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Integrated Effects of Tillage and Sunflower–Mung Bean Intercropping on Weed Management and Productivity

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Abstract

This study aimed to evaluate the integrated effects of tillage practices and sunflower–mung bean intercropping on weed suppression, crop productivity, and land-use efficiency in a semi-arid environment. A field experiment was conducted at Faisalabad using two tillage systems (deep tillage and conventional tillage) combined with sole sunflower and sunflower–mung bean intercropping arrangements. Weed density and weed dry biomass were recorded at different crop growth stages, while yield attributes of sunflower and mung bean, along with land equivalent ratio (LER), were used to assess system productivity. Results showed that deep tillage significantly reduced weed density (23.4 plants m^{-2}) and weed dry biomass (118.6 g m^{-2}) compared with conventional tillage (31.7 plants m^{-2} and 156.8 g m^{-2}, respectively). Intercropping sunflower with mung bean further enhanced weed suppression, lowering weed density to 21.8 plants m^{-2} and weed dry biomass to 110.4 g m^{-2} compared with sole sunflower. The combined effect of deep tillage and sunflower–mung bean intercropping produced the highest sunflower seed yield (3.28 t ha^{-1}), representing a 27% increase over sole sunflower under conventional tillage (2.58 t ha^{-1}). Although the sole sunflower produced a higher individual crop yield, intercropping systems demonstrated superior overall productivity. The sunflower–mung bean intercropping system with double-row sunflower at 90 cm spacing and three rows of mung bean achieved the highest land-use efficiency (LER = 1.68), followed by sunflower at 60 cm intercropped with two rows of mung bean (LER = 1.66). Overall, the study demonstrates that integrating deep tillage with sunflower–mung bean intercropping is a sustainable agronomic strategy that enhances weed suppression, improves land productivity, and reduces reliance on chemical weed control.

Keywords: Tillage, Intercropping, Weed suppression, Sunflower yield, Land Equivalent Ratio.

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1. Introduction

Sunflower (Helianthus annuus L.), a member of the family Compositae (Asteraceae), is one of the world's most important oilseed crops, ranking fourth after soybean, rapeseed, and groundnut (Petcu et al., 2010). It is valued for its high-quality oil rich in essential fatty acids and vitamins A, D, E, and K. Despite its importance, Pakistan remains heavily dependent on edible oil imports due to insufficient domestic production, highlighting the need to promote high-yielding oilseed crops such as sunflower to enhance national oil security (Adeleke & Babalola, 2020).

In Pakistan, traditional oilseed sources include rapeseed, mustard, sesame, linseed, groundnut, and castor bean, while sunflower, safflower, and soybean are non-traditional sources. Although rapeseed and mustard contribute 11–13% of edible oil production, their high erucic acid and glucosinolate contents limit consumption. Cotton contributes 55–60% of total oil production, but its primary focus on fibre restricts further improvement for oil yield (Hussain et al., 2023). Sunflower has gained popularity due to its short growth duration (90–120 days) and adaptability to diverse agro-ecological conditions (POPY, 2020). Sunflower oil contains 40–50% oil and 23% protein, while its by-product serves as valuable animal feed(Khurana & Singh, 2020; Singh et al., 2022). Globally, sunflower is cultivated in over 40 countries, producing approximately 26.55 million tons annually (Sydiakina, 2024).

Despite its potential, sunflower yield in Pakistan remains low due to poor agronomic practices, soil fertility decline, and severe weed infestation. Weeds can cause yield losses of up to 54.6% by competing for nutrients, water, and light (Debaeke et al., 2021). While herbicides are effective, their environmental and health concerns necessitate sustainable alternatives such as conservation tillage and intercropping. Conservation tillage improves soil health but may increase weed pressure, while intercropping enhances resource-use efficiency and weed suppression through canopy competition (Hofmeijer et al., 2019; Kugbe et al., 2018). Mung bean (Vigna radiata L.), a short-duration legume with nitrogen-fixing ability, is an ideal intercrop for sunflower. However, limited research has examined the combined effects of tillage and intercropping under semi-arid conditions. Therefore, this study was conducted to test the hypothesis that the integration of deep tillage with sunflower–mung bean intercropping would synergistically enhance weed suppression and improve overall system productivity and land-use efficiency more effectively than either practice alone, providing a sustainable alternative to herbicide-dependent sole cropping systems.

2. Materials And Methods

2.1 Experimental site

The field experiment was conducted at the Agronomic Research Area, University of Agriculture, Faisalabad, Pakistan, during the spring season of 2023. The site is located at 31°26′ N latitude and 73°06′ E longitude, with an elevation of approximately 184 m above sea level. The region falls under the semi-arid, subtropical climate zone, characterized by hot summers and mild winters. The soil at the experimental site was classified as sandy clay loam, with pH 7.8, organic matter 0.74%, available phosphorus 7.9 mg kg^{-1}, and available potassium 158 mg kg^{-1}.

2.2 Experimental Design and Layout

The experiment was laid out in a randomized complete block design (RCBD) with a split-plot arrangement and three replications as reported previously (Sammy, 2019). Tillage systems were assigned to main plots, while cropping systems were allocated to subplots.

Two tillage systems (Figure 1) were evaluated:

T_1: Deep tillage – mouldboard ploughing followed by planking

T_2: Conventional tillage – two cultivations followed by planking

Each main plot was subdivided into five subplots (Figure 2) representing different sunflower–mung bean planting systems:

S_1: Sunflower sole crop at 60 cm row spacing

S_2: Sunflower sole crop at 90 cm row spacing

S_3: Mung bean sole crop at 30 cm row spacing

S_4: Sunflower (60 cm) intercropped with mung bean (two rows between sunflower rows)

S_5: Sunflower (90 cm double-row strips) intercropped with mung bean (three rows between sunflower strips)

The net subplot size was 4.0 m × 3.6 m, while the gross plot size measured 5.0 m × 3.6 m. The total experimental area was 46.2 m × 19.0 m (878 m²). Detailed arrangements of S1–S5 treatments are shown within the figures. Non-experimental plots (N.E.P.) and non-experimental areas (N.E.A.) were maintained, while service paths (1.5 m main path and 1.0 m sub path) and irrigation channels (1.5 m main channel and 1.0 m sub channel) were included for field operations.

Figure 1. Experimental field layout (RCBD with split-plot arrangement, three replications). Main plots: T1 = Deep tillage; T2 = Shallow tillage. Each main plot was subdivided into five subplots (S1–S5). Non-experimental plots (N.E.P.), non-experimental areas (N.E.A.), service paths, and irrigation channels are indicated.

Figure 2. Subplot arrangements of sunflower–mungbean systems under different planting patterns (S1–S5).

2.3 Crop husbandry

Sunflower (Helianthus annuus L.) hybrid Hysun-33 and mung bean (Vigna radiata L.) variety AZRI-2006 were used as test crops. Both crops were sown manually with a single-row hand drill according to the respective row spacing. A recommended seed rate of 6 kg ha^{-1} for sunflower and 20 kg ha^{-1} for mung bean was applied (Muhammad Imran et al., 2011).

Nitrogen, phosphorus, and potassium were applied at the rates of 60:90:60 kg ha^{-1}, respectively. Full doses of P and K and half of N were applied as basal, while the remaining N was top-dressed at flowering. Standard agronomic practices such as irrigation, hoeing, and plant protection were adopted uniformly.

2.4 Data collection

Data were recorded for both sunflower and mung bean, as well as for weed dynamics.

2.4.1 Weeds

Weed density (plants m^{-2}) was recorded at 15, 30, and 45 days after sowing (DAS) using a 1 m^2 quadrat placed randomly at three locations in each plot.

2.4.2 Sunflower parameters

Plant height, head diameter, number of achenes per head, 1000-achene weight, achene yield, biological yield, and harvest index were measured following standard procedures.

4.2.3 Mung bean parameters:

Plant height, pod length, number of branches per plant, pods per plant, grains per pod, 1000-grain weight, grain yield, biological yield, and harvest index were recorded.

2.5 Land Equivalent Ratio (LER):

LER was calculated using the formula of Mead and Willey as reported previously to assess the efficiency of intercropping systems relative to sole cropping (Atabo & Umaru, 2015).

2.6 Statistical analysis

The recorded data were subjected to analysis of variance (ANOVA) using the Fisher's analysis technique as described by Das et al. (Das et al., 2022), employing Minitab statistical software (version 19). Treatment means were compared using the least significant difference (LSD) test at a 5% probability level.

3. Results

3.1 Weeds

3.1.1 Effect of tillage practices and intercropping on weed density

Tillage practices exerted a progressively stronger effect on weed density as the season advanced, while intercropping significantly influenced weed density at all observation stages (Tables 1 and 2). At 15 days after sowing (DAS), tillage effects were non-significant, whereas intercropping treatments differed markedly. The highest weed density (32.8 m^{-2}) occurred in sunflower intercropped with mung bean at 60 cm spacing with two rows, while the lowest density (20.4 m^{-2}) was recorded in sole sunflower planted at 90 cm spacing. Reduced weed density under wider sole cropping can be attributed to improved light interception and more effective canopy development, which enhanced crop competitiveness against weeds, as also reported previously (Kaka Ahmed & Maaroof, 2022).

At 30 DAS, intercropping continued to significantly affect weed density, while tillage and the tillage × intercropping interaction remained non-significant. Weed density was again highest (42.5 m^{-2}) in sunflower intercropped with mung bean at 60 cm spacing and lowest (27.3 m^{-2}) in sole sunflower at 90 cm spacing. Higher weed pressure under intercropping at this stage may be linked to wider inter-row spaces and overlapping resource demand between component crops, which favours weed establishment (AKTER, 2018).

By 45 DAS, overall weed density declined compared with earlier stages, and the suppressive effect of tillage became more evident, with deep tillage resulting in lower weed density than conventional tillage. Intercropping effects remained significant, while interaction effects were non-significant. This decline in weed density at later stages reflects the increasing role of sunflower canopy expansion and shading in suppressing weed growth, consistent with previous reports emphasizing the importance of canopy development in late-season weed suppression (Hofmeijer et al., 2019; Smith et al., 2023).

Annexure (A)

Annexure (B)

LSD values:

- At 15 DAS: Tillage =NS , Intercropping = 3.85, Interaction = NS
- At 30 DAS: Tillage = 51.64, Intercropping = 16.88, Interaction = NS
- At 45 DAS: Tillage = 40.08, Intercropping = 28.58, Interaction = NS

Note: Values not sharing the same letters differ significantly at 5% probability level.

3.2 Sunflower

3.2.1 Effect of tillage practices and intercropping on sunflower growth traits

Sunflower growth attributes, including plant height and stem diameter, were not significantly influenced by tillage practices, intercropping systems, or their interaction (Tables 3 and4). Across all treatments, sunflower plant height and stem diameter remained relatively stable, indicating that these vegetative traits were largely governed by genetic potential rather than management practices. Similar findings have been reported in sunflower, where plant height showed limited responsiveness to variations in tillage intensity and cropping systems (Kaka Ahmed & Maaroof, 2022; Selolo, 2021).

In contrast, head diameter was significantly affected by both tillage and intercropping systems (Tables 3 and 4). Deep tillage resulted in a larger head diameter compared with conventional tillage, while sole sunflower planted at wider spacing (90 cm) produced the largest heads among cropping systems. Improved head development under deep tillage may be associated with better soil physical conditions and enhanced nutrient availability, as reported previously (Ahmad et al., 2021).

3.2.2 Effect of tillage practices and intercropping on sunflower yield components

Yield components of sunflower, including the number of achenes per head and thousand-achene weight, were significantly influenced by intercropping systems, with significant tillage × intercropping interactions observed for these traits (Tables 3 and 4). Sole sunflower planted at wider spacing consistently recorded higher values for these yield components, whereas intercropping systems exhibited moderate reductions, likely due to interspecific competition with mung bean. Similar reductions in yield components under intercropping have been documented in sunflower–legume systems, where competition for light and nutrients affects reproductive development (Gordeyeva et al., 2023; Kaka Ahmed & Maaroof, 2022).

The significant interaction between tillage and intercropping suggests that the response of yield components depended on the combined effect of soil disturbance and cropping geometry. Enhanced yield components under deep tillage may be attributed to improved root growth and resource uptake, which have been reported as key drivers of yield formation in sunflower (Nouraein et al., 2019).

3.2.3 Effect of tillage practices and intercropping on sunflower yield

Sunflower achene yield was significantly influenced by intercropping systems, whereas tillage practices and the tillage × intercropping interaction showed no significant effects (Table 4). The highest achene yield was recorded in a sole sunflower planted at wider spacing, while intercropping with mung bean resulted in a reduction in sunflower yield per unit area. This yield reduction under intercropping may be attributed to competition for light, moisture, and nutrients during overlapping growth periods, as previously reported for sunflower-based intercropping systems (Gordeyeva et al., 2023).

Although the effect of tillage on achene yield was statistically non-significant, deep tillage consistently produced numerically higher sunflower yields than conventional tillage across cropping systems (Figure 3). Biological yield followed a similar trend, with significant effects of both tillage and intercropping, indicating improved biomass production under deep tillage conditions. Comparable responses of sunflower biomass to tillage intensity have also been reported by Nouraein et al (Nouraein et al., 2019).

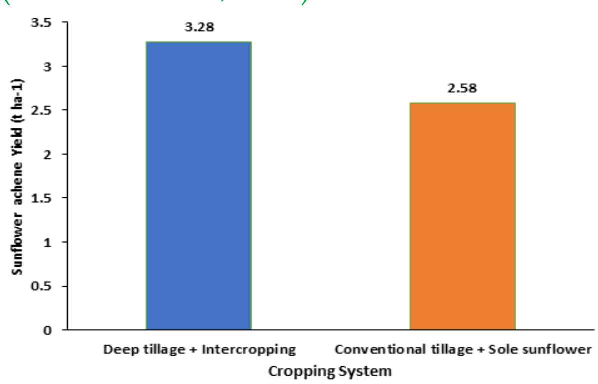

Figure 3. Effect of tillage practices and sunflower–mung bean intercropping on sunflower achene yield. Bars represent mean values; vertical bars indicate least significant difference (LSD) at 5% probability

3.2.4 Effect of tillage practices and intercropping on the harvest index of sunflower

Harvest index of sunflower was significantly influenced by intercropping systems, while tillage and interaction effects were non-significant (Table 4). Higher harvest index values were observed in sole sunflower compared with intercropping treatments, reflecting greater allocation of assimilates toward economic yield under reduced interspecific competition. Similar trends in harvest index under sole cropping have been reported in sunflower and other oilseed crops (Sekhon, 2017).

Annexure (C)

* = Significant at 5% probability level
** = Highly significant
NS = Non-significant

Annexure (D)

Values not sharing the same letters differ significantly at 5% probability level.

3.3 Mung Bean

3.3.1 Effect of tillage practices and intercropping on mung bean growth traits

Mung bean growth attributes were significantly influenced by intercropping systems, whereas the effects of tillage and the tillage × intercropping interaction were largely non-significant (Tables 5 and 6). Plant height and pod length were greater in sole mung bean compared with intercropping systems, indicating reduced competition for light and nutrients under sole cropping. Similar responses of mung bean growth to cropping geometry have been reported, where wider spacing and absence of interspecific competition enhanced vegetative growth(Ahmad et al., 2021; Sekhon, 2017).

Fruit-bearing branches per plant were significantly affected by both tillage and intercropping systems, with the sole mung bean producing the highest number of branches. The reduction in branching under intercropping treatments reflects competitive effects imposed by sunflower, as previously documented in legume-based intercropping systems (Otieno, 2017; Sekhon, 2017).

3.3.2 Effect of tillage practices and intercropping on the yield components of the mung bean

Yield components of mung bean, including pods per plant, grains per pod, and grains per plant, were significantly influenced by intercropping systems, with variable responses to tillage and significant tillage × intercropping interactions for some traits (Tables 5 and 6). Sole mung bean consistently recorded higher values for pods per plant and grains per pod, whereas intercropping with sunflower resulted in reductions due to increased competition for assimilates and light interception. Similar reductions in yield components of legumes under intercropping have been reported by several researchers (Muhammad Imran et al., 2011; Otieno, 2017). The significant interaction between tillage and intercropping for grains per pod and grains per plant suggests that soil disturbance level influenced mung bean response under different cropping systems. Enhanced yield components under deep tillage may be associated with improved soil structure and root development, as reported in earlier studies on legumes (Omondi, 2017).

3.3.3 Effect of tillage practices and intercropping on mung bean yield and biological yield

Mung bean grain yield was significantly affected by intercropping systems, whereas tillage and interaction effects were non-significant (Table 6). Sole mung bean produced the highest grain yield, while intercropping with sunflower, particularly under narrow planting geometry, resulted in reduced yield. Yield reduction under intercropping has been widely attributed to shading and asymmetric competition from taller companion crops such as sunflower (AKTER, 2018; Sekhon, 2017).

The biological yield of the mung bean was significantly influenced by both tillage and intercropping systems, with deep tillage producing higher biomass compared with conventional tillage. Similar improvements in legume biomass under deep tillage have been reported due to improved soil aeration and nutrient availability(Omondi, 2017).

3.3.4 Effect of tillage practices and intercropping on the harvest index of mung bean

Harvest index of mung bean was significantly influenced by both tillage and intercropping systems, while their interaction remained non-significant (Table 6). Higher harvest index values were observed under conventional tillage and wider intercropping arrangements, indicating more efficient partitioning of biomass toward grain production. Comparable effects of cropping systems on harvest index have been reported in mung bean and other grain legumes (AKTER, 2018; Thapa et al., 2014).

Annexure (E)

Values not sharing the same letters differ significantly at 5% probability level. Table 6

Annexure (F)

3.4 Land Equivalent Ratio (LER)

The results revealed that intercropping consistently outperformed monocropping, as indicated by LER values exceeding 1. The sunflower–mungbean system at 90 cm double rows with 3 rows of mungbean achieved the highest land-use efficiency (LER = 1.68), corresponding to a 68% yield advantage over sole cropping. Similarly, sunflowers at 60 cm in single rows with 2 rows of mungbean recorded an LER of 1.66, providing a 66% advantage. These results confirm the enhanced resource-use efficiency of intercropping systems, owing to better utilization of light, water, nutrients, and space. Comparable findings were reported by Anas and Tang et al (Muhammad Anas et al., 2017; Tang et al., 2021) who also documented higher LER values in sunflower–mungbean intercropping compared to monoculture.

4. Discussion

4.1 influence of tillage and intercropping on weed dynamics

Tillage and cropping systems significantly influenced weed dynamics throughout the growing season. Deep tillage reduced weed density more effectively at later growth stages, likely due to greater soil disturbance that buried weed seeds deeper in the soil profile and disrupted established weeds. Similar effects have been attributed to altered vertical seed distribution and reduced germination potential under deep tillage (Hofmeijer et al., 2019). The limited tillage effect during early growth stages suggests that initial weed emergence was mainly driven by the surface seed bank. These findings indicate that deep tillage is particularly effective for late-season weed suppression when integrated with other management practices. Intercropping also modified weed pressure across growth stages. Higher early-season weed density in intercropped plots may be associated with delayed canopy closure and wider inter-row spacing. However, as crop growth progressed, weed density declined markedly due to increased canopy cover, shading, and competitive exclusion. Similar weed-suppressive effects of intercropping have been widely reported (Smith et al., 2023). This demonstrates that biological weed suppression through intercropping complements the mechanical control provided by tillage.

4.2 Response of Sunflower Growth and Yield

Sunflower vegetative traits were largely unaffected by tillage and intercropping, whereas reproductive traits and yield components were more responsive to management practices. The absence of significant effects on plant height and stem diameter suggests strong genetic control, consistent with previous findings (Selolo, 2021). In contrast, improved head diameter and yield components under deep tillage reflect enhanced soil physical conditions, such as reduced compaction and improved root growth, leading to better access to water and nutrients (Nouraein et al., 2019). Intercropping reduced sunflower yield per unit area, particularly under narrow spacing, due to competition with mung bean for light, water, and nutrients. Similar yield reductions have been reported in sunflower–legume intercropping systems (Gordeyeva et al., 2023). However, relatively smaller yield penalties under wider spacing indicate that optimized planting geometry can partially mitigate competitive effects.

4.3 Performance of Mung Bean under Intercropping

Mung bean growth and yield were reduced under intercropping due to shading and asymmetric competition from sunflowers. Decreases in plant height, branching, and yield components are consistent with previous reports in legume-based intercropping systems, where limited light interception restricts photosynthesis (Otieno, 2017; Sekhon, 2017). These results confirm that yield trade-offs at the component crop level are inherent in intercropping systems. Deep tillage partially alleviated competitive stress on mung bean by improving soil aeration and nutrient availability, resulting in higher biological yield. Similar benefits of deep tillage on legume biomass have been documented previously (Omondi, 2017), indicating that appropriate soil management can improve legume performance under competitive conditions.

4.4 System Productivity and Land-Use Efficiency

Despite reductions in individual crop yields, intercropping significantly improved overall system productivity, as indicated by land equivalent ratio (LER) values greater than one. Higher LER values under wider intercropping arrangements reflect more efficient utilization of light, water, nutrients, and space through complementary resource use between sunflower and mung bean. Similar enhancements in land-use efficiency have been reported in sunflower–legume intercropping systems (Tang et al., 2021). The integration of deep tillage with optimized intercropping geometry resulted in the highest system efficiency by combining effective weed suppression, improved soil conditions, and biological complementarity. This integrated approach aligns with sustainable intensification principles and represents a practical strategy for enhancing productivity and sustainability in semi-arid agro-ecosystems.

6. Conclusion

This study clearly demonstrated that the integration of tillage practices with sunflower–mung bean intercropping significantly influences weed suppression, crop performance, and overall system productivity under semi-arid conditions. The results explicitly validated the study hypothesis, confirming that deep tillage combined with sunflower–mung bean intercropping was superior to conventional sole cropping systems in reducing weed pressure and enhancing land-use efficiency. Although intercropping caused moderate yield reductions in individual component crops due to interspecific competition, the integrated system consistently achieved higher total productivity, as reflected by land equivalent ratio (LER) values greater than unity. These findings establish that the combined application of deep tillage and optimized intercropping geometry offers a sustainable, resource-efficient, and environmentally friendly alternative to herbicide-dependent sunflower monocropping.

7. Recommendations

To strengthen the applicability and long-term sustainability of the integrated tillage–intercropping system, future research should focus on validating these findings through multi-location and multi-year field trials to assess performance stability under varying agro-climatic conditions. In addition, economic analyses are needed to quantify the cost–benefit advantages of this integrated system relative to conventional practices, thereby supporting farmer-level adoption. Furthermore, long-term soil health investigations should be undertaken to evaluate changes in soil organic carbon, microbial biomass, and biological activity, ensuring that productivity gains are maintained without compromising soil quality.

8. Innovation

This study is innovative in demonstrating the synergistic integration of tillage intensity and sunflower–mung bean intercropping as a unified strategy for weed management and productivity enhancement, rather than treating these practices independently. By combining mechanical soil disturbance with biological weed suppression, the approach provides an eco-efficient, practical, and scalable solution for reducing reliance on chemical herbicides while improving land-use efficiency. The findings align strongly with the mission of "Empowering Humanity with Knowledge through Research" by offering a scientifically validated, farmer-friendly strategy that promotes sustainable intensification and environmental stewardship in oilseed-based cropping systems.

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Annexure (A)

Table 1. Effect of tillage practices and intercropping on the weed density (plants m^{-2}) at 15, 30, 45 days.

Analysis of Variance				
Source of variation	**DF**	**SS**	**MS**	**F-value**
15 days				
Replication	2	145.2	72.6	
Tillage (A)	1	19.7	19.7	0.35 NS
Error 1	2	112.1	56.1	
Intercropping (B)	3	845.6	281.9	4.87 *
A × B	3	56.3	18.8	0.49 NS
Error 2	12	694.3	57.9	
Total	23	1873.2		
30 DAYS				
Replication	2	1092.27	546.13	
Tillage (A)	1	17424.3	17424.3	18.64 *
Error 1	2	1864.8	932.4	
Intercropping (B)	4	16803.47	4200.87	22.63 **
A × B	4	531.87	132.97	0.71 NS
Error 2	16	2964.27	185.27	
Total	29	40680.97		
45 DAYS				
Replication	2	523.97	261.93	
Tillage (A)	1	14699.66	14699.66	22.68 *
Error 1	2	1296.97	648.43	
Intercropping (B)	4	13748.59	3437.17	6.39 **
A × B	4	229.713	57.43	0.17 NS
Error 2	16	8704.76	544.04	
Total	29	39203.44		

Annexure (B)

Table 2. Individual comparisons of treatments' means at different crop growth stages (15, 30 and 45 DAS).

DAS / Tillage	**Sunflower 60 cm sole**	**Sunflower 90 cm sole**	**Mung alone (30 cm)**	**Sunflower 60 cm + Mung (2 rows)**	**Sunflower 90 cm + Mung (3 rows)**	**Mean**
15 DAYS						
Deep tillage	23.7	20.8	-	32.1	28.3	26.2
Conv. Tillage	25.3	20.0	-	33.6	29.2	27.0
Mean	24.5 B	20.4 C	-	32.8 A	28.7 AB	
30 DAYS						
Deep tillage	132.33	122.33	76.67	102.33	61.00	98.93 A
Conv. tillage	173.67	158.00	127.33	158.33	118.33	147.13 A
Mean	153.00 A	140.17 AB	102.00 C	130.33 B	89.67 C	

45 DAYS						
Deep tillage	120.33	111.67	80.33	107.33	63.43	96.60 A
Conv. tillage	171.67	154.00	118.69	146.33	113.67	140.83 B
Mean	146.00 A	132.83 A	99.57 BC	126.83 AB	88.50 C	

Annexure (C)

Table 3. Combined Analysis of Variance for Sunflower Traits under Tillage Practices and Intercropping

Source of Variation	DF	SS	MS	F-value
Plant Height (cm)				
Replication	2	917.23	458.67	
Tillage (A)	1	32.57	32.57	3.26 NS
Error 1	2	19.83	9.97	
Intercropping (B)	3	75.65	25.23	0.53 NS
A × B	3	0.95	0.35	0.06 NS
Error 2	12	549.88	45.77	
Total	23	1595.66	69.36	
Stem Diameter (cm)				
Replication	2	0.03	0.07	
Tillage (A)	1	0.05	0.05	12.73 NS
Error 1	2	0.05	0.05	
Intercropping (B)	3	0.03	0.04	1.41 NS
A × B	3	0.05	0.03	0.79 NS
Error 2	12	0.07	0.09	
Total	23	0.23		
Head Diameter (cm)				
Replication	2	0.575	0.285	
Tillage (A)	1	4.007	4.007	20.51 *
Error 1	2	0.393	0.197	
Intercropping (B)	3	14.707	4.919	31.39 **
A × B	3	0.893	0.274	1.94 NS
Error 2	12	1.875	0.135	
Total	23	22.455		
Number of Achenes per Head				
Replication	2	2598.25	1299.125	
Tillage (A)	1	6402.667	6402.667	14.969 NS
Error 1	2	855.583	427.797	
Intercropping (B)	3	11441.5	3813.833	21.491 **
A × B	3	2117	705.667	3.971 *
Error 2	12	2129.5	177.453	
Total	23	25544.5		
1000-Achene Weight				
Replication	2	34.443	17.227	
Tillage (A)	1	98.867	98.817	11.848

Error 1	2	16.683	8.347	
Intercropping (B)	3	182.728	60.908	6.287 **
A × B	3	103.018	34.334	3.549 *
Error 2	12	116.223	9.688	
Total	23	551.968		
Achene Yield				
Replication	2	116981.153	58490.579	
Tillage (A)	1	204546.034	204546.034	14.717 NS
Error 1	2	27808.683	13904.346	
Intercropping (B)	3	1018080.088	339360.024	9.977 **
A × B	3	8471.813	2823.934	0.0851 NS
Error 2	12	408239.284	34019.948	
Total	23	1784127.063		
Biological Yield				
Replication	2	63.55	316694.275	
Tillage (A)	1	135163.545	135163.545	55.021 *
Error 1	2	4913.123	2456.561667	
Intercropping (B)	3	7836539.301	2612179.767	272.8614 **
A × B	3	10926.91	3642.327	0.380 NS
Error 2	12	114879.34	9573.279	
Total	23	8735810.816		
Harvest Index				
Replication	2	12.825	6.415	
Tillage (A)	1	14.437	14.437	9.511 NS
Error 1	2	3.033	1.517	
Intercropping (B)	3	55.53	18.511	5.146 *
A × B	3	1.073	0.358	0.097 NS
Error 2	12	43.13	3.591	
Total	23	130.105		

Annexure (D)

Table 4. Effect of tillage and intercropping on sunflower growth and yield attributes: mean

Trait	**Tillage**	**Sunflower 60 cm**	**Sunflower 90 cm double strips**	**Sunflower + mung (2 rows)**	**Sunflower + mung (3 rows)**	**Mean**
Plant Height (cm)	Deep tillage	151.35	153.90	149.97	149.19	151.17
	Conventional tillage	149.59	151.30	147.20	147.00	148.75
	Mean	150.47	152.60	148.53	148.95	—
	LSD (0.05)	Tillage = NS	Intercropping = NS	Interaction = NS		
Stem Diameter (cm)	Deep tillage	2.03	2.01	2.147	1.97	2.07
	Conventional tillage	1.97	1.93	1.97	1.99	1.97
	Mean	1.98	1.97	2.07	1.93	—

	LSD (0.05)	Tillage = NS	Intercropping = NS	Interaction = NS		
Head Diameter (cm)	Deep tillage	16.90	17.60	15.303	15.433	16.323 A
	Conventional tillage	15.67	16.433	14.933	14.983	15.507 B
	Mean	16.283 B	17.017 A	15.117 C	15.233 C	—
	LSD (0.05)	Tillage = 0.7759	Intercropping = 0.4972	Interaction = NS		
Achenes per Head	Deep tillage	901.667 b	951.333 a	865 cd	896.333 b	903.583
	Conventional tillage	876 bc	887.333 bc	851 d	869.333 bcd	870.917
	Mean	888.833 B	919.333 A	858 C	882.833 B	—
	LSD (0.05)	Tillage = NS	Intercropping = 16.757	Interaction = 23.699		
1000-Achene Weight (g)	Deep tillage	66.45 ab	68.81 a	57.33 c	59.807 c	63.097
	Conventional tillage	61.123 bc	58.907 c	58.78 c	57.35 c	59.04
	Mean	63.787 A	63.853 A	58.055 B	58.573 B	—
	LSD (0.05)	Tillage = NS	Intercropping = 3.9149	Interaction = 5.5365		
Achene Yield (kg ha^{-1})	Deep tillage	2688.87	2963.47	2356.50	2593.02	2650.46
	Conventional tillage	2450.35	2766.74	2219.43	2426.77	2465.83
	Mean	2569.59 B	2865.10 A	2287.97 C	2509.90 BC	—
	LSD (0.05)	Tillage = NS, Intercropping = 232.02, Interaction = NS				
Biological Yield (kg ha^{-1})	Deep tillage	8867.37	9923.47	8688.57	9816.98	9324.30 A
	Conventional tillage	8694.26	9831.90	8483.98	9685.88	9174.50 B
	Mean	8780.82 C	9877.68 A	8586.28 D	9751.43 B	—
	LSD (0.05)	Tillage = 87.061, Intercropping = 123.08, Interaction = NS				
Harvest Index (%)	Deep tillage	30.347	29.863	27.127	26.400	28.437
	Conventional tillage	28.223	28.133	26.143	25.033	26.833
	Mean	29.285 A	28.993 AB	26.635 BC	25.717 C	—
	LSD (0.05)	Tillage = NS, Intercropping = 2.3865, Interaction = NS				

Annexure (E)

Table 5. Combined Analysis of Variance for Mung Bean Traits under Tillage Practices and Intercropping

Source of Variation	DF	SS	MS	F-value
Plant Height (cm)				
Replication	2	18.054	9.022	
Tillage (A)	1	18.402	18.402	10.954 NS
Error 1	2	3.361	1.686	
Intercropping (B)	2	653.738	326.869	182.806 **
A × B	2	2.538	1.2689	0.7091 NS
Error 2	8	14.304	1.7886	
Total	17	710.398		
Pod Length (cm)				

Replication	2	0.171	0.086	
Tillage (A)	1	0.902	0.902	211.195 **
Error 1	2	0.004	0.002	
Intercropping (B)	2	16.944	8.472	131.332 **
A × B	2	0.004	0.002	0.055 NS
Error 2	8	0.518	0.062	
Total	17	18.554		
Fruit-Bearing Branches				
Replication	2	0.174	0.082	
Tillage (A)	1	0.232	0.252	64.457 *
Error 1	2	0.007	0.002	
Intercropping (B)	2	51.304	25.652	1464.696 **
A × B	2	0.001	0.006	0.028 NS
Error 2	8	0.141	0.0179	
Total	17	51.868		
Pods per Plant				
Replication	2	0.194	0.092	
Tillage (A)	1	1.28	1.28	20.756 *
Error 1	2	0.123	0.067	
Intercropping (B)	2	39.721	19.876	86.872 **
A × B	2	0.243	0.127	0.531 NS
Error 2	8	1.829	0.221	
Total	17	43.391		
Grains per Pod				
Replication	2	0.921	0.4606	
Tillage (A)	1	6.125	6.125	16.782 NS
Error 1	2	0.73	0.365	
Intercropping (B)	2	6.004	3.002	30.189 **
A × B	2	1.24	0.62	6.234 *
Error 2	8	0.796	0.094	
Total	17	15.811		
Grains per Plant				
Replication	2	251.444	125.722	
Tillage (A)	1	1720.889	1720.889	21.407 *
Error 1	2	160.778	80.369	
Intercropping (B)	2	7304.101	3652.076	100.599 **
A × B	2	410.788	205.389	5.658 *
Error 2	8	290.444	36.396	
Total	17	10138.444		
1000-Grain Weight (g)				
Replication	2	0.243	0.127	
Tillage (A)	1	5.199	5.199	16.679 NS
Error 1	2	0.624	0.312	

Intercropping (B)	2	9.729	4.865	30.495 **
A × B	2	4.401	2.206	13.804 **
Error 2	8	1.272	0.158	
Total	17	21.455		
Grain Yield (t ha⁻¹)				
Replication	2	0.008	0.009	
Tillage (A)	1	0.009	0.009	14.348 NS
Error 1	2	0.004	0.002	
Intercropping (B)	2	0.218	0.109	500.677 **
A × B	2	0.013	0.006	0.727 NS
Error 2	8	0.001	0.009	
Total	17	0.221		
Biological Yield (t ha⁻¹)				
Replication	2	0.034	0.012	
Tillage (A)	1	0.3362	0.332	101.362 **
Error 1	2	0.003	0.007	
Intercropping (B)	2	5.991	2.996	296.744 **
A × B	2	0.019	0.005	0.687 NS
Error 2	8	0.082	0.018	
Total	17	6.461		
Harvest Index (%)				
Replication	2	1.054	0.542	
Tillage (A)	1	2.582	2.582	43.524 *
Error 1	2	0.114	0.052	
Intercropping (B)	2	7.898	3.949	9.622 **
A × B	2	0.581	0.296	0.702 NS
Error 2	8	3.278	0.402	
Total	17	15.548		

Annexure (F)

Table 6. Effect of tillage and intercropping on mung bean growth and yield attributes

Trait	Tillage	Mung alone (30 cm, 12 rows)	Sunflower 60 cm + Mung (2 rows)	Sunflower 90 cm double strips + Mung (3 rows)	Mean
Plant Height (cm)	Deep tillage	50.733	36.967	41.9	43.2
	Conventional tillage	49.4	33.9	40.233	41.178
	Mean	50.067 A	35.433 B	41.067 C	
	LSD (0.05)	Tillage = NS, Intercropping = 1.7803, Interaction = NS			
Pod Length (cm)	Deep tillage	9.427	7.133	7.9	8.153 A
	Conventional tillage	9.067	6.633	7.467	7.706 B
	Mean	9.227 A	6.883 C	7.683 B	
	LSD (0.05)	Tillage = 0.1326, Intercropping = 0.3382, Interaction = NS			
	Deep tillage	8.06	4.067	5.183	5.77 A

Fruit-Bearing Branches	Conventional tillage	7.85	3.83	4.947	5.542 B
	Mean	7.955 A	3.943 C	5.065 B	
	LSD (0.05)	Tillage = 0.1221, Intercropping = 0.1762, Interaction = NS			
Pods per Plant	Deep tillage	14.067	10.233	12.867	12.389 A
	Conventional tillage	13.267	10	12.3	11.856 B
	Mean	13.667 A	10.117 C	12.583 B	
	LSD (0.05)	Tillage = 0.5037, Intercropping = 0.6366, Interaction = NS			
Grains per Pod	Deep tillage	10.867 a	9 b	9.267 b	9.711
	Conventional tillage	8.967 bc	8.1 d	8.567 cd	8.544
	Mean	9.917 A	8.55 B	8.917 B	
	LSD (0.05)	Tillage = NS, Intercropping = 0.4198, Interaction = 0.5938			
Grains per Plant	Deep tillage	152 a	92.33 de	119 bc	121.22 A
	Conventional tillage	119.33 b	80.67 e	105 cd	101.67 B
	Mean	135.33 A	86.5 C	112 B	
	LSD (0.05)	Tillage = 18.186, Intercropping = 8.0221, Interaction = 11.345			
Thousand-Grain Weight (g)	Deep tillage	62.257 a	59.517 c	61.533 a	61.102
	Conventional tillage	60.683 b	59.823 c	59.5767 c	60.028
	Mean	61.47 A	59.67 C	60.555 B	
	LSD (0.05)	Tillage = NS, Intercropping = 0.5315, Interaction = 0.7517			
Grain Yield ($t\ ha^{-1}$)	Deep tillage	1.103	0.847	0.9	0.95
	Conventional tillage	1.067	0.823	0.857	0.96
	Mean	1.085 A	0.835 C	0.873 B	
	LSD (0.05)	Tillage = NS, Intercropping = 0.0195, Interaction = NS			
Biological Yield ($t\ ha^{-1}$)	Deep tillage	4.983	3.747	3.853	4.194 A
	Conventional tillage	4.763	3.497	3.503	3.921 B
	Mean	4.873 A	3.627 B	3.673 B	
	LSD (0.05)	Tillage = 0.1168, Intercropping = 0.1338, Interaction = NS			
Harvest Index (%)	Deep tillage	22.147	22.603	23.35	22.7 B
	Conventional tillage	22.467	23.52	24.447	23.458 A
	Mean	22.277 B	23.067 AB	23.893 A	
	LSD (0.05)	Tillage = 0.4942, Intercropping = 0.8524, Interaction = NS			