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COMPARATIVE EVALUATION OF ZERO - TILLAGE CUM MULCHING WITH CONVENTIONAL POTATO PRODUCTION UNDER TRANSPLANTED RICE – POTATO CROPPING SYSTEM

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ABSTRACT: Environmental problems such as GHG emissions like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emission from rice-residue burning, the over exploitation of underground water, land degradation, and productivity reductions in rice-based agricultural systems is negatively impacting productivity of rice based cropping system and increasing environmental concerns. A field study was conducted at the research farm of ICAR- Central Potato Research Institute RS, Patna (Bihar) during the Rabi seasons of 2022- 23 and 2023-24 with seven treatment combinations having Farmer's practice, zero tillage + mulching, Regional AICRP/ ICAR-CPRI recommendations, Flat-bed planting with slit, Flat-bed planting & mulching, Flat-bed planting & ridging and Flat-bed planting, ridging & mulching. Treatments were replicated thrice. Highest rice grain yield (5.1 t/ha) was recorded with Flat-bed planting, ridging & mulching (T7) which was statistically same compared to other treatments. Highest B:C (1.62) of rice cultivation was recorded with T7 which was statistically same compared to all other treatments. The highest number of total tubers was recorded with Zero tillage + mulching (T2) (624 thousand/ha) which was statistically same with all other treatments. The highest total tuber yield (26.8 t/ha) was recorded with T2 which was significantly higher than all other treatments except T5 and T7. The highest net return (₹114554/ha) of potato was recorded with T5 which was significantly higher than all other treatments except T2. Highest water use efficiency of potato was recorded with T2 (76.63 kg tuber/ha-mm water) which was significantly higher than all other treatments except T5 and T7. The highest rice equivalent yield (14.86 t/ha) was highest with T2 which was significantly higher than all other treatments except T5 and T7. Zero tillage in combination with paddy straw mulch will enhance crop productivity, system sustainability, system vitality, economic profitability, and environmental quality.

KEYWORDS: Equivalent yield, mulch, potato, rice, water use efficiency, zero – tillage

INTRODUCTION

Potato (*Solanum tuberosum* L.) is grown worldwide and is very sensitive to soil and water conditions as it grows and produces better on deep and well-drained soils (Djaman *et al.*, 2021).

Potato is the fourth-largest crop produced worldwide after rice, wheat, and maize (FAOSTAT, 2021). Tillage practices are adopted to create the proper environment for potato growth and yield potential. Tillage is essential for preparing a seedbed

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and for weed control. Potato production is associated with different practices such as planting, diking, cultivation, hilling, and harvest that significantly disturb the soil environment with heavy machinery. Soil and water management in potatoes are therefore critical to assure optimal crop growth and development. Commercial potato production under traditional management practices involves heavy to very heavy machinery and equipment during seedbed preparation and growing season for different operations such as cultivation, herbicide and pesticides application and harvest, exposing the soil to compaction. Compaction before and during planting can restrict root growth (Huntenburg *et al*., 2021). Soil compaction in combination with decrease plant water availability limit biomass production and potato tuber dry weight (Huntenburg *et al*., (2021). Larney *et al*., (2016) reported that integration of conservation management practices led to yield and disease control benefits without negatively impacting tuber quality. Rice - based systems occupy the most important agricultural lands in some of the vastest countries of Asia (Liu *et al*., 2021). Environmental problems such as carbon emission from rice-residue burning, the overexploitation of underground water table, land degradation, and productivity reductions in rice-based agricultural systems have been reported in Asia (Bhatt *et al*., 2016). In general, nitrogen recovery in flooded rice is only 30-35% of applied dose, rest nitrogen is either volatilized or leached out beyond root zone. It ultimately reaches to ground water and enhances nitrate content of ground water. On the other hand, there have been significant efforts to adopt sustainability index (SI) in these systems, with substantial results for soil re-carbonization (Jat *et al*., 2020). In rice - dominant areas, intensification with potato could diversify diets and create additional incomes. Area's having high moisture content where tillage is not possible after rice harvesting, potato under zero tillage can be planted advancing potato planting 10-15 day before, adopting zero tillage. Similarly, area's having salt problem in soil, Zero tillage in combination with mulching makes micro climate suitable for potato production. Thus, agronomic gain is a current, more inclusive concept related to reducing yield gaps through practices that aim to improve productivity, resource use efficiencies, and soil health. Agronomic gain considers different environments, is socially inclusive, and can easily be framed as a key performance indicator (KPIs) (Saito *et al*., 2021). There is inconsistent evidence that zero-tillage benefits weed control, but its effectiveness is enhanced by mulching. Even if soil organic matter is increased (+13–33%) and zero-tillage is the main factor driving the reduction in C footprint, no values of kg CO_2 eqha^{-1} have been reported in PZTM to date. Agronomic gain, related to productivity, requires a combination of improved agronomic practices that allow for high and stable yields and economic profitability (Saito *et al*., 2021). The burning of crop residues is a particular issue in Punjab, but it is also increasing in the Eastern States of Indo-Gangetic Plains. Farmers are looking for non-burning alternatives, and mulching is a convenient, sustainable practice in regions where straw resources are locally available. Together with zero-tillage, this can help to reduce burning and, thus, air pollution (Thakur *et al*., 2018). Farmers burn crop residues because they cannot leave them on the field due to their long decay period and they can spread diseases from the last/ previous paddy season, as well as farmers having short sowing period window that does not allow them to manually clear the fields (Bhatt *et al*., 2021). South India, have a crop residue production potential of 912 Mt, especially in the rice–wheat system. About 372 Mt residues are surplus. Conservation tillage practices increase soil organic matter of the topsoil and can improve soil structure and soil biological properties following zero tillage along with mulching.

MATERIALS AND METHODS

A field study was conducted at the research farm of ICAR-Central Potato Research Institute RS, Patna (Bihar) during 2022-23 and 2023-24. Geographically, Patna is located at 25°35′47″N and 85°04′32″E, at an elevation of 76.9 m as per GPS location which lies in the South tract of Bihar. The soil of the experimental site was clay loam with approximately 0.42% organic carbon, EC 0.11 mSm-1 and pH 6.8, bulk density 1.46 g/cm3 and available N, P, K were 238.2, 23.4 and 262.4 kg/ha, respectively. Potato cv. 'Kufri Himalini' was grown with seven treatment combinations. Treatments consisted of conservation tillage for potato cultivation *viz* T-1: Farmer's practice: Removing/ Burning of straw from field, tillage, planting, and irrigation afterwards; T-2: Flat planting of seed tubers after FYM & fertilizer application + covering with paddy straw mulch; T-3: Regional AICRP/ ICAR-CPRI recommendations; T-4: Flat-bed planting: Direct planting of potato by opening slit and covering it with soil (Root zone tillage in 10 cm width and 15 cm depth) and no mulching or earthing; T-5: Flat-bed planting & mulching: Direct planting of potato by opening slit and covering it with soil (Root zone tillage in 10 cm width and 15 cm depth) + mulching by chopped straw and no earthing; T-6: Flat-bed planting & ridging: Direct planting of potato by opening slit and covering it with soil (Root zone tillage in 10 cm width and 15 cm depth), earthing after 20-25 days by tilling soil between rows and no mulching; T-7: Flat-bed planting, ridging & mulching: Direct planting of potato by opening slit and covering it with soil (Root zone tillage in 10 cm width and 15 cm depth) and earthing after 20-25 days by tilling soil between rows + mulching of chopped straw after earthing. Treatments were replicated thrice. Transplanted rice was grown before potato crop. Transplanting was done on 1.7.2022 and 5.7.2023 and crop was harvested on 3.11.22 and 26.10.2023. The crop was fertilized with 120 kg N, 50 kg P_2O_5 and 40 kg K_2O/ha. Potato tubers were planted just after harvest of rice as per treatment. Recommended dose of nutrients, *i.e.* 180:80:100 kg/ha of N:P_2O_5:K_2O, respectively were applied as per schedule during crop raising. Half N and full quantity of P_2O_5 and K_2O were applied before planting and the remaining half dose was applied at earthing up. Gross plot size was 4.2 m x 4.0m. Well sprouted potato tubers were planted on 9.11.2022 and 29.10.2023. Four/five irrigations were applied as per requirement in addition to winter rains on 10.12.22, 31.12.2022, 17.1.2023, 8.2.2023 and 7.11.23, 24.11.23, 30.11.23, 15.12.23 23.1.24. The crop was sprayed with herbicide oxyfluorfen 23.5% EC @ 500 ml/ha on 10.11.22 and 1.11.23 for control of weeds. For control of late blight and insects, insecticide imidacloprid 17.8sl was sprayed @ 4ml/10-liter water and dithane M45 and moximate @ 2.5 and 3 kg/ha respectively on 26.12.22, 17.1.23 and 1.2.23 during 2022-23 and 30.12.2023, 10.1.24 and 20.1.2024 respectively during first and second years. Haulm killing of potato was done at 90 days after planting (physiological maturity) on 17.2.23 and 28.2.2024. Potato crop was harvested after haulm killing on 21.2.23 and 28.2.24. To assess the economic viability of different treatments for potato production, both fixed and operating costs were taken into consideration. The economics of rice, potato and both crops production under variable treatments were calculated. Net returns were estimated as the difference between gross income and total production cost. Gross returns were a product of yield and wholesale market price of potato. The experiment was laid out in a completely randomized block design (CRBD). The data were analyzed statistically by standard analysis of variance (ANOVA). Least significant difference (LSD) test was used to determine whether differences exist between certain comparisons. The probability level for determination of significance was 0.05.

RESULTS AND DISCUSSION

Growth and yield attributes and economics of rice cultivation: Number of ear /plant (16.70) was highest with T7 which was statistically same compared to other treatments. The highest number of tillers/ plant (17.7) was recorded with T7 which was statistically same compared to other treatments. Paddy dry weight (0.10 kg/Plant) was highest with T4. Highest rice grain yield (5.1 t/ha) was recorded with T7 which was statistically same compared to other treatments. Similarly, the highest straw yield (7.0 t/ha) was recorded with T7 which was statistically same with all other treatments. Cost of cultivation of rice was ₹ 54851/ha. Highest gross return of ₹ 88645/ha of rice was recorded with T7 which was statistically same with all other treatments. Highest net return ₹ 33794 was recorded with T7 which was statistically same compared to other treatments. Highest B:C (1.62) was recorded with T7 which was statistically same compared to all other treatments (Table 1).

Growth, yield attributes, yield and economics of potato cultivation: Emergence count (94.2%), stem/plant (3.3), compound leaf/ plant (39.3) and fresh haulm weight/plant (10.8 t/ha) were highest with T2 which was statistically same compared to all other treatments. The highest plant height of potato was recorded with T7 (51.4 cm) which was statistically same with all other treatments. The reduced soil temperature is considered

Table 1. Effect of tillage and mulching on growth, yield and economics of rice and growth attributes of potato (mean data of two years)

Treatments	Rice										Potato				
	Tiller/plant	Eear/plant	Paddy straw dry wt /plant (kg)	Weight in (kg/ plant)	Rice yield (t/ha)	Straw yield (t/ ha)	Cost of cultivation (₹/ha)	Gross return (₹/ ha)	Net return (₹/ha)	B:C	Emergence (%)	Plant height (cm)	Stem/plant	compound leaves/plant	fresh Haulm wt t/ha
T1	12.4	12.0	0.1	0.2	4.8	6.6	54,851	82,207	27,356	1.50	93.2	49.6	3.0	34.7	2.7
T2	14.3	13.7	0.1	0.2	4.5	6.5	54,851	81,953	27,102	1.49	95.2	53.5	3.3	39.3	10.8
T3	14.8	14.3	0.1	0.2	5.0	6.1	54,851	85,638	30,787	1.56	93.3	47.3	3.1	36.4	4.1
T4	15.1	14.3	0.1	0.3	4.3	6.0	54,851	79,666	24,815	1.45	92.9	51.9	3.0	34.3	5.3
T5	12.3	11.1	0.1	0.2	4.7	5.8	54,851	84,028	29,177	1.53	92.3	53.5	2.6	32.9	8.4
T6	14.3	14.1	0.1	0.2	4.6	6.5	54,851	87,162	32,311	1.59	93.7	49.5	2.8	35.0	4.6
T7	17.7	16.7	0.1	0.3	5.1	7.0	54,851	88,645	33,794	1.62	94.0	51.4	3.1	36.6	7.3
SE(m)	1.3	1.2	0.0	0.0	0.3	0.3		7,190	7,190	0.13	1.5	2.5	0.4	3.4	0.6
C.D.0.005	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS	1.9

the main factor that improves potato plant development due to mulching. This could be due to the low heat transmissivity, which resulted in a more significant fraction of solar radiation being absorbed at the top of the mulch layer (Kar and Kumar, 2007). Additionally, organic mulching can maintain a higher soil and plant water status over non-mulched soil with only half of the amount of N (60 vs. 120 kg N ha^{-1}, respectively), resulting in a water-saving of 40 mm without affecting leaf area index and yield (Acharya and Kapoor, 2001)

Number of Tubers: Highest number of <25 g tubers were recorded with T1 (297 thousand/ ha) which was significantly higher than T4, T5, T6 and T7 but statistically on par with T2 & T3. The highest number of 25-50 g tubers was recorded with T7 (212 thousand/ha) which was statistically same with all other treatments. The number of 50-75 g tuber was recorded with T3 (115 thousand/ha) which was statistically same with all other treatments. The highest number of >75 g tuber was recorded with T2 (57 thousand/ ha) which was significantly higher than all other treatments except T3, T5 and T7. The highest number of total tubers was recorded with T2 (624 thousand/ha) which was statistically same with all other treatments. The increased tuber rate in the large- and medium-sized tubers and the corresponding weight contributed the most to the increase in the tuber yield in addition to hassle free tuberization and tuber survival.

Tuber Yield: Highest tuber yield of <25 g tuber was recorded with T1 (3.0 t/ha) which was statistically same with all other treatments. Yield of 25-50 g tubers was recorded with T7 (7.8 t/ha) which was significantly higher than all other treatments except T1 and T2. David *et al.*, (2022) reported that mulch can mitigate water and heat stresses by increasing soil moisture and reducing soil temperature, respectively, promoting a higher yield (Genger *et al.*, 2018). The yield of 50-75 g tubers was highest with T5 (7.9 t/ha) which was significantly higher than all other treatments except T2, T3 and T7. Highest yield of >75g tubers was recorded with T5 (9.4 t/ha) which was significantly higher than all other treatments except T2. The highest total tuber yield (26.8 t/ha) was recorded with T2 which was significantly higher than T5 and T7 (Table 2). David *et al.*, (2022) reported that combination of mulch

Table 2. Effect of tillage and mulching on yield attributes, yield and economics of potato cultivation (mean data of two years)

Treatments	Number of tubers (000/ha)					Tuber yield (t/ha)					Potato			
	0-25	25-50	50-75	>75	Total	0-25	25-50	50-75	>75	Total	Cost of cultivation (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	B:C
T1	297	200	89	35	621	3.0	7.4	5.2	4.5	20.2	1,45,396	2,01,933	56,537	1.39
T2	252	201	114	57	624	2.7	7.5	7.7	8.9	26.8	1,64,896	2,68,190	1,03,294	1.63
T3	259	167	115	45	586	2.2	5.8	6.8	5.7	20.4	1,45,396	2,04,440	59,045	1.41
T4	197	156	76	42	471	2.2	5.4	5.2	5.4	18.3	1,28,896	1,82,616	53,720	1.42
T5	174	172	113	62	520	1.9	6.5	7.9	9.4	25.6	1,41,896	2,56,450	1,14,554	1.81
T6	228	166	84	28	506	2.4	5.8	5.9	3.6	17.7	1,44,896	1,76,906	32,010	1.22
T7	213	212	105	49	579	2.8	7.8	7.2	7.0	24.8	1,57,896	2,48,260	90,365	1.57
SEm+	22	15	10	4	35	0.3	0.4	0.4	0.6	0.7		7,132	7,132	0.05
CD(P=0.05)	69	NS	NS	13	NS	NS	1.2	1.2	1.9	2.2		22,220	22,218	0.17

and a closer distance (between 30 and 60 cm between plants and rows, respectively) was more appropriate when comparing different plant spacings because the lower soil temperature promoted a better accumulation of carbohydrates in the tubers. Soil water and effective accumulated temperature during the tuber formation stage were the main factors affecting potato total yield, with stronger effect of soil water than that of soil effective accumulated temperature. Therefore, straw mulch could improve soil moisture and heat condition and realize potato yield and income increases (Yang *et al*., 2023). The increased tuber rate in the large- and medium-sized tubers and the corresponding weight contributed the most to the increase in the tuber yield in addition to hassle free tuberization and tuber survival.

Economics of potato cultivation: Highest Cost of cultivation of potato was with T2 (₹ 164896/ha). Although the cost of crop residue for mulching application is higher than that needed for tillage operations, studies have shown that the combination of zero/ minimum tillage with mulching has better gross/net return and monetary efficiency than conventional tillage practice (Prasad *et al*., 2014). The highest gross return of potato was recorded with T2 (₹ 268190/ha) which was significantly higher than all other treatments except T5 and T7. The highest net return of potato was recorded with T5 (₹ 114554/ha) which was significantly higher than all other treatments except T2. Highest B:C (1.81) of potato was recorded with T5 which was significantly higher than all other treatments. Tuber yields under mulch increased by 20% or more compared to non-mulched production (Sadawarti *et al*., 2013). Some other studies have achieved increases of up to 100% and 173%. On an average, mulching increases the benefit–cost ratio (BCR; i.e., revenues per rupee invested) by +10% over no-mulching practice (BCR = 1.55) (Dash *et al*., 2018).

***Water use efficiency (WUE) of potato production*:** Highest water use efficiency of potato was recorded with T2 (76.63 kg tuber/ ha-mm water) which was significantly higher than all other treatments except T5 and T7 (Table 3). Huiying *et al*., (2022) reported that higher water use efficiency was obtained with straw mulch treatments. Some of the reviewed

Table 3. Water use efficiency of potato, rice equivalent and economics of rice-potato sequence (mean data of two years)

Treatment	WUE of potato (kg/ ha-mm)	REY (t/ha)	System Economics			
			Cost of cultivation (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	B:C
T1-Farmer's practice	57.70	12.06	₹ 2,00,247	2,84,140	83,893	1.42
T2-Zero tillage + mulching	76.63	14.86	₹ 2,19,747	3,50,143	1,30,396	1.59
T3- CPRI recommendations	58.41	12.14	₹ 2,00,247	2,90,078	89,831	1.45
T4-Flat-bed planting	52.18	10.90	₹ 1,83,747	2,62,282	78,535	1.43
T5-Flat-bed planting & mulching	73.27	14.41	₹ 1,96,747	3,40,478	1,43,732	1.73
T6-Flat-bed planting & ridging	50.54	10.95	₹ 1,99,747	2,64,068	64,321	1.32
T7-Flat-bed planting, ridging & mulching	70.93	14.49	₹ 2,12,747	3,36,905	1,24,158	1.58
SEm±	2.04	0.31		7,881	7,881	0.04
CD(P=0.05)	6.35	0.95		24,552	24,554	0.13
CV (%)	5.62	4.11		4	13	4.69

REY-Rice equivalent yield of system, WUE- water use efficiency studies (29%) combined mulch cover with irrigation schedule treatments, from which mulched crops recorded an increment of 10% in water productivity (WP) over non-mulched crops Sadawarti *et al.*, (2013). The reduction in water evaporation promoted by a low solar energy incidence under organic mulching conditions leads to increased soil moisture conservation in potatoes. However, the data are very variable; for instance, Li *et al.*, (*2018*) reported an increase in WP by 7.7% at air temperatures ranging from 15 to 20°C without significant effects over 20°C. Li *et al*. 2018 also stated that straw mulching significantly increased potato WP by 8.3% in areas with low water input, but had no significant effect in areas with high water input. When combining zero-tillage and rice-straw mulching, about 200 mm of irrigation (compared with conventional tillage) water can be saved, thereby reducing the water footprint (Sarangi *et al*., (2020). Li and Hou (2015) reported that straw mulch in potato increased yield and water use efficiency by 37.3%, and 41.2%, respectively, when compared with the conventional tillage treatment.

Rice equivalent *yield and economics of rice – potato sequence:* Highest rice equivalent yield (14.86 t/ha) was recorded with T2 which was significantly higher than all other treatments except T5 and T7. Highest cost of cultivation ₹ 2,19,747/ha of rice - potato sequence was recorded with T2. Highest gross return of rice - potato cropping system was recorded with T2 (₹ 350143/ha) which was significantly higher than all other treatments except T5 & T7. Highest net return was recorded with T5 (₹ 143732/ha) which was significantly higher than all other treatments. Highest B:C was recorded with T5 (1.73) which was significantly higher than T4, T6 &T7. Soil treated with crop residues contained 5–10 times more aerobic bacteria and 1.5–11 times more fungi than soil from which residues were either burned or removed. However, it should be noted that, to obtain a significant improvement in soil health through minimum tillage, a certain set of 3–5 years is required. This could be caused by the reduction in soil water evaporation promoted by soil temperature reduction and moisture retention. Sarangi *et al*., (2020) state that rice-straw mulching can eliminate weed germination, so there is no need for the intercultural operations required in conventional practices which reduces on cost of cultivation. Singh *et al*., (2023) reported that zero-tillage was beneficial for potato cultivation under rice – potato sequence.

CONCLUSION

The adoption of zero-tillage with mulching in potato cultivation resulted in enhanced yield, profitability, and water productivity, alongside a probable elevation in soil organic carbon (SOC) levels. It also achieved complete savings in chemical weed control and machinery costs associated with ploughing and digging. However, this practice entailed additional expenses for paddy straw mulch (requiring 12–15 t/ha), challenges such as rat infestations in mulched plots, disturbances by dogs, and the need for extra labor during mulching. Consequently, while zero-tillage with mulching holds substantial potential to drive agro-ecological transformation, effective management of these challenges- particularly the labor- intensive and costly processes of spreading paddy straw at planting and harvest- is essential.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

ETHICAL STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors

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