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Research Article

Preceding Rainy-Season Crops and Residue Management Practices on Growth, Productivity and Profitability of Succeeding Chickpea under Zero-Till Semi-Arid Ecosystem

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Abstract

To identify suitable chickpea-based cropping system, a field experiment for two years (2010-11 and 2011-12) was conducted with three preceding rainy-season crops: pearl millet, cluster bean and green gram along with no residue, crop residue and *Leucaena* twigs mulching. All rainy season crops and chickpea were grown with zero-tillage by providing recommended package of practices under rainfed conditions. The pooled analysis showed significant yearly variations on seed yield of chickpea. Pearl millet as preceding crop resulted in significantly higher yield of chickpea (1.31 t ha^{-1} in 2010-11 and 1.06 t ha^{-1} in 2011-12), followed by green gram and cluster bean. The interaction effect of pearl millet as preceding crop with *Leucaena* twigs resulted in significantly higher chickpea yield (1.68 t ha^{-1}) than other treatments in 2010-11, but it was higher (1.46 t ha^{-1}) with crop residues in 2011-12. The nutrient uptake also followed the same trend as seed and stover yields. Economic analysis showed the highest gross returns (37.72 x 10^3 ` $ha^{-1}$), net returns (25.52 x $10^3$ ` ha^{-1}), and net returns/invested (2.09) after pearl millet with *Leucaena* twigs in 2010-11. However, the highest gross returns (44.02 x 10^3 ` $ha^{-1}$), net returns (25.87 x $10^3$ `ha^{-1}), and net returns/invested (1.42) was earned after pearl millet with crop residues in 2011-12. It was concluded that chickpea after pearl millet with crop residues or *Leucaena* twigs was high-yielding and profitable cropping system under zero-till semi-arid conditions.

Keywords: Chickpea; Preceding Rainy-Season Crops; Productivity; Profitability; Semi-Arid Rainfed; Residue Management; Zero-Till

Introduction

The average productivity of rainy- and winter-season crops in rainfed areas is only half as that in irrigated ecosystem [1-2]. Keeping land fallow or cultivating short-duration crops like pearl millet [*Pennisetum glaucum* (L.) R. Br. emend Stuntz], clusterbean [*Cyamopsis tetragonoloba* (L.) Taub.], and greengram (*Vigna radiata* L.) during rainy-season, followed by long-duration and drought-hardy winter-season crops like chickpea (*Cicer arietinum* L) on the preserved soil moisture is the common cultivation practice under semi-arid rainfed areas of India [3]. Mostly these crops are grown under ploughed land, which not only deteriorates the soil environment, but also increases the cost of production.

Zero tillage is emerging as a way of transition to the sustainability of intensive production systems both under irrigated and rainfed conditions. It permits proper management of water and soil for agricultural production without excessive disturbance to soil. The sowing of seeds with zero-till drill not only facilitates timely sowing of crops on residual soil moisture, but also improves soil health as the plants stand is influenced by moisture content, tillage and sowing time [4]. Returning organic crop residues through zero-tillage to the soil improves soil quality and production through the favourable effects on physico-chemical properties [5]. Favourable effect of residue mulching on soil organic C, water retention, temperature moderation and increasing water stable aggregates have also been reported for the surface layer [6-7]. Increased porosity due to mulch application was more important to crop development, since it had a direct effect on soil aeration and enhanced root growth [8,9]. The improved root growth under conservation agriculture makes it possible for the plant to absorb soil water and nutrients from the soil. Inclusion of legumes under rainfed conditions plays a vital role in improving balanced human nutrition [10] and build-up of the soil fertility through addition of biologically-fixed N2 [11].

The practice of mulching through *in-situ* vegetative materials and brought-in mulch from the pruning of various trees and shrubs grown in non-cropped lands are common practices for maintaining soil fertility [12,13]. Application of mulch of *Leucaena leucocephala* and other legume species in standing crops helps in conservation and carryover of soil moisture for proper growth and development [12,14,15]. Increased root growth owing to favourable soil environment and decreased infestation of weeds are responsible for better growth of crops and higher crop yields under zero-tillage condition [16]. The present investigation was aimed at understanding the effects of preceding rainy-season crops and residue management practices on growth, productivity, nutrient uptake and profitability of chickpea under zero-till semi-arid rainfed condition.

Materials and Methods

A field experiment was conducted on sandy loam soil with 147.2 kg ha^{-1} alkaline KMnO4-oxidizable N, 17.0 kg ha^{-1} $NaHCO_3$-extractable P, 225.1 kg ha^{-1} 1N NH_4OAc-exchangeable K, 0.40% organic C with 7.5 pH (1: 2.5 soil and water ratio) at the Indian Agricultural Research Institute, New Delhi (28o 40'N, 77012'E at an altitude of 228 m above mean sea level during 2010-11 and 2011-12 to study the effect of residue management and preceding rainy-season crops on growth, productivity, nutrient uptake and profitability of chickpea-based cropping systems. The daily meteorological data showed that there was higher rainfall (954 mm) in 2010, while it was 30.6% less in (662 mm), and 10.4% less than the average of last 10 years (739 mm) in 2011. There were more rains (10 rainy days, 85 mm) during winter (October to April) in 2010-11, but rains were negligible (3 rainy days, 34 mm) in 2011-12. Chickpea crop sown on 3 October in 2011 did not germinate up to 25 days; and therefore, a limited irrigation (20 mm) in crop-rows was given for ensuring germination.

Three cropping systems involving combinations of three crops each in rainy-season (pearlmillet, clusterbean and greengram) followed by chickpea were grown in sequence, exclusively under zero-till rainfed condition following other recommended package of practices. Three treatments of surface cover management, viz. control (no-residue), crop residues @ 5 t ha^{-1} and *Leucaena* twigs @ 10 t ha^{-1} green biomass were maintained in both the seasons. The experiment for both the years was laid out in Randomized Block Design with four replications. Chickpea cv 'BGD-72' was sown on 18 October in 2010, and on 3 October in 2011 at 40 cm row spacing with the help of Happy Seeder. A plant population of about 25 plants m^{-2} was maintained after thinning and gap filling as per need. Crop was grown with 20:40:20 kg N-P_2O_5-K_2O ha^{-1}, wherein DAP, MOP and Urea were applied basally. Muriate of Potash and Urea were applied broadcast, while DAP was drilled in crop rows with Happy-Seeder. The crop matured in third week of March in both years was harvested by cutting shoots from the ground layer and threshed with Pullman Thresher.

Growth analysis like Leaf area index (LAI) was calculated by dividing total leaf area with the corresponding ground area. Crop growth rate (CGR) was calculated as: $(W_2–W_1) \div (T_2–T_1)$ and expressed as g $day^{-1}m^{-2}$. Net assimilation rate is the net gain of assimilates per unit leaf area time, representing the photosynthetic efficiency of leaves. This was calculated as: $(W_2 – W_1)$ $(\ln LA_2 – \ln LA_1) \div (T_2–T_1)$ $(LA_2 –LA_1)$ and expressed as mg $day^{-1}m^{-2}$. Relative growth rate (RGR) expresses the dry matter increase in a time interval in relation to initial weight. It was calculated as: $(Log_e W_2–Log_e W_1) \div (T_2–T_1)$ and expressed in g $g^{-1}day^{-1}$, where, W_1 and W_2 are the dry weights recorded at time T_1 and T_2, LA_1 and LA_2 are the leaf area values recorded at times T_1 and T_2; and T_1 and T_2 are time in days. All growth indices were estimated from 30 DAS to harvesting stage of the chickpea. Plant population m^{-2} at maturity was counted from the fixed 1 m row inserted with wooden pegs from beginning of measuring growth attributes, while pods $plant^{-1}$ was counted from randomly selected five plants $plot^{-1}$. Number of seeds pod^{-1} was taken from randomly selected ten pods of chickpea; however, 1000-seed weight was taken from seed lots of each treatment. The seed and stover yield, and harvest index were recorded from the net plot of 10 m^2 area, and the seed yield was adjusted at 12% moisture. Pooled analysis of seed yield was done for evaluation of year and treatment interaction effect. The concentration of N, P and K in seed and stover was analyzed as per the standard methods [17], and the uptake was calculated on the basis of their dry matter yield at harvest. Economic analysis was done and expressed as cost of cultivation, gross and net returns, and net returns/ ` invested. The biometric data on ancillary and yield parameters were analyzed by standard statistical techniques and regression and correlation analysis for major yield attributes and seed yield was done [18].

Results

Growth analysis and soil moisture

Crop growth rate (CGR), relative growth rate (RGR), and net assimilation rate (NAR) presented in table 1 and 2 showed that these parameters were higher in chickpea under crop residues mulching, followed by *Leucaena* twigs and no-residue after pearlmillet and greengram as preceding crops, and from 0-30 DAS and 30-60 DAS in 2010-11, and from 60-90 DAS and 90-120 DAS in 2011-12.

Treatment	CGR (g day^{-1} m^{-2})				RGR (g g^{-1}day^{-1})			NAR (mg day^{-1} m^{-2})	
	0 - 30 DAS	30 - 60 DAS	60 - 90 DAS	90 - 120 DAS	30 - 60 DAS	60 - 90 DAS	90 - 120 DAS	30 - 60 DAS	60 - 90 DAS
PM- NR	4.29	2.86	1.63	1.20	0.064	0.056	0.052	1.040	0.705
PM - CR	5.77	2.39	1.96	1.38	0.069	0.063	0.064	0.876	0.595
PM - LT	4.86	3.88	2.52	2.81	0.062	0.059	0.054	1.073	0.645
CB - NR	2.95	2.13	2.67	0.98	0.060	0.063	0.049	0.792	0.551
CB - CR	4.25	3.56	2.00	2.68	0.063	0.063	0.059	1.050	0.456
CB - LT	4.05	2.53	2.62	2.01	0.068	0.059	0.063	1.020	0.479
GG - NR	2.73	3.14	2.37	1.17	0.066	0.062	0.051	1.042	0.700
GG - CR	3.28	5.41	3.11	1.21	0.075	0.066	0.060	0.651	0.900
GG - LT	3.46	5.98	3.14	2.17	0.074	0.066	0.052	0.751	1.249

Table 1: Effect of crop residues and *Leucaena* twigs on crop growth indices of chickpea after rainy-season crops in 2010-11

Treatment	CGR (g day^{-1} m^{-2})				RGR (g g^{-1}day^{-1})			NAR (mg day^{-1} m^{-2})	
	0 - 30 DAS	30 - 60 DAS	60 - 90 DAS	90 - 120 DAS	30 - 60 DAS	60 - 90 DAS	90 - 120 DAS	30 - 60 DAS	60 - 90 DAS
PM- NR	1.73	0.99	0.80	6.16	0.049	0.046	0.076	1.180	0.619
PM - CR	2.87	0.72	0.20	9.58	0.057	0.030	0.077	1.484	1.402
PM - LT	1.73	1.71	0.27	6.67	0.044	0.026	0.082	1.182	0.333
CB - NR	0.86	1.09	2.12	2.30	0.050	0.060	0.061	2.035	0.129
CB - CR	1.51	1.02	5.34	4.26	0.046	0.063	0.073	2.017	0.102
CB - LT	1.27	0.81	2.58	5.20	0.050	0.073	0.070	1.847	0.089
GG - NR	1.33	0.35	2.84	3.35	0.034	0.064	0.067	1.164	0.166
GG - CR	1.77	0.15	5.53	4.42	0.030	0.071	0.070	0.979	0.098
GG - LT	1.56	0.26	4.38	4.27	0.022	0.074	0.071	0.905	0.089

Table 2. Effect of crop residues and *Leucaena* twigs on crop growth indices of chickpea after rainy-season crops in 2011-12.

Chickpea grown as rainfed followed no definite pattern in crop growth indices. The CGR was governed as according to the pattern of profile soil moisture as given in figure 1. The growth picked up only after the availability of soil moisture through rainfall. The rainfall received on 7th February 2011 (49 mm), on 6th and 13th January 2012 (14 mm) and on 13th March 2012 (20 mm) increased the CGR in later stages of crop growth after the crop was rejuvenated following rainfall. Application of crop residues in chickpea after pearlmillet and greengram, and *Leucaena* twigs after clusterbean provided comparatively higher CGR, RGR and NAR than with and without residues. There was comparatively higher CGR during the period from 0-30 DAS in 2010-11.

Yield performance

The effect of preceding crops and residues management on seed, stover and biological yields of chickpea is presented in figure

Figure 1: Profile soil moisture (w/w %) in chickpea field as influenced by residue retention practices.

2. Interaction effect of preceding crops and residues management practices exerted the significant variations on seed and stover and biological yields, l in 2010-11, and on seed, stover and biological yields in 2011-12. Leucaena twigs after pearlmillet recorded significantly higher seed yield (1.68 t ha^{-1}) than other treatments in 2010-11. The yield was significantly higher (1.46 t ha^{-1}) with crop residues after pearlmillet in 2011-12. Uniform distribution of rainfall during the cropping season of 2010-11 and conserved soil moisture under crop residues in 2011-12 resulted better crop performance. By the end of two cropping cycles in 2011-12, the crop residues showed significantly superior yield after pearlmillet and greengram over no-residue and *Leucaena* twigs.

Pooled analysis of chickpea seed yields as affected by years, preceding crops and residues management practices are presented in table 3. The effect of years was found to be significant. The rainfall equivalent to 20 mm occurred on 13 March in 2012 was beneficial for pod filling resulting higher yield. There was uniform distribution of rainfall throughout the crop season during 2010-11, and the last rainfall received in mid-February (49 mm) helped to

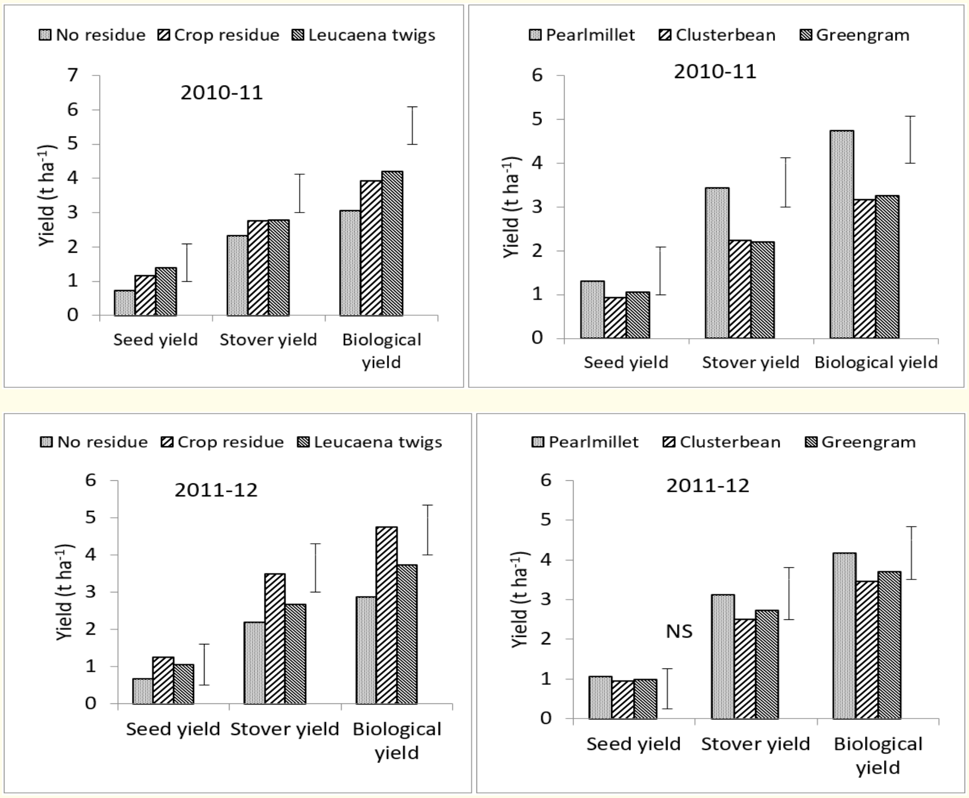

Figure 2: Yield performance of chickpea as influenced by residue management and preceding rainy-season crops.

Treatment	2010-11				2011-12				Overall mean
	NR	CR	LR	Mean	NR	CR	LR	Mean	
Pearlmillet	0.89	1.38	1.68	1.31	0.71	1.47	1.00	1.06	1.12
Clusterbean	0.59	1.00	1.21	0.93	0.64	0.99	1.24	0.96	0.89
Greengram	0.70	1.13	1.31	1.05	0.69	1.34	0.94	0.99	0.90
Mean	0.73	1.17	1.40		0.68	1.27	1.06		
	Year (A)	Preceding Crop (B)		Residues (C)		A x B	A x C	B x C	A x B x C
SEm±	0.019	0.024		0.024		0.033	0.033	0.043	0.059
CD (P = 0.05)	0.057	0.069		0.069		0.098	0.098	0.121	0.171

Table 3: Pooled analysis on seed yield of chickpea (t ha^{-1}) as affected by year, preceding crops and residue management.

increase the chickpea yield. Minimizing rate of evaporation by use of crop residues and increased fertility status after decomposition helped to increase the yield in later years over *Leucaena* twigs and no-residue.

Regression analysis between yield and yield attributes of chickpea (Figure 3) showed highly significant positive correlation with plant m^{-2} in 2011-12. Significant positive correlation with plants m^{-2} in 2010-11 and number of pods $plant^{-1}$ in both years was observed.

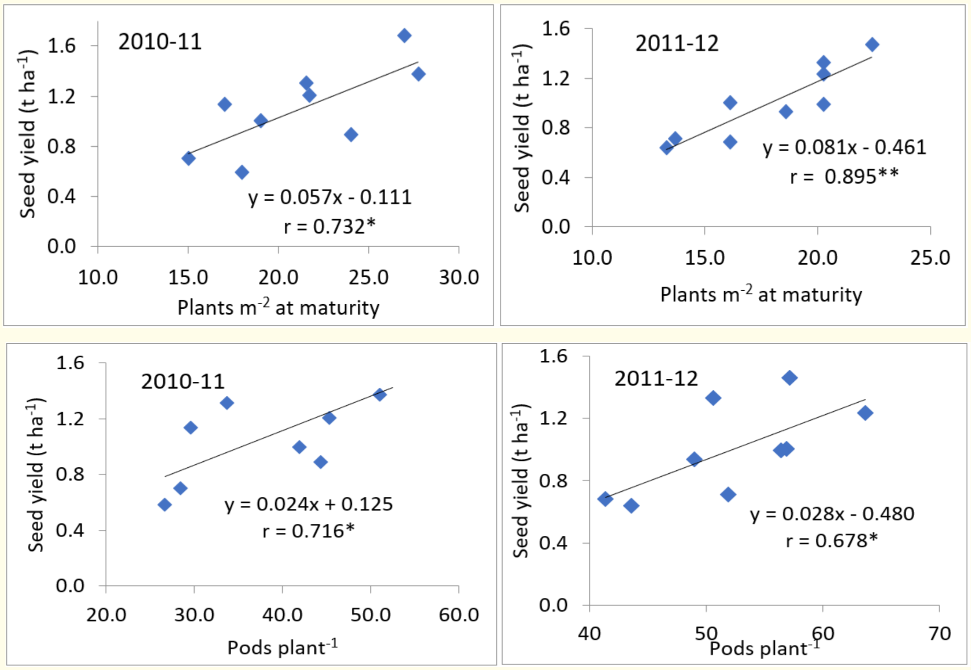

Figure 3: Regression and correlation of chickpea yield (y) with major yield attributes (x).

Nutrient uptake

Nutrient uptake by chickpea for 2010-11 and 2011-12 are presented in table 4 and 5. In general, the pattern of seed and stover yield was followed in total nutrient uptake as well. Rainy-season crops showed significant variation in N, P and K uptake of both seed and stover. Preceding pearlmillet resulted in significantly higher seed and stover yield, and hence nutrient uptake due to the better crop performance with *Leucaena* twigs in 2010-11, and with crop residue retention in 2011-12. Similarly, crop residues retention also showed significant variation in nutrient uptake in both years with maximum uptake under crop residues in 2011-12. Statistically at par result for NPK uptake under crop residues and *Leucaena* twigs was recorded in 2010-11.

Interaction effect of preceding crop and residue management was found significant on nutrient uptake and resulted the same trend as that on seed and stover yield, except N and P uptake in stover, and total K-uptake by seeds in 2010-11. The higher uptake of N, P and K in seed and stover after pearlmillet as preceding crop was noticed. Moreover, the magnitude of total nutrient uptake was equal in both years, and this was due to almost similar seed and stover yields of chickpea in both years.

Economics

Nutrient uptake by chickpea for 2010-11 and 2011-12 are presented in table 4 and 5. In general, the pattern of seed and stover yield was followed in total nutrient uptake as well. Rainy-season crops showed significant variation in N, P and K uptake of both seed and stover. Preceding pearlmillet resulted in significantly higher seed and stover yield, and hence nutrient uptake due to the better crop performance with *Leucaena* twigs in 2010-11, and with crop residue retention in 2011-12. Similarly, crop residues retention also showed significant variation in nutrient uptake in both years with maximum uptake under crop residues in 2011-12. Statistically at par result for NPK uptake under crop residues and *Leucaena* twigs was recorded in 2010-11.

Discussion

Soil and weather conditions

Rainfed agriculture covers about 80% of global crop land, contributes 67% area and 60% production of the cereal grain production in India and most of them are arid and semi-arid eco-systems [2,10]. Minimizing evaporation loss and conserving soil moisture by adopting conservation agriculture (CA) practices may result in significant increase in productivity and resource-use efficiency in

Treatment	N uptake (kg ha^{-1})			P uptake (kg ha^{-1})			K uptake (kg ha^{-1})		
	Seed	Stover	Total	Seed	Stover	Total	Seed	Stover	Total
Preceding crops (A)									
Pearlmillet (PM)	41.1	30.4	71.4	3.26	3.61	6.87	6.34	45.0	51.4
Clusterbean (CB)	30.0	21.1	51.1	2.47	2.43	4.90	4.71	28.6	33.3
Greengram (GG)	33.8	21.4	55.1	2.69	2.39	5.08	5.18	28.6	33.8
SEm±	0.91	0.84	1.07	0.09	0.10	0.12	0.18	1.08	1.04
CD (P = 0.05)	2.65	2.45	3.13	0.26	0.30	0.36	0.52	3.17	3.04
Residues management (B)									
No residue (NR)	23.1	21.3	44.4	1.92	2.51	4.43	3.67	30.1	33.7
Crop residues (CR)	37.1	25.3	62.4	2.96	2.91	5.87	5.69	36.0	41.7
Leucaena twigs (LT)	44.6	26.2	70.8	3.54	3.01	6.55	6.87	36.2	43.0
SEm±	0.91	0.84	1.07	0.09	0.10	0.12	0.18	1.08	1.04
CD (P = 0.05)	2.65	2.45	3.13	0.26	0.30	0.36	0.52	3.17	3.04
Interaction (A x B)									
PM - NR	27.8	28.9	56.6	2.31	3.49	5.79	4.49	42.3	46.8
PM - CR	42.7	31.8	74.5	3.35	3.69	7.04	6.56	48.0	54.6
PM - LT	52.7	30.4	83.1	4.13	3.66	7.79	7.95	44.7	52.7
CB - NR	19.0	16.1	35.0	1.59	1.86	3.45	3.05	22.2	25.3
CB - CR	32.0	21.1	53.1	2.62	2.46	5.07	5.05	28.6	33.7
CB - LT	38.9	26.2	65.1	3.19	2.97	6.16	6.02	34.8	40.9
GG - NR	22.6	18.9	41.5	1.86	2.17	4.03	3.45	25.6	29.1
GG - CR	36.5	23.1	59.7	2.90	2.60	5.50	5.45	31.2	36.7
GG - LT	42.2	22.1	64.3	3.31	2.40	5.71	6.63	28.9	35.6
SEm ±	1.57	1.45	1.86	0.15	0.18	0.21	0.307	1.88	1.81
CD (P = 0.05)	NS	NS	NS	NS	NS	NS	NS	5.48	3.04

Table 4: Effect of crop residues and *Leucaena* twigs on nutrient uptake (kg ha^{-1}) in chickpea after rainy-season crops in 2010-11.

such rainfed cropping systems. It is also looked upon that horizontal as well as vertical expansion of crop production is essential to meet the growing food needs of the world. The adaptation of the diversified crops and cropping systems is essential for sustainable crop production of semi-arid dry lands in the long-run.

It is also imperative to be noted that the growth and development of any crop is dependent on favourable environment of weather elements. The climate at the experimental site at New Delhi is characterized by sub-tropical and semi-arid conditions, with hot and dry summers and cold winters, under the agro-climatic zone 'Trans-Gangetic plains. Weather conditions over the 10-years period in New Delhi indicated that July to September are the assured rainy months, while there is scanty rainfall with poor distribution in the rest of the months. Initial crop establishment, growth and yield of both rainy and winter season crops were higher in 2010-11 compared with 2011-12 due to favourable weather conditions, mainly well-distributed rainfall in the first year. There was a record of high rainfall in the first year (954 mm), while it was 30.6% less than that of first year, and 10.4% less of 10 years average (2000-2009) in second year (662 mm). Rainfall during winter was well distributed in first year (10 rainy days, 85 mm rain), while it was almost negligible (3 rainy days, 34 mm rain) in second year. During winter of second year, the highest maximum temperature was noted on October 2011, resulting in high rate of evapo-transpiration. There was long drought-spell from September 2011 to January 2012, the conserved soil moisture at sowing time of winter crops was in-sufficient for inducing germination and, therefore, a

Treatment	N uptake (kg ha^{-1})			P uptake (kg ha^{-1})			K uptake (kg ha^{-1})		
	Seed	Stover	Total	Seed	Stover	Total	Seed	Stover	Total
Preceding crops (A)									
Pearlmillet (PM)	33.5	28.3	61.8	2.70	3.44	6.14	5.39	41.9	47.2
Clusterbean (CB)	31.0	24.3	55.4	2.56	2.80	5.36	5.10	32.7	37.8
Greengram (GG)	32.0	26.5	58.5	2.57	3.11	5.68	5.07	36.0	41.0
SEm ±	1.24	1.08	1.74	0.12	0.15	0.21	0.24	1.45	1.52
CD (P = 0.05)	NS	3.15	5.07	NS	0.44	NS	NS	4.22	4.44
Residues management (B)									
No residue (NR)	21.9	21.0	42.9	1.81	2.47	4.28	3.59	29.0	32.6
Crop residues (CR)	40.5	33.0	73.4	3.27	3.89	7.15	6.46	46.2	52.7
Leucaena twigs (LT)	34.1	25.2	59.3	2.75	3.00	5.75	5.50	35.4	40.9
SEm±	1.24	1.08	1.74	0.12	0.15	0.21	0.24	1.45	1.52
CD (P = 0.05)	3.63	3.15	5.07	0.35	0.44	0.62	0.71	4.22	4.44
Interaction (A x B)									
PM - NR	22.6	22.0	44.56	1.87	2.68	4.54	3.79	31.9	35.74
PM - CR	46.0	40.3	86.27	3.69	4.89	8.57	7.33	60.1	67.44
PM - LT	31.8	22.7	54.54	2.55	2.75	5.29	5.03	33.5	38.56
CB - NR	20.8	21.0	41.81	1.73	2.35	4.08	3.46	27.7	31.19
CB - CR	32.3	24.8	57.12	2.65	2.85	5.50	5.32	33.3	38.59
CB - LT	39.9	27.3	67.27	3.29	3.17	6.46	6.53	37.0	43.55
GG - NR	22.4	20.2	42.53	1.82	2.37	4.19	3.52	27.3	30.85
GG - CR	43.2	33.8	77.00	3.47	3.86	7.33	6.73	44.9	51.60
GG - LT	30.4	25.5	55.97	2.42	3.04	5.46	4.95	35.5	40.50
SEm ±	2.16	1.87	3.01	0.21	0.26	0.37	0.42	2.50	2.64
CD (P = 0.05)	6.29	5.45	8.78	0.60	0.76	1.08	1.23	7.31	7.70

Table 5: Effect of crop residues and *Leucaena* twigs on nutrient uptake (kg ha^{-1}) of chickpea after rainy-season crops in 2011-12.

Treatment	Cost of cultivation (x10 ^{3} ` ha^{-1})		Gross returns (x10 ^{3} ` ha^{-1})		Net returns (x10 ^{3} ` ha^{-1})		Net returns/ ` invested	
	2010 - 11	2011 - 12	2010 - 11	2011 - 12	2010 - 11	2011 - 12	2010 - 11	2011 - 12
Pearlmillet - no residue	10.71	15.05	20.75	21.76	10.04	6.71	0.94	0.45
Pearlmillet - crop residue	13.16	18.15	31.38	44.02	18.23	25.87	1.39	1.42
Pearlmillet - *Leucaena* twigs	12.21	17.05	37.72	30.22	25.52	13.17	2.09	0.77
Clusterbean - no residue	10.71	15.05	13.45	19.64	2.74	4.58	0.26	0.30
Clusterbean - crop residue	13.16	18.15	22.63	29.71	9.47	11.56	0.72	0.64
Clusterbean - *Leucaena* twigs	12.21	17.05	27.32	36.87	15.12	19.82	1.24	1.16
Greengram - no residue	10.71	15.05	16.05	20.74	5.34	5.69	0.50	0.38
Greengram - crop residue	13.16	18.15	25.55	39.74	12.39	21.59	0.94	1.19
Greengram - *Leucaena* twigs	12.21	17.05	29.33	28.38	17.13	11.33	1.40	0.66

Table 6: Economics of chickpea as affected by preceding summer season crops and residue management practices in semi-arid ecosystem in 2010-11 and 2012.

limited-irrigation (2 cm) in crop-rows to chickpea was given during first week of November for ensuring their germination. Thus, the two experimental years were contrastingly different in-terms of weather conditions, which accordingly governed the growth, development and yields of crops.

Crop growth, yield and nutrient uptake

Winter–season crops grown under rainfed environment followed no definite trend on crop growth indices as observed in irrigated crops due to variable rainfall and availability of profile soil moisture (Figure 1). The rainfall received on 7 February (49 mm) in 2010-11, and in first and second weeks of January (14 mm), and on 13 March (20 mm) in 2011-12 increased the CGR in later stage of growth, since the crops were rejuvenated after getting soil moisture. The effect of retention of residues was significant in moisture conservation, which was responsible for optimizing crop growth. Retaining crop residues and *Leucaena* twigs, and following clusterbean and greengram as preceding crops increased crop growth indices in both years, and that was due to favourable soil environment created by legume crops. Higher crop growth rate and RGR with crop residues under legume–based systems was reported [12,19-21]. Chickpea is a drought-hardy crop and initial good germination can sustain its growth and give satisfactory yield with the preserved soil moisture under semi-arid rainfed areas. *Leucaena* and crop residues helped to hold more moisture and augment the crop growth rate than no-residue treatment. This indicated that favourable soil environment could be obtained with application of crop residues and preceding legume crops in chickpea-based system. Legumes took more water from the deeper soil layers by virtue of their nature and showed better performance even under rainfed condition [11]. More availability of soil moisture after legumes and crop residues mulching might be due to greater shoot and root biomass production owing to deep-rooted system and leaf fall of the legumes, which consequently added more organic matter, and helped to conserve more soil moisture, resulting in higher growth parameters. Residue retention ensured more water supplies to the crop from the effective root-zone due to decreasing runoff, improving infiltration and checking evaporation loss [22]. Significant interaction effect of rainy-season crops and residue management on most of the growth parameters was due to improved moisture and nutrient availability, and enhanced crop performance, while mulching effect on the micro-climatic variations was also considerable [23].

Preceding rainy-season crops and residue management showed significant influence on the seed and stover yields of chickpea (Figure 2). Preceding pearlmillet in chickpea resulted higher yield. Pearlmillet extracted more surface soil moisture, wherein, the sub-surface soil moisture was utilized better by deep rooted and hardy chickpea crop, leading to better productivity under pearlmillet–chickpea system. Crop residues had profounding effect on chickpea yield. Crop residues having higher C:N ratio decomposed slowly and did not add much to soil fertility in first year. However, in the second year, these helped to control evaporation and conserved more soil moisture, resulting in higher yield. Higher yields under *Leucaena* twigs over no-residue might be due to the addition of N through *Leucaena* twigs. Rapid decomposition of *Leucaena* twigs helped in quick release of nutrients, which increased growth and yield attributes higher yield performance. Crop residues having high C:N ratio took more time to decompose, which in the first season did not add to soil fertility but helped positively in absorbing moisture obtained either from rainfall or dew. The physico-chemical properties of soil change slowly, and the contributory effect of organic residues and legume crops becomes visible after 2-3 years, depending on the nature of soil, temperature and moisture status [24]. There was higher rainfall (85 mm) in winter season of 2010-11, and it was well-distributed throughout the crop period (10 rainy days), which helped to produce more yield under rainfed environment. In 2011-12, the early period of crop growth was comparatively dry due to early cessation of monsoon. The supplemental irrigation (20 mm) given after 1 month of sowing in crop-rows helped to induce germination and maintain early growth of chickpea. Subsequent rainfall of 34 mm helped to produce yield attributes and seed yield similar to that in 2010-11. This was attributed to higher availability of nutrients and moderate soil moisture provided by the crop residues. Pearlmillet–chickpea system was also found to be high yielding than other pearlmillet– based systems in Rajasthan [25].

Pooled analysis on data on economic yield of chickpea (Table 3) as affected by years, preceding crops and residue management showed a significant influence. There was 9% higher chickpea yield in first year than second year. The evenly distributed rainfall throughout the winter season during the first year (2010-11) was beneficial to chickpea because of coincidence of rain with their flowering and fruiting period. Moreover, the roots of chickpea penetrated to deeper layers due to their tap-root system. It was reported that chickpea extracted more water from upper soil surface under enough moisture condition, but depletion was more from sub-surface layer under the scanty moisture condition [11,26-28]. Regression analysis between yield and major yield attributes revealed significant positive correlation between the yield and their yield attributes in chickpea (Figure 3).

Nutrient uptake showed a similar trend as that of yield (Table 4 and 5). The highest N, P and K uptake in chickpea was recorded after pearlmillet. The increased uptake of NPK under residue retention could also be attributed to greater availability of conserved soil moisture to the plants. Crop residue mulch resulted in higher plant stand; and therefore, more biomass yield and NPK uptake were recorded. The overall improvement in growth of chickpea due to residual effect of residues applied to previous legumes like clusterbean and greengram and with *Leucaena* twigs could be ascribed to their pivotal role in several physiological and biochemical processes, viz. root development, photosynthesis, energy transformation (ATP and ADP) and symbiotic biological N2 fixation. Significantly higher nutrient uptake with crop residues and *Lecuaena* twigs was due to higher seed and stover yield than control. There was poor crop growth under no-residue; and, therefore NPK uptake was also less in no-residue treatment. Pearlmillet as preceding crop gave higher dry mater yield and nutrient uptake of chickpea [11,21].

Economic returns

The economics of chickpea resulted the higher returns with Leucaena twigs in first year, and with crop residues in second year (Table 6). There were higher gross and net returns, and net returns/ ` invested for Leucaena twigs, followed by crop residues. Higher cost of cultivation for all rainy-season crop-based systems with retention of crop residues and Leucaena twigs was due to the cost associated with the residues and their application. Leucaena twigs were freely available around the farm periphery, only application costs were incurred. Residue application improved the soil moisture, then physico-chemical and biological environment of the soil through the addition of nutrients and enhanced microbial activity and helped the cropping system to be more productive [29]. Our findings are in conformity with those of other workers in pearlmillet–based systems [21].

Conclusion

Pearlmillet as preceding crops resulted in better growth, yields and nutrient uptake in chickpea over clusterbean and greengram as preceding crops. Both Leucaena twigs and crop residue after pearlmilet led to higher returns and net returns/ ` invested in chickpea. Therefore, it was recommended to grow chickpea after pearlmillet with crop residues or Leucaena twigs for higher productivity and profitability under zero-till semi-arid condition.

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