PLANT SCIENCE TODAY
Vol 12(sp2): 01–07
https://doi.org/10.14719/pst.5228

eISSN 2348-1900

RESEARCH ARTICLE

Growth, yield and profitability of green gram (*Vigna radiata* L.) as impacted by different tillage practices

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Received: 23 September 2024; Accepted: 07 February 2025; Available online: Version 1.0: 30 June 2025

Cite this article: Sharma H, Saini A, Kumar D, Rana BB, Suman S, Upadhyay RG, Sahoo C, Barwant MM, Bhardwaj B, Yadav N. Growth, yield and profitability of green gram (*Vigna radiata* L.) as impacted by different tillage practices. Plant Science Today. 2025;12(sp2):01–07. https://doi.org/10.14719/pst.5228

Abstract

Tillage practices significantly influence the growth, yield and economic viability of green gram (*Vigna radiata* L.). A field experiment was conducted during the *kharif* season of 2023 in Baru Sahib (sub-temperate region) of Himachal Pradesh, India, to evaluate the impact of different tillage systems on green gram productivity. The experiment was laid out in a randomized block design with six treatments: conventional tillage, conservation tillage with straw application, zero tillage, furrow-raised bed, stubble mulch tillage and minimum tillage without residue. The results demonstrated that conventional tillage significantly enhanced crop performance, recording the highest emergence count, pod length, seed number pod^{-1} and pod number plant^{-1}, leading to the highest grain and straw yield, biological yield and net economic returns. Conservation and minimum tillage without residue produced statistically similar results to conventional tillage, suggesting their potential as sustainable alternatives. Whereas, zero tillage exhibited the lowest values across all parameters. Economic analysis revealed the highest net returns and benefit-cost ratio under conventional tillage, whereas zero tillage recorded the lowest profitability. These findings suggest that while conventional tillage remains optimal for maximizing green gram yield and profitability, conservation tillage with strategic residue management could be a sustainable alternative. Future research should focus on the long-term implications of conservation tillage on soil health, nutrient dynamics and resource-use efficiency in green gram production systems.

Keywords: minimum tillage; nutrient uptake; root growth; tillage practice

Introduction

Green gram (*Vigna radiata* L.), a key short-duration and drought-tolerant pulse crop, is predominantly indigenous to India and widely cultivated across Southeast Asia and the Indian subcontinent. Belonging to the Fabaceae family, it is recognized for its high nutritional value, with seeds containing approximately 25 % protein, making it a significant source of high-quality plant-based protein (1). It is eaten as whole and split pulses and is an essential addition to a vegetarian diet high in cereal. The mung dal *khichdi* is suitable for ill or aged people as it is easily edible. India contributes 70 % of the world's production in mung bean (2). In India, it was farmed on 166.1 M ha in 2021-2022, yielding about 263.9 M t of grain with a productivity of about 158.8 q ha^{-1}(3). In contrast, it was produced on 154.0 hectares in the state of Himachal Pradesh in 2022-2023, producing roughly 77.0 tons of grains overall and 5.0 q of productivity per hectare (4).

Tillage practices are pivotal in agricultural systems, influencing soil health, crop growth and overall farm productivity. Inappropriate ploughing, however, can lead to significant negative impacts, including accelerated erosion of soil structure, depletion of soil fertility and nutrients and disruption of plant-water-nutrient interactions. Proper management of tillage techniques can mitigate these effects by alleviating edaphic constraints (5). Conversely, excessive or improper tillage often results in adverse outcomes, such as reduced soil integrity and long-term productivity losses (6). Conventional tillage methods alter soil composition and structure, frequently weakening the soil's resilience. In contrast, conservation tillage methods, including zero-tillage and minimum tillage, offer sustainable alternatives by preserving soil structure and enhancing biological functions (7).

The adoption of conservation agriculture (CA) is increasingly recognized as a strategy to reduce production costs, specifically the substantial 30 % energy input required for field preparation and crop establishment. Zero-tillage and minimum-tillage practices are more efficient, cost-effective and environmentally friendly than traditional methods, promoting timely planting and vigorous germination using residual soil moisture [8-10]. Additionally, the strategic application of mulch in these systems has been shown to enhance water-use efficiency, suppress weed infestation and improve crop yields (11). Weed competition for nutrients, water and light, a critical challenge in green gram/mungbean cultivation, can also be mitigated through appropriate mulch management (12).

The principles of conservation agriculture emphasize using cover crops, implementing more efficient farming techniques and adopting controlled traffic to minimize soil compaction and degradation (13). Despite the evident advantages, limited research has been conducted to identify optimal tillage methods for green gram under varying conditions. Considering the significance of tillage practices in influencing soil health, crop performance and profitability, this study evaluated the growth, yield and economic viability of green gram under different tillage practices.

Materials and methods

Experimental site

The research was conducted at the Eternal University Research Farm (30˚ 75` N latitude, 77˚ 29`E longitude), Baru Sahib, Himachal Pradesh, India, during the Kharif season of 2023 (July to October). The farm is located at an altitude of 1900 m above sea level. The experimental site falls under the sub-temperate zone of Himachal Pradesh (Fig. 1).

Weather conditions

During the green gram growing season, the crop received an average cumulative rainfall of 235.1 mm, adequate to support critical growth stages such as germination and pod development. The mean weekly maximum and minimum temperatures ranged between 31 °C and 16 °C and 14 °C and 2 °C, respectively. These temperatures were conducive to the vegetative and reproductive phases, with the highest temperatures observed in September promoting early growth and the cooler conditions in October favouring pod filling and maturation. The average relative humidity during the cropping period fluctuated between 45 % and 80 %, which provided

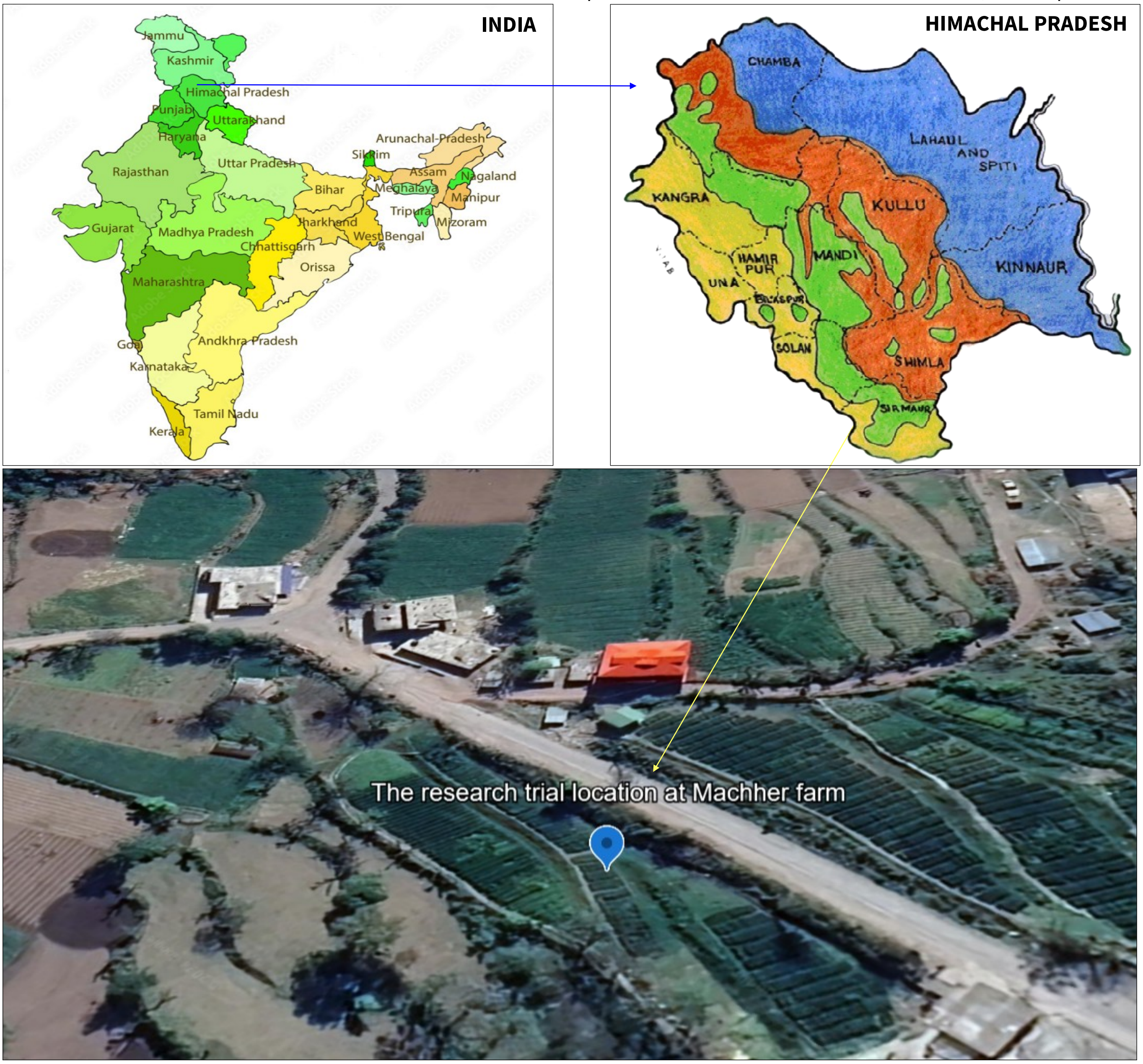

Fig. 1. Geographical location of experiment site.

favourable moisture conditions for plant development and minimized excessive evapotranspiration stress (Fig. 2).

Experimental design and management of crop

The present experiment was laid out in randomized block design with four replications to study the effect of different tillage practices on the growth, yield and productivity of mung bean. The experiment included Conventional tillage (T_1), Conservation tillage with straw at 3 t ha^{-1} (T_2), Zero tillage (T_3), Furrow raised bed (T_4), Stubble mulch tillage (T_5) and Minimum tillage without residue (T_6). The study location was classified as medium for available nitrogen (363.8 kg ha^{-1}), phosphorous (20.0 kg ha^{-1}) and potassium (185.5 kg ha^{-1}), with a sandy loam texture and an alkaline character. The ascorbic acid blue color method, flame photometer method and Micro-Kjeldahl's techniques were employed to ascertain the experimental sites' relative contents of potassium, phosphorus and nitrogen (14-16).

The application of the inorganic fertilizers urea, Single Super Phosphate (SSP) and Muriate of Potash (MOP) followed the suggested nutrient doses (20:40:20). The full supply of potassium, phosphorus and nitrogen was given at the time of sowing. In the plots with zero tillage and conservation tillage, wheat straw was used as a mulch at 3 t ha^{-1}. In plots with zero tillage, glyphosate was applied to remove off-season weeds. Weeds were controlled in the green gram field by applying Pendimethalin at 1.5 kg ha^{-1}. The green gram crop was cultivated using the regular planting dates and suggested methods, arranged 30 x 20 cm apart. Data on numerous parameters related to growth, yield and yield components were recorded using standardized techniques such as grain and straw yield, pod length, number of seed pod^{-1} emergence count, number of pods plant^{-1}, harvest index and biological yield. The analysis of variance (ANOVA) method and the statistical application OPSTAT were used to investigate the data, as explained by (17).

Results and Discussion

Emergence count

The data on green gram emergence count, recorded at 15 DAS and 30 DAS under different tillage treatments, indicate no significant variation in emergence across the treatments throughout the observation period (Table 1). The conventional tillage treatment showed a statistically greater emergence count at 15 DAS. This was followed by conservation and minimum tillage without residue treatment. In the zero-tillage treatment, emergence count was observed to be numerically lower. In the zero-tillage condition, the emergence count at 15 DAS was reported to be lower. Similar results for the emergence count have been reported at 30 DAS. The conventional tillage treatment showed a greater emergence count at 30 DAS, whereas the zero-tillage condition showed a lower emergence count. At the same time, lower values recorded in the zero-tillage treatment may be related to increased soil compaction, which reduced the root growth and nutrient absorption and ultimately resulted in a lower value of emergence count, higher values recorded in the application of traditional tillage treatment may be justified by improved soil aeration, increased soil moisture content and ideal growing conditions. Similar results were reported (18, 19).

Pod length

The analysis of various tillage techniques revealed a significant impact on the pod length of green gram, with conventional tillage producing the longest pods (Table 2). This treatment was significantly similar to conservation and minimum tillage without residue treatment. There were reports of significantly shorter pod lengths in the zero-tillage treatment. The reason behind the higher values of pod length seen with conventional tillage could be that tillage activities facilitate optimal root development and air exchange by loosening the soil and increasing porosity. The plants can absorb water & nutrients from ample soil profile due to their increased root development, which fortifies crop establishment and lengthens pods. Similar results indicating higher values of green gram pod length under conventional tillage were also reported by several co-workers (20-22).

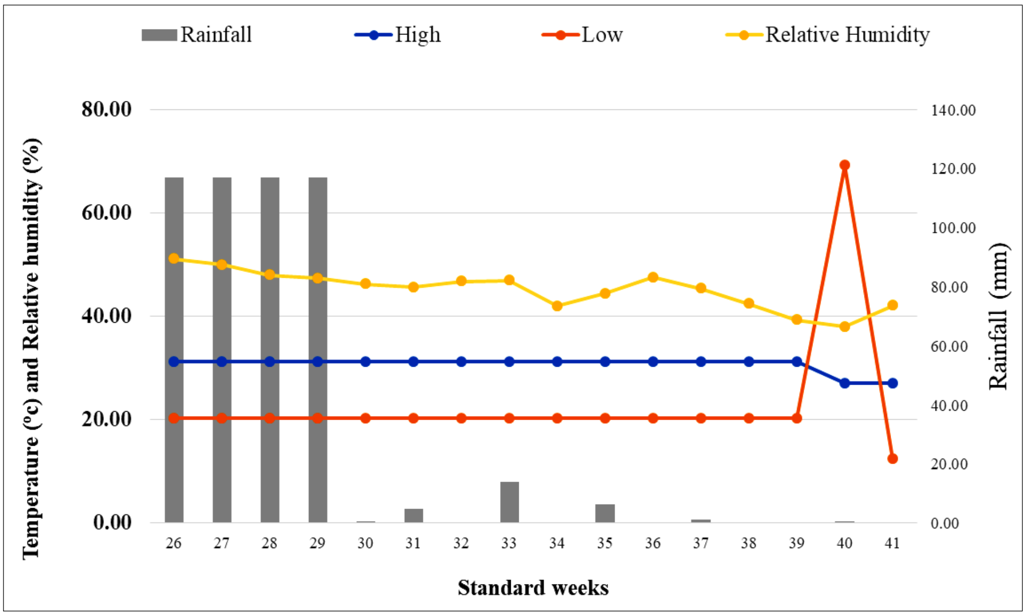

Fig. 2. Mean weekly meteorological data at Maccher during July 2023 to October 2023.

Table 1. Impact of tillage practices of emergence count (m^{-1} row length) of mung bean

Treatment	Emergence count	
	15 DAS	30 DAS
Conventional tillage	48.5	28.2
Conservation tillage	47.5	27.5
Zero tillage	44.5	23.2
Furrow raised bed	46.0	24.7
Stubble mulch tillage	46.2	26.0
Minimum tillage - residue	47.2	27.0
SEm±	1.20	3.32
CD (P = 0.05)	NS	NS

Table 2. Effect of tillage practices on yield attributes of mung bean

Treatment	Pod length (cm)	No. of seed pod^{-1}	No. of pods $plant^{-1}$
Conventional tillage	9.55	10.8	48.7
Conservation tillage	9.47	10.5	48.1
Zero tillage	8.12	8.7	34.7
Furrow raised bed	8.45	9.1	39.6
Stubble mulch tillage	8.75	10.0	44.5
Minimum tillage - residue	9.05	10.1	46.4
SEm±	0.30	0.32	1.87
CD (P = 0.05)	0.92	0.98	5.65

Number of seed pod^{-1}

Upon close examination of the data, it is evident that tillage techniques significantly influenced the number of seed pod^{-1} (Table 2). A significant increase in number of seed pod^{-1} was reported in conventional tillage, which was followed by conservation tillage treatment. Conversely, lower number of seed pod^{-1} was reported in zero tillage treatment. The higher number of seeds pod^{-1} reported in traditional tillage can be ascribed to improved chemical and physical characteristics such as reduced bulk density and increased nutrient availability and uptake. The lower number of seeds pod-1 was reported in zero tillage due to poor growth of roots, which results in lower nutrient availability and uptake and ultimately in lower no. of seeds pod^{-1}. Similar findings were documented in previous studies (20-22).

Number of pods $plant^{-1}$

Upon close examination of the data, it was evident that the different tillage methods significantly affected the number of pods $plant^{-1}$ (Table 2). The pod number $plant^{-1}$ produced by zero tillage was significantly lower, while significantly higher values were noticed in conventional tillage, which was statistically equivalent to the conservation tillage treatment. Conversely, a much higher pod number of $plant^{-1}$ was noticed in conventional tillage. Zero tillage operations resulted in poor root growth and soil compaction, which in turn caused poor yield, growth and nutrient absorption, as was previously discussed in the discussion of the zero-tillage treatment. Improved soil physical and chemical characteristics, enhanced crop growth and enhanced macro- and micronutrient availability due to enhanced field aeration all contributed to higher values of this parameter under traditional tillage. Also, higher values of this parameter under conservation tillage were assumed to be caused by the addition or assimilation of crop residue. This occurred due to the agricultural residue's breakdown, increasing macro - and micronutrient availability, which improved growth. The addition of residue also enhanced the organic state of the soil, which increased growth by creating a steadier hydration schedule for the growing season. Similar results were reported by (20-22).

Grain yield

An overview of how different tillage methods affect the grain yield of mung bean found that productivity was significantly impacted by tillage practices (Table 3 and Fig. 3). Conventional tillage, for instance, yielded a significantly higher grain yield than conservation tillage and minimum tillage without residue treatment. There was a noticeable decrease in the output of mung bean with zero tillage. Under traditional tillage, higher values of contributing qualities or increased grain yield could result from yield components. Soil becomes softer due to tillage operations in traditional tillage, which also improves soil's physical and chemical characteristics, promotes better root development and creates a more favourable environment for crops by being loose and having low porosity. Increased root growth contributed to increased nutrient extraction from the soil, improving treatment-related growth and yield. Lower values were seen in the zero-tillage condition, which may be related to the minimal tillage practices used in this treatment, which caused soil compaction, poor root development and reduced plant nutrient uptake, all contributing to subpar growth and give-in. Similar outcomes indicating higher values under conventional tillage have been documented (21-36)

Straw yield

A significant impact on this parameter was found by analyzing the data on how tillage practices affected the yield of mung bean straw (Table 3 & Fig. 3). Conventional tillage produces a considerably higher yield of straw. Conservation and minimum tillage without residue treatment yield much less straw than conventional tillage. Conventional tillage practices have been shown to promote greater root growth, nutrient uptake and photosynthetic efficiency, leading to increased straw yields compared to zero-tillage methods. The reduced yields observed with zero-tillage may be attributed to hindered root development, limited nutrient availability and decreased nutrient absorption. These findings align with previous research (27-33) reporting higher straw yields under conventional tillage conditions.

Biological yield

The effects of different tillage systems on biological yield showed that the zero-tillage condition produced a significantly lower biological yield, while conventional tillage treatment reported a higher yield (Table 3). This treatment was considerably equal to conservation tillage. Higher yield in conventional tillage can be ascribed to the increased soil aeration, which results in superior root development and greater nutrient availability and absorption, resulting in faster initial growth and heightened photosynthetic activity. Similar results in the case of conventional tillage were documented (23, 36).

Harvest index

The effects of different tillage strategies on the harvest index found that the zero-tillage condition produced a harvest index significantly lower than all other treatments tested (Table 3). Conventional tillage produced a higher harvest index similar to conservation tillage and minimum tillage without residue treatment. The higher harvest index in conventional tillage might be due to an adequate supply of nutrients during the blossoming and maturity phases, which results in the optimal transfer of photosynthates to the economic component (grain), resulting in a better value of the harvest index.

Table 3. Effect of tillage practices on yield (kg ha^{-1}) of mung bean

Treatment	Grain yield	Straw yield	Biological yield	Harvest index (%)
Conventional tillage	1854	3575	5432	34.2
Conservation tillage	1792	3520	5312	33.7
Zero tillage	1076	2903	3979	27.0
Furrow raised bed	1229	2982	4282	30.2
Stubble mulch tillage	1335	3010	4345	30.7
Minimum tillage - residue	1578	3276	4855	32.4
SEm±	52	106	130	0.90
CD (P = 0.05)	157	320	392	2.80

Economics

The economic feasibility of the various treatments was determined by computing the economic indices, which indicated that the gross returns followed a trend similar to grain yield (Table 4). The treatments with traditional tillage yielded the highest gross returns, followed by those with conservation and minimum tillage-residue treatment, & the treatments with zero tillage yielded the lowest gross returns. An agricultural business's net profit is its return on investment after all production expenses have been subtracted. The best net return is achieved by conventional tillage, similar to conservation tillage, minimum tillage - residue treatment and stubble mulch tillage. The lowest net return is obtained from zero tillage. Several workers reported similar results with conventional tillage, showing higher net return values (37, 38). The net return per rupee invested is displayed by the B: C ratio, which assesses the effectiveness of each treatment on the crop.

Table 4. Effect of tillage practices on economics (INR ha^{-1}) of mung bean

Treatment	Cost of cultivation	Gross returns	Net returns	B: C ratio
Conventional tillage	41470	109140	67670	1.63
Conservation tillage	41070	105628	64558	1.57
Zero tillage	37970	65000	27030	0.7
Furrow raised bed	40570	77439	36869	0.91
Stubble mulch tillage	41070	79448	38378	0.93
Minimum tillage - residue	39070	93384	54314	1.39

Conventional tillage methods consistently exhibited a higher B: C ratio than zero tillage practices throughout the study period. Conversely, zero tillage demonstrated the lowest B: C ratio, primarily attributed to a reduction in crop yield without a commensurate decrease in cultivation expenses. Similar results have been reported in previous studies by (39-41).

Conclusion

This study concluded the significant influence of tillage practices on green gram emergence, growth, yield and economic returns. Conventional tillage consistently showed superior performance across all measured observations. The improved performance under conventional tillage is attributed to enhanced soil aeration, better root growth and increased nutrient uptake, which collectively contributed to improved crop establishment and yield. Conservation tillage and minimum tillage without residue treatment also showed results similar to conventional tillage, indicating their potential as sustainable alternatives. However, zero tillage resulted in significantly lower values for all observations, primarily due to increased soil compaction, restricted root development and limited nutrient availability. Economic analysis further indicated the benefits of conventional tillage, as it recorded the highest net returns and benefit-cost ratio. In contrast, zero tillage exhibited the lowest profitability due to reduced crop yields. Future research should focus on refining conservation tillage techniques by integrating strategic residue management to improve soil fertility.

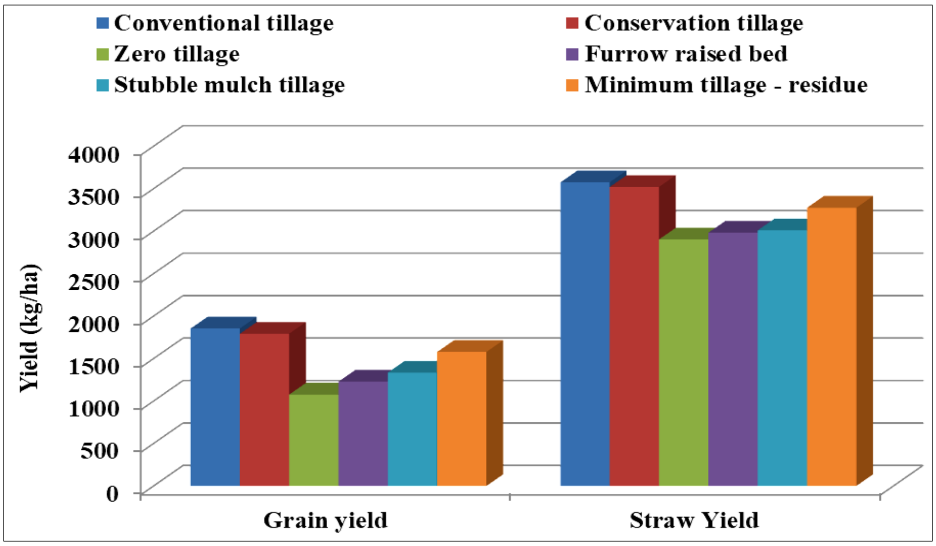

Fig. 3. Effect of tillage practices on grain yield and straw yield of mung bean.

Acknowledgements

The authors feel privileged to thank the Head, Department of Agronomy, Eternal University, Baru Sahib, Sirmaur H.P. and major advisor for providing the financial support and technical guidance to undertake experiment.

Authors' contributions

HS, AS and DK performed the experiments AS, DK and BB designed the research. HS, AS, BBR, MMB and BB wrote the manuscript. BBR, SS and RGU revised and corrected the manuscript. HS, AS, CS and MMB have done analysis of manuscript. MMB, NY and BBR corrected the whole plagiarism of manuscript. All authors have contributed for different sections of writing, reviewing, correction and statistical analysis. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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