**Is sustainable groundnut cultivation achievable through residue application and tillage optimization in a groundnut–wheat system?**

**Abstract**

The growing concern for food security necessitates the identification of an environmental friendly and crop yield sustainable system of tillage production, which would ensure soil protection and restoration of natural biocoenosis. This study aimed to evaluate the conservation tillage practices for efficient utilization of resources and increasing crop productivity and profitability. The study was carried out on a fixed site at Research Farm, College of Agriculture, RVSKVV, Gwalior, Madhya Pradesh. We studied the impact of tillage practices with residue management on the growth, productivity and profitability of *kharif* groundnut under groundnut-wheat cropping system. The results revealed that the conventional tillage-raised bed system with residue incorporated on the surface (CT-raised bed+Residue) resulted in significantly higher crop growth, yield and profitability during both years over conventional and conservation tillage systems. The pooled analysis of the data exhibited that kernel (2135 kg/ha) and pod yields (3100 kg/ha) were significantly higher under a conventional tillage-raised bed system with residue incorporation. However, this treatment was found at par with conventional tillage-flat bed with residue for kernel and pod yields values during both years. The same treatment recorded significantly the highest uptake of nutrients (N, P, K) during both years and on pooled basis. The pooled economic analysis of the data showed that significantly the highest net and gross returns were fetched with conventional tillage practised on raised bed with residues incorporated on the surface in comparison to other tillage practices. However, during the two experimental years, this treatment was statistically similar to conventional tillage-flat bed with residue incorporation. With respect to benefit cost ratio and harvest index the treatments significantly varied and recorded higher values of B:C (2.18) and HI (0.55) on a pooled basis under conventional tillage-raised bed with residues and conventional tillage-flat bed with residues, respectively. Zero tillage without residue incorporation remained the least performing treatment, recording the lowest values of all parameters.

**Keywords:** Wheat,Cropping system, Groundnut, Residue application, Sustainable agriculture, Zero tillage.

**Introduction**

Proper crop residue management helps in improvement in soil organic matter, increases the physical, chemical and biological properties of soil which leads to increase the production and productivity. The short planting season following the previous crop's harvest, insufficient agricultural equipment, a manpower shortage, and declining acceptance of crop residue as feed are just a few of the major causes of residue burning (Gatkal et al., 2024; Alsamin et al., 2022). With the increasing world population, the increased demand for food has raised the need to increase crop production. In traditional farming, continuous intensive tillage systems commonly practiced for preparing the soil favorable for crop establishment and growth, adversely affects the long term productivity of soil by accelerating oxidation of soil organic matter (Mathew *et al.* 2021), disrupting soil physical structure, decreasing soil moisture incorporation and disturbing soil biological diversity (Peng *et al*., 2023; Degrune *et al.,* 2017; Wang *et al.,* 2018). As per the reports of IPCC (2023), agricultural practices are responsible for 30% greenhouse gas emissions, contribute to global warming and climate change. Population growth, an increasing proportion of animal-based food consumption, shortage of water and land resources, and impacts of climate change all make the situation of world food security more and more severe (Tian et al., 2021). Thus, the growing concern for food security necessitates the identification of an environmentally friendly and crop yield sustainable system of tillage production which would ensure soil protection and restoration of natural biocoenosis, especially in areas where high-intensity management practices are followed.

Conservation tillage, along with some complementary practices such as soil cover and crop diversity (Corsi, Friedrich, Kassam, Pisante, & de Moraes Sà, 2012), is now seen as a resource conservation strategy for ensuring sustainable food production and maintaining environmental integrity. It is being practised over an area of 120 million ha around the world and found to be more sustainable under rainfed conditions (Singh and Meena, 2023). It minimises or excludes certain agro-technical treatments to reduce the negative impact on soil and leaves at least 30% of the soil surface covered with crop residue after planting (CTIC, 2004). Till now, scientists have mainly emphasized on increasing the production of cereal-cereal based cropping system and very little information is available on cereal-legume based cropping systems. Fuentes *et al.,* (2023) found crop yields with conservation tillage to be equal to, or better than, yields with conventional tillage, while others have reported lower yields with conservation tillage when compared to conventional tillage (Li *et al.* 2018). Mosaddeghi *et al.* (2019) reported that soil conditions under a no-tillage conservation system were better than those under a conventional system in arid and semi-arid environments. Due to inconsistent findings, it is necessary to investigate the impact of tillage methods on plant growth, root development and yield components of the crop to reach to more rigorous conclusion.

Groundnut (*Arachis hypogaea* L.) is a major cash crop of India, which is widely grown in the tropic. It ranks 13th among the food crops and is world’s largest source of edible oil. However, due to dependency on rainfall and monoculture, its productivity in our country is still low. Thus, there is a need to diversify the groundnut-based cropping system and adopt effective tillage practices. This study was proposed with an objective to evaluate the conservation tillage practices for efficient utilization of resources and increasing crop productivity and profitability.

**Materials and Methods**

The experimental site was located at 23010’ N latitude, 790 54’ E longitudes with an elevation of 411.98 meter above the mean sea level, in the northern tract of M.P. The field experiment was conducted in *Kharif* 2019 and 2020 on groundnut at the Research farm, College of Agriculture, R.V.S.K.V.V., Gwalior. The experimental site had uniform land topography with adequate surface drainage. The internal drainage of the experimental site was medium. During the experimental period, the total rainfall was recorded 966.8 and mm in kharif 2019 and 2020, respectively. Average monthly relative humidity was recorded between 43 to 95% during the year 2019-20 and 43 to 85% during the year 2020-21. Soil of the experimental field was well drained, having a sandy loam texture in the upper 30 cm layer. Soil was low in available N (187 kg/ha), low in organic carbon (0.49 %), medium in available P (12.4 kg/ha) and K (224 kg/ha). Well distribution of rainfall during kharif season ensured good crop stand, growth and yield of the groundnut crop.

The experiments were identical in all cases during both years and laid-out in a randomized complete block design (RCBD) with six tillage treatments (T1: Conventional tillage-flat bed without residue incorporation, T2: zero tillage without residue incorporation, T3: Conventional tillage-raised bed without residue incorporation, T4: Conventional tillage-flat bed with residue incorporation, T5: Zero tillage with residue incorporation and T6: Conventional tillage-raised bed with residue incorporation). The conventional tillage was performed using a combination of mouldboard plough and cultivator and zero tillage treatment included none tillage operation except drilling/ planting of seeds. In conventional tillage with crop residues incorporation plots, residues were incorporated at the time of ploughing and in no-residue plots the entire crop residues were removed after harvesting of both *Kharif* and *Rabi* crops and the land was ploughed. The weeds were killed by spraying Volar-32 @0.75 kg *a.i*./ha at two days after sowing and two hand weedings along with interculturing, were done in conventional tillage plots at 30 and 60 DAS. The raised beds were prepared forming the furrows of 50 cm width and 100 cm top width. The groundnut seeds were treated with Rhizobium culture @5g/kg seed, fungicide Dithane M45@2g/kg seed and Bavistin @1g/kg seed to prevent seed-borne disease prior to sowing. Dimethoate 30 EC @2ml/litre water was sprayed at 45 DAS to control thrips and bud necrosis virus. Chlorpyriphos @1.5 litre/ha was sprayed before sowing and at 40 DAS to control termite infestation. Minor incidence of Tikka disease was also observed, which was controlled by applying Hexaconazole @ 1.5ml/ litre water. Gypsum @ 400 kg/ha and the recommended dose of fertilizer 60:40:20 kg of N, P and K were applied. The groundnut variety Mallika (ICHG0440) was sown at a row spacing of 30 cm x10 cm with a seed rate of 100 kg/ha. This allowed 20 rows on flat bed and 4 rows on a raised bed under each replication. The outer five rows in each replication were used as a buffer between treatment plots. At physiological maturity, harvesting was done manually.

For both experiments, soil sampling was done before sowing at 0-15 cm and after harvest using a composite sampling method at three randomly selected locations under each replication. The soil samples were processed by air-drying and passing through a 2 mm sieve. Observations on various morphological and yield traits of groundnut were taken during the both the experimental years. The data collected from the experimental field and laboratory analysis were subjected to statistical analysis. Standard statistical methods were used (Gomez and Gomez, 1984).

**Results and Discussion**

***Effect of tillage practices on growth parameters***

The result exhibited a significant influence of tillage treatments with residue management on growth attributes *i.e.* plant height, number of branches, nodule numbers, dry matter accumulation, days to 50% flowering and maturity. It shows that practising conventional tillage on raised bed with residue incorporated on the surface recorded significantly taller plants, maximum number of branches and nodules per plant, highest dry matter accumulation and minimum number of days taken to 50% maturity and flowering. On pooled basis, conventional tillage on raised bed with residue incorporation was found superior over other tillage systems and recorded the highest plant height (16.3, 50 and 53.1 cm, respectively) at 30, and 90 DAS whereas, remained at par with the treatment conventional tillage-flat bed+ residue at 60 DAS. At 90 DAS, the treatment was not significantly different from conventional tillage-flat bed+ residue during 1st year and conventional tillage-raised bed-residue during 2nd year of study. Moreover, the treatments, conventional tillage-flat bed with residue and conventional tillage-raised bed without residue at 60 DAS were found at par to this treatment during 2020. Zero tillage without residue resulted in shorter plant height at 30, 60 and 90 DAS on pooled basis. The increased height under bed tilled and mulched plots might be due to the availability of more soil moisture contents for plant growth, which positively influenced the plant height. Umoh *et al.* (2021) observed improved nutrient release in soil under tillage treatments, making them easily available for plant uptake, thereby resulting in better growth and development. Similar results were obtained by Aikins & Afuakwa (2020) for cowpea.

The analysis of variance of pooled data revealed that number of branches/plant (6.1, 9.5 and 9.5, respectively) and number of nodules/plant (55.7, 70.6 and 91.5, respectively) were significantly highest under conventional tillage-raised bed+ residue incorporation at 30, 60 and 90 DAS over rest of the tillage treatments. Based on a study on Alfisols in savanna zone of Nigeria, Omeke (2017) concluded that tillage stimulates nitrogen fixation contributing to better nodulation.

The pooled analysis of data of DMA recorded significantly highest values (17.9 and 68.4 g, respectively) with conventional tillage on raised with residue in comparison to other tillage practices at both 30 and 60 DAS (Fig 1a). At 90 DAS, however, the treatments conventional tillage-flat bed+ residue, conventional tillage-raised bed-residue and conventional tillage flat bed-residue remained at par with this treatment and recorded statistically similar values. The results are in conformity with those reported by Manasseh *et al.,* (2015), who found higher dry matter yield in conventional tillage plots in comparison with that of the Zero Tillage plots.

|  |  |
| --- | --- |
|  |  |
| Fig1(a): Effect of tillage practices and residue application on dry matter accumulation (DMA) at 30, 60 and 90 DAS (g/plant) | Fig1(b): Effect of tillage practices and residue application on Leaf area index (LAI) at 30, 60 and 90 DAS |

The improvement in these growth attributes is a clear indication that performing tillage on raised beds helped in better growth, produced maximum number of branches which ultimately favored the translocation of assimilates toward increasing numbers of nodules. The data followed a trend CT-Raised bed with residue > Conventional tillage-flat bed with residue > Conventional tillage-raised bed without residue > Conventional tillage-flat bed without residue > zero tillage with residue > zero tillage without residue. Similar results were observed by Aikins *et al*. (2012). The least number of branches, number of nodules and dry matter accumulation were recorded with zero tillage without residue treatment at all growth stages on pooled data basis.

The pooled data presented in Table 1. clearly stated that the minimum number of days to 50% flowering (27) and to reach 50% maturity (89.4) was taken by the crop when it was grown under conventional tillage on a raised bed with residues incorporated on the soil surface. Practising zero tillage with residues incorporated on the surface resulted in a maximum number of days (31.5 and 104.1, respectively) taken by the crop to flower 50% and reach 50% maturity. These results are a clear indication that Conventional tillage proved significantly superior in all growth attributes as compared to zero tillage. The results also support the findings of Dauda and Aluko (2019) and Kumar *et al.* (2022), who found a significant effect of conventional tillage on the growth response of soybean.

**Table 1.** Effect of tillage practices with residue management on pooled data of plant height, number of branches/plant, number of nodules/plant, days to 50% flowering and days to maturity of groundnut

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Plant height (cm) of groundnut** | | | **Number of Branches/plant** | | | **Number of nodules/plant** | | | **Days to 50% flowering** | **Days to maturity** |
| 30 DAS | 60 DAS | 90 DAS | 30 DAS | 60 DAS | 90 DAS | 30 DAS | 60 DAS | 90 DAS |
| **Conventional tillage Flat bed without residue** | 12.3 | 44.3 | 46.4 | 4.8 | 7.6 | 7.6 | 40.3 | 52.7 | 67.5 | 28.3 | 98.8 |
| **Zero tillage without residue** | 9.3 | 36.5 | 37.9 | 4.0 | 5.9 | 5.9 | 29.6 | 40.7 | 51.3 | 31.5 | 104.1 |
| **Conventional tillage Raised bed without residue** | 14.0 | 46.9 | 48.9 | 5.1 | 8.0 | 8.0 | 45.5 | 60.1 | 72.0 | 28.0 | 98.1 |
| **Conventional tillage Flat bed with**  **residue** | 15.1 | 48.0 | 50.5 | 5.4 | 8.8 | 8.8 | 49.2 | 61.5 | 77.7 | 27.8 | 95.6 |
| **Zero tillage with residue** | 11.1 | 39.5 | 41.0 | 4.3 | 6.9 | 6.9 | 37.7 | 48.9 | 62.8 | 29.5 | 102.6 |
| **Conventional tillage Raised bed with residue** | 16.3 | 50.0 | 53.1 | 6.1 | 9.5 | 9.5 | 55.7 | 70.6 | 91.5 | 27.0 | 89.4 |
| **SEm±** | **0.24** | **0.62** | **0.83** | **0.09** | **0.19** | **0.19** | **0.97** | **1.12** | **1.68** | **0.31** | **2.35** |
| **CD (0.05)** | **0.68** | **1.79** | **2.40** | **0.25** | **0.54** | **0.54** | **2.81** | **3.25** | **4.85** | **0.90** | **6.79** |

***Effect of tillage practices on LAI, CGR and RGR***

It was determined from the variance analysis results of LAI, CGR and RGR that tillage treatments with and without residue incorporation significantly influenced these parameters at all growth stages during two years of study. The average of two years data revealed that leaf area index at 30, 60 and 90 DAS was significantly highest (3.1, 3.8 and 4.5, respectively) under conventionally tilled raised bed plots with residues incorporated the surface. However, the treatment was found at par with conventional tillage raised bed without residue and conventional tillage flat bed with residue during both the years of study. Likewise, on a pooled basis, crop growth rate was recorded significantly highest (1.7 and 3.7 g/m2/day, respectively) with conventional tillage raised bed+ residue at both 30-60 and 60-90 DAS in comparison to other tillage treatments (Fig 2 a & b).

With respect to relative growth rate, treatments showed a different trend at all growth stages during two years of study and on pooled basis. The treatment conventional tillage flat bed + residue remained superior over zero tillage treatments and recorded significantly the highest RGR (0.0456 and 0.0328 g/g/day, respectively) at 30-60 and 60-90 DAS. However, statistically similar values were recorded under Conventional tillage raised bed with residue, Conventional tillage raised bed without residue and Conventional tillage Flat bed without residue. This might be due to better conservation of rain water, improved soil aeration under tillage with residue incorporation leading to high root proliferation and better growth. In addition, residues incorporated on the surface led to slower and continuous release of nutrients in the soil ensuring their availability throughout the crop growth. The conventional and conservation tillage treatments did not influence RGR at 60-90 DAS during both the years.

|  |  |
| --- | --- |
|  |  |
| Fig 2(a): Effect of tillage practices and residue application on dry matter accumulation (DMA) at 30, 60 and 90 DAS (g/plant) | Fig 2(b): Effect of tillage practices and residue application on Leaf area index (LAI) at 30, 60 and 90 DAS |

***Effect of tillage practices on nutrient contents and their total uptake***

The results of variance analysis of N, P and K contents in kernel and haulm indicated a significant and positive influence of tillage practices and residue incorporation on nutrient concentrations in both kernel and haulm and their total uptake by the crop (Figure 2 & 3). Based on pooled analysis, it was clear that conventional tillage-raised bed integrated with residue incorporation resulted in significantly highest N, P and K concentrations in kernel (5.08, 0.74 and 0.44 %, respectively) and haulms (3.17, 0.17 and 1.44 %, respectively) over other conventional and zero tillage systems (Fig 3a & b). However, the treatment was found at par with conventional tillage on flat bed+ residue incorporation for K concentration in kernel. The higher nutrient contents might be attributed to enhanced release of nutrients in soil due to increased mineralization of soil organic matter with tillage (Janzen *et al*., 2018). Meena *et al.* (2015) and Usman *et al.* (2024) also stated in their study that conventional tillage practices integrated with residue incorporation help in releasing the locked nutrients in soil organic matter thereby improving soil nutrient availability and crop uptake.

|  |  |
| --- | --- |
|  |  |
| Fig 3(a): Effect of tillage practices and residue application on N, P and K contents in kernel (%) | Fig 3(b): Effect of tillage practices and residue application on N, P and K contents in haulm (%) |

With respect to nutrient uptake, the data (Fig 4) followed the same trend where conventional tillage on raised bed with residue incorporation was found superior over zero tillage and rest of the conventional tillage practices and total uptake of N, P and K (333.8, 29.9 and 131.8 kg, respectively based on pooled data) was significantly highest under this treatment. Zero tillage could not perform well in comparison to conventional tillage and resulted in recording the least contents of N, P and K and their uptake. The higher uptake of these nutrients by the crop could be due to better root development in terms of better root proliferation and root density on raised bed and tilled plots, which improved foliage and growth, resulting in enhanced nutrient uptake. The results are in concordance with the findings of Arya *et al.* (2015), who reported enhanced and continuous availability of nutrients in soil and their efficient translocation to the economic sink under conventional tillage. Similar results were reported by Nayak *et al.* (2018).

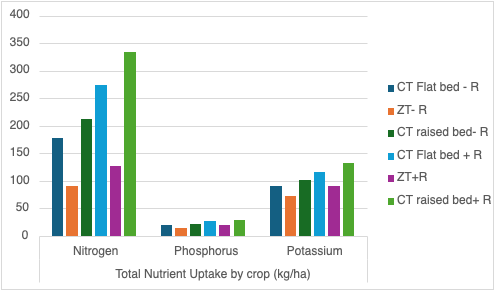


Fig 4. Effect of tillage practices and residue management on total uptake of N, P and K (both kernel and haulm) by crop (kg/ha)

***Effect of tillage practices on yields and yield attributes***

The tillage practices exhibited a significant influence on all yield-attributing characters and yields of groundnut (Table 2). Significantly, the highest number of pods/plant, pod weight/plant 100-kernel weight, shelling%, SMK% were recorded under conventionally tilled raised bed plots with residues incorporated on the surface in both years and the pooled study. Mathukia *et al*. (2015) and Kumar *et al.* (2014) had reported similar results. This treatment, however, was found statistically similar to conventional tillage on flat bed+ residue for most of these characters. The pod, kernel, haulm and biological yields of the crop (3100, 2135, 8487 and 11586.8 kg/ha, respectively) were obtained significantly higher with the same treatment (CT raised bed + residue) in comparison to zero and other conventional tillage treatments. The treatment, conventional tillage flat bed + residue remained at par with this treatment and obtained similar yields during both years. The yields of groundnut under the treatment conventional tillage raised bed with residue increased by 13.9 & 14.5% (pod), 22 & 20.6% (kernel) and 22.3% & 19.6% (haulm) during 2019 and 16.7 and 13.1% (pod), 21.4 and 19.1% (kernel) and 8.9 and 19.2% (haulm) higher over that obtained with conventional tillage raised bed- residue and zero tillage+residue system, respectively. Our results are in contrast with those reported by Ghuman and Sur (2001), Aulakh *et al.* (2012) and Thierfelder *et al.* (2013). Who reported increased crop yields under conservation agriculture plots. Pedersen and Lauer (2014) also observed a 6% greater yield in soybeans planted in zero-tilled plots compared to a conventional tillage system.

**Table 2.** Effect of tillage practices with residue management on pooled data of both the years at yield attributes and yield of groundnut

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Number of pods/plant** | **Pod weight/plant (g)** | **100 kernel weight**  **(g)** | **Sound Mature Kernel (%)** | **Shelling (%)** | **Pod Yield**  **(kg/ha)** | **Kernel Yield (kg/ha)** | **Haulm Yield (kg/ha)** | **Biological Yield (kg/ha)** | **HI** |
| **Conventional tillage Flat bed without residue** | 27.7 | 13.6 | 24.1 | 61.3 | 65 | 2562 | 1673 | 7081 | 9643 | 0.37 |
| **Zero tillage without residue** | 18.5 | 8.9 | 20.0 | 54.9 | 63 | 2350 | 1489 | 6018 | 8368 | 0.41 |
| **Conventional tillage Raised bed without residue** | 31.6 | 16.1 | 25.9 | 64.8 | 66 | 2641 | 1753 | 7393 | 10034 | 0.40 |
| **Conventional tillage Flat bed with**  **residue** | 35.6 | 18.3 | 27.1 | 67.5 | 67 | 2998 | 2016 | 7994 | 10993 | 0.51 |
| **Zero tillage with residue** | 23.6 | 12.3 | 22.1 | 58.6 | 65 | 2723 | 1782 | 7198 | 9921 | 0.55 |
| **Conventional tillage Raised bed with residue** | 38.0 | 20.1 | 28.5 | 71.0 | 69 | 3100 | 2135 | 8487 | 11587 | 0.50 |
| **SEm±** | **0.61** | **0.32** | **0.45** | **1.00** | **0.3** | **48.6** | **37.4** | **134.0** | **174.3** | **0.070** |
| **CD (0.05)** | **1.77** | **0.92** | **1.29** | **2.89** | **0.8** | **140.5** | **108.1** | **387.0** | **503.5** | **0.201** |

***Effect of tillage practices on economics***

The results of pooled analysis (Table 3) showed that the gross and net monetary returns with maximum BC ratio (2.18) were found to be significantly highest with practice of conventional tillage on raised bed along with residue incorporation over rest of the treatments. Statistically similar value was recorded under zero tillage + residue plots for BC ratio. However, lowest B:C was realised on conventionally tilled flat bed plots-residue. The lowest net and gross returns were fetched under zero tillage with no residue incorporation. The increase in gross and net returns under conventional tillage raised bed system+ residue was 21.7 and 19.8% and 43 and 21.1%, respectively, higher over conventional tillage raised bed without residue and zero tillage with residue systems in pooled study. Adoption of raised beds periodically maintained the soil moisture was in the root zone as while residue incorporated on the surface provided a suitable condition for plant growth by influencing soil temperature, moisture incorporation, improved soil texture and microbial activities. Nayak *et al.* (2018) who found similar results, opined that higher yield of different crops in conventional tillage resulted in higher net and gross realisations when compared to zero tillage. The cost of cultivation in conventional tillage was higher as compared to zero tillage; nevertheless, higher gross returns compensated the high cost of cultivation and resulted in higher net returns and B: C ratio. The results corroborate the findings of Prabhamani and Babalad (2018).

**Table 3.** Effect of tillage practices with residue management on pooled data of both the years at economics of groundnut

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatment** | **Gross returns (Rs/ha)** | **Net returns (Rs/ha)** | **Benefit Cost Ratio** |
| **Conventional tillage Flat bed without residue** | 85149 | 47080 | 1.24 |
| **Zero tillage without residue** | 75809 | 42941 | 1.31 |
| **Conventional tillage Raised bed without residue** | 89248 | 51180 | 1.34 |
| **Conventional tillage Flat bed with**  **residue** | 102592 | 67126 | 2.00 |
| **Zero tillage with residue** | 90714 | 60448 | 2.13 |
| **Conventional tillage Raised bed with residue** | 108659 | 73192 | 2.18 |
| **SEm±** | **1904.8** | **2004.1** | **0.059** |
| **CD (0.05)** | **5501.5** | **5788.1** | **0.171** |

**Conclusion**

Based on the results obtained in a two-year study, it is concluded that groundnut showed a positive response in terms of growth, yield, nutrient status and economic returns under conventional tillage raised beds with residues incorporated on the surface. Thus, this system of groundnut production is proven to be advantageous in the sandy clay soils of Gird region of Madhya Pradesh Zone VIII, (Gwalior). Therefore, it is recommended for the farmers of the region to adopt a tillage on raised bed system along with residue application as a sustainable management practice for increasing the profitability of groundnut production. From the experiment, zero-tillage system performed the least amongst all the treatments. Hence, it is not advantageous except there is a frequent supply of either chemical or organic fertilizer to compensate for the inability of the root system to penetrate deeper.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

**References:**

Aikins, S. H. M., & Afuakwa. J. J. (2012). Effect of four different tillage practices on soil properties under cowpea. *Agricultural and Biological Journal of North America,* 3(1): 17 – 24.

Aikins, S. H. M., & Afuakwa. J. J. (2020). Effect of four different tillage practices on cowpea performance. *World Journal of Agricultural Sciences,* 6(6): 644 – 651.

Arya RL, Kumar L, Singh KK and B.L. Kushwaha (2015). Effect of fertilizers and tillage management in rice (*Oryza sativa*) chickpea (*Cicer arietinum*) cropping system under varying irrigation schedules. *Indian J Agron*, 50(4):256-259.

Aulakh, M. S., Manchanda, J. S., Garg, A. K., Shrvan Kumar, Dercon, G. and Nguyen, M. L., 2012, Crop production and nutrient use efficiency of conservation agriculture for soybean–wheat rotation in the Indo-Gangetic Plains of north western India. *Soil Till. Res.,* 120: 50–60.

Conservation Tillage Information Center(CTIC), M.R. (2004). National crop residue management survey. West Lafayette, IN: Conservation Technology Information Center.

Corsi,S.,Friedrich,T.,Kassam,A.,Pisante,M.,&deMoraesSà,J.C.(2012). Soil organic carbon accumulation and greenhouse gas emission reductions from conservation agriculture: A literature review, integrated crop management, 16: 101

Degrune, F., Theodorakopoulos, N., Colinet, G., Hiel, M. P., Bodson, B., Taminiau, B., *et al*. (2017). Temporal dynamics of soil microbial communities below the seedbed under two contrasting tillage regimes. *Front. Microbiol*, 8:1127. doi: 10.3389/fmicb.2017.01127

Florence O. Umoh1, Otobong A. Essien, Okon E. Udoh and Mfonobong E.Ukpong (2021). Effect of Four Different Tillage Methods on Growth and Yield of Groundnut (*Arachis hypogea L*) in Coastal Plain Sand of Akwa Ibom State, AKSU *Journal of Agriculture and Food Sciences*, 5(1): 34-45.

Fuentes, J.P., Flury, M., Huggins, D.R. and Bezdicek, D.F. (2023). Soil water and nitrogen dynamics in dryland cropping systems of Washington State. *Soil & Tillage Research*, 71: 33-47.

Ghuman, B. S. and Sur, H. S., 2001, Tillage and residue management effects on soil properties and yields of rainfed maize and wheat in a subhumid subtropical climate*. Soil Till. Res.,* 58: 1-10.

Gomez, K.A., and Gomez, A.A. (1984). Statistical procedures for agricultural research. 2nd ed. John Wiley and Sons, New York.

IPCC (2023). Climate Change 2022: Synthesis Report. Geneva: Intergovernmental Panel on Climate Change.

Janzen, H.H., C.A. Campbell, R.C. Izanrrable, B.H. Ellert, H. Juma, McGill and R.F. Zenter, 2018.Management effects of soil storage on the Canadian Practices. *Soil Tillage Research*, 47: 187-203

Kumar, A., Thakur, T.C and Gautam, R.C. 2014. Evaluation of pant-winged sub-soiler in relation to soil properties and maize crop response. *Journal of Agricultural Engineering*. 51(2): 54-59.

Kumar, R & Singh, Rama & Singh, D & Kumar, S. (2022). Effect of Tillage and Irrigation Levels on Growth and Yield of Indian Mustard (Brassica juncea L.). *Environment & Ecology*, 34(4C): 2345—2348.

Lal, R. (2015). Sequestering carbon and increasing productivity by conservation agriculture. *J. Soil Water Conserv*. 70: 55A–62A. doi: 10.2489/jswc.70.3.55A.

Lasisi, Dauda & Aluko, O.. (2009). Effects of tillage methods on soybean growth and yield in a tropical sandy loam soil. International Agrophysics, 23.

Li, S.J., Chen, J.K., Chen F., Li, L. and Zhang, H.L. (2018). Characteristics of growth and development of winter wheat under zero tillage in North China Plain. *Acta Agronomica Sinica,* 34: 290-296.

Li, Y.J., Wu, J.Z., Huang, M., Yao, Y.Q., Zhang, C.J., Cai, D.X. and Jin, K. (2006). Effects of different tillage systems on photosynthesis characteristics of flag leaf and water use efficiency in winter wheat. *Trans CSAE*, 22: 44-48 (in Chinese with English abstract).

Manasseh, E. A., Abimiku, S. E., Ojo, P. O & Ishiak O. K. (2015). Correlation and Path Coefficient Analysis of yield and Agronomic characters in Hybrids and OPV maize (zea mays L) in Northern Guinea Savana. *Nigerian Journal of Soil and Environmental Research.* 13: 27-32.

Mathukia, R.K., Mathukia, P.R and Polara, A.M. 2015. Effect of preparatory tillage and mulch on productivity of rainfed pigeonpea [*Cajanus cajan* (L.) Millsp.]. *Indian Journal of Dryland Agriculture Research and Development.* 30(2): 58-61.

Meena, J.R.; Behera, U.K.; Chakraborty, D.; Sharma, A.R. (2015). Tillage and residue management eﬀect on soil properties, crop performance and energy relations in greengram (*Vigna radiata* L.) under maize-based cropping systems. *Int. Soil Water Conserv. Res.,*3: 261–272.

Mosaddeghi, M. R., Mahboubi, A. A., & Safadoust, A. (2019). Short-term effects of tillage and manure on some soil physical properties and maize root growth in a sandy loam soil in western Iran *Soil and Tillage Research,* 104*:* 173–179.

Nayak, S.K., Narkhede,W.N., Jadhav,S.G., Asewar, B.V. and Alse, U.N. (2018). Effect of tillage practices and nutrient levels on economic, uptake and available nutrient in soybean based cropping systems. *Journal of Pharmacognosy and Phytochemistry*, SP1: 3090-3095.

Omeke, J. (2017). Tillage practices and rhizobium inoculation effect on soil nitrogen and soybean nodulation in Savanna Altisol of Nigeria. *Applied Tropical Agriculture.,* 22(2), 94-100.

Patel, P. K., Viradiya, M. B., Kadivala, V. H & Shind, R. D. (2018). Effect of potassium and sulphur on yield attributes, yield and quality of summer groundnut (*Arachis hypogaea* L.) under middle Gufarat condition. *International Journal of Current microbiology and Applied Sciences,* 7(9): 2268 – 2273.

Peng, G., Bing, W., Guangpo, G., and Guangcan, Z. (2023). Spatial distribution of soil organic carbon and total nitrogen based on GIS and geostatistics in a small watershed in a hilly area of northern China. *PloS One*, 8: e83592. doi: 10.1371/journal.pone.0083592.

Prabhamani, P. & Babalad, Hanamantraya. (2018). Effect of conservation tillage and nutrient management practices on system productivity and economics of different crops under rainfed conditions of Karnataka.

Singh, K. M. and Meena, M. S., 2023, Economics of conservation agriculture: an overview. Munich Personal RePEc Archive, Paper No. 49381.

Thierfelder, C., Baudron, F., Setimela, P., Nyagumbo, I., Mupangwa, W., Mhlanga, B., et al. (2018). Complementary practices supporting conservation agriculture in southern Africa. A review. *Agron. Sustain. Dev*., 38:16. doi: 10.1007/s13593- 018-0492-498

Usman, K.; Khan, E.A.; Khan, N.; Rashid, A.; Yazdan, F.; Ud Din, S. (2024). Response of wheat to tillage plus rice residue and nitrogen management in rice-wheat system. *J. Integr. Agric*., 13: 2389–2398.

Wang, Y., Wang, Z. L., Zhang, Q., Hu, N., Li, Z., Lou, Y., et al. (2018). Long-term effects of nitrogen fertilization on aggregation and localization of carbon, nitrogen and microbial activities in soil. Sci. Total Environ. 624, 1131–1139. doi: 10.1016/j.scitotenv.2017.12.113

Zhang, W., Ricketts, T. H., Kremen, C., Carney, K., and Swinton, S. M. (2007). Ecosystem services and dis-services to agriculture. *Ecol. Econ*. 64: 253–260. doi: 10.1016/j.ecolecon.2007.02.024

Gatkal, N. R., Nalawade, S. M., Sahni, R. K., Walunj, A. A., Kadam, P. B., Bhanage, G. B., & Datta, R. (2024). Present trends, sustainable strategies and energy potentials of crop residue management in India: A review. Heliyon.

Alsamin, B., El-Hendawy, S., Refay, Y., Tola, E., Mattar, M. A., & Marey, S. (2022). Integrating tillage and mulching practices as an avenue to promote soil water storage, growth, production, and water productivity of wheat under deficit irrigation in arid countries. Agronomy, 12(9), 2235.

Tian, X., Engel, B. A., Qian, H., Hua, E., Sun, S., & Wang, Y. (2021). Will reaching the maximum achievable yield potential meet future global food demand?. Journal of Cleaner Production, 294, 126285.