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Impact of Live Mulch-Based Conservation Tillage on Soil Properties and Productivity of Summer Maize in Indian Himalayas

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Abstract: Food security and soil sustainability are the prime challenges to researchers and policy planners across the globe. The task is much more daunting in the fragile ecosystem of the Eastern Himalayan region of India. Soil disturbance from conventional tillage reduces soil productivity and is not sustainable and environmentally friendly. Conservation tillage is regarded as the best crop production practice in the Indian Himalayas, where soil is very easily erodible. Zero tillage alone encourages the growth of different species of weed flora in fragile hill ecosystems. However, live mulching of a pulse crop under zero tillage may be a very beneficial practice, as it aids several soil quality benefits and promotes root proliferation with good crop harvest. Hence, a field investigation was carried out for 3 consecutive years to assess the impact of live mulch-based conservation tillage on soil properties and productivity of summer maize. Five tillage practices, viz. no-till (NT), NT and cowpea coculture live mulch (CLM), minimum tillage (MT), MT+CLM, and conventional tillage (CT), were assessed in a randomized complete block design with three replications. Results revealed that continuous adoption of MT+CLM had the lowest bulk density (1.31 and 1.37 Mg m^{-3}) and maximum water holding capacity (48.49% and 43.1%) and moisture content (22.4% and 25%) at 0–10 and 10–20 cm soil layers, respectively, after 3 years. The infiltration rate (2.35 mm min^{-1}) was also maximum under MT+CLM, followed by NT+CLM. MT+LMC had 13.8 and 27.15% higher available nitrogen and phosphorus, respectively, than CT at 0–10 cm soil depth. The MT+CLM gave a significantly higher maize grain yield (2.63 Mg ha^{-1}), followed by NT+CLM (2.63 Mg ha^{-1}) over the others. A cowpea green pod yield of 1.65 Mg ha^{-1} was also obtained from the legume coculture. Thus, the study found that live mulch of cowpea under MT/NT improved soil quality and subsequently led to greater productivity of summer maize in the Himalayan region of India.

Keywords: biomass production; no-till; soil chemical composition; soil physical properties; yield

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1. Introduction

Soil quality is severely affected by excessive tillage [1], and reduced biomass production is implied by soil susceptibility to soil organic carbon (SOC) and moisture losses [2]. Moisture stress and continuous depletion of soil quality severely reduce crop productivity [3,4]. Hence, it worsens the region's food and nutritional security [5]. Conservation-effective tillage practices (no-till (NT) and minimum tillage (MT)), along with living mulches, are suggested worldwide for improving soil properties and subsequent system productivity [6]. Conservation agriculture (CA) based on conservation agriculture is based upon three pillars, namely: minimum soil disturbance, permanent soil cover, and diversified crop rotation [7]. CA improves soil properties and environmental quality and minimizes the cost of cultivation with sustainable crop productivity [8]. Any tillage method that leaves at least 30% of the soil's surface covered with crop residue after planting is considered conservation tillage. Conservation tillage has emerged as a viable option to ensure sustainable food production and maintain environmental integrity.

Globally, CA is practiced on about 180.4 million ha of the world's arable land [9]. A meta-analysis from South Asia in a variety of cropping systems indicated that CA components, viz., NT with residue retention, increased mean yield by 5.8% over CT practices. Further, a 6-year study on CA in fine loamy soils involving NT and residue retention reported enhancing yield by 14.3% over CT in rice/maize–wheat–mungbean cropping systems in the semiarid region of the northwestern Indo-Gangetic Plains [10]. NT, along with residue retention, conserves soil moisture, improves soil nitrogen availability, and increases crop uptake, thereby enhancing nutrient use efficiency in crops [11]. In India, most CA areas are confined to the irrigated belt of the Indo-Gangetic Plains, in a world where most areas are under rainfed conditions. CA can rehabilitate degraded soils and improve soil fertility through increased water holding capacity, reducing runoff, higher infiltration, the buildup of soil organic carbon (SOC), and improved nutrient cycling in soil [6,12].

Adoption of rational tillage such as minimum tillage (MT)/no-tillage (NT), along with additional mulch as a CA practice, can increase the SOC [11], thus improving soil quality [13] and, hence, increasing agricultural production and profitability [14]. There has been ongoing controversy about CA practices among researchers regarding the changes in soil physical properties that can be attributed to NT as well as other tillage methods [15,16]. In some instances, it was reported that conservation tillage (MT/NT with residues) did not affect soil bulk density in the short run, while, on the contrary, some studies reported higher bulk density under NT than conventional tillage (CT) [17]. The degradation of soil physical properties was reported under CT compared with NT [18,19]. It was also reported that after a 6-year-long experiment in sandy soil, no difference was observed in soil bulk density among CT, MT, and NT [20]. The ambiguity in results probably indicates the need for a detailed assessment of the impact of NT/MT on each soil type and series of farming practices in which the soil conditions and prior crop production activities would have had an effect on the physical properties of the soil during crop growing season.

NT/MT, along with mulching, was reported to increase organic carbon (OC) and nutrients accumulation [21], soil microbial activity [22], soil aggregate stability, and soil water holding capacity [23], which probably should be healthy in comparison with tilled soil due to improvement in soil properties, leading to higher crop growth under NT/MT with mulch than under a CT system. In most previous studies, the effect of NT management practice on soil properties was evaluated at the end of the experimentation. However, the effect of NT on soil properties within the crop growing season has not been widely assessed [24,25]. Hence, limited information is available on soil properties about the influence of NT/MT with live mulch at the reproductive stage of maize (*Zea mays* L.) during the crop growing season, especially in the Himalayan region. There has been disagreement on the long-term effect of NT concerning soil physical quality in row crops and inter-row space [19,26]. Thus, it becomes essential to understand the mechanisms of the changes in soil physical properties that are taking place during the cropping season, whereas some reports showed that the impact of disruption might not be long-lasting [27,28]. Tillage and cover crops in a crop season change the seasonal macroporosity and the percentage of microaggregates [24]. A 3-year trial conducted in Brazil confirmed that the impact of tillage on soil properties during crop season did not continue in the subsequent crop season [25]. Moreover, restricting tillage practices to row regions did not improve soil properties in a single crop season. Thus, more emphasis should be given to evaluating the changes in soil properties at the reproductive stage (R_1-silking) of a cropping season under different tillage systems.

Crop mulch improves soil properties, which can regulate its role in soil functioning [6]. NT with mulch lowers soil bulk density because the decomposition of crop residues facilitates soil aggregation and, hence, the formation of soil organic matter [12]. There is an increase in the number of pores under MT, thereby increasing soil porosity over CT [6]. MT and NT raise soil moisture content by 0–10 cm more than CT [6]. Cover crop/residue mulching increases the soil water reserves, hence, an increase in matric potential [29]. Maintenance of live mulch in association with the consequent rise in SOC owing to better soil aggregation opens faunal pores, along with an increase in soil macroporosity, which enhances infiltration and soil moisture content [6]. Crop residue retention as a mulch slows down organic matter degradation, thus promoting more aggregation than tilling [30,31]. Mulching promotes healthy plant growth by increasing overall soil stability, organic carbon, and soil moisture content [12]. Moreover, live mulching allows the flow of liquid, mineral nutrients, and air into the soil by producing many micro- and macropores [6]. Thus, soil's physical properties improve suitably with NT and the inclusion of mulch. Plentiful rainfall is received by the North Eastern Hill (NEH) region of India (located in the Eastern Himalayas), which favors the high biomass production of plants. Thus, using off-farm perennial leguminous species as mulch could be a good alternative to reduce inputs and increase agricultural sustainability [6]. However, since the leaves of perennial leguminous trees to be used as mulch require a higher investment in terms of cost and labor for the collection and transportation of biomass into crop fields, the implementation of legume coculture operation to produce in situ biomass could be a viable alternative [12]. Thus, we visualized that innovative legume coculture (legume intercropping with the main crop for mulching) of cowpea (*Vigna unguiculata*) (high-biomass-producing annual legume crop) for the generation of high-quality mulching plant biomass and additional legume green pods for sustainable summer maize production under an NT/MT system. In the current study, for an initial 60–70 days, two rows of cowpea were raised and used as live mulch in standing maize; later, cowpea was killed in situ with an herbicide. Thus, it could be a good strategy to shrink the growth of weeds and provide soil fertility with in situ nitrogen (N). However, the impact of live mulching under conservation tillage compared with unmulched tillage on growing season soil properties and crop productivity has not been objectively studied all over the world as well in the NEH, India.

Summer maize is a good endeavor for farmers of the NEH region with the assurance of higher grain yield and quality fodder availability [32,33]. From the above discussion, it can be seen that no-tillage practice alone is inadequate for different crops, as it limits some of the benefits. Conversely, combining live mulching of legumes (cowpea) with conservation tillage improves soil and environmental quality and increases crop productivity by reducing cultivation costs. No-till mulch is always more beneficial if residues can be produced from live legumes. Legume cultivation can provide mulch and maintain soil moisture, improving the root biosphere of both crops through root growth by adding different nutrients and organic carbon into the soil, besides achieving good grain yield.

To address the soil quality and productivity issues of crops under different tillage systems, this field study was conducted in which the production performance of the HQPM 1 variety of maize in the summer season was also evaluated. The present investigation mainly focused on the impact of NT/MT and cowpea live mulch on soil properties and crop productivity in the subtropical climate of NEH, India. It was hypothesized that NT/MT systems and live mulching would be beneficial in improving soil physical and chemical properties within the growing season, which might lead to higher productivity of summer maize than CT.

2. Methods and Materials

2.1. Study Site

A 3-year field study was conducted from 2013 to 2016 at Tripura Centre, Indian Council of Agricultural Research (ICAR) Research Complex for North Eastern Hill Region, Lembucherra, India. The experimental site was a well-drained, leveled upland and is located at 23°54′24.02″ N and 91°18′58.35″ E at an altitude of 52 m ASL (meters above sea level) (Figure 1). The weather of the experimental site was hot and humid from April to October and mild–cool and dry from November to March. The annual rainfall of the study site was 2200 mm (Figure 1). The soil of the experiment site was sandy clay in texture, and it belongs to the Acrisols. The soil was acidic in reaction, high in soil organic carbon, available nitrogen, and potassium, and medium in phosphorus [13].

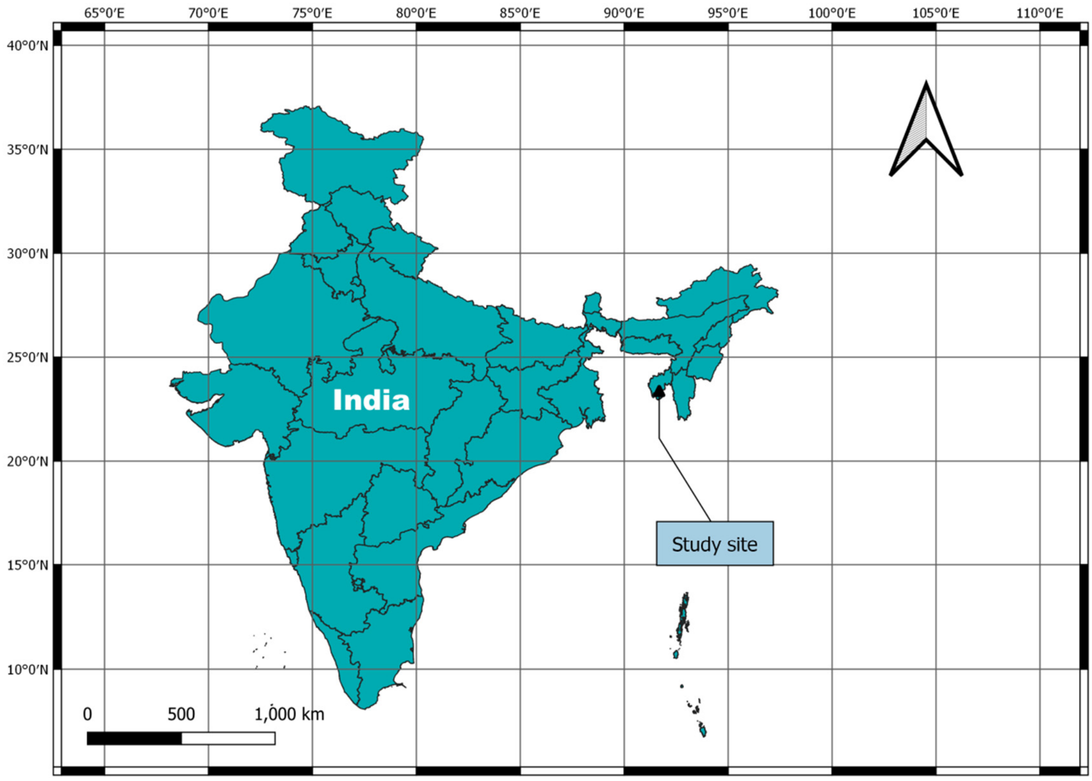

Figure 1. Location of the study site in Eastern Himalayan region.

2.2. Experimental Field Setup and Treatments

In this study, the impact of five tillage practices, viz., (1) no-till (NT), (2) NT and cowpea live mulch (CLM), (3) minimum tillage (MT), (4) MT+CLM, and (5) conventional tillage (CT), were assessed on the soil physical properties, chemical composition, and productivity of summer maize in the Tripura region of the Indian Himalayas. After every harvest, ~30% of crop residues were left on the soil surface under NT treatment, removed under CT, and partially incorporated under MT. Cowpea as a cover crop/live mulch was intercropped in two rows between every two rows of summer maize at a rate of 10 kg seed ha^{-1}. The component of herbicide responsible for the herbicidal effect (active ingredient; a.i) ha^{-1}, 2,4-D at the rate of 0.5 kg active ingredient, was sprayed 70 days after sowing (DAS) to kill the cowpea. The cowpea biomass was retained on the surface to act as live mulch. The plot size was 7.2 × 6.0 m. Two tilling under MT and four under CT were performed to a depth of about 10 cm by using a power tiller. While under the NT system, the soil was kept completely undisturbed.

2.3. Crop Culture and Yield Contributing Parameters Recording

The hybrid maize variety "HQPM 1" was manually sown at a 15 kg ha^{-1} seed rate in the first week of April with 60 × 20 cm spacing between the rows and plants, respectively, and harvested during the second week of July. About 30% of maize residues were subdued and retained on the surface with the application of herbicide (glyphosate at 5 cm^3) under NT and MT. In contrast, the entire maize residue was removed under the CT plot. The application of NPK was performed at 60:18:33 kg ha^{-1} across all the treatments. A half dose of N and the full amount of P and K were applied as basal at the sowing time. The remaining N was applied in two equal splits at 30 and 75 DAS, respectively. To reduce the weed problem under the NT plot, glyphosate (herbicide) was applied at 5 cm^3 before one week of sowing. However, pendimethalin was applied at1 kg ha^{-1} to all the plots to reduce weed infestations. At 20 DAS, one-handed weeding was performed to maintain the optimum plant population and to control weeds at the time of thinning. The cob length, kernel cob^{-1}, and kernel weight cob^{-1} of 10 cobs were taken out from the randomly selected tagged cobs of each plot. The cob length was measured with the help of a thread and meter scale and expressed in cm. After length measurement, the kernel was removed from the five selected cobs from each plot with the help of a manual maize sheller, counted, average weighted, and expressed as the number of kernels per cob and kernel weight (g) per cob. For counting of cobs m^{-2}, at harvest, one square meter area at three places in each plot was demarcated, and cobs were counted, averaged, and expressed as cob m^{-2}.

2.4. Harvesting, Biomass, and Yield Measurement

Maize cobs and stover were harvested with the help of an iron sickle manually. After harvesting, the maize grains were separated from the cobs, and the grain yield was recorded (at 14% moisture content). The grain yield was expressed in Mg ha^{-1}. After harvesting the cowpea pods, the aboveground biomass was left in their respective plots as mulch. The maize stover weight from a marked area (1 m^2) in each plot was measured after oven-drying at 60 ± 1 °C temperature [34] to a constant weight, recorded, and expressed as Mg ha^{-1}. Root samples were collected from 0–40 cm soil depth at harvest using a core sampler (5.8 cm height and 5.4 cm diameter) in each season. The core samples with roots and soil were soaked in water for 12 h. The soil–root mixtures from each core sample were separated from the core samples and then mixed with clean water, stirred, and the suspension was passed through a 0.5 mm sieve. The roots were removed from the soil, and the fresh roots, along with dead organic debris, were oven-dried at 60 ± 1 °C until they attained a constant weight to determine the dry biomass. The kernel yield was divided with the biological yield (kernel +stover) to work out the harvest index.

2.5. Soil Properties Evaluation

A core sampler (5.6 cm inner diameter) was used to collect the soil samples from each soil depth (0–10 and 10–20 cm) during the silking (R_1-silks extend outside husk leaves) stage of maize. After oven-drying, the soil samples were weighed, and the initial mass of water during the soil sampling resulted in a difference in weight. The moisture content was determined by the gravimetric method. The core method [35] was used to determine the soil bulk density (ρ_b) at 0–10 and 10–20 cm depths. Air-dried bulk soil samples were finely grounded with a wooden hammer and sieved by a 2 mm sieve. The remaining soil bulk after sieving was kept in sealed plastic bags for further analysis of soil physicochemical properties.

Soil pH, available soil nitrogen (N), phosphorus (P), and potassium (K) were determined by the procedure outlined by Prasad et al. [36].

2.6. Soil Infiltration and Water Holding Capacity Estimation

The Kneer–Raczkowski box method was employed to determine the water holding capacity (WHC) at 0–10 and 10–20 cm depths at the reproductive stage (R_1) of summer maize [37].

$$\text{WHC}(\%) = \frac{\text{Total Water in the Saturated Soil}}{\text{Oven dry weight of soil}} \times 100 \quad (1)$$

A double-ring infiltrometer (the diameters of outer and inner rings were 30 and 20 cm, respectively, and the height of both rings were 20 cm) was used to determine the soil infiltration rate (IR) [38]. The estimation was unrelenting for 180 min, with specific measurements made at 10 min intervals.

2.7. Statistical Analysis

For statistical validation, all the tillage practices were assigned to three times replicated randomized block design (RBD). The GLM procedure of SAS 9.4 [39] was employed for statistical analysis of all the data. The significance of treatment effects was evaluated by using the F-test, and the significance of differences was assessed by calculating the least significant difference (LSD) at $p = 0.05$.

3. Results

3.1. Soil Physical Properties

The inclusion of cowpea live mulch with tillage practices considerably affected the soil's physical properties (Table 1). As soil depth progressed, the bulk density (ρ_b) was also increased under all tillage practices; however, it failed to produce a significant effect at 10–20 cm depth. A reduction in tillage operations (MT and NT) lowered ρ_b compared with CT. The ρ_b was noticed to be significantly higher under NT (1.36 Mg m^{-3}), which was comparable with that of CT and MT (1.35 and 1.34 Mg m^{-3}), respectively, at 0–10 cm depth of soil. The lowest ρ_b was obtained with MT+CLM (1.31 Mg m^{-3}), which was on par with NT+CLM (1.32 Mg m^{-3}) for the same depth. The greatest increase in ρ_b was observed under NT at 0–10 cm, which might be due to the undisturbed soil. The water holding capacity (WHC) followed the trend of decreasing with increasing depth. At both 0–10 cm and 10–20 cm depths, WHC was significantly higher under MT+CLM, followed by MT, NT+CLM, and NT, respectively. Irrespective of soil depths, the lowest WHC was observed under CT. The results on soil moisture content indicated that the soil under MT+CLM had the maximum moisture content, which was comparable with MT, NT+CLM, and NT. The CT practice reduced the WHC of the soil more than those other tillage practices. The infiltration rate (IR) was found to be maximum under the MT+CLM treatment (2.35 mm min^{-1}) (Figure 2). Next to MT+CLM, the infiltration rate was found to be higher under NT+CLM (2.27 mm min^{-1}) than under the CT treatment (1.80 mm min^{-1}). The data about the cumulative infiltration rate also followed a similar trend as that of IR (Figure 3).

Table 1. Effect of live mulch-based conservation tillage on soil physical properties during active growing season of summer maize.

Treatment	Bulk Density (Mg m^{-3})		Maximum Water Holding Capacity (%)		Soil Moisture Content (%)	
	0–10 cm	10–20 cm	0–10 cm	10–20 cm	0–10 cm	10–20 cm
NT	1.36	1.40	46.8	40.8	19.8	22.2
NT+CLM	1.32	1.38	47.7	42.0	20.7	24.0
MT	1.34	1.38	46.7	41.0	20.9	22.7
MT+CLM	1.31	1.37	48.9	43.1	22.4	25.0
CT	1.35	1.39	39.8	34.1	15.3	16.6
SEm±	0.01	0.01	2.0	1.2	1.0	0.9
$LSD_{0.05}$	0.03	NS	5.9	3.5	2.8	2.7

NT, no-till; NT+CLM, no-till and cowpea live mulch; MT, minimum tillage; MT+CLM, minimum tillage and cowpea live mulch; CT, conventional tillage; SEm±, Standard Error of Mean; LSD, Least Significant Difference at $p = 0.05$.

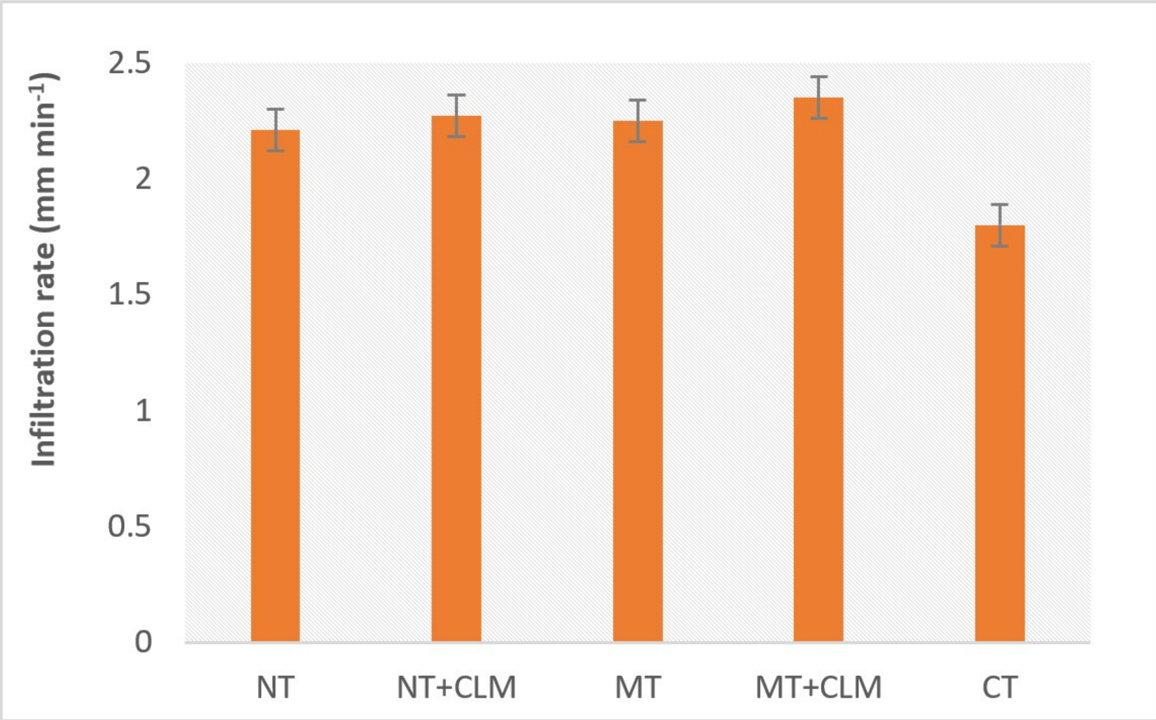

Figure 2. Effect of live mulch-based conservation tillage on infiltration rate during active growing season of summer maize: NT, no-till; NT+CLM, no-till and cowpea live mulch; MT, minimum tillage; MT+CLM, minimum tillage and cowpea live mulch; CT, conventional tillage. Error bars indicate least significance difference (LSD) at p = 0.05.

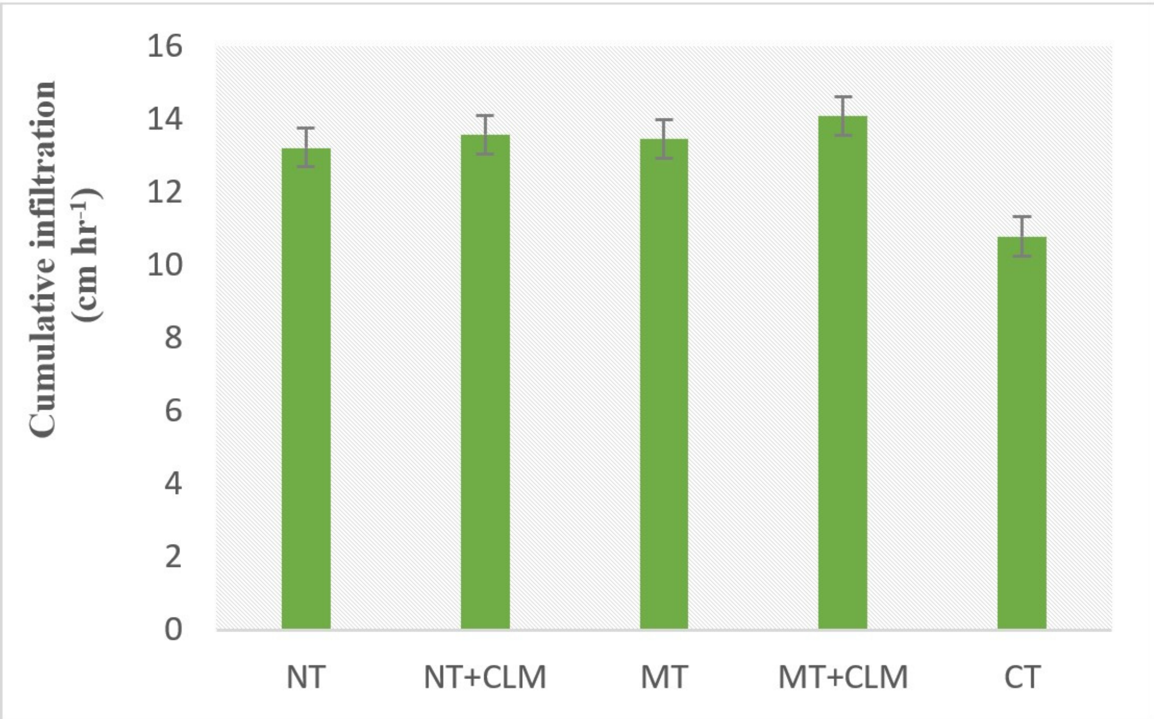

Figure 3. Effect of live mulch-based conservation tillage on cumulative infiltration rate during active growing season of summer maize: NT, no-till; NT+CLM, no-till and cowpea live mulch; MT, minimum tillage; MT+CLM, minimum tillage and cowpea live mulch; CT, conventional tillage. Error bars indicate least significance difference (LSD) at p = 0.05.

3.2. Soil Chemical Composition

Tillage practices in association with live mulching exerted a significant impact on soil chemical properties (Table 2). Soil pH decreased as depth increased and a perusal of the data on soil pH revealed that the tillage practices NT, NT+CLM, MT, and MT+CLM are comparable to each other; however, the highest pH was obtained in soil under MT+CLM for both the depths. Irrespective of soil depths, CT had the least pH value. MT+CLM had a 4.5% higher soil pH than the CT system. The soils under MT+CLM and NT+CLM had ~12–14% higher available N than CT. The effect of tillage and live mulching on soil available phosphorus and potassium was significant only at 0–10 cm. Significantly higher available P and K were observed under MT systems, along with living mulch, over CT. The soil under the MT+CLM system resulted in the highest available P and K (12.9 and 371.7 kg ha^{-1}, respectively), which was, however, comparable with NT, NT+CLM, and MT. CT had the lowest available P (9.4 kg ha^{-1}) and K (329.7 kg ha^{-1}) for 0–10 cm depth of soil.

Table 2. Effect of live mulch-based conservation tillage on soil chemical properties during active growing season of summer maize.

Treatment	pH		Available Nitrogen (kg ha^{-1})		Available Phosphorus (kg ha^{-1})		Available Potassium (kg ha^{-1})	
	0–10 cm	10–20 cm	0–10 cm	10–20 cm	0–10 cm	10–20 cm	0–10 cm	10–20 cm
NT	5.21	5.16	466.0	445.5	11.3	9.3	363.7	347.3
NT+CLM	5.27	5.19	489.5	470.5	12.0	9.7	370.0	355.0
MT	5.26	5.14	466.0	449.0	11.3	9.0	368.2	351.5
MT+CLM	5.29	5.20	495.0	473.0	12.9	10.1	371.7	352.7
CT	5.05	5.05	426.5	409.5	9.4	8.1	329.7	341.0
SEm±	0.04	0.03	4.0	4.6	0.6	0.5	6.3	5.6
$LSD_{0.05}$	0.11	0.08	11.8	13.5	1.8	NS	18.5	NS

NT, no-till; NT+CLM, no-till and cowpea live mulch; MT, minimum tillage; MT+CLM, minimum tillage and cowpea live mulch; CT, conventional tillage; SEm±, Standard Error of Mean; LSD, Least Significant Difference at $p = 0.05$.

3.3. Above- and Belowground Biomass

The patterns of maize above- and belowground biomass were similar in that MT+CLM produced significantly higher biomass than did NT, NT+CLM, MT, and CT (Table 3). A significant reduction in maize biomass production was observed under CT, which was comparable with NT. The results of the maize aboveground biomass yield indicated that significantly higher biomass was produced under MT+CLM over NT, NT+CLM, MT, and CT by 12.33%, 22.89%, 24.49%, and 32.7%, respectively. A similar trend was noticed for the maize root mass yield, which was significantly higher with MT+CLM over NT, NT+CLM, MT, and CT (14.62%, 27.27%, 28.10%, and 28.95%, respectively). Similarly, the aboveground biomass and root mass yield of cowpea was found to be relatively higher under MT+CLM than NT+CLM. A perusal of data on biomass revealed that MT+CLM had a significantly higher aboveground biomass yield (12.17 Mg ha^{-1}) than CT. Similarly, total belowground biomass was found to be highest under MT+CLM (2.27 Mg ha^{-1}), followed by NT+CLM (2.00 Mg ha^{-1}).

Table 3. Effect of live mulch-based conservation tillage on above- and belowground biomass yield of summer maize.

Treatment	Maize		Cowpea		Total (Maize + Cowpea)	
	AGB (Mg ha^{-1})	BGB (Mg ha^{-1})	AGB (Mg ha^{-1})	BGB (Mg ha^{-1})	AGB (Mg ha^{-1})	BGB (Mg ha^{-1})
NT	8.41	1.54	0.00	0.00	8.41	1.54
NT+ CLM	9.32	1.71	1.60	0.29	10.92	2.00

Table 3. *Cont.*

Treatment	Maize		Cowpea		Total (Maize + Cowpea)	
	AGB ($Mg\ ha^{-1}$)	BGB ($Mg\ ha^{-1}$)	AGB ($Mg\ ha^{-1}$)	BGB ($Mg\ ha^{-1}$)	AGB ($Mg\ ha^{-1}$)	BGB ($Mg\ ha^{-1}$)
MT	8.52	1.52	0.00	0.00	8.52	1.52
MT+CLM	10.47	1.96	1.70	0.31	12.17	2.27
CT	7.89	1.53	0.00	0.00	7.89	1.53
SEm±	0.21	0.04	0.03	0.00	0.21	0.04
$LSD_{0.05}$	0.62	0.11	0.08	0.01	0.62	0.12

NT, no-till; NT+CLM, no-till and cowpea live mulch; MT, minimum tillage; MT+CLM, minimum tillage and cowpea live mulch; CT, conventional tillage AGB, aboveground biomass; BGB, belowground biomass; SEm±, Standard Error of Mean; LSD, Least Significant Difference at $p = 0.05$.

3.4. Yield Parameter and Yields

The increase in yield of maize under MT+CLM and NT+CLM is related to its cumulative effect on the yield attributes. Yield and yield attributes were significantly influenced by CA-based NT/MT management with live mulching (Table 4). Yield attributes, viz., cob length, kernel per cob, kernel weight per cob, and cobs per square meter, were found higher under MT+CLM than under other tillage systems. There was a significant reduction in yield attributes under CT treatment. An overall disparity in yield data was observed under the various treatments. The variation in grain yield of maize followed the trend of MT+CLM = NT+CLM > MT = NT > CT. A similar trend was observed with stover yield, thus, giving a significantly higher yield under MT+CLM followed by NT+CLM than under others. The NT+CLM out-yielded other treatments by 1.65%, 9.29%, and 39.55%, (grain) and 11.92%, 11.38%, and 12.30% (stover), respectively. The harvest index was found to be highest under MT (0.29%). The cowpea green pod yields under NT+CLM and MT+CLM were 1.6 and 1.7 Mg ha^{-1}, respectively.

Table 4. Effect of live mulch-based conservation tillage on yield attributes and yields of summer maize.

Treatment	Cob Length (cm)	Kernels cob^{-1}	Kernel Weight (g) cob^{-1}	Cobs m^{-2}	Grain Yield ($Mg\ ha^{-1}$)	Stover Yield ($Mg\ ha^{-1}$)	Harvest Index	Cowpea Pod Yield ($Mg\ ha^{-1}$)
NT	14.8	321.2	57.0	4.73	2.26	6.15	0.27	0.00
NT+ CLM	15.0	336.9	61.5	4.98	2.47	6.85	0.27	1.60
MT	15.7	337.2	63.7	5.54	2.43	6.10	0.29	0.00
MT+CLM	15.8	371.6	68.0	5.77	2.63	7.84	0.25	1.70
CT	13.9	272.4	45.4	4.45	1.77	6.12	0.22	0.00
SEm±	0.2	12.3	3.5	0.23	0.06	0.16	0.001	0.03
$LSD_{0.05}$	0.7	36.2	10.2	0.68	0.18	0.46	0.01	0.08

NT, no-till; NT+CLM, no-till and cowpea live mulch; MT, minimum tillage; MT+CLM, minimum tillage and cowpea live mulch; CT, conventional tillage; SEm±, Standard Error of Mean; LSD, Least Significant Difference at $p = 0.05$.

4. Discussion

During the third year of the tillage and mulched-based experiment, scrutinizing the soil's physical properties after 70 to 80 days of sowing summer maize (at the silking stage, the most active growing stage) indicated a reduction in ρ_b and an overall improvement in soil physicochemical properties, viz., WHC, soil moisture content, infiltration rate, and cumulative infiltration of soil where cowpea was intercropped for live mulching. MT+CLM reduced ρ_b by 2.96% and increased maximum soil WHC and moisture content by 18.6% and 31.7% at 0–10 cm depth over CT, respectively. This might be attributed to an increase in SOM deposition and root and shoot biomass under MT/NT+CLM systems. In general, a short-term increase in ρ_b under NT than under CT has been reported by many investigators [22,40,41]. However, with higher biological activities and the development of roots in the soil at the reproductive stage of crops, the response to ρ_b with NT and CT was found nonsignificant. Live mulching of cowpea further accelerates soil biological activities and root diversity, perhaps reducing soil ρ_b under NT+CLM and MT+CLM. On the other hand, reduced soil ρ_b could be attributed to higher biological activity, greater root diversity, and increased pore space under NT/MT with mulch, thus, leading to higher WHC, soil moisture content, and infiltration rate than CT with unmulched soils [41,42]. Lower ρ_b, which enhances the infiltration rate, WHC, soil moisture content, soil organic C and total N, productivity, profitability, and overall soil health due to the live mulch of legumes with maize, has also been reported from the Western Himalayan region of India [41]. The improved soil physical parameters due to an increase in WHC, soil moisture content, and infiltrations that occurred under NT+CLM and MT+CLM at 0–10 and 10–20 cm soil depths might be attributed to higher pore space, biological activities, and improvement in soil aggregation [42–44]. The CLM-based conservation tillage treatments (NT+CLM and MT+CLM) improved soil pH and plant available N, P, and K during the summer maize growing season, which implied that being a legume crop, cowpea, as a mulch (CLM), corrected the atmospheric nitrogen [45,46] and also increased soil biological activities, which may improve soil P and K status.

The inclusion of live mulch in NT/MT systems increases the soil moisture content and nutrient availability and decreases soil ρb, which might have resulted in enhanced biological activity in the present study. Generally, soils have lower ρ_b under CT and are accompanied by higher porosity within the plow layer than under NT [47,48]. Thus, due to the compression of larger pores, a subsequent reduction in soil volume may occur as ρ_b increases, thereby reducing soil porosity. The findings of the present investigation suggest that the insertion of cowpea live mulch in conservation tillage practices improves soil functionality. Improved soil functionality has been reported due to enhanced WHC, pH, and available macronutrients under NT+CLM and MT+CLM [49]. This could be due to the nitrogen-fixing ability of legume live mulch, which further creates a favorable environment through soil pH and temperature moderation and soil organic matter accumulation, thereby enhancing soil aggregate stability. The presence of organic matter resulted in better soil aggregation, which may have concomitantly augmented soil porosity. Studies revealed that reduced soil perturbation and SOC accumulation improves soil structure and porosity. The occurrence of significantly higher soil water content implied by higher surface water retention potential under NT+CLM and MT+CLM than CT helped to conserve more water later. Furthermore, NT promotes pore continuity due to no soil disturbances, and mulch promotes the formation of biopores by increasing surface infiltration, whereas CT disrupts and breaks the continuity of soil pores due to soil conversion. Thus, integration of CLM and conservation tillage promotes crop productivity and sustains long-term soil health in crop production [19]. The association of MT/NT and CLM might have influenced soil physical properties during critical crop growth stages and, consequently, crop growth and yields [50]. MT+CLM and NT+CLM significantly improved the soil available nitrogen, phosphorus, and potassium status and water infiltration rate as compared with CT. The inclusion of cowpea as a legume coculture might have contributed to the addition of quality biomass rich in nutrients, especially N, to the soil. Further residues are also a rich source of potash. Improvement in soil microbial activities and the addition of biomass might have also contributed to increasing the available P status in soil. Further, the treatment MT+CLM produced the highest aboveground biomass, followed by NT+CLM, thus contributing to nutrient recycling and fertility buildup. Higher WHC, soil moisture content, infiltration rate, pH, and available N, P, and K during the active crop growing season helped to achieve better crop growth and, subsequently, contributed to higher yield attributes and above and belowground biomass of summer maize. The inclusion of cowpea live mulch increases the biomass production of maize, thereby increasing the economic yield over unmulched plots [51]. The inclusion of cowpea as a live mulch improves the soil's physical and chemical properties, which stimulates the nutrients available to crops [33]. Further, in situ biological nitrogen fixation by cowpea as a cover crop mulch also increases the supply of N to maize plants [49,52], which might have facilitated higher total above- and belowground biomass of maize and grain yield over unmulched treatments [27,50,53]. Moreover, the inclusion of cowpea as a live mulch produced more biomass of summer maize, which further contributed to the production of higher total above- and belowground biomass under NT+CLM and MT+CLM than other treatments. Therefore, in the fragile ecosystem of the Indian Himalayas, especially the eastern region, the adoption and practice of NT/MT with the addition of CLM during the summer maize season can be a major practice that can contribute toward water conservation in rainfed areas and, subsequently, produce a higher yield. The ability to conserve water through NT+CLM/MT+CLM provides a better prospect for crop production in the region, where the occurrence of a dry spell is a common phenomenon during the pre/post-monsoon seasons in which the conserved water can be used for supplemental irrigation [7,54,55].

5. Conclusions

The study concluded that minimum tillage along with cowpea live mulch (MT+CLM) reduced bulk density and increased the maximum soil water holding capacity and moisture content at 0–10 cm depth over conventional tillage. MT+CLM and NT+CLM significantly improved the soil available nutrient status and water infiltration rate as compared with CT. MT+CLM significantly enhanced the grain yield of summer maize over CT. Thus, the study proved the hypothesis that NT/MT systems, along with cowpea live mulching, improve soil physical properties and chemical composition within the growing season and lead to higher productivity of summer maize than CT. Hence, cultivation of summer maize under NT/MT systems along with cowpea live mulching may be a focal policy recommendation to improve farm productivity and profitability in addition to restoring the soil properties in the fragile ecosystem of the Eastern Indian Himalayas. The present study recommends promoting no-tillage/minimum tillage with living mulch to improve crop yield and resource sustainability in India's Northeastern Himalayas rather than just only no-tillage/minimum tillage.

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