



Tillage and Weed Management on Yield and Nutrient Uptake of Greengram under Maize-greengram Cropping System in Conservation Agriculture

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ABSTRACT

Background: The cropping systems in any agro-ecological zone in the globe are driven by a number of critical issues, including rising food demands, the depletion of land and the degradation of land resources. The goal of traditional cropping methods has been to maximise crop yields. Cropping systems that take into account the new social, economic and ecological or environmental considerations are urgently needed nowadays. Due to their adaptability to diverse cropping patterns and capacity to fix nitrogen, legumes can offer prospects for continuous increases in productivity. Legume-based crop rotations help to maintain of organic matter, increase of soil nitrogen, nutrient balance, maintenance of soil physical qualities and disruption of soil-borne disease cycles. Conservation tillage is centered on minimum tillage, permanent raised beds, zero tillage with low soil disturbance and the preservation of protective plant cover or plant residues on the soil surface to prevent soil losses, stimulate microbial population and retain moisture and nutrients.

Methods: Field experiment were conducted during 2019-20 and 2020-21 at the Main Research Station (MRS), GKVK, University of Agricultural Sciences, Bangalore On sandy loam soil to study the performance of Weed management in maize-based cropping system in conservation agriculture. The experiment was laid out under split plot design with five main plots on different tillage treatments *i.e.*, Conventional tillage, Zero Tillage, minimum tillage, minimum tillage and permanent raised bed and three sub plots of different weed management practices *i.e.*, Chemical weed management practices, Integrated weed management practices and unweeded control replicated thrice.

Result: Among tillage practices, permanent raised bed recorded the least total weed density and weed dry weight at harvest when compared to other tillage practices and also high seed yield, haulm yield and B: C ratio due to less weed infestation, good root growth, adequate aeration and nutrient availability compared to other tillage practices. Permanent raised beds had significantly higher nitrogen, phosphorus and potassium uptake than zero tillage. Among weed, management practices, Integrated weed management (Pendimethalin-750 g/ha (PE) + Hand weeding at 30 DAS) recorded the least total weed density and weed dry weight at harvest compared to unweeded treatment and also high seed yield, haulm yield and B: C ratio due to less weed infestation, compared to unweeded treatment. Integrated weed management resulted in significantly higher nitrogen, phosphorus and potassium uptake compared to unweeded (control).

Key words: Minimum tillage, Nutrient uptake, Permanent raised bed, Weed management, Yield, Zero tillage.

INTRODUCTION

Greengram, also known as mung bean, is a tiny, spherical legume with a green exterior. It is among the most widely eaten pulses, particularly in Asian nations like China, India and Southeast Asia. Warm-season crops like greengram are usually grown in tropical and subtropical climates. It needs moderate rainfall and grows best in sandy loam soils with good drainage. It is a great crop for intercropping or rotation because of its quick maturation period-roughly 60 to 75 days. Once cooked, the beans have a delicate texture and a hint of sweetness. Rich in dietary fibre, protein and vitamins (particularly B vitamins), greengram are also a great source of important minerals like potassium, magnesium and iron. Because it is low in calories and fat, it is a great food to keep a healthy diet.

High protein content

For vegetarians and vegans in particular, this is a great plant-based source of protein. High in Fibre, Promotes a healthy digestive tract and facilitates digestion. Comprised

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of antioxidants, which aid in shielding cells from harm resulting from free radical damage. Low Glycaemic Index, Helps regulate blood sugar levels, making it suitable for diabetics). Cardiovascular health, by controlling blood pressure, the magnesium and potassium components of this food promote heart health. A healthy and adaptable legume, green gram are simple to include in a wide range of recipes. It is a valuable food source all over the world because of its health benefits and versatility in different cuisines.

In order to maximise crop productivity, quality and profitability, weed control is crucial in the cultivation of greengram, often known as mung beans. Unchecked weed growth can result in considerable reductions in greengram yields. According to studies, the amount of green gram yield that weeds can lower can range from 30% to 80%, depending on the type of plant and the extent of the infestation. When weeds are controlled effectively, the crop is given access to the resources it needs to reach its maximum yield potential. Some types of weeds can have deep roots, which over time can deplete soil moisture and nutrients and cause degradation of the soil. Since they may grow again from their roots or rhizomes, weeds like nut grass and Bermuda grass are especially difficult to entirely remove. Certain weed species may become resistant to frequently used herbicides in the absence of appropriate weed management. Future weed control may become more difficult and expensive as a result, since resistant weeds could need stronger pesticides or other, frequently more expensive, treatments. Because uncontrolled weeds require more labour, equipment, or herbicide applications, production costs are increased. By reducing production and quality, they also lessen the crop's overall profitability. The reduction of these financial losses by efficient weed control increases the sustainability and profitability of greengram farming. In greengram, weed control is essential to maintaining crop profitability, quality and output. Efficient weed control techniques enhance the overall prosperity of greengram farming by mitigating resource rivalry, averting pest and disease issues and preserving soil quality.

Under conventional agricultural systems, principle indicator of non-sustainability is soil erosion and declining of soil organic matter as mainly caused by: heavy field traffic induced degradation of soil structure, water and wind erosion leading to poor infiltration rate, crusting of soil surface, soil compaction, poor recycling of organic materials and also monocropping (Swaminathan *et al.*, 2022). Due to reduced tillage activity, soil compaction get decrease, soil micro flora activity get increase. It is helpful for the higher nutrient availability and improves soil structure by secreting sticky organic substances. So soil aeration, moisture retention capacity also improve Selvakumar and Sivakumar, (2021). Crop rotation has to be followed in conservation agriculture like cereals followed by pulses or deep root followed by shallow rooted crops etc. It helped to avoid the depletion of single nutrient from the same depth of soil and also it was highly helpful for the restoration of

nutrient in case of growing legume crop in rotation (Negi and Rana, 2016). Moreover as organic matter is lesser in most of the Indian soils, conservation agriculture plays a vital role in soil and water conservation compared to zero tillage. Mostly farmers are not aware of this technology due to lesser level of communication through extension activities (Podder *et al.*, 2017).

MATERIALS AND METHODS

The field experiment was carried out in the *rabi* of 2019 and 2020 at the Main Research Station (MRS), GKVK, University of Agricultural Sciences, Bangalore to examine the impact of various weed control and tillage practices on weed occurrence, growth characteristics, yields, nutrient uptake and economics of greengram. Which focuses on weed management and soil properties. The soil at the experiment's site was a sandy loam with a pH of 6.34 and low organic carbon (0.34%). The experiment comprised 5 main plot treatments (tillage practices) and 3 sub-plot treatments (weed management practices), replicated thrice. The tillage practices consisted of zero tillage, minimum tillage, minimum tillage + zero tillage (zero tillage + minimum tillage) and permanent raised bed (15.0 m length $\times$ 0.8 m width). The weed management practices consisted of Recommended herbicides (Pendimethalin-750 g ha⁻¹ (PE) *fb* imazethpyr 75 g/ha at 20 DAS) (W₁), Integrated weed management (Pendimethalin-750 g ha⁻¹ (PE) + Hand weeding at 30 DAS) (W₂) and Unweeded (W₃).

The greengram (KKM-3) was sown at a spacing of 30 cm³ 10 cm. Fertilizer level of 25 kg N, 50 kg P₂O₅ and 25 kg K₂O ha⁻¹ was applied as per the recommendation, all the fertilizers were given as basal dose only. Irrigation was given at intervals of 10-15 days. The pre-emergence (one day after sowing) and post-emergence (20-25 days after sowing) herbicides were applied using a spray volume of 750 litres per ha and 500 liters per ha with a knapsack sprayer with a single standard flat fan nozzle. The data on species wise weed count in a quadrant of 50 cm $\times$ 50 cm were recorded at 30, 60 DAS (days after sowing) and at harvest. Data were averaged over three replications. From density of major weed species per m² and density of weeds -wise sedges, grass and broad leaf weeds at harvest were worked out. In addition, total dry weight was also recorded at harvest. The data on weeds density and dry weight were subjected to square root transformation ($x+0.5$) depending on the variability and weed index was calculated by using the formula suggested by Gill and Kumar (1969). Leaf area index was calculated at 60 DAS by using the below formula given by Watson (1947). The LI-3100C is a rugged bench-top instrument was used for calculating leaf area. The LI-3100C records the area of individual leaves and quickly computes cumulative area for a group of leaves, making it easy to compare treatments or experimental groups.

$$LAI = \frac{\text{Leaf area of plant}}{\text{Ground area covered by plant}}$$

The data collected on different traits were statistically analyzed using the standard procedure and the results were tested at a five per cent level of significance as given by Gomez and Gomez (1984). The least significant differences were used to compare treatment means.

RESULTS AND DISCUSSION

Weed density and weed dry matter

Major weed flora observed in the experimental plots were *Cyperus rotundus* (from initial stage-among sedges) *Cynodon dactylon*, *Digitaria marginata*; (among grasses). Whereas, among broad leaf weeds, major weeds were *Commelina benghalensis*, *Alternanthera sessilis*, *Spillanthus acmella*, *Euphorbia geniculata*, *Leucas aspera* and *Ageratum conyzoides*, were dominant till 90 days after sowing. Among different tillage practices, permanent raised beds recorded significantly lower total weed density at 30 DAS 60.0 m², at 60 DAS 46.4 m² and at harvest 49.4 m² as compared to zero tillage at 30 DAS 97.0 m², at 60 DAS 76.7 m² and at harvest 77.6 m². Addition of crop residue as mulch in permanent raised beds can cause a remarkable reduction in weed density and encourage the emergence and establishment of seedlings, as well as improve plant growth and reduce the density and growth of weeds in permanent raised beds. Similar results were observed by Murphy *et al.* (2006) and Nichols *et al.* (2015). In weed management practices integrated weed management (Pendimethalin 750 g ha⁻¹ PE + Hand weeding at 30 DAS) resulted in significantly lower total weed density at 30 DAS 70.3 m², at 60 DAS 55.3 m² and at harvest 56.2 m², when compared to unweeded (control) at 30 DAS 101.9 m², at 60 DAS 80.5 m² and at harvest 81.4 m² (Table 1). Integrated weed management it could be because there was less crop weed competition when hand weeding was used in the beginning. Similar finding were noticed by (Sunitha and Kalyani, 2012; Kumar *et al.*, 2012; Samanth *et al.*, 2015; Singh *et al.*, 2015; Barad *et al.*, 2016).

Permanent raised beds recorded significantly lower total dry weight of weeds at 30 DAS 5.41 g m⁻², at 60 DAS 6.31 g m⁻² and at harvest 6.30 g m⁻². Significantly higher weed dry weight were observed under zero tillage at 30 DAS 7.73 g m⁻², at 60 DAS 9.31 g m⁻² and at harvest 9.09 g m⁻². Among weed management practices Integrated weed management (Pendimethalin 750 g ha⁻¹ PE + Hand weeding at 30 DAS) resulted in significantly lower total dry weight of weeds at 30 DAS 6.12 g m⁻², at 60 DAS 7.13 g m⁻² and at harvest 6.88 g m⁻² when compared to unweeded (control) at 30 DAS 7.97 g m⁻² at 60 DAS 9.33 g m⁻² and at harvest 9.09 g m⁻² (Table 2). Lower weed density in permanent raised beds, might be associated with lower penetration resistance provided by loose soil aided proper emergence and establishment of seedlings, as well as improved plant growth due to superior soil physical conditions in permanent raised beds. These findings are consistent with those of Gopinath *et al.* (2007) and Baskaran and Kavimani (2014), who found that weed density and dry

weight were significantly lower in conventional tillage and significantly higher in zero tillage in wheat and sunflower.

Nutrient uptake of crop

The nutrient uptake of greengram at harvest was significantly influenced by tillage and weed management strategies. Permanent raised beds (42.6, 12.1 and 41.54 kg N, P₂O₅ and K₂O ha⁻¹, respectively), had significantly higher nitrogen, phosphorus and potassium uptake than zero tillage (34.5, 28.1 and 9.2 kg N, P₂O₅ and 35.54 K₂O ha⁻¹, respectively) (Table 3). Nutrient uptake is the total uptake (seed+haulm) of nutrients by the crop. Similar results were noticed by Powlson *et al.* (2011); Fraser *et al.* (2013); Busari *et al.* (2015) and Guzzetti *et al.* (2020).

Weed management practices had a significant impact on the nutrient uptake of greengram at harvest. Integrated weed management (45.9, 12.4 and 46.30 kg N, P₂O₅ and K₂O ha⁻¹, respectively) resulted in significantly higher nitrogen, phosphorus and potassium uptake compared to unweeded (control) (24.3, 6.1 and 24.7 kg N, P₂O₅ and K₂O ha⁻¹, respectively) (Table 3). Maximum nitrogen, phosphorus and potassium uptake in greengram is generally recorded with application of pendimethalin at 0.75 kg ha⁻¹ followed by hand weeding at 30 DAS, which significantly increased the nutrient uptake as compared to weedy control (Komal *et al.*, 2015). This is in agreement with the findings of Gaikwad *et al.* (2009; Kade *et al.* (2014; Komal *et al.* (2015); Lal *et al.* (2017) and Muthuram *et al.*, (2018).

Microbial population and enzyme activities

Among the different tillage practices tested zero tillage recorded significantly higher population of bacteria, fungi and actinomycetes (35.5 × 10⁵, 22.9 × 10⁴ and 14.4 × 10³ CFU g soil⁻¹, respectively) and increased soil microbial biomass carbon and nitrogen (445.5 µg g soil⁻¹ and 37.4 µg g soil⁻¹, respectively) when compared to minimum tillage and conventional tillage (21.6 × 10⁵, 12.3 × 10⁴ and 9.7 × 10³ CFU g soil⁻¹, 334.7 µg g soil⁻¹ and 18.2 µg g soil⁻¹, respectively) (Table 4). As a result of improved microbial population, zero tillage also had much higher activity of urease, dehydrogenase and total (26.1 µg NH₄-N g soil⁻¹ hr⁻¹, 179.2 µg TPF g soil⁻¹ 24 hr⁻¹ and 174.4 g PNP g soil⁻¹ hr⁻¹, respectively) compared to minimum tillage and conventional tillage (16.3 µg NH₄-N g soil⁻¹ hr⁻¹, 94.9 µg TPF g soil⁻¹ 24 hr⁻¹ and 148.0 g PNP g soil⁻¹ hr⁻¹, respectively) (Table 5).

Compared to integrated weed management (26.5 × 10⁵, 16.2 × 10⁴ and 11.8 × 10³ CFU g soil⁻¹, 401.7 µg g soil⁻¹ and 27.8 µg g soil⁻¹, respectively), unweeded (control) practice had significantly higher populations of bacteria, fungi and actinomycetes (28.0 × 10⁵, 17.3 × 10⁴ and 12.6 × 10³ CFU g soil⁻¹, respectively) and increased soil microbial biomass carbon and nitrogen (420.3 µg g soil⁻¹ and 29.2 µg g soil⁻¹, respectively) (Table 4). Unweeded (control) practice had significantly higher activity of urease, dehydrogenase and total phosphatase (23.1 µg NH₄-N g soil⁻¹ hr⁻¹, 142.9 µg TPF g soil⁻¹ 24 hr⁻¹ and 171.9 g PNP g

Table 1: Effect of tillage and weed management practices on total weed density in greengram.

Treatments	Total weed density (no. m ⁻²)							
	30 DAS				60 DAS			
	2019	2020	Pooled		2019	2020	Pooled	At harvest
Tillage practices (T)								
T ₁ = Conventional tillage (CT)	14.0 (69.7)	17.5 (111.2)	15.8 (90.4)		14.1 (73.1)	15.1 (77.7)	14.6 (75.2)	14.4 (75.1)
T ₂ = Zero tillage (ZT)	14.6 (74.7)	18.2 (119.4)	16.4 (97.0)		14.1 (70.7)	15.6 (82.8)	14.8 (76.7)	15.0 (77.4)
T ₃ = Minimum tillage (MT)	13.8 (68.2)	17.0 (106.9)	15.4 (87.4)		13.4 (63.4)	14.4 (71.1)	13.9 (67.2)	14.4 (70.9)
T ₄ = Zero tillage (ZT)	13.4 (63.2)	16.1 (97.9)	14.7 (80.4)		13.5 (64.1)	13.2 (59.2)	13.4 (61.6)	13.7 (65.4)
T ₅ = Permanent bed (PB)	11.0 (46.8)	13.8 (71.4)	12.4 (60.0)		11.0 (43.6)	12.0 (49.3)	11.5 (46.4)	13.8 (66.1)
SEM $\pm$	0.168	0.130	0.134		0.136	0.052	0.080	12.0 (49.8)
LSD (P=0.05)	0.527	0.423	0.406		0.408	0.171	0.242	11.9 (49.1)
Weed management practices (W)								0.048
W ₁ = Recommended herbicide- Pendimethalin-750 g ha ⁻¹ (PE) + fb tembotrione 120 g ha ⁻¹ + atrazine 500 g ha ⁻¹	13.5 (63.6)	16.1 (95.3)	14.8 (79.4)		12.7 (57.6)	13.8 (65.9)	13.2 (61.6)	0.156
W ₂ = IWM - Pendimethalin 750 g ha ⁻¹ PE + Hand weeding at 30 DAS	13 (58.4)	14.7 (82.3)	13.8 (70.3)		12.1 (52.3)	13.0 (58.5)	12.6 (55.3)	13.7 (65.7)
W ₃ = Unweeded control	15 (77.5)	18.8 (126.5)	16.9 (101.9)		15.4 (81.5)	15.4 (79.7)	15.4 (80.5)	12.4 (54.3)
SEM $\pm$	0.202	0.105	0.139		0.162	0.058	0.096	15.6 (83.5)
LSD (P=0.05)	0.535	0.278	0.412		0.434	0.152	0.288	15.3 (79.5)
Interaction (T x W)								0.081
SEM $\pm$	0.405	0.211	0.292		0.336	0.115	0.210	0.215
LSD (P=0.05)	NS	NS	NS		NS	NS	NS	0.163
								0.164
								NS
								NS
								0.152
								NS

Table 2: Effect of tillage and weed management practices on total weed biomass in greengram.

Treatments	Total weed biomass (g/m ²)								
	30 DAS		60 DAS		At harvest		Pooled		
	2019	2020	Pooled	2019	2020	Pooled			
Tillage practices (T)									
T ₁ = Conventional tillage (CT)	2.85 (7.68)	2.81 (7.46)	2.83 (7.57)	2.79 (7.51)	3.33 (10.6)	3.06 (9.07)	2.91 (7.96)	3.20 (9.78)	3.06 (8.87)
T ₂ = Zero tillage (ZT)	2.88 (7.83)	2.84 (7.61)	2.86 (7.73)	2.81 (7.23)	3.44 (11.3)	3.13 (9.31)	2.85 (7.63)	3.32 (10.5)	3.09 (9.09)
T ₃ = Minimum tillage (MT)	2.88 (7.82)	2.62 (6.41)	2.75 (7.12)	2.68 (6.54)	3.26 (10.1)	2.97 (8.35)	2.73 (6.99)	3.12 (9.30)	2.93 (8.16)
T ₄ = Zero tillage (ZT)	2.87 (7.77)	2.45 (5.57)	2.66 (6.68)	2.60 (6.50)	2.95 (8.25)	2.78 (7.38)	2.71 (6.90)	2.81 (7.41)	2.76 (7.16)
T ₅ = Permanent bed (PB)	2.36 (6.93)	2.08 (3.90)	2.22 (5.41)	2.44 (5.62)	2.74 (7.03)	2.59 (6.31)	2.62 (6.42)	2.58 (6.19)	2.60 (6.30)
SEm±	0.016	0.029	0.015	0.064	0.016	0.028	0.016	0.017	0.013
LSD (P=0.05)	0.048	0.096	0.045	0.192	0.052	0.084	0.053	0.056	0.040
Weed management practices (W)									
W ₁ = Recommended herbicide -pendimethalin-750 g ha ⁻¹ (PE)+ fb tembotrione 120 g ha ⁻¹ + atrazine 500 g ha ⁻¹	2.86 (7.67)	2.53 (5.95)	2.70 (6.81)	2.69 (6.67)	3.11 (9.27)	2.90 (7.97)	2.75 (7.08)	2.97 (8.43)	2.86 (7.76)
W ₂ = IWM - Pendimethalin 750 g ha ⁻¹ PE + Hand weeding at 30 DAS	2.55 (7.54)	2.25 (4.69)	2.40 (6.12)	2.64 (5.16)	2.95 (8.42)	2.80 (7.13)	2.61 (6.33)	2.80 (7.43)	2.71 (6.88)
W ₃ = Unweeded control	2.90 (8.04)	2.89 (7.93)	2.90 (7.97)	2.77 (7.77)	3.37 (10.9)	3.07 (9.33)	2.94 (8.12)	3.24 (10.0)	3.09 (9.09)
SEm±	0.026	0.023	0.020	0.046	0.018	0.022	0.026	0.028	0.022
LSD (P=0.05)	0.078	0.060	0.060	0.116	0.046	0.066	0.068	0.075	0.067
Interaction (T × W)									
SEm±	0.033	0.046	0.032	0.082	0.035	0.042	0.052	0.057	0.045
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 3: Effect of tillage and weed management practices on nutrient uptake by greengram (grain + haulm).

Treatments	Nutrient uptake by crop (kg/ha)							
	N				P			
	2019	2020	Pooled		2019	2020	Pooled	
Tillage practices (T)								
T ₁ = Conventional tillage (CT)	37.6	39.2	38.4		10.3	11.3	10.8	38.01
T ₂ = Zero tillage (ZT)	34.2	34.7	34.5		8.8	9.6	9.2	35.92
T ₃ = Minimum tillage (MT)	33.6	34.0	33.8		8.2	8.9	8.5	36.08
T ₄ = Zero tillage (ZT)	31.9	32.7	32.3		7.4	8.3	7.9	33.35
T ₅ = Permanent bed (PB)	42.4	42.8	42.6		11.8	12.5	12.1	34.54
SEm±	1.1	1.2	0.8		0.65	0.66	0.46	41.85
LSD (P=0.05)	3.5	3.8	2.3		2.11	2.14	1.38	1.09
Weed management practices (W)								
W ₁ = Recommended herbicide -pendimethalin-750 g ha ⁻¹ (PE)+ fb tembotrione 120 g ha ⁻¹ + atrazine 500 g ha ⁻¹	37.1	40.4	38.7		9.8	11.4	10.6	38.97
W ₂ = IWM - Pendimethalin 750 g ha ⁻¹ PE + Hand weeding at 30 DAS	48.9	42.9	45.9		12.9	12.0	12.4	50.11
W ₃ = Unweeded control	21.9	26.7	24.3		5.2	7.0	6.1	22.76
SEm±	0.95	1.24	0.78		0.39	0.28	0.24	1.09
LSD (P=0.05)	2.80	3.65	2.23		1.14	0.84	0.69	3.21
Interaction (T × W)								
SEm±	1.83	2.00	2.21		1.12	1.14	0.96	1.88
LSD (P=0.05)	NS	NS	NS		NS	NS	NS	NS

Table 4: Soil microbial parameters 15 days after application of herbicide in green gram (*rab*) as influenced by different tillage and Weed management practices.

Treatments	Bacteria ($\times 10^5$ CFU g soil $^{-1}$)				Fungi ($\times 10^4$ CFU g soil $^{-1}$)				Actinomycetes ($\times 10^3$ CFU g soil $^{-1}$)				Microbial biomass carbon (μ g g soil $^{-1}$)				Microbial biomass nitrogen (μ g g soil $^{-1}$)			
	2019	2020	Pooled		2019	2020	Pooled		2019	2020	Pooled		2019	2020	Pooled		2019	2020	Pooled	
Tillage practices (T)																				
T ₁	21.2	21.9	21.6		12.1	12.6	12.3		9.6	9.9	9.7		328.7	340.8	334.7		17.6	18.7	18.2	
T ₂	35.0	36.0	35.5		22.4	23.4	22.9		14.2	14.6	14.4		437.4	453.5	445.5		36.3	38.6	37.4	
T ₃	25.3	26.0	25.7		15.4	16.1	15.8		11.8	12.1	12.0		391.0	405.4	398.2		23.8	25.4	24.6	
T ₄	25.4	26.2	25.8		16.3	17.0	16.7		12.7	13.1	12.9		400.6	415.4	408.0		25.9	27.6	26.7	
T ₅	23.8	24.5	24.2		13.2	13.8	13.5		10.4	10.7	10.6		426.9	442.5	434.7		31.1	33.1	32.1	
SEm $\pm$	1.01	1.03	0.72		0.84	0.87	0.60		0.43	0.44	0.31		9.31	10.38	6.97		1.14	1.25	0.84	
LSD (P=0.05)	3.30	3.37	2.17		2.73	2.84	1.81		1.40	1.45	0.92		30.36	33.85	20.90		3.70	4.07	2.53	
Weed management practices (W)																				
W ₁	24.8	25.5	25.1		15.0	15.6	15.3		11.1	11.4	11.3		383.6	397.7	390.6		25.6	27.2	26.4	
W ₂	26.1	26.9	26.5		15.8	16.5	16.2		11.7	12.0	11.8		394.5	408.9	401.7		27.0	28.7	27.8	
W ₃	27.5	28.4	28.0		16.9	17.6	17.3		12.5	12.8	12.6		412.7	428.0	420.3		28.3	30.1	29.2	
SEm $\pm$	0.72	0.74	0.52		0.51	0.53	0.37		0.35	0.36	0.25		6.09	6.26	4.37		0.59	0.63	0.43	
LSD (P=0.05)	2.13	2.19	1.48		1.50	1.56	1.05		1.03	1.07	0.72		17.96	18.48	12.48		1.75	1.85	1.23	
Interaction (T $\times$ W)																				
SEm $\pm$	1.76	1.79	1.71		1.45	1.51	1.33		0.74	0.77	0.78		10.76	11.26	12.11		1.13	1.19	1.29	
LSD (P=0.05)	NS	NS	NS		NS	NS	NS		NS	NS	NS		NS	NS	NS		NS	NS	NS	

soil¹ hr⁻¹, respectively) than integrated weed management (21.9 µg NH₄-N g soil⁻¹ hr⁻¹, 136.2 µg TPF g soil⁻¹ 24 hr⁻¹ and 163.5.0 g PNP g soil⁻¹ hr⁻¹, respectively) (Table 5). Higher soil enzymatic activity under NT than CT were attributed to an increase in soil organic carbon fractions, microbial C and N and soil enzymes. Similar findings were reported by (Balota *et al.*, 2004; Panettieri *et al.*, 2013; Alvaro-Fuentes *et al.*, 2013; Das *et al.*, 2018, Lal *et al.*, 2019).

Table 5: Soil enzymatic activities 15 days after application of herbicide in green gram (*ragi*) as influenced by different tillage and weed management practices.

Treatments	Urease activity (µg NH ₄ -N g soil ⁻¹ hr ⁻¹)			Dehydrogenase activity (µg TPF g soil ⁻¹ 24 hr ⁻¹)			Total phosphatase activity (µg PNP g ⁻¹ hr ⁻¹)		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
Tillage practices (T)									
T ₁	16.0	16.5	16.3	93.0	96.7	94.9	146.0	150.0	148.0
T ₂	25.7	26.5	26.1	175.7	182.7	179.2	172.1	176.7	174.4
T ₃	21.4	22.0	21.7	113.7	118.2	116.0	159.6	163.9	161.8
T ₄	20.3	20.9	20.6	115.7	120.4	118.0	161.7	166.0	163.9
T ₅	24.6	25.3	25.0	169.4	176.2	172.8	166.9	171.4	169.1
SEm±	0.70	0.72	0.50	5.15	6.13	4.00	4.62	4.91	3.37
LSD (P=0.05)	2.28	2.34	1.50	16.79	19.99	12.00	15.07	16.02	10.11
Weed management practices (W)									
W ₁	20.5	21.1	20.8	126.9	132.0	129.4	152.9	157.0	155.0
W ₂	21.6	22.3	21.9	133.5	138.8	136.2	161.3	165.6	163.5
W ₃	22.7	23.4	23.1	140.1	145.7	142.9	169.6	174.2	171.9
SEm±	0.54	0.55	0.39	2.54	2.62	1.82	3.78	3.63	2.62
LSD (P=0.05)	1.59	1.63	1.10	7.49	7.71	5.21	11.16	10.70	7.49
Interaction (T × W)									
SEm±	1.21	1.24	1.22	3.15	3.36	4.56	3.62	3.73	5.33
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 6: Effect of tillage and weed management practices on haulm yield, seed yield and economics of greengram.

Treatments	Seed yield (t ha ⁻¹)			Haulm yield (t ha ⁻¹)			B:C ratio		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
Tillage practices (T)									
T ₁ = Conventional tillage (CT)	0.83	0.78	0.80	2.33	2.21	2.27	1.47	1.18	1.33
T ₂ = Zero tillage (ZT)	0.78	0.74	0.76	2.29	2.11	2.20	1.47	1.26	1.37
T ₃ = Minimum tillage (MT)	0.77	0.72	0.74	2.37	2.16	2.26	1.46	1.25	1.36
T ₄ = Zero tillage (ZT)	0.74	0.71	0.72	2.31	2.11	2.21	1.43	1.25	1.34
T ₅ = Permanent bed (PB)	0.90	0.87	0.88	2.50	2.26	2.38	1.49	1.38	1.44
SEm±	0.030	0.015	0.022	0.039	0.033	0.025	-	-	-
LSD (P=0.05)	0.10	0.050	0.061	0.126	0.107	0.076	-	-	-
Weed management practices (W)									
W ₁ = Recommended herbicide -pendimethalin-750 g ha ⁻¹ (PE) + <i>fb</i> tembotrione 120 g ha ⁻¹ + atrazine 500 g ha ⁻¹	0.84	0.80	0.82	2.51	2.43	2.47	1.46	1.26	1.36
W ₂ = IWM - Pendimethalin 750 g ha ⁻¹ PE + Hand weeding at 30 DAS	1.07	0.90	0.98	2.99	2.36	2.67	1.53	1.37	1.45
W ₃ = Unweeded control	0.51	0.59	0.55	1.58	1.72	1.65	1.40	1.17	1.29
SEm±	0.02	0.012	0.016	0.041	0.033	0.026	-	-	-
LSD (P=0.05)	0.05	0.040	0.041	0.121	0.099	0.075	-	-	-
Interaction (T × W)									
SEm±	0.04	0.02	0.03	0.07	0.06	0.07	-	-	-
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	-	-	-

Yield

Conservation tillage practices influenced greengram seed and haulm yields significantly. Permanent raised beds exhibited considerably greater seed yield, haulm yield, greengram (0.88 and 2.38, t ha⁻¹) than zero tillage (0.76 and 2.20, t ha⁻¹) (Table 6). The increased seed yield in permanent raised beds might be due to higher soil moisture in permanent raised beds than in conventional tillage. These findings are in agreement with Singh and Singh (2010) and Saad *et al.* (2015).

Significantly higher seed and haulm yield were recorded in integrated weed management (0.98 and 2.67, t ha⁻¹) as compared to unweeded (0.55 and 1.65, t ha⁻¹) (Table 4). It could be attributed to the application of pendimethalin 0.75 kg ha⁻¹ as pre-emergence followed by one hand weeding which was effective in managing weeds in greengram and resulting in superior growth and yields attributes, viz. plant height, dry weight of nodules, dry matter accumulation, number of pods per plant, seeds per pod and seed yield in greengram. These results are similar to earlier research by (Choudhary *et al.*, 2012; Komal *et al.*, 2015; Nagender *et al.*, 2015 and Kaur *et al.*, 2016).

Economics

When compared to conventional tillage 2.65 and zero tillage 2.75, permanent raised beds had higher B: C ratio 2.82. Unweeded (control) had lower B:C ratio 2.08 than integrated weed management 3.16 (Table 6).

CONCLUSION

In the maize-green gram-maize cropping system under conservation agriculture, permanent raised beds and integrated weed management practices realised higher net returns and B:C ratios and also managed the agro-ecosystem for improved and sustained productivity compared to other tillage and weed management practices. The present study revealed that most practical weed control strategy for both weed control and sustainability in crop productivity was integrated weed management.

Conflict of interest

All authors declare that they have no conflicts of interest.

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