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Effect of Zero Tillage on Soil Properties, Weed Dynamics and Performance of Chickpea under Rice –Chickpea Cropping System: A Review

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This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

In many nations across the world, farming is an important industry. Sustainable farming methods known as zero tillage systems entail planting seeds without tillage, which disturbs the soil. With this approach, crop residues from the previous year are left on the earth's surface and new plants are planted straight into the undisturbed soil, as opposed to plowing. This method aids in preserving the structure of the soil, decreasing soil erosion, retaining more water, and enhancing soil health. Farmers can benefit from enhanced soil health, decreased soil erosion, higher crop yields, and environmental sustainability by implementing sustainable farming practices. By limiting soil disturbance and shielding soil particles from the elements, this system aids in the reduction of soil erosion. Additionally contributes to improved soil structure, which raises soil fertility, and helps hold onto soil moisture, which lessens the need for irrigation. The amount of tillage and fuel used in zero-tillage systems can be less than in conventional tillage methods. In comparison to traditional tillage methods, systems require less fuel and tillage, which can save farmers money and lessen their carbon footprint. This is true because these systems raise soil organic matter levels, which in turn raise soil nutrient availability and improve soil fertility. Moreover, zero tillage systems can increase water retention in the soil, which can enhances crop growth and yield by improving soil structure and moisture retention, while also reducing weed competition. By reducing soil erosion, conserving soil moisture, and improving soil health, these systems help to promote environmental sustainability. Also reduce greenhouse gas emissions by reducing fuel usage and sequester carbon in the soil through the accumulation of crop residues. Therefore, farmers should adopt zero-tillage systems to enhance their productivity, reduce costs, and promote environmental sustainability.

Keywords: Zero tillage; soil properties; weed dynamics; rice – chickpea system; benefits.

1. INTRODUCTION

"Chickpea (*Cicer arietinum* L.) is grown in the winter season in sequence with different crops like rice, maize, soybean, sorghum and pearlmillet in the states of Madhya Pradesh, Maharashtra, Rajasthan, Andhra Pradesh, Tamil Nadu, Karnataka, Uttar Pradesh and Gujarat" [1]. "Rice- chickpea cropping system (RCCS) predominantly cultivated in northern part of the country next to rice-wheat cropping system" [2]. Beside wheat, the introduction of chickpea in rice based cropping system is a feasible option to ensure sustainable food production and maintain environmental integrity. It can fix N up to 140 kg ha^{-1} in a growing period [3] and helps in eradicating obnoxious weeds like wild oat (*Avena fatua*) and canary grass (*Phalaris minor*) [4]. "Chickpea, sown during rabi season after harvesting of the rice, it considers as a most valuable and drought tolerant crop" [5]. "Present agriculture has globally been facing major challenges including soil erosion which drastically lowers the crop yield. Chickpea can increase the productivity both in terms of N saving from fertilizer sources and build up soil fertility through biological source of N" [6]. "In rice-chickpea cropping system (RCCS), the sowing of chickpea often delayed until last November or early December either due to late harvesting of rice or more time required to seedbed preparation for chickpea seeding. Late sowing put negative effects on germination, seedling establishment, reproductive stage due the less soil moisture and low temperature. Conventional tillage (CT) affect the sustainable resources through its influence on soil properties, crop growth and the use of excessive and un-necessary tillage operations is often harmful to soil" [7]. "Conservation agriculture (CA) techniques involve zero tillage which reduces risk of late sowing of chickpea. Zero tillage seeding of chickpea helps in timely sowing, because it facilitates direct sowing in previous unprepared crop field. ZT also reduce the negative environmental effects of agriculture such as soil erosion and degradation of physical properties of soil leading to decrease crop productivity" [8].

Chickpeas work perfectly into a lot of different cropping schemes. The main cropping sequences that are followed in India's various climatic circumstances include pearl millet/sorghum-chickpea, rice/maize-chickpea, and cotton-chickpea [9]. One of the main agricultural systems in the Bundelkhand region is fodder sorghum–chickpea [10] Similarly, Andhra Pradesh and Karnataka follow the rice-chickpea, maize/sorghum-chickpea, and pearl millet-chickpea systems. These cereal-legume cropping systems aid in interrupting monocropping sequences, conserving nitrogen, halting soil erosion, and enhancing soil health. This review assesses the impact of zero tillage on performance of chickpea as well as impact on weed dynamics within the context of rice-chickpea cropping systems.

2. WHAT IS ZERO TILLAGE?

"Zero tillage has emerged as a promising approach in sustainable agriculture, offering benefits such as improved soil health and reduced erosion. One of the conservation tillage techniques is zero-tillage systems, where soil disturbance is limited to sowing activities. It keeps crop leftovers on the soil surface, which raises the amount of soil organic carbon and enhances soil quality and health. In comparison to conventional tillage, zero tillage systems typically needed less maintenance and provided higher economic returns" [11]. Zero tillage reduces cost by 3.8 % to 13.7 % and frees up at least 8 days for the growth of succeeding crops. Zero tillage farming is an option for low-income farmers [12].

Zero tillage globally advocated to it benefits. Zero tillage in rice-based system will not only enable the earlier planting of chickpea, also reduce the land preparation cost, avert the water logging by just utilizing the residual moisture, but also it will let the weeds stay dormant below the soil for their lack of exposure to light.

3. EFFECT OF ZERO TILLAGE

Mishra et al. [13] reported that "zero tillage in chickpea had better impact on crop growth and yield parameters such as plant population, number of branches, height of plants, number of pods per plant etc". "When compared with conventional tillage. This may have been due to improved moisture conditions near the soil surface or greater seed-soil contact in ZT systems" [14] "Tillage systems positively affect soil disturbance, weed management, and weed seed production, a change in tillage systems will influence the species composition and vertical distribution of weed seeds in agricultural soils" [15].

According to Hemmat and Eskandari [16], the grain production of chickpea at the Dryland Agricultural Research Station in Iran was higher under the minimum tillage-sweep ploughing, reduced tillage-tandem disk, and zero tillage techniques, respectively, than under the conventional tillage-mould board method.

3.1 Effect on Growth and Yield Attributes of Chickpea

Research by Quddus et al. [12] showed "variation in growth and yield attributes of chickpea due to different tillage (zero, single, two, three and four times tillage) practices except 100-seed weight. They obtained tallest plant (48.9 cm and 50.1 cm) under zero tillage treatment as compared to the single, two, three and four times tillage treatments, they stated that tallest plant under zero tillage condition observed might be due to availability of optimum soil moisture in soil for available nutrients to plant uptake". "Performance of zero tillage and minimum tillage both achieved well and produced taller plant, maximum number of branches per plant, the highest number of pods per plant. The highest number of pods plant^{-1} was realized in zero tillage which is related with more branching" [6]. "The climatic condition of zero tillage plots might be favoured to growth and development of chickpea plant. They stated that zero tillage system successfully adopts the weather conditions in the growing season. In an experiment carried out in ICARDA, Syria, tillage, residue, and weed control techniques had a significant impact on the growth and yield performance of chickpea. Compared to conventional tillage, zero-till seeded chickpea had a 26.3% greater grain yield" [17].

4. EFFECT OF ZERO TILLAGE ON SOIL PROPERTIES

Zero tillage have impact on physical, chemical and biological properties of the soil [18]. "No-till in the context of CA can also lead to improvements in soil quality by improving soil structure and enhancing soil biological activity, nutrient cycling, soil water holding capacity, water infiltration and water use efficiency [19].

4.1 Soil Physical Properties

4.1.1 Effect on bulk density

"Bulk density significantly influenced ($P \leq 0.05$) by the different tillage practice [20]. "Under zero tillage and minimum tillage practices lower value of bulk density (1.36 and 1.39)" observed by Lal et al. [21,22]. "Under conventional tillage the bulk density was 1.39Mgm^{-3}. They explain that this bulk density increase was the result of the natural reconsolidation of soil particles because of subsequent irrigation and summer drying. The gradual increase the disturbances in the soil by increased number of tillage and intercultural operations resulting more compaction of soil that leads to increased bulk density" [23]. The increase in bulk density under tilled soils may be due to increase in non-capillary porosity and low soil mass per unit volume. Owing to the progressive increase in bulk density after tillage, the difference between the tilled and no tilled treatments becomes smaller and smaller with the time since tillage progresses. The no tillage system maintained a significantly greater amount of residue on the soil surface increase soil organic carbon and biotic activity, thereby decreasing bulk density, particularly near the soil surface.

4.1.2 Effect on Water Stable Aggregate (WSA)

Reduced tillage practices showing the higher WSA compare with the intensive tillage and more intercultural operations. The highest WSA was recorded in Zero tillage (59.32%) followed by under minimum tillage (59.22%). It is shown in the work of worsened soil structure under conventional tillage in comparison to reduced tillage. According to various authors [24,25], "zero tillage, in comparison to conventional methods, increases the amount of water stable aggregates and improves (soil) structure due to a combination of greater amounts of organic matter, reduced bulk weight of soil, and a greater share of larger aggregates. Enhanced in physical parameters of soil resulting in increased porosity and water stable aggregate hence more available water content".

4.1.3 Effect on soil aggregation

Soil aggregation is an important physical property and is affected by divergent tillage methods. According to Mannering et al. [26] and [27], "soil aggregation decreased in CT plots as tillage break down the aggregates. Aggregation was highest in the 0-0.05 m layer of ZT plots". Long term adoption of the ZT "certainly" improve the aggregate stability of the topsoil [21] reported that aggregate size tended to be around 22% higher under ZT treatments in comparison to that of tilled plots. Soil under ZT have better aggregates, aggregate stability, increased porosity which further improved rhizosphere environment for the better plant growth while intensive tillage led to decline in soil organic matter through accelerated oxidation of the organic matter [28]. Francis and Knight [29,30,31]. Zero tillage canimproved macro-aggregation (>0.25 mm) and mean weight diameter which further improved carbon sequestration potential of the soil [32,33]. Most studies coined that aggregation improved with the adoption of the ZT, ZT must be adopted for about 5-8 years [34] and [35].

5. EFFECT ON SOIL CHEMICAL PROPERTIES

"Tillage operations and soil disturbance generally cause an increase in soil aeration, residue decomposition; Organic N mineralization and availability of N for plant use" [36]. Moussa-Machraoui et al. [37] observed that "some of the chemical parameters of soil were significantly modified under no tillage when compared to conventional tillage system. The nutrient (N, P, K, P_2O_5 and K_2O) contents were more under no tillage than conventional tillage".

5.1 Effect on EC

Lower electrical conductivity of soil under the ZT system compared with CT pertains to the enhanced water movement in the soil and improved soil aggregate development. Anomalous effect of zero tillage on soil electrical conductivity (EC) is observed and reported by Singh et al. [38] and [39,40] also reported decrease in soil EC under NT which might be due to more downward movement of salts along with water infiltration into deeper layers [41]

5.2 Effect on Soil pH

"Long term adoption of the ZT resulting in acidification of the surface soil which further affects the supply and distribution of other nutrients within the rhizosphere. Under ZT as compared to CT, a significant lowering of pH observed at the upper soil 0-7.5 cm on silt loam soil" [42] and [43] "Soil acidity with ZT observed due to decomposition of organic residues at the surface with subsequent leaching of resultant organic acids into mineral soil" [44]. While Rahman et al*.*, 2008 observed no significant differences in soil pH among no tillage and conventional tillage practices.

5.3 Effect on Soil Organic Matter

"Organic matter (OM) content and quality in a particular soil act as indicators of its quality, and they affect almost all the physico-chemical properties. Generally, OM content of upper soil under ZT is higher, than for tilled soil. The OM quantity will generally improve with conservation tillage, but remain fairly constant, or perhaps decrease further, with intensive tillage [45] Improvement in soil OM status in the upper 0.2 m to 0.4 m soil depth under ZT reported by Freitas et al. [46] and [47]. “The surface soil beneath the canopy had higher OM content in both tillage systems, particularly under no tillage. Contents of SOC were slightly greater under no tillage than under conventional tillage. The enhancement of SOC and SOM contents in the soil under no tillage is often accompanied by the enhancement of the cation exchange capacity” [37] The SOC was significantly higher when stubble was left on surface. Under conservation tillage the organic carbon increased by 11 per cent [48] and 14-17 percent [49], while a reverse trend was observed in the lower depths.

6. EFFECT ON BIOLOGICAL PROPERTIES OF SOIL

6.1 Soil Microbial Populations

“As compared to conventional tillage (CT), zero tillage (ZT) conditions were observed to be better for both micro and macro soil organisms. Greater number of worm channels and to their continuity, which was better in no-tilled soil than in plowed soil attributed the higher infiltration rate of loess soil in Germany” [50]. Reported that “earthworm channels, which increase soil porosity, are highly stable and provide for rapid water entry into a soil”. In comparison to that of conventional tilled plots, [51] reported greater earthworm activity (up to five times) in ZT plots. Doran [52] reported 35 and 57 per cent higher aerobic counts and facultative anaerobic counts under ZT conditions.

6.2 Soil Respiration

“CO_2 flux as impacted by agricultural management practice need to be delineated” [53]. “Tillage opens the soil, thus improves the soil respiration and increased the emission of the CO_2” [54]. “Nowadays, a rapid increase of CO_2 in environment is one of the main issues because of reported global warming consequences” [55]. However, soil management practices need to be refined to reduce soil respiration and organic matter decomposition without decreasing crop yield, ZT might be suitable answer. But scientists are of different opinions as some reported similar soil CO_2 emission rates from ZT and CT [56], while [57] observed large CO_2 emissions under zero tillage in comparison to the CT. Thus, a bridge between the two tillage systems might be an answer.

7. EFFECT ON NODULATION AND ROOT GROWTH

“A long-term chickpea experiment showed that, in comparison to a conventional tillage system, the quantity and dry weight of root nodules/plant under a zero tillage system were 33.3 and 21.1% greater, respectively” [58]. According to a study “conducted in Spain, during conventional tillage (0.34 mm/cm^2), chickpea root length in the 0-15 cm layer was 38 and 27% larger than under zero tillage (0.18 mm/cm^2)” [59].

“The study carried out in Jabalpur revealed that ZTs chickpea produced after transplanted rice had a considerably greater nodule dry weight (71.8 mg/plant) than both ZTs direct-seeded rice (55.2 g/plant) and direct-seeded rice (59.2 mg/plant)” [13].

8. EFFECT ON CROP PRODUCTION ECONOMICS AND ENERGY EFFICIENCY

“The data on economics of rabi chickpea crop emphasized that conventional tillage requires higher cost of cultivation (Rs.16799.40 per ha) as compared to minimum (16790.70 per ha) and zero tillage (Rs.16277.50 per ha)” [60]. The conventional tillage method yielded the highest gross return and net return among the tillage management techniques, with a B:C ratio of 2.62 for (60599.78 per ha) gross return and (43800.38 per ha) net return, respectively. The minimum and zero tillage methods were determined to be the least effectively. The higher returns under above conventional tillage might be due to higher seed yield coupled with lower cost of weed management treatments.

Mishra and Singh [61] reported that “total cost of cultivation in Transplanted Rice-Conventional Tillage chickpea system (TPR-CT chickpea) (₹ 31410/ha) was higher than other systems due to higher costs involved in field preparation and transplanting operations in rice. The highest net returns (₹33,600/ ha) and benefit: cost ratio (2.33) was accrued with Zero tillage – Direct Seeded Rice (ZT-DSR), ZT- chickpea cropping system and the lowest with DSR-CT chickpea system (₹ 20 222/ha and 1.67). The Puddled broadcast rice- conventional tillage (PBR-CT chickpea) system required maximum energy (₹

20 867 MJ/ha) closely followed by TPR-CT chickpea (20,594 MJ/ha) due to higher energy required for puddling in rice and tillage operations in chickpea. The energy productivity (yield per unit energy consumed) was maximum (0.401 kg/MJ) in ZT-DSR-ZT chickpea, followed by TPR-CT chickpea (0.327 kg/MJ). The output energy was maximum in TPR-CT chickpea (99 049 MJ/ha), followed by ZT-DSR-ZT chickpea (96 344 MJ/ha) due to higher system productivity. The energy output:input ratio (5.90) was the highest in ZT-DSR-ZT- chickpea, followed by TPR-CT-chickpea (4.81). The lowest energy productivity (0.253 kg/MJ), output energy (72 765 MJ/ha) and output: input ratio (3.71) was observed from DSR-CT chickpea system".

According to Mishra and Singh [61], on the sandy loam soils of Ludhiana, Punjab, the net monetary returns of chickpea were higher under ZT with Pantnagar seed drill (₹2650/ha) and ZT with paddy stubbles (₹2100/ha) than under reduced tillage-RT (₹1950/ha). Similar view also reported by Kumari et al. [62] by conducting an experiment on chickpea at Bhagalpur**.**

9. EFFECT OF ZERO TILLAGE ON WEED DYNAMICS IN CHICKPEA

Weed is also serious problem in rice based cropping system. Infestation of weeds suppresses the crop especially during initial growth period. Weeds can reduce the chickpea yield by the tune of 10-50% loss of crop yield depends upon the intensity of weed flora and management practices [63]. A significant obstacle to achieving potential chickpea yield is weeds. The weed species infesting the chickpea fields vary from one location to another depending on the agro-climatic conditions, prevailing cropping systems, tillage practices and weed management strategies adopted.

The site of experiment of chickpea was dominated with broad-leaved weeds (95.4%), viz. Clover (*Medicago hispida* Gaertn) (50 %), common vetch (*Vicia sativa* L.) (22.6 %), common lambsquarters (*Chenopodium album* L.) (7.3 %), and others including field bindweed (*Convolvulus arvensis* L.), *V. hirsuta* L., sweet clover (*Melilitus indica* All.) and *M. alba* L. (15.5 %). The grassy weeds, viz littleseed canary grass (*Phalaris minor* Retz.) (3.1%) and wild oats (*Avena sterilis*) (1.5%) were of minor importance [61] stated that Zero till chickpea significantly increased the population of *V. sativa* but reduced the problem of *C. album* as compared to conventional tillage. The population of *M. hispida*, *A. luduviciana*, *P. minor* and total weeds did not vary significantly due to change in tillage systems. Under zero tillage significantly reduced dry matter of *M. hispida* and *C. Album* was observed by 20.3 and 58% as compared to conventional tillage, however, the dry matter of *A. luduviciana* and *V. sativa* increased.

In a study at Kanpur, [64] observed that, "post–rainy seasons zero tillage with and without residues attributed higher weed diversity indices (Shannon and Simpson) compared with conventional tillage in seedbank. Importantly, Conventional tillage –Zero tillage + Residue mulch (CT–ZT + R) with rice-chickpea-mungbean (R–C–Mb) (interaction) reduced 24% total viable seed density at 0–15 cm depth than CT–CT with R–W. Zero tillage in post-rainy seasons after puddled transplanted rice and intensive pulse based cropping (rice-chickpea-mungbean) can minimize viable weed seeds in soil vis–a–vis above–ground weed density over time than conventional tillage and rice-wheat system. The reduced weed density reduce soil fertility degradation, enhance crop/system productivity, restore soil health and provides opportunity for sustainable cropping intensification in rice ecologies of the Indo-Gangetic plains".

In a study conducted at IGFRI, Jhansi, zero tillage in the chickpea cropping sequence considerably reduced the weed density by 14.5-19.5% when compared to reduced and conventional tillage conditions [65].

10. CONCLUSION

Based on the research work carried by various workers as reviewed, it may be concluded that:

1. Zero tillage significantly reduces weed density and biomass, mitigating weed competition and enhancing chickpea growth and development.
2. Weed dynamics under zero tillage exhibit a favourable trend, facilitating improved resource utilization by chickpea crops and reducing the need for intensive weed management.
3. Chickpea yields demonstrate marked improvement under zero tillage, attributed to decreased weed interference and enhanced soil health.
4. The adoption of zero tillage offers a sustainable approach to weed

management, promoting soil conservation and minimizing environmental impact.

5. Integrating zero tillage into rice-chickpea cropping systems holds promise for optimizing agricultural productivity while fostering long-term sustainability.

By reviewing the research work done by several workersit may be concluded that the efficacy and benefits of zero till chickpea in enhancing chickpea productivity and efficient weed management under rice-chickpea cropping systems, thereby offering a pathway towards sustainable agricultural practices and improved farm profitability.

Based on the review of literature on the effect of zero tillage on soil properties, weed dynamics, and chickpea performance in the rice-chickpea cropping system, the following points for future research could be identified:

1. **Soil Health Monitoring:** Conduct longitudinal studies to monitor changes in soil health indicators over time under zero tillage, including soil organic matter content, soil structure, microbial activity, and nutrient availability.
2. **Weed Species Composition:** Investigate the shifts in weed species composition and abundance under zero tillage compared to conventional tillage, particularly focusing on the emergence patterns, competitive abilities, and herbicide resistance of dominant weed species.
3. **Integrated Weed Management Strategies:** Develop and evaluate integrated weed management strategies tailored specifically to zero tillage systems in the rice-chickpea cropping system, incorporating cultural, mechanical, biological, and chemical control methods.
4. **Chickpea Genotype Selection:** Assess the performance of different chickpea genotypes under zero tillage conditions, considering traits such as early vigor, root architecture, disease resistance, and yield stability.
5. **Nutrient Cycling Dynamics:** Investigate the effects of zero tillage on nutrient cycling processes, including nutrient mineralization, immobilization, and leaching, to optimize nutrient management practices and improve chickpea productivity while minimizing environmental impacts.
6. **Water Use Efficiency:** Evaluate the water use efficiency of chickpea under zero tillage compared to conventional tillage systems, considering factors such as soil moisture retention, evapotranspiration rates, and irrigation requirements.
7. **Economic Viability:** Conduct economic assessments to determine the cost-effectiveness and profitability of adopting zero tillage practices in the rice-chickpea cropping system, considering both short-term input costs and long-term benefits such as soil conservation and yield stability.
8. **Climate Change Resilience:** Investigate the role of zero tillage in enhancing the resilience of rice-chickpea cropping systems to climate change impacts, including drought stress, extreme weather events, and temperature fluctuations.
9. **Farmer Knowledge Exchange:** Facilitate knowledge exchange and farmer-to-farmer learning networks to disseminate information about the benefits and challenges of zero tillage adoption in the rice-chickpea cropping system and promote its uptake among farming communities.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

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 writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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