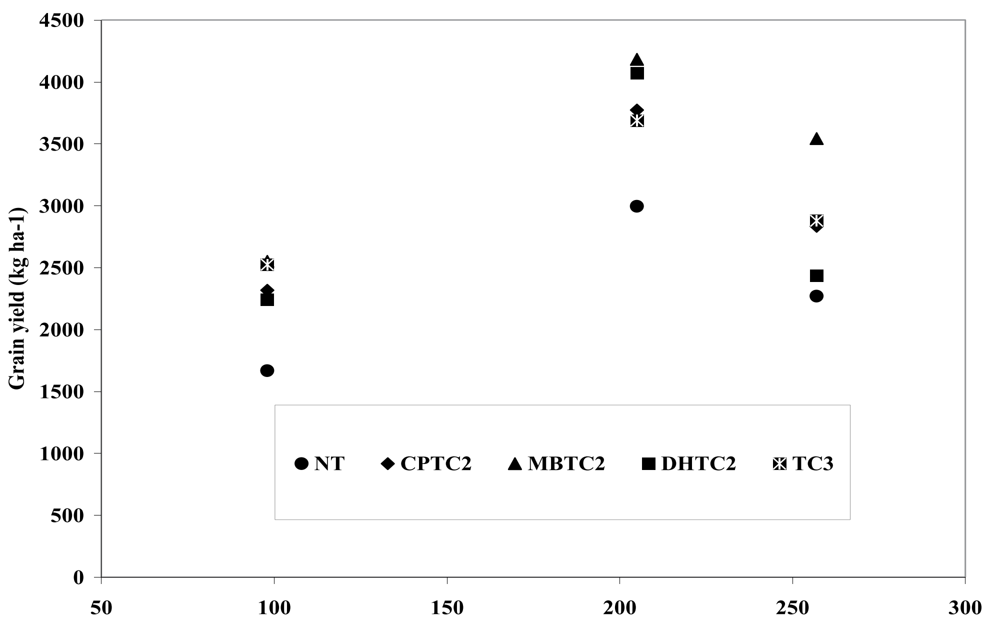

Fig. 2. Variations in chickpea grain yield with rainfall under different tillage treatments during the study period, 2002-2005.

Based on the chickpea yield and an amount of rainfall and available water in the root zone, the water use efficiencies (WUE) were determined as shown in Fig. 4, with the highest (6.93 kg ha^{-1} mm^{-1}) was obtained from plots plowed with CPTC2, followed by NT and lowest (5.56 kg ha^{-1} mm^{-1}) from DHTC2 plots. However, better WUE of biomass yield of chickpea was obtained from MBTC2, followed by CPTC2 and lowest from NT plots. Overall, the WUE of seed yield of chickpea of CPTC2 was 16.28% and 17.66% greater than NT and TC3 (farmers' practice) respectively. One of the reasons of the lower WUE of NT was due to runoff from plots during heavy rainfall events and the moisture content in the root zone was relatively lower as compared to tillage treatments. It can be

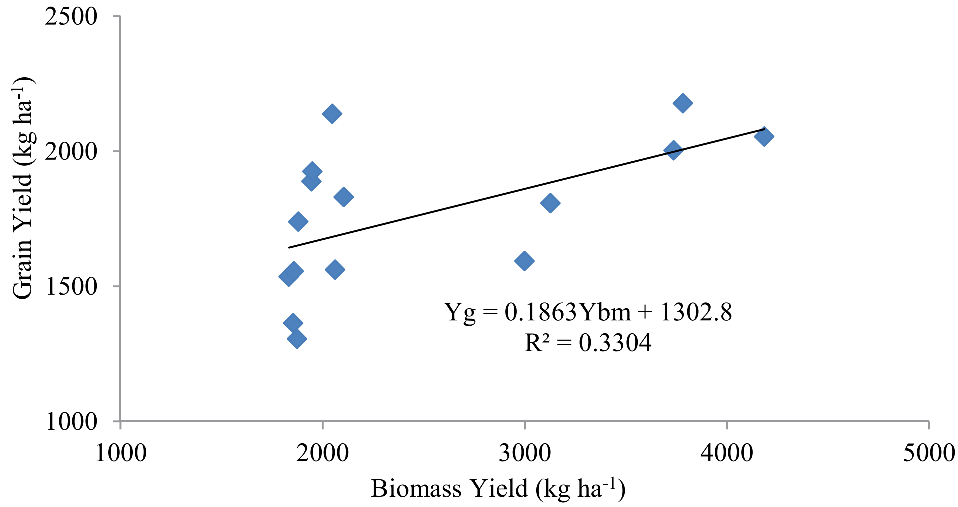

Fig. 3. Relationship between chickpea grain and biomass yield during the study period, 2002-2005.

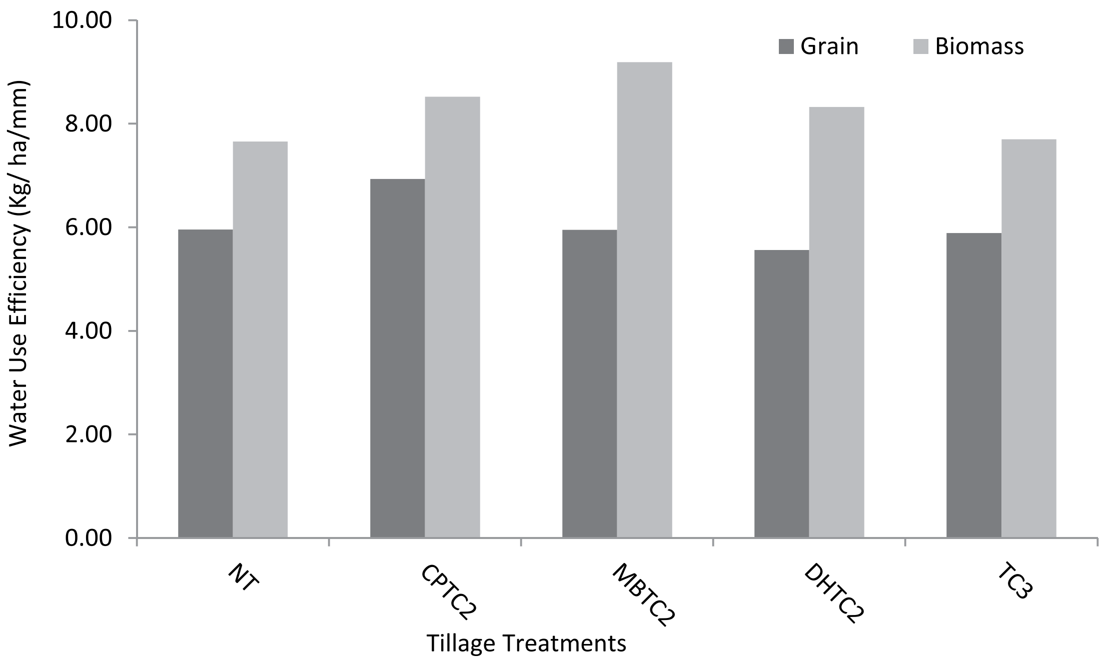

Fig. 4. Water use efficiency of chickpea under different tillage treatment during the study period 2002-2005.

concluded that chickpea required minimum tillage and heavy tillage under sandy clay loam soils should be avoided.

5. DISCUSSION

The overall mean maximum bulk density was recorded for NT of 1.48 g cm^{-3} and the mean minimum was recorded for CPTC2 of 1.40 g cm^{-3}. Significant difference in bulk densities of various tillage treatments was observed. Plots plowed with deep tillage resulted low bulk density as compared to NT or TC3. No significant difference in mean bulk densities of various treatments was found at depth of 61-100 cm soil. In general, the deep tillage loosened the soil and resulted to decreased bulk density as compared to shallow tillage. These findings are in agreement with those reported by [8, 10], who found significant difference in bulk densities after tillage in root zone.

Before tillage operation the soil moisture at depths of 0-30, 31-60 and 61-100 cm ranged from 4.01 to 6.44% during June, 2002. There will be significant difference in overall mean moisture content of different tillage treatments was observed at 0-30 cm soil depth, and no significant difference at soil depth of 31-60 cm was observed among various tillage treatments, which are in agreement with findings of Hobbs et al. [12]. In general, deep tillage conserved more soil moisture as compared to NT or TC3. It showed the significant difference in mean soil strength of different treatments was found at depth of 0-30 cm. In general, deep tillage loosened the soil and decreased the soil penetration resistance as compared to shallow and NT. The mean maximum soil strength was recorded for NT after the tillage operations as 827 N cm^{-2}, while the mean minimum was recorded for CPTC2 573 N cm^{-2}. Significant difference in mean soil strength of different treatments was found (Table 2) at depth of 0-60 cm. At depth of 61-100 cm soil penetration resistance ranged from 792 to 856 N cm^{-2}. The maximum soil strength was recorded for NT after the tillage operations as 856 N cm^{-2}, while the minimum was recorded for CPTC2 792 N cm^{-2}. Significant difference in mean soil strength of different treatments was found at depth of 61-100 cm and similar results were reported by [7, 9].

The percent aggregates based on dry sieving from different tillage treatments under chickpea are shown in Table 5. Due to sandy in nature and low organic content the aggregates were smaller in size. However, MBTC2 produced relatively greater size aggregates as compared to other treatments. Chickpea crop slightly improved cumulative infiltration in NT plots as compared to four hours cumulative infiltration before tillage. In general, deep tillage loosened the soil and enhanced the cumulative infiltration (Fig. 1) and similar findings were reported by other researchers [15, 19].

There was no significant difference among the tillage treatments for the primary root length of chickpea as shown in Table 8. In general, deep tillage treatments created better root environment and enhanced the length of primary roots of chickpea as compared to NT and TC3, similar findings were reported by [4, 7]. There was no significant difference in number of pods per plant among the various tillage treatments (Table 9). Seed yield of chickpea ranged from 1549 to 2177 kg. ha^{-1} during 2002-2005. The mean highest seed yield of chickpea 1968 kg ha^{-1} was recorded in the tillage treatment CPTC2, while the mean lowest 1695 kg ha^{-1} was found in NT (Table 9), similar findings were reported by [22].

Water use efficiency (WUE) of 6.93 kg ha^{-1}. mm^{-1} was obtained from treatment CPTC2 followed by treatment NT where crop water productivity was only 5.56 kg ha^{-1} mm^{-1} as shown in Fig. 4. WUE was increased by using Chisel Plough once and Tine Type Cultivator twice in the field operations. This is due to less infiltration rate and improves water content and nutrient use efficiency that ultimately resulted in higher WUE under treatment CPTC2. These results are supported by [2, 21] who reported that 0.13 to 0.22 kg m^{-3} is the averages WUE on six irrigation treatments over four years in California, while [24] reported that DP 0935 was highest WUE in the fully irrigated treatment with 0.22 kg m^{-3}.

6. CONCLUSIONS

- More chickpea grain and biomass yield were obtained from chisel plow (CPTC2) as compared to no till (NT) or conventional tillage (tine type cultivator) in this semi-arid rainfed environment.
- Deep tillage resulted in 50-60% higher rain infiltration as compared to no till; thus, increased soil moisture content.
- Poor correlation was observed between grain and biomass yields of chickpea.
- Chickpea grain yield increased with increase in root length and decreased with increase in soil bulk density and soil penetration resistance.
- Higher water use efficiency by chickpea was observed with chisel plowing (CPTC2) as compared to no till (NT) or conventional tillage.
- Chisel plowing or disc plowing are recommended for rainfed chickpea crop as compared to the other treatment.

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