Journal of Agriculture and Natural Resources (2021) 4(1): 203-221
ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v4i1.33273

Research Article

Conservation tillage and preceding rainy-season crops on root: shoot characteristics, productivity, profitability and nutrient uptake of succeeding mustard under semi-arid rainfed ecosystem

Lal Prasad Amgain[1*] and Ajit Ram Sharma[2]

[1]Institute of Agriculture and Animal Science, Rampur Campus, Tribhuvan University, Chitwan, Nepal
[2]Agronomy Division, Indian Agriculture Research Institute (IARI), Pusa, New Delhi, India
[*]Correspondence: lalprasad@iaas.edu.np
*ORCID: https://orcid.org./0000-0003-2470-542X
Received: August 27, 2020; Accepted: December 1, 2020; Published: January 1, 2021

ABSTRACT

Conservation tillage practices are poplar, environmental friendly and economically feasible approaches to increase the productivity and resource-use efficiency of arid and semi-arid rainfed ecosystems. Rainfed field experiments were accomplished at IARI, Pusa, New Delhi in 2010-11 and 2011-12 to evaluate root: shoot growth, productivity, profitability and nutrient uptake in mustard under the various conservation tillage practices with preceding rainy- season crops; pearlmillet, clusterbean and greengram; and organic mulches, *viz.* no residues, crop residues and *Leucaena* twigs applied to both rainy- season crops and mustard grown with common recommended package of practices. Higher root length density (RLD), root surface area (RSA), root volume density (RVD), average root diameter (RD), crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR) were recorded under clusterbean–mustard and greengram–mustard systems over the pearlmillet- mustard system. Interaction between crop residues and preceding rainy-season crops on growth parameters exerted significant variations, while yield attributes showed the mixed responses. Mustard seed yield was significantly higher (+51%) in 2010-11 (1.80 t ha^{-1}) than that of 2011-12 (1.19 t ha^{-1}). Economic analysis exhibited the highest returns and net returns/ Rs invested after clusterbean with *Leucaena* twigs mulching. The nutrient uptake followed the same trend as that of seed and stalk yield. It was concluded that growing mustard after clusterbean with *Leucaena* twigs mulching was high-yielding and profitable cropping system under conservation tilled semi-arid rainfed ecosystem.

Keywords: Conservation tillage, Mustard, Preceding rainy-season crops, Productivity and profitability, Root: shoot growth, Semi-arid rainfed ecosystem

Correct Citation: Amgain, L.P., & Sharma, A. R. (2021). Conservation tillage and preceding rainy-season crops on root: shoot characteristics, productivity, profitability and nutrient uptake of succeeding mustard under semi-arid rainfed ecosystem. *Journal of Agriculture and Natural Resources, 4*(1), 203-221.
DOI: https://doi.org/10.3126/janr.v4i1.33273

ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v4i1.33273

INTRODUCTION

The practice of fallowing or cultivation of short-duration crops like pearlmillet [*Pennisetum glaucum* (L.) R. Br. Emend Stuntz], clusterbean [*Cyamopsis tetragonoloba* (L.) Taub.], and greengram (*Vigna radiata* L.) during rainy-season, followed by a long-duration, drought-hardy crops like mustard (*Brassica juncea* L. Czern. & Coss.) during winter-season on the conserved soil moisture is commonly followed in semi-arid areas of India and Pakistan (Samra, 2002; Faroda *et al.*, 2007; Singh *et al.*, 2008). These crops are mostly grown under conventional ploughed land, which not only deteriorates the soil environment, but also increases the cost of cultivation. Conservation tillage (zero-tillage + residues mulching + crop diversification) is a most scientific and recommended practice in rainfed areas for controlling erosion, weed growth and conserving moisture as well as nutrients in the graded soil profile (Narain & Singh, 1997; Sharma *et al.*, 2005). Moreover, the crop diversification like inclusion of legumes plays a vital role in improving balanced human nutrition (Saxena, 2012) and build-up of the soil fertility through addition of biologically fixed N_2 (Amgain *et al.*, 2013, Acharya *et al.*, 1998; Ali *et al.*, 2002).

Before the introduction of herbicides and chemical fertilizers in the world, the practice of organic mulching through *in-situ* grown, and *brought-in* vegetative materials from the pruning of various trees and shrubs grown in non-cropped alley lands was common practices for conserving moisture and maintaining soil fertility. But, the adoption of this practice has declined due to various reasons like dominance of livestock, fuel for farmers, and cost incurred to transport the bulky-mass of organic residues (Sharma & Acharya, 2000; Dhyani *et al.*, 2009). However, there are several evidences of remarkable crop yield increase in rainfed cropping systems through the maintenance of appropriate vegetative cover under zero-till conditions. For an instance, application of *Leucaena leucocephala* mulch in standing crops helps in conservation and carryover of soil moisture for proper growth and development of crops (Sharma *et al.*, 2010). Similarly, increased root growth owing to more favourable soil environment and decreased infestation of weeds are responsible for better growth of winter crops, and higher crop yields under zero-tillage (Singh *et al.*, 1998). *In-situ* application of residues of crops like pearlmillet, clusterbean and greengram for succeeding mustard and mustard crop residues for the next rainy-season crops would be used because of their easy access from the seasonal harvest. Moreover, the introduction of happy-seeder machines has made it easier to sow seeds of any crop in standing residue under conservation-till conditions (Jat *et al.*, 2009). It is also well known that root is a vital component of plant system and to ensure normal plant growth and proper root development, the soil must have enough air, water and nutrients (Husnjak *et al.*, 2002). Root penetration to a greater depth is necessary for anchorage and uptake of water and nutrients from soil. It is the finer roots with larger length density (RLD) and surface area that contribute to more water and nutrient uptake from surface as well as sub-surface than the thicker roots, which remain confined to upper surface layers especially under zero-tillage (Box and Ramseur, 1993). Zero-tillage practices with a permanent residue cover also resulted in higher infiltration of water due to the creation of higher macro-aggregates even though bulk density was higher (Hobbs *et al.*, 2008).

In view of these considerations, adoption of resource-conserving technologies involving conservation-tillage and residue management is essential as low-input agriculture to improve root and shoot development, productivity, resource-use efficiency and achieve sustainability in semi-arid rainfed ecosystem. The present investigation was therefore aimed at

ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v4i1.33273

understanding the effects of preceding rainy season-crops and residues management practices on root: shoot growth, productivity, profitability and nutrient uptake in mustard grown under conservation-tilled semi-arid rainfed condition.

MATERIALS AND METHODS

Weather, soil and treatment details

Field experiments were conducted at the Indian Agricultural Research Institute, New Delhi (28^o 40'N, $77^0$12'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 root: shoot characteristics, productivity, profitability and nutrient uptake of mustard and mustard–based cropping systems. The daily meteorological data showed that there was high rainfall (954 mm) in 2010-11, while it was 30.6% less than that of 2010-11 in 2011-12 (662 mm) and 10.4% less (739 mm) than that of average of the previous 10 years period (2000-2009). There were more rains (10 rainy days with 85 mm rainfall) during the mustard growing season (October to March) in 2010-11, but rains were negligible (only 2 rainy days with 14 mm rainfall) in 2011-12. Mustard crop sown on 3rd October in 2011 did not germinate up to 25 days of sowing; and, therefore, a small irrigation measuring 20 mm on crop-rows was given for ensuring germination.

The soil of the experimental field was sandy-loam in texture, with 147.2 kg ha^{-1} alkaline $KMnO_4$-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). The moisture content at 1/3 and 15 atmospheric tensions was 18.8 and 6.5%, respectively, with bulk density of 1.55 Mg m^{-3} in surface soil layer (0-15 cm). Three cropping systems based on succeeding mustard with preceding rainy season crops: pearlmillet, clusterbean and greengram were grown in sequence, exclusively under zero-till rainfed condition following other recommended package of practices (Reddy & Reddy, 2009). Three treatments of surface cover management, viz. control (no-residue), crop residues @ 5 t ha^{-1} and *Leucaena* twigs @ 10.0 t ha^{-1} green biomass (moisture content of about 76.5% w/w) were maintained in both the seasons. The experiment was laid out in Randomized Block Design with four replications.

Mustard cv. 'Pusa Vijaya' was sown on 18 October in 2010, and on 3 October in 2011 at 40 cm row spacing with happy-seeder. Crop was grown with 60:40:20 kg N-P_2O_5-K_2O ha^{-1}, wherein full dose of P and K along with half N through DAP, MOP and urea was applied basally. Diammonium phosphate was mixed with seeds of mustard and placed together in seed box of happy seeder for its proper distribution. Muriate of potash and Urea were applied as broadcast (Sidhu *et al.*, 2007). Mustard crop was matured in second to third week of March in both years. The preceding rainy-season crops pearlmillet, clusterbean and greengram were also grown rainfed as per their recomended practices with zero-tillage practices (Reddy & Reddy, 2009) differing the residues management treatments.

Records on root and shoot growth, mustard yield, nutrient uptake and statistical analysis

Root samples were taken from third row of each crop at flowering stage (60-70 DAS) in mustard. A root auger of 4.8 cm diameter and 10 cm height (core volume = 180.86 cm^3) was used to take root samples up to 0-15 cm depth. Cleanliness and other procedures for root

ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v4i1.33273

scanning were accomplished as per standard protocol (Aggarwal & Sharma, 2002). The root parameters like root length density, surface area, root volume and diameter of different thickness of roots of mustard were recorded. Scanning and image analysis using RHIZO system was operated in a computer mounted with the scanner of RHIZO system. Growth attributes of mustard (plant height and dry matter), and other growth indices like LAI, CGR, RGR and NAR were calculated from 30 DAS to the one meter row inserted with pegs from the beginning, while primary branches plant^{-1} and siliquae plant^{-1} were counted from randomly selected five plants of each plot. Number of seeds siliqua^{-1} and 1000-seed weight were taken from randomly selected ten siliquae. The seed and stalk yields, and harvest index were recorded from the net plot of 10 m^2 area and seed yield was adjusted at 12% moisture.
Pooled analysis on seed yield was done for evaluation of year effect. Profitability analysis was done, and expressed as cost of cultivation, gross and net returns, and net returns/ IRs invested. The concentration of N, P and K in seed and stalk yields of mustard was analyzed as per the standard methods (Prasad *et al.*, 2006), and the uptake values were calculated on the basis of their dry matter yield at harvest. The biometric data on ancillary and yield parameters were analyzed by standard statistical techniques (Gomez & Gomez, 1984) and the regression and correlation analysis for major yield attributes and seed yield in mustard was also overcomplished.

RESULTS AND DISCUSSION

Root growth and development

Root morphological parameters, viz. root length density (RLD), surface area density (RSD), root volume density (RVD) and average diameter of roots (AD) taken at flowering stages of mustard during 2010-11 and 2011-12 are presented in Table 1. The residue management practices influenced root parameters of mustard. The higher root morphological parameters of mustard were recorded with crop residue, followed by *Leucaena* twigs, and the least with no-residue. Mustard showed higher root morphological parameters in 2010-11 due to their vigorous growth in congenial environment under uniform application of residues. Mustard after *Leucaena* twigs recorded higher root morphological parameters after clusterbean, while crop residues led to higher root growth after pearlmillet and greengram. Preceding clusterbean and greengram led to higher root morphological parameters in mustard and that might be due to more porous soil environment resulting from deep-rooted legumes and their leaf litters.

The RLD and RSD were lower in zero-tillage due to compaction of soil, which did not permit smooth growth of root in to down layers, and resulted in thick and lateral spreading of roots. Legumes are soil restorative crops and have tap root system; and therefore, acted as 'biological plough' and resulted the higher average root diameter in mustard, whereas, reverse trend was observed after soil exhaustive crop, pearlmillet ,where fibrous root system is dominant. Thick roots obtained almost for mustard under no-residue treatment due to less fertile zero-till soil having high bulk density corroborated the findings of Maurya and Lal (1980), and Chassot and Richner (2002). More root dry weight and root volume of wheat under zero-tillage was reported earlier by Meena and Behera (2008).

ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v4i1.33273

Table 1: Effect of residue management and preceding rainy-season crops on root parameters of mustard at flowering stages

Treatments	2010-11				2011-12			
	PM	CB	GG	Mean	PM	CB	GG	Mean
				1.Root length density (cm cm^{-3})				
No residue	0.426	0.448	0.531	0.468±0.056	0.260	0.389	0.270	0.307±0.071
Crop residue	0.729	0.719	1.023	0.824±0.173	0.465	0.757	0.518	0.580±0.155
Leucaena twigs	0.530	0.820	0.747	0.699±0.151	0.402	0.421	0.372	0.398±0.024
Mean	0.561	0.662	0.767		0.376	0.522	0.387	
				2. Surface area density (cm^2 cm^{-3})				
No residue	0.252	0.186	0.607	0.348±0.227	0.338	0.371	0.542	0.417±0.110
Crop residue	0.317	0.552	1.012	0.627±0.354	0.803	0.500	0.428	0.577±0.149
Leucaena twigs	0.321	1.130	1.194	0.882±0.486	0.415	0.703	0.967	0.695±0.276
Mean	0.297	0.623	0.938		0.519	0.524	0.646	
				3. Root volume density (cm^3 cm^{-3})				
No residue	0.021	0.007	0.018	0.015±0.007	0.024	0.019	0.027	0.024±0.004
Crop residue	0.022	0.008	0.038	0.022±0.015	0.052	0.037	0.039	0.043±0.003
Leucaena twigs	0.028	0.010	0.041	0.026±0.016	0.034	0.051	0.037	0.041±0.009
Mean	0.023	0.008	0.032		0.037	0.036	0.034	
				4. Average diameter of root (mm)				
No residue	4.11	5.41	5.31	4.94 ±0.72	3.27	2.42	3.66	3.12 ±0.63
Crop residue	5.02	7.6	7.85	6.82 ±1.57	3.45	2.91	5.14	3.83 ±1.16
Leucaena twigs	5.6	8.33	8.22	7.38 ±1.55	5.30	3.19	6.36	4.95 ±1.61
Mean	4.91	7.11	7.13		4.01	2.84	5.05	

Growth parameters and development indices

Data pertaining to growth parameters, *viz.* plant height, LAI and dry matter accumulation of mustard as influenced by previous rainy-season crops and residue management are presented in Table 2 and 3. Results showed that all growth characters in mustard increased with the advancement of age of the crop and were comparatively higher in 2010-11 than in 2011-12. The lowest plant height, LAI and dry matter accumulation were recorded at all growth stages in 2011-12 than in 2010-11 due to hindered crop growth owing to scanty and poorly-distributed rainfall. In 2010-11, there was uniform distribution of rain, just 4 days after sowing (22 mm on 22 October), and about 10 mm in the first week of November. Moreover, another effective rainfall (49 mm) was received in first week of February, which activated the growth and development of rainfed mustard crop. However, in 2011-12, mustard was supplied with supplemental irrigation (20 mm) in crop-rows in November first week, and the crop was gap filled immediately after irrigation. There was no rainfall up to January first week in 2012. That abnormal situation created a moisture-stress environment for growth and development of mustard, and thus comparatively less growth was recorded.

Journal of Agriculture and Natural Resources (2021) 4(1): 203-221
ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v4i1.33273

Table 2: Effect of crop residue and *Leucaena* twigs on growth parameters of mustard after rainy-season crops in 2010-11

Treatment	Plant height (cm)					LAI			Dry matter (g m^{-2})			
	30 DAS	60 DAS	90 DAS	120 DAS	At Maturity	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	120 DAS
Preceding crops (A)												
PM	25.1	105.2	148.5	174.1	174.8	0.43	1.65	3.60	90.5	196.9	313.5	411.2
CB	26.9	115.9	177.6	187.2	187.5	0.77	1.67	6.68	124.5	235.8	498.0	555.8
GG	24.9	106.2	167.8	174.9	176.0	0.75	1.39	5.55	119.4	194.8	401.3	563.6
LSD (P=0.05)	1.59	5.34	6.78	7.83	6.97	0.073	0.172	0.365	10.4	17.5	26.8	49.9
Residue management (B)												
NR	20.2	88.5	153.7	159.5	160.2	0.51	1.08	4.17	77.4	142.5	290.8	362.8
CR	27.6	114.7	164.3	185.1	194.8	0.64	1.50	5.36	94.9	213.0	418.7	539.7
LT	29.0	124.1	176.0	191.7	183.2	0.79	2.12	6.30	162.1	272.0	503.2	628.2
LSD (P=0.05)	1.59	5.34	6.78	7.83	6.97	0.073	0.172	0.365	10.4	17.5	26.8	49.9
Interaction (A x B)												
PM - NR	22.0	101.1	145.4	165.3	164.9	0.35	1.35	3.31	50.4	113.8	205.2	287.9
PM - CR	25.2	103.5	149.5	187.4	188.4	0.42	1.61	3.68	67.1	191.4	329.7	420.5
PM - LT	28.0	111.1	150.7	169.8	171.0	0.51	1.99	3.81	154.1	285.6	405.6	525.3
CB - NR	20.8	102.0	165.7	157.1	158.7	0.55	0.94	4.90	82.6	166.9	368.7	402.8
CB - CR	30.0	120.6	179.4	196.5	197.6	0.83	1.43	6.44	120.6	233.0	486.6	546.3
CB - LT	29.9	125.0	187.6	208.0	206.1	0.93	2.63	8.70	170.2	307.5	638.7	718.2
GG - NR	18.0	62.3	149.8	156.1	157.1	0.63	0.97	4.29	99.2	146.9	298.6	397.5
GG - CR	27.7	120.1	164.1	171.4	198.4	0.67	1.45	5.97	96.9	214.5	439.9	652.1
GG - LT	29.1	136.3	189.6	197.2	172.5	0.94	1.75	6.41	162.1	223.0	465.4	641.1
LSD (P=0.05)	2.75	9.24	12.1	13.6	12.1	0.127	0.298	0.631	18.0	30.4	46.4	86.3

PM = Pearlmillet, CB =Clusterbean, GG= Greengram, NR = No residue, CR = Crop residues, LT = *Leucaena* twigs

Table 3: Effect of crop residue and *Leucaena* twigs on growth parameters of mustard after rainy-season crops in 2011-12

Treatment	Plant height (cm)					LAI			Dry matter (gm^{-2})			
	30 DAS	60 DAS	90 DAS	120 DAS	At Maturity	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	120 DAS
Preceding crops (A)												
PM	22.8	71.8	165.0	173.4	177.1	1.52	2.84	3.58	123.5	208.9	328.6	456.8
CB	21.6	78.6	178.5	186.9	190.6	1.12	3.59	4.21	97.4	244.3	396.8	532.9
GG	19.3	74.3	165.7	180.3	184.0	0.87	2.96	3.37	75.3	201.0	316.9	430.3
LSD (P=0.05)	1.22	3.56	7.80	6.96	7.48	0.112	0.270	0.320	6.84	14.7	27.5	27.9
Residue management (B)												
NR	19.2	66.7	152.3	166.8	169.2	1.04	2.22	2.80	77.5	150.7	255.2	366.0
CR	22.8	81.2	185.0	190.6	195.1	1.25	3.77	3.94	113.0	256.7	371.0	533.0
LT	21.6	76.8	171.9	183.3	187.3	1.22	3.40	4.42	105.8	246.8	416.1	521.2
LSD (P=0.05)	1.22	3.56	7.80	6.96	7.48	0.112	0.270	0.320	6.84	14.7	27.5	27.9
Interaction (A x B)												
PM – NR	19.7	61.9	152.8	159.3	161.7	1.32	2.11	3.13	89.5	143.2	270.2	338.1
PM – CR	26.3	83.5	179.4	188.3	192.8	1.74	3.89	3.83	150.8	264.7	360.4	571.8
PM – LT	22.4	70.1	162.9	172.8	176.8	1.50	2.52	3.77	130.3	218.8	355.1	460.5
CB – NR	20.4	69.6	152.4	167.3	169.7	0.95	2.40	2.74	82.5	163.0	257.6	418.7
CB – CR	21.7	82.3	187.6	191.5	196.0	1.12	3.83	3.82	96.8	260.7	360.2	507.1
CB – LT	22.7	83.9	195.6	202.0	206.0	1.30	4.55	6.08	112.9	309.3	572.8	673.1
GG – NR	17.6	68.6	151.9	173.8	176.3	0.70	2.15	2.53	60.4	145.9	237.8	341.1
GG – CR	20.5	77.9	188.0	192.1	196.6	1.05	3.60	4.17	91.4	244.7	392.4	520.0
GG – LT	19.9	76.3	157.1	175.1	179.1	0.86	3.12	3.40	74.2	212.3	320.6	430.0
LSD (P=0.05)	2.11	6.17	13.5	12.1	12.5	0.195	0.469	0.554	11.8	25.4	47.6	48.3

PM = Pearlmillet, CB = Clusterbean, GG = Greengram, NR = No residue, CR = Crop residue, LT = *Leucaena* twigs

Journal of Agriculture and Natural Resources (2021) 4(1): 203-221
ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v4i1.33273

Mustard being a deep-rooted and cold-hardy crop, maintained its growth due to dew and fog. Rainfall received during first and second week of January in 2012 (14 mm) catalyzed the crop to extend its further growth and development.

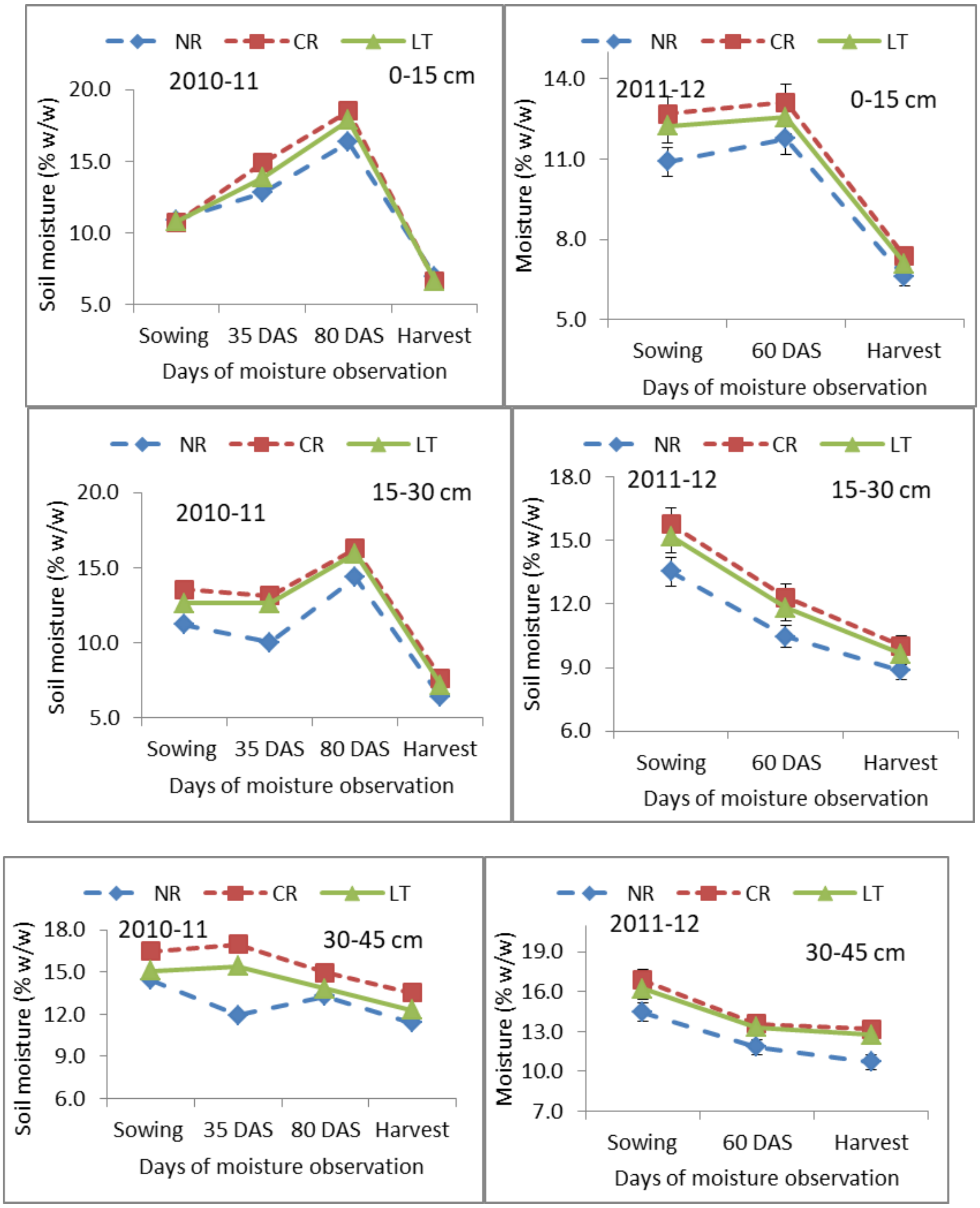

Figure 1: Profile soil moisture (w/w % in mustard field as influenced by residue retention practices (NR = No-residue, CR = Crop residues and LT = *Leucaena* twigs)

The effect of preceding rainy-season crops on growth parameters of mustard was significant except LAI at 60 DAS in 2010-11. Clusterbean and greengram as preceding crops maintained more soil water due to their deep-rooted systems and leaf fall before their maturity (Figure 1). Thus, significantly higher growth parameters were noted after those crops than after pearlmillet. Mustard extracted more water from upper soil surface under enough moisture

Journal of Agriculture and Natural Resources (2021) 4(1): 203-221
ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v4i1.33273

condition, but the depletion was more from sub-surface layer under the scanty moisture condition (Parihar *et al.*, 2010). Crop residue management exerted significant influence on growth parameters in 2011-12 compared with *Leucaena* twigs and no-residue. This was because of greater conservation of soil moisture due to crop residue. Though crop residues had wider C:N ratio and took longer time to decompose and mix in the soil organic matter, the effect was more in conserving soil moisture especially during winter (Figure 1). Moreover, it helped to conserve soil moisture available through rainfall for a longer time and continuously provided to the needs of crops. *Leucaena* twigs showed superiority because of rapid decomposition due to narrower C: N ratio resulting easy excess of soil N. The residue treatments ensured more water to supply to the crop from the effective root-zone due to decreasing runoff, improving infiltration and checking evaporation loss by increasing cumulative infiltration period (Narain and Singh, 1997).

Interaction effect of rainy-season crops and residue management practices on most growth parameters was found to be significant. Growing mustard after clusterbean and greengram, followed by pearlmillet with *Leucaena* twigs and crop residue mulching improved moisture and nutrient availability, and enhanced crop performance, whereas mulching effect on the micro-climatic variations was also dominant (Kumar *et al.*, 1992). The greater availability of soil moisture after legumes and crop residue mulching might be due to more shoot and root biomass addition due to the deep-rooted system and leaf litters of legumes, which consequently added more organic matter, and helped to hold more soil moisture, resulting in higher growth parameters. Adequate availability of water to plants resulted in cell turgidity and eventually high meristematic activity, leading to more foliage development, greater photosynthetic activity.

Table 4: Effect of crop residue and *Leucaena* twigs on crop growth indices of mustard after rainy-season crops in 2010-11 and 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
2010-11									
PM- NR	1.68	2.11	3.05	2.76	0.060	0.065	0.064	0.526	0.318
PM – CR	2.24	4.14	4.61	3.03	0.070	0.071	0.065	0.523	0.332
PM – LT	5.14	4.38	4.00	3.99	0.071	0.069	0.069	0.440	0.360
CB – NR	2.75	2.81	6.72	1.14	0.064	0.077	0.051	1.262	0.200
CB – CR	4.02	3.75	8.45	1.99	0.068	0.080	0.059	0.930	0.170
CB – LT	5.67	4.58	11.04	2.65	0.071	0.084	0.063	0.392	0.150
GG – NR	3.31	1.59	5.06	3.30	0.056	0.073	0.067	1.251	0.222
GG – CR	3.23	3.92	7.51	7.08	0.069	0.078	0.078	0.753	0.182
GG – LT	5.40	2.03	8.08	5.86	0.059	0.079	0.075	0.625	0.180
2011-12									
PM- NR	3.81	1.79	4.23	2.26	0.058	0.070	0.061	0.619	0.601
PM – CR	5.03	3.80	3.19	7.04	0.069	0.066	0.077	0.307	0.923
PM – LT	4.34	2.95	4.54	3.51	0.065	0.071	0.067	0.561	0.511
CB – NR	2.75	2.68	3.15	5.37	0.064	0.066	0.074	0.403	1.460
CB – CR	3.23	5.46	3.32	4.90	0.074	0.067	0.072	0.269	0.828
CB – LT	3.76	6.54	8.78	3.34	0.076	0.081	0.067	0.238	0.486
GG – NR	2.01	2.85	3.06	3.44	0.064	0.065	0.067	0.408	1.317
GG – CR	3.05	5.11	4.93	4.25	0.073	0.072	0.070	0.281	1.030
GG – LT	2.47	4.60	3.61	3.65	0.071	0.068	0.068	0.305	1.753

ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v4i1.33273

Crop growth rate (CGR), relative growth rate (RGR), and net assimilation rate (NAR) in mustard showed that higher values of these parameters were recorded under *Leucaena* twigs, followed by crop residue after clusterbean and greengram as preceding crops, and in between 30-60 DAS and 60-90 DAS (Table 4). In 2010-11, comparatively higher CGR occurred between 0-30 DAS, which might be because of the rain of 22 and 10 mm received within two to three weeks of sowing. However, in 2011-12, the initial moisture content of soil was very less due to high evaporation rate coinciding with high ambient temperature during October, 2011 and limited irrigation in crop-rows could not improve the growth of the crop. The profile soil moisture availability at flowering stages of mustard was directly influencing the CGR, RGR and NAR in mustard (Figure 1).

'Pusa Vijaya' cultivar of mustard tested in the experiment being drought and high temperature tolerant and indeterminate type and grown as rainfed, had followed no-definite trend in growth indices as observed in irrigated crops due to variable availability of soil moisture supplied through rainfall. *Leucaena* twigs and crop residues mulching plots recorded more soil moisture, and helped to augment growth more than no-residue. The rainfall received on February 2011 (49 mm) and on January 2012 (14 mm) helped to augment the CGR in later stage of growth since the crop was rejuvenated after getting soil moisture. Crop residue of most crops and *Leucaena* twigs in clusterbean provided relatively higher CGR, RGR and NAR than without residue and after greengram and clusterbean as preceding crops. This indicated that favourable soil environment could be obtained with the application of crop residue and preceding legume crops in mustard-based system. Several workers (Rathore *et al.*, 1998; Singh *et al.*, 2003, Ratore *et al.*, 2008) found higher crop growth rate and RGR with crop residue followed in legume–based systems.

Mustard yield attributes

Yield attributes of mustard as affected by preceding rainy-season crops and residue management practices are presented in Table 5. The effect of preceding crops on most of the yield attributes, except plant population m^{-2} at maturity in 2010-11, seeds siliqua^{-1} in 2011-12 and 1000-seed weight in both years showed significant variation. The legumes have greater effect on build-up of soil fertility and conserved soil moisture, which led to more yield attributes than pearlmillet as preceding crop. All major yield attributes, viz. plant population m^{-2} at maturity, primary branches plant^{-1}, siliquae plant^{-1} and 1000-seed weight were found to be significantly higher due to residue management. There was high rainfall (49 mm) during siliquae filling period of mustard on second week of February in 2011 which helped to augment growth and development of mustard siliquae. The soil moisture provided as row-irrigation was just enough for initiating germination and initial growth of mustard. There existed long drought period from September 2011 up to January first week 2012, and rainfall of 14 mm during January 2012 provided some relief on flowering and seed filling. Residue management practices exhibited significant variation on yield attributes of mustard, except seeds siliqua^{-1} in 2011-12. *Leucaena* twigs and crop residue mulching showed significant superiority over no-residue because of more conservation of soil moisture due to less evaporation and addition of more organic matter. However, branches plant^{-1} was found to be less at higher plant population. There existed wide space and more aeration, comparatively higher availability of soil moisture and nutrients due to less plant in no-residue plot. Singh *et al.* (2003) and Singh *et al.* (2008) found significant increase in yield attributes of mustard grown after clusterbean and greengram through crop residue after legume crops.

Journal of Agriculture and Natural Resources (2021) 4(1): 203-221
ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v4i1.33273

Table 5: Effect of crop residue and *Leucaena* twigs on yield attributes of mustard after rainy-season crops

Treat	2010-11					2011-12				
	Plants m^{-2} at maturity	Primary branches $plant^{-1}$	Siliquae $plant^{-1}$	Seeds $siliqua^{-1}$	1000-seed weight (g)	Plants m^{-2} at maturity	Primary branches $plant^{-1}$	Siliquae $plant^{-1}$	Seeds $siliqua^{-1}$	1000-seed weight (g)
Preceding crops (A)										
PM	23.2	9.45	377.7	13.8	4.41	14.9	10.1	228.9	9.13	4.46
CB	22.2	11.87	434.4	13.5	4.71	18.6	12.3	351.0	9.72	4.48
GG	21.8	12.11	452.6	15.3	4.51	17.1	12.3	276.3	10.0	4.32
LSD (P=0.05)	NS	0.55	33.0	1.03	NS	1.28	1.05	18.0	NS	NS
Residues management (B)										
NR	18.8	11.85	217.2	13.5	4.27	13.7	12.4	197.0	9.12	4.20
CR	22.8	10.11	474.8	14.2	4.67	19.6	10.7	339.0	9.80	4.46
LT	25.5	11.47	572.7	15.0	4.70	17.3	11.6	320.2	9.94	4.60
LSD (P=0.05)	2.14	0.55	33.0	1.03	0.32	1.28	1.05	18.0	NS	0.16
Interaction (A x B)										
PM – NR	21.0	9.95	161.3	12.8	4.34	11.3	11.0	177.4	8.28	4.34
PM – CR	23.0	8.70	383.8	14.5	4.42	19.0	9.5	265.2	9.60	4.60
PM – LT	25.5	9.70	588.0	14.3	4.48	14.5	9.8	244.1	9.53	4.44
CB – NR	18.3	12.75	241.8	13.1	4.17	16.3	13.0	217.1	9.30	4.14
CB – CR	23.5	10.25	531.5	13.4	4.88	19.5	11.0	382.5	9.63	4.39
CB – LT	24.8	12.60	530.0	13.9	5.07	20.0	13.1	453.5	10.03	4.92
GG – NR	17.3	12.85	248.5	14.6	4.30	13.5	13.2	196.6	9.83	4.12
GG – CR	22.0	11.38	509.1	14.7	4.70	20.3	11.8	369.4	10.28	4.40
GG – LT	26.3	12.10	600.2	16.8	4.54	17.5	11.9	262.9	10.03	4.44
LSD (P=0.05)	NS	NS	57.2	NS	NS	2.22	NS	31.1	NS	0.28

Interaction effect of crop residue and preceding crops was significant for siliquae $plant^{-1}$ in both years and plant population m^{-2} at maturity and 1000-seed weight in 2011-12 (Table 5). Clusterbean as previous crop with *Leucaena* twigs and greengram and pearlmillet with crop residue showed significantly higher plant population m^{-2} at maturity and 1000-seed weight in 2011-12, and siliquae $plant^{-1}$ in both years. *Leucaena* twigs and crop residue mulching resulted in higher yield attributes. Application of *Leucaena* twigs over two years in the fixed plots increased fertility status and moisture holding capacity, and thus maintained higher plant population m^{-2} (20.3) and 1000-seed weight (4.92 g) after clusterbean in 2011-12. The favourable improvement in yield attributes could be attributed to the influence of previous legume crops and organic mulches on growth parameters, finally leading to greater nutrient

Journal of Agriculture and Natural Resources (2021) 4(1): 203-221
ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v4i1.33273

uptake, efficient partitioning of metabolites and adequate accumulation of translocation of photosynthates. Adequate supply of moisture enhances the growth and dry matter production of crops directly and indirectly by increasing the availability and utilization of nutrients in dryland production (Tetarwal & Rana, 2006; Parihar *et al.*, 2010).

Mustard yield and their performance

Data on mustard yield and their performance (seed and stalk yields, and harvest index) due to preceding rainy-season crops and residue management practices are presented in Figure 2 and the relationship between mustard yield and major yield attributes have been presented in Figure 3.

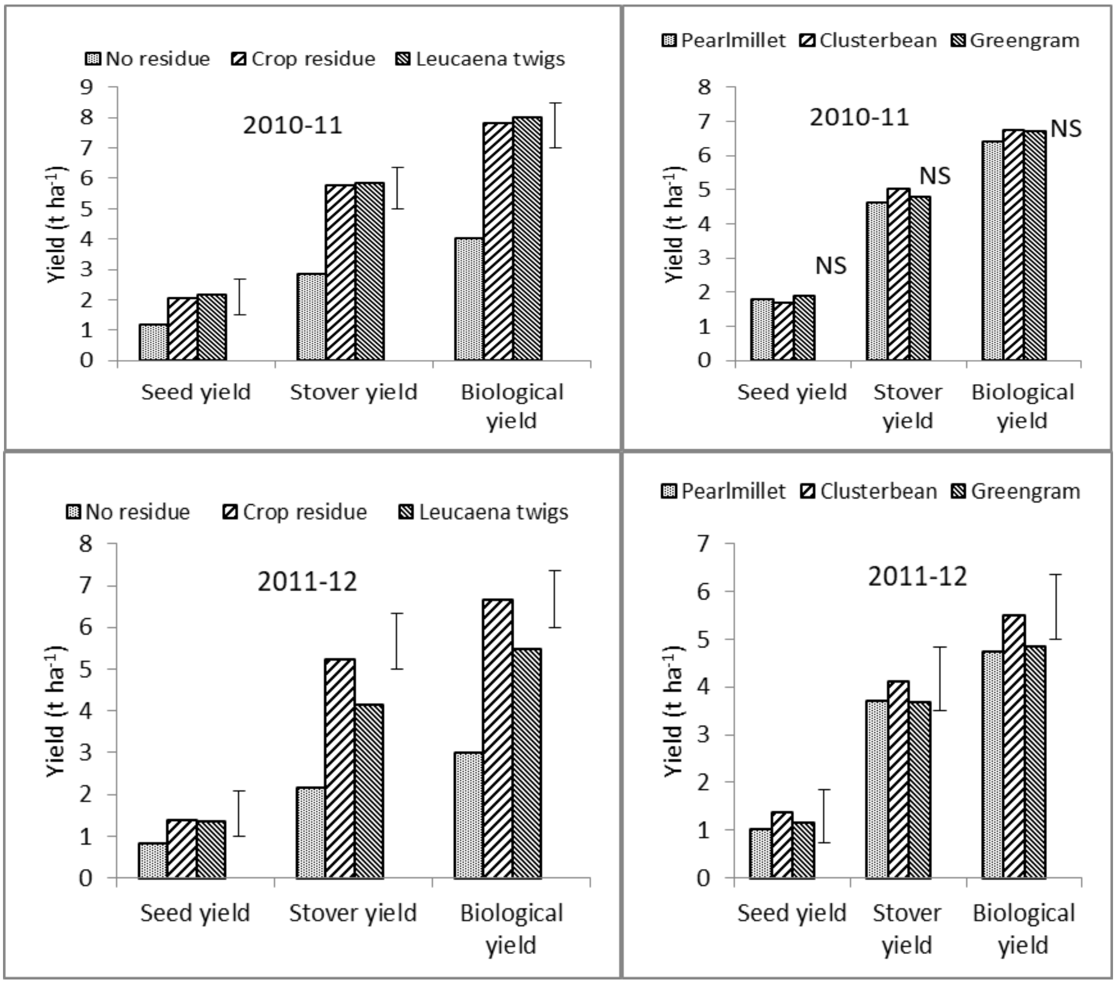

Figure 2: Yield performance of mustard as influenced by residue management and preceding rainy-season crops

The preceding crops has significant effect only in 2011-12, where clusterbean resulted in significantly higher seed and stalk yields followed by greengram and pearlmillet. The translocation of photosynthates could not be fairly expressed in sink, as a result, it remained non-significant in 2010-11. The physico-chemical properties of soil change slowly, and the effect of organic residue and legume crops becomes visible only after some years, depending on nature of soil, temperature and moisture status of the soil (Tisdale *et al.,* 1995) which might have happened in this experimentation too. Crop residues having high C: N ratio took more time to decompose, which in the first season did not add fertility to crop, but helped in conserving more amounts of moisture from rainfall and dew.

Journal of Agriculture and Natural Resources (2021) 4(1): 203-221
ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v4i1.33273

Table 6: Pooled analysis on seed yield of mustard (t ha^{-1}) as affected by year, preceding crops and residue management

Preceding crops	2010-11				2011-12				Overall mean
	NR	CR	LR	Mean	NR	CR	LR	Mean	
Pearlmillet	1.34	1.81	2.25	1.80	0.74	1.38	0.99	1.04	1.42
Clusterbean	0.74	2.11	2.29	1.71	0.96	1.26	1.93	1.38	1.55
Greengram	1.49	2.23	1.98	1.90	0.81	1.56	1.13	1.17	1.53
Mean	1.19	2.05	2.17		0.84	1.40	1.35	1.20	

	Year (A)	Preceding crop (B)	Residue (C)	A x B	A x C	B x C	A x B x C
LSD (P=0.05)	0.075	0.093	0.093	0.131	0.131	0.161	0.227

Interaction effect of preceding crops and residue management exerted significant variations on seed yield and harvest index of mustard in both years. Clusterbean with *Leucaena* twigs mulching resulted in significantly higher seed yield (2.29 t ha^{-1}), followed by pearlmillet with *Leucaena* twigs (2.25 t ha^{-1}) and greengram with crop residue (2.23 t ha^{-1}) in 2010-11. The same trend was also noticed in 2011-12. Crop residues showed significantly superior seed yield after pearlmillet and greengram as preceding crops over no-residue and *Leucaena* twigs in 2011-12. This could be attributed to higher availability of nutrients and moderate soil moisture provided by crop residues. Clusterbean-mustard system was found to be high yielding at Hisar than sole mustard-based system (Saxena *et al.*, 1997). Singh *et al.* (2008) working in semi-arid region of Rajasthan reported the superiority of organic mulching and leguminous system over the cereal-cereal system with and without residue.

Pooled analysis of mustard seed yield as affected by years, preceding crops and residue management is presented in Table 6. Results showed that there was significant effect of all production factors singly as well as in combination. There was 51% higher yield (1.80 t ha^{-1}) in 2010-11 than in 2011-12 (1.20 t ha^{-1}) due to favorable weather conditions experienced in the first year. There was only 14 mm rainfall throughout the growth period of mustard in 2011-12. Rainfall of 20 mm occurred on 13 March, 2012, which was much beneficial to the crop as the crop was nearing physiological maturity. There was fair distribution of rainfall throughout the mustard growing season in 2010-11, and the last rainfall received by crop in mid-February (49 mm) coincided with flowering and fruiting. Controlling evaporation by use of crop residue and increase in fertility status due to the decomposition of residue applied in previous season crops helped to maintain the yield over the *Leucaena* twigs and no-residue. Regression analysis between yields and major yield attributes of mustard revealed significant positive correlation between mustard yield with plant stand m^{-2} at maturity and number of siliquae plant^{-1}, but primary branches plant^{-1} was found non-significant during both years (Figure 3). The system yields of different nine rainfed cropping systems have also been reported (Amgain *et al.*, 2020).

ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v4i1.33273

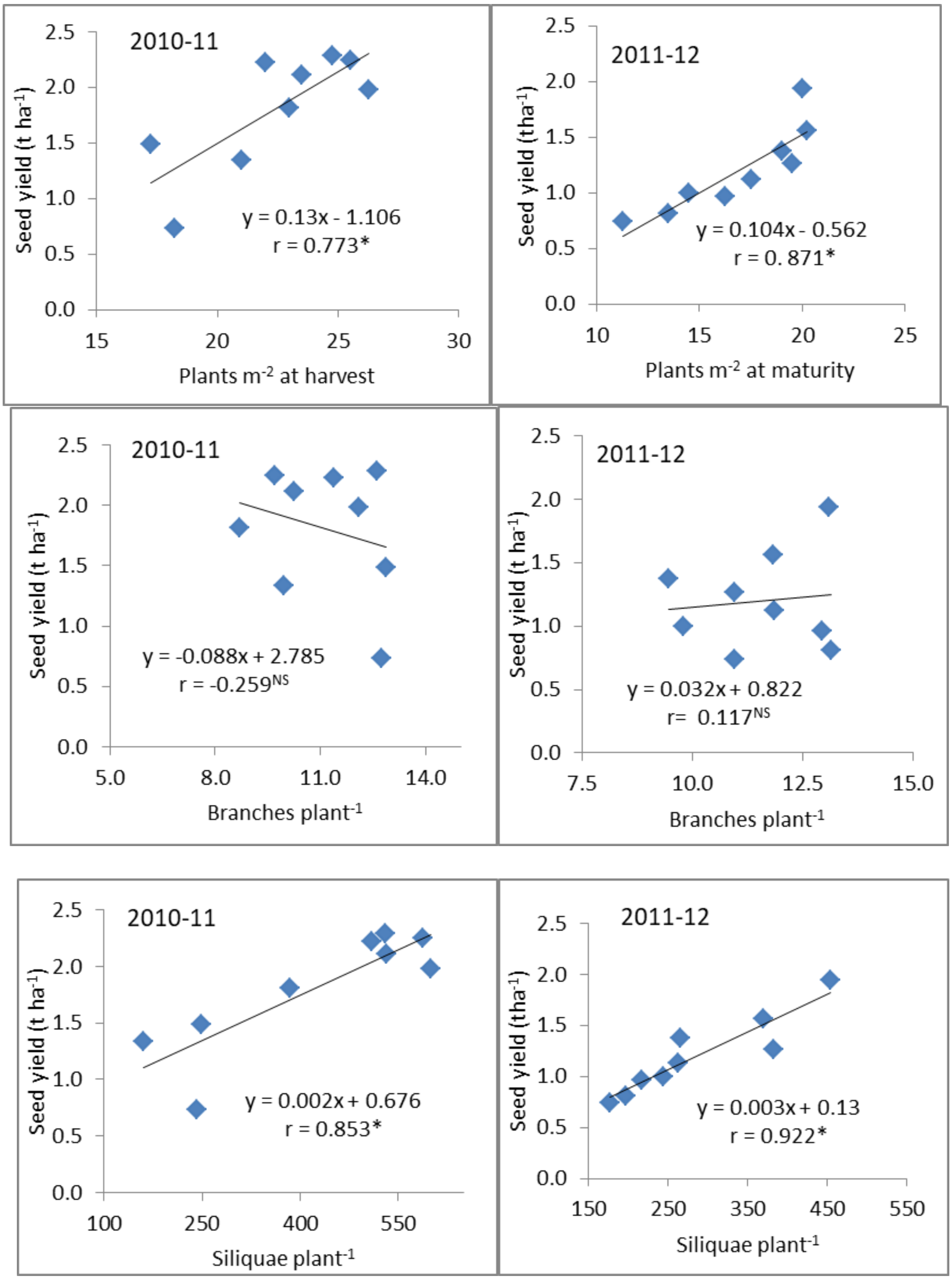

Figure 3: Regression and correlation of mustard yield (y) with their yield attributes (x)

Economic analysis in mustard

Economic analysis of mustard as influenced by preceding rainy-season crops and residue management revealed that cost of cultivation was relatively higher in 2011-12 than 2010-11, while the returns were almost half of that in 2011-12 (Table 7). The increase in production cost in 2011-12 was due to increase in labour wages by 33% of 2010-11 (IRs 250/ man-day) and other input costs). Though the output price was higher in 2011-12, it resulted comparatively less net returns due to lower yield. The crop residues have economic value and

ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v4i1.33273

addition of their market price in the estimation of production costs increased the total cost of cultivation than *Leucaena* twigs because it was freely available and only application costs were involved. The highest returns and net returns/ IRs invested were achieved under clusterbean with *Leucaena* twigs. Therefore, it can be concluded that growing mustard after clusterbean and greengram with crop residue and *Leucaena* twigs helped in improving profitability under zero-till semi-arid condition. These findings are in accordance with Amgain *et al.* (2019), Saxena *et al.* (1998); Singh *et al.* (2003); Singh *et al.* (2008).

Table 7: Effect of crop residue and *Leucaena* twigs on economics of mustard after rainy-season crops

Treatment	Cost of cultivation ($x10^3$ IRs ha^{-1})		Gross returns ($x10^3$ IRs ha^{-1})		Net returns ($x10^3$ IRs ha^{-1})		Net returns/ IRs invested	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Pearlmillet–no residue	10.23	14.26	26.12	19.91	15.89	5.65	1.55	0.40
Pearlmillet–crop residues	12.68	17.36	36.36	37.75	23.68	20.40	1.87	1.18
Pearlmillet–*Leucaena* twigs	11.73	16.26	44.37	27.05	32.64	10.79	2.78	0.66
Clusterbean–no residue	10.23	14.26	15.04	25.38	4.81	11.12	0.47	0.78
Clusterbean–crop residues	12.68	17.36	41.86	34.49	29.18	17.14	2.30	0.99
Clusterbean–*Leucaena* twigs	11.73	16.26	45.75	51.56	34.02	35.30	2.90	2.17
Greengram–no residue	10.23	14.26	29.19	21.34	18.96	7.08	1.85	0.50
Greengram–crop residues	12.68	17.36	44.21	42.21	31.53	24.85	2.49	1.43
Greengram–*Leucaena* twigs	11.73	16.26	39.27	30.60	27.54	14.35	2.35	0.88

Nutrient uptake in mustard

Nutrient uptake by mustard is presented in Table 8 and 9. Similar to seed and stalk yield, the uptake of N and K in seed, P uptake in stalk and total P-uptake were found significant due to the preceding rainy-season crops. Greengram as preceding crop, followed by clusterbean showed significant variation on N, P and K uptake. Legumes as preceding crop resulted in higher seed and stalk yield, and hence in uptake of NPK. Similarly, residue management showed significant variation in nutrient uptake with maximum values under crop residue management. Higher total uptake was due to higher dry matter production under crop residue treatment, followed by *Leucaena* twigs and no-residue. Interaction effect of preceding crops and residue management practices was found significant on nutrient uptake. The highest values on N, P and K uptake in seed and stalk under clusterbean and greengram as preceding crops were noticed. The magnitude of total nutrient uptake by mustard in 2010-11 was about 25% more than in 2011-12 due to higher seed and stalk yields. Significantly higher nutrient uptake with crop residue and *Lecuaena* twigs was due to higher growth, resulting in better yield over no-residue. There was poor growth in no-residue treatment; and therefore, nutrient uptake was also less than with residue application. The increased uptake of NPK under residue application could be attributed to greater availability of conserved soil moisture to the plants. The overall improvement in growth of mustard due to the effect of residue applied to previous legumes like clusterbean and greengram, and with *Leucaena* twigs could be ascribed to their pivotal role in several physiological and bio-chemical processes, viz. root development, photosynthesis, energy transformation (ATP and ADP) and symbiotic biological N_2 fixation processes and in protein synthesis (Tisdale *et al.*, 1995; Ali *et al.*, 2002; Singh *et al.*, 2003).

Journal of Agriculture and Natural Resources (2021) 4(1): 203-221
ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v4i1.33273

Table 8: Effect of crop residue and *Leucaena* twigs on nutrient uptake (kg ha^{-1}) in mustard after rainy-season crops in 2010-11

Treatment	N			P			K		
	Seed	Stover	Total	Seed	Stover	Total	Seed	Stover	Total
Preceding crops (A)									
Pearlmillet (PM)	44.2	18.0	62.2	5.03	8.18	13.21	12.74	55.7	68.4
Clusterbean (CB)	43.0	20.0	63.1	4.82	9.19	14.01	11.82	60.2	72.0
Greengram (GG)	48.0	19.7	67.7	5.41	9.23	14.65	13.24	58.2	71.5
LSD (P=0.05)	3.92	NS	NS	NS	0.78	0.98	NS	NS	NS
Residue management (B)									
No residue (NR)	29.6	11.7	41.3	3.47	5.62	9.09	8.43	34.8	43.2
Crop residue (CR)	51.2	22.7	73.9	5.73	10.33	16.06	14.21	69.1	83.4
Leucaena twigs (LT)	54.4	23.3	77.7	6.05	10.66	16.71	15.16	70.2	85.4
LSD (P=0.05)	3.92	2.01	4.86	0.60	0.78	0.98	1.31	5.22	6.00
Interaction (A x B)									
PM - NR	32.7	10.6	43.3	3.91	5.10	9.01	9.69	32.5	42.2
PM - CR	44.3	22.0	66.3	4.96	9.53	14.49	12.60	68.7	81.3
PM - LT	55.6	21.2	76.8	6.22	9.90	16.12	15.94	65.9	81.8
CB - NR	18.4	10.9	29.3	2.23	5.27	7.50	5.12	32.5	37.6
CB - CR	52.9	22.1	75.0	5.97	10.37	16.33	14.69	67.6	82.3
CB - LT	57.8	27.1	84.9	6.25	11.94	18.19	15.64	80.7	96.3
GG - NR	37.7	13.5	51.2	4.28	6.48	10.77	10.47	39.5	49.9
GG - CR	56.5	24.0	80.5	6.27	11.08	17.35	15.35	71.1	86.5
GG - LT	49.8	21.5	71.3	5.69	10.14	15.83	13.92	64.0	78.0
LSD (P=0.05)	6.80	3.48	8.42	1.05	1.35	1.70	2.27	9.04	10.4

Table 9: Effect of crop residue and *Leucaena* twigs on nutrient uptake (kg ha^{-1}) in mustard after rainy-season crops in 2011-12

Treatment	N			P			K		
	Seed	Stover	Total	Seed	Stover	Total	Seed	Stover	Total
Preceding crops (A)									
Pearlmillet (PM)	26.0	15.5	41.5	3.26	7.04	10.30	7.58	46.8	54.4
Clusterbean (CB)	35.2	17.7	52.9	4.30	7.76	12.06	9.95	50.7	60.7
Greengram (GG)	29.8	16.1	45.9	3.64	7.23	10.87	8.49	45.9	54.4
LSD (P=0.05)	2.49	NS	3.04	0.56	NS	0.81	0.86	NS	4.49
Residues management (B)									
No residue (NR)	21.3	9.32	30.7	2.70	4.26	6.96	6.14	26.9	33.1
Crop residues (CR)	35.4	22.3	57.6	4.36	9.98	14.34	10.10	65.3	75.4
Leucaena twigs (LT)	34.3	17.8	52.0	4.14	7.79	11.92	9.78	51.3	61.0
LSD (P=0.05)	2.49	1.97	3.04	0.56	0.63	0.81	0.86	4.31	4.49
Interaction (A x B)									
PM – NR	18.5	10.1	28.6	2.32	4.57	6.90	5.53	29.6	35.1
PM – CR	34.3	22.4	56.7	4.30	10.23	14.53	9.89	68.1	78.0
PM – LT	25.1	14.1	39.3	3.17	6.30	9.47	7.32	42.8	50.2
CB – NR	24.7	9.8	34.5	3.21	4.51	7.72	6.98	28.5	35.5
CB – CR	32.1	21.2	53.4	3.96	9.42	13.38	9.06	61.2	70.3
CB – LT	48.8	22.0	70.8	5.73	9.35	15.08	13.80	62.5	76.3
GG – NR	20.9	8.1	28.9	2.58	3.69	6.27	5.91	22.7	28.6
GG – CR	39.7	23.1	62.8	4.82	10.28	15.10	11.35	66.6	77.9
GG – LT	28.8	17.2	46.0	3.51	7.72	11.23	8.20	48.5	56.7
LSD (P=0.05)	4.31	3.41	5.27	0.97	1.09	1.49	1.50	7.46	7.79

ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v4i1.33273

CONCLUSION

It was concluded that root: shoot characteristics, growth parameters, yield and yield attributes, profitability and nutrient uptake in mustard were influenced significantly by preceding rainy-season crops and crop residue application. The effect of *Leucaena* twigs was found better in 2010-11, while both crop residues and *Leucaena* twigs mulching were equally effective in 2011-12. Clusterbean as preceding crop to mustard resulted in higher yield and net returns, followed by greengram and clusterbean with crop residues. It was suggested that mustard after clusterbean with *Leucaena* twigs was a high-yielding and profitable cropping systems under conservation-tilled semi-arid rainfed condition. The cropping system in Nepal are mostly rainfed and this sort of experimentation would be beneficial to increase the crop productivity, profitability and system sustainability.

ACKNOWLEDGEMENTS

The research is the part of PhD (Agronomy) manuscript of the first author at IARI, Pusa, New Delhi. Indian Council of Cultural Relations (ICCR), Government of India and Tribhuvan University, IAAS Rampur Campus, Chitwan, Nepal, are highly acknowledged for providing the financial assistance by the scheme of South Asian Association for Regional Co-operations (SAARC) Scholarship and granting the study leave to the first author, respectively.

Authors' Contributions

LPA planned to frame this compiled article as a principle researcher while, ARS helped in supervising the student as a major supervisor.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

REFERENCES

Acharya, C.L., Kapur, O.C., & Dixit, S.P. (1998). Moisture conservation for rainfed wheat production with alternative mulches and conservation tillage in hills of north-west India. *Soil and Tillage Research, 46,* 153–163.

Aggarwal, P., & Sharma, N.K. (2002). Water uptake and yield of rainfed wheat in relation to tillage and mulch. *Indian Journal of Soil Conservation*, *30*(2), 155–160.

Aggarwal, P., Chaudhary, K.K., Singh, A.K., & Chakraborty, D. (2006). Variation in soil strength and rooting characteristics of wheat in relation to soil management. *Geoderma, 136*, 353–363.

Ali, Masood, Ganeshsmurthy, A.N., & Srinivasan Rao, Ch. 2002. Role of pulses in soil health and sustainable crop prodcution. *Indian Journal of Pulse Research, 15* (2), 107–117.

Amgain, L. P., Sharma, A. R., Das, T. K., & Behera, U.K.(2013). Effect of residue management on productivity and economics of pearl millet (*Pennisetum glaucum)*-based cropping system under zero-till condition. *Indian Journal of Agronomy*, *58* (3),298-303.

ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v4i1.33273

Amgain, L. P. Sharma, A. R., Timsina, J., & Wagle, P. (2019). Water, nutrient, and energy use efficiencies of no-till rainfed cropping systems with or without residue retention in a semi-arid dryland area. *Global J. Agriculture and Allied Sciences,1*(1), 30-42. dx.doi.org.10.35251 giaas. 2019.004.

Bhagat, R.M., & Acharya, C.L. (1988). Soil water dynamics during wheat growth under different soil management practices. *Journal of Indian Society of Soil Science, 36,* 389–396.

Bhattacharyya, R., Ved Prakash, Kundu, S., Srivastva, A.K., & Gupta, H.S. (2009). Soil aggregation and organic matter in a sandy clay loam soil of the Indian Himalayas under different tillage and crop regimes. *Agriculture, Ecosystems and Environment*, *132*(1/2, 126–134.

Amgain, L. P., Sharma, A. R., Timsina, J., & Shrestha, J. (2020). Assessments of the productivity and profitability of diverse crops and cropping systems as influenced by conservation agriculture practices under a semi-arid rainfed environment of western India. *Anadolu Journal of Agricultural Sciences, 35*, 469-482. *Doi:10.7161/omuanajas.715749*

Box, J.E., & Ramseur, E.L. (1993). Mini-rhizotron wheat root data: comparisons to soil core root data. *Agronomy Journal*, *85*, 1058–1060.

Chassot, A., & Richner, W. (2002). Root characteristics and phosphorus uptake of maize seedlings in a bilayered soil. *Agronomy Journal*, *94*, 114–127.

Dhyani, S.K., Newaj, R., & Sharma, A.R. (2009). Agroforestry: its relation with agronomy, challenges and opportunities. *Indian Journal of Agronomy*, *54* (3), 259–266.

Faroda, A.S., Joshi, N.L., Singh, R., & Saxena, A. (2007). Resource management for sustainable crop production n arid-zone: a review. *Indian Journal of Agronomy, 52* (3), 181–193.

Gomez, K.A., & Gomez, A.A. 1984. *Statistical Procedures for Agricultural Research.* John Willley and Sons, NY.

Hobbs, P., Sayre, K., & Gupta, R. (2008). The role of conservation agriculture in sustainable agriculture. *Philosophical Transactions of the Royal Society*, *B 363*, 543–555.

Husnjak, S., Filipovic, D., & Kosutic, S. (2002). Influence of different tillage systems on soil physical properties and crop yield. *Rostlinna Vyroba*, *48*(6), 249–254.

Jat, M.L, Gathala, M.K., Ladha, J.K., Saharawat, Y.S., Jat, A.S, Sharma, S.K., Kumar, V., & Gupta, R. (2009). Evaluation of precision land leveling and double zero-till systems in the rice–wheat rotation: Water use, productivity, profitability and soil physical properties. *Soil and Tillage Research*, *105*, 112–121.

Kumar, K., Mavi, H.S., Khera, K.L., Singh, L., & Jhorar, O.P. (1992). Effect of shelterbelt, mulching and reflectant on field micro-climate yield of greengram (*Vigna radiata*) in south-west Punjab. *Annals of Agricultural Research*, *13*(4), 335–339.

Maurya, P.R., & Lal, R. (1980). Effect of no-tillage and ploughing on roots of maize and leguminous crops. *Experimental Agriculture*, *14*, 341–358.

Meena, J.R., & Behera, U.K. (2008). Tillage and residue management effects on performance of greengram (*Vigna radiata*) and carbon sequestration in maize–based cropping system. In: *Abstracts of 4th World Congress on Conservation Agriculture*. New Delhi, India.

Narain, P., & Singh, R.K. (1997). Erosion control and productivity through sunhemp mulching and green manuring, pp. 40–41. In: *Annual Report.* Central Soil and Water Conservation Research and Training Institute, Deharadun.

Parihar, C.M., Rana, K.S., & Kantwa, S.R. (2010). Nutrient management in pearlmillet (*Pennisetum glaucum*)–mustard (*Brassica juncea*) cropping system as affected by land configuration under limited irrigation. *Indian Journal of Agronomy, 55* (3), 191-196.

Prasad, R., Shivay, Y.S., Kumar, D., & Sharma, S.N. (2006). *Learning by Doing Exercises in soil Fertility - A Practical Manual for Soil Fertility,* pp. 1–68. Division of Agronomy, Indian Agricultural Research Institute, New Delhi.

Rathore, A.L., Pal, A.R, Sahu, R.K., & Chaudhary, J.L. (1996). On-farm rain-water and crop management for improving productivity of rainfed areas. *Agriculture Water Management, 31*, 253–267.

Rathore, A.L., Pal, A.R., & Sahu, K.K. (1998). Tillage and mulching effects 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*(2), 149–161.

Rathore, B.S., Rana, V.S., & Nanwal, R.K. (2008). Effect of plant density and fertility levels on growth and yield of pearlmillet (*Pennisetum glaucum*) hybrids under limited irrigation conditions in semi-arid environment. *Indian Journal of Agricultural Sciences, 78*(1): 667–670.

Reddy, T.Y., & Reddy, G.S.H. (2009). Principles of Agronomy. Kalyani Publishers, New Delhi.

Samra, J.S. (2002). Institutional innovation for enhancing income from rainfed agriculture, pp. 207–211. In: *Human Input on Desert Environment.* Eds. Narin, P., Kathja, S., Kar, A., Singh, M.P. and Kumar, P. Scientific Publishers, Jodhpur.

Saxena, A., Singh, D.V., & Joshi, N.L. (1997) Effects of tillage and cropping systems on soil moisture balance and pearlmillet yield. *Journal Agronomy and Crop Science, 178,* 251–257.

Saxena, A., Singh, D.V., & Joshi, N.L. (1998). Allelopathy in cropping and agroforestry systems of arid regions, pp. 187–198. In: Recent advances in management of arid ecosystem. Proceedings of a symposium held in India, March 1997.

Saxena, M.C. (2012). Challenges and opportunities for food legume research and development. Paper presented on the 6th M.S. Swaminathan Award Lecture at IARI, Pusa, New Delhi, January 25, 2012.

Sharma, A.R., Singh, R., & Dhyani, S.K. (2005). Conservation tillage and mulching for optimizing productivity in maize–wheat cropping system in the western Himalayan region. *Indian Journal of Soil Conservation, 33*(1), 35–53.

Sharma, A.R., Singh, R., Dhyani, S.K., & Dube, R.K. (2010). Moisture conservation and nitrogen recycling through legume mulching in rainfed maize (*Zea mays*)–wheat (*Triticum aestivum*) cropping system. *Nutrient Cycling in Agroecosystems, 87*(2), 187–197.

Sharma, P.K., & Acharya, C.L. (2000). Carry-over of residual soil moisture with mulching and conservation tillage practices for sowing of rainfed wheat (*Triticum aestivum*) in north-west India. *Soil and Tillage Research, 57*, 43–52.

Sidhu, H.S., Singh, M., Humphreys, E., Singh, Y., Blackwell, J., & Singh, S. (2007). The Happy Seeder enables direct drilling of wheat into rice stubble. *Aus. J. Exp. Agric., 47*, 844–854.

Singh, B.P., Mundra, M.C., & Gupta, S.C. (2003). Productivity, stability and economics of various cropping systems in semi-arid ecosystem. *Crop Research (Hisar), 25*(3), 472-477.

Journal of Agriculture and Natural Resources (2021) 4(1): 203-221
ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v4i1.33273

Singh, R., Singh, B., & Patidar, M. (2008). Effect of preceding crops and nutrient maangemetn on productivity of wheat (*Triticum aestivum*)–based cropping system in arid region. *Indian Journal of Agronomy, 53* (4), 267–272.

Singh, Ved, Sharma, S.K., Dev Ram, Siag, R. K., & Verma, B.L. (1998). Performance of different crops sequences under various irrigation levels. *Indian Journal of Agronomy, 35*, 287–296.

Tetarwal, J.P., & Rana, K.S. (2006). Impact of cropping system, fertility level and moisture-conservation practice on productivity, nutrient uptake, water use and profitability of pearlmillet (*Pennisetum glaucum*) under rainfed conditions. *Indian Journal of Agronomy, 51*(4), 263–266.

Tisdale, S.L., Nelson, W.L., Beaton, J.D., & Havlin, J.L. (1995). Soil Fertility and Fertilizers, 5th edition, pp. 62–75. Prentice Hall of India Pvt. Ltd., New Delhi.