Improvement of Jhum with Crop Model and Carbon Sequestration Techniques to Mitigate Climate Change in Eastern Himalayan Region, India

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Abstract

Slash and burn cultivation (*jhum*) is the most disadvantageous method of cultivation in the Eastern Himalayan Region. This practice causes soil, nutrient, water erosion and biodiversity loss. Therefore, alternate conservation practice is required urgently. Field experiment was conducted at two villages *viz.,* Digbak and Belo with two sites at each village on Dumporijo circle district Daporijo, Arunachal Pradesh during 2008 to 2010. The experiment was laid out in such a way that farmers practice was considered as control (T_1); T_2: T_1 + Mulching with crop residues; T_3: Improved crop management (includes plant population, application of manure and fertilizer, pesticides, weed management, hedge row incorporation); T_4: T_3 + mulching with crop residues. T_4 gave higher yield of rice, maize, chilli, tomato, french bean, okra (69, 107, 163, 211, 98.6 and 126% respectively) over T_1. Whereas, pea and soybean were additional crop harvested from T_2, T_3 and T_4. Similarly the biomass (crop, hedge row plants and weeds) was recorded 225.8, 208.5 and 19.9% higher on T_4, T_3 and T_2, respectively over T_1. The final status of porosity was recorded 7.6, 6.7 and 2.4% respectively higher for T_4, T_3 and T_2 over traditional *jhum* cultivation. Similarly the chemical parameters like soil organic carbon (SOC; 43.3, 39.2 and 21.6% respectively), N (25.4, 19.6 and 6.7% respectively), P (45.2, 39.8 and 12.9% respectively) and K (31.3, 25.9, and 5.0% respectively) were recorded higher on T_4, T_3 and T_2 over traditional *jhum* cultivation. The rice equivalent yield, production efficiency, land use efficiency and income were recorded higher on T_4 followed by T_3. However the employment generation was higher for T_3 followed by T_4. All the economic parameters were recorded higher when crops were grown under the T_4 followed by T_3 except B: C and MC: MR.

Keyword: *Jhum*, Crop model, Economics, Soil health, Arunachal Pradesh

1. Introduction

The Eastern Himalayan Region (EHR) despite being bestowed with a bountiful of water resources and receiving the highest rainfall, experiences acute shortage of water during post-rainy period (October- March). Out of total 42.0 million ha-m of the water resources only 0.88 million ha-m has been utilized due to lack of proper water management practice (NEH, 2005). The irrigation potential of the region remains untapped and about 80% of the cultivated area is rainfed. The average rainfall is about 2930 mm per annum in Arunachal Pradesh whereas the ET loss is 905 mm which contributes 31% of loss, 7% contribute to ground water recharge and 62% water goes unutilized as runoff. This runoff causes severe soil loss and land degradation (Arunachalam et al., 2002, Saha and Ghosh, 2010).

Four distinguished types of system of cultivations are existing in EHR, namely *jhum*, upland, terrace wetland rice cultivation (TWRC) and wetland rice cultivation (WRC). These systems are classified on the basis of rice cultivation as rice is the major food crop occupies the highest area in the state followed by maize.

Jhum occupies an average of 75% of rice growing area in the state followed by upland, WRC and TWRC in order. Besides rice, maize/ginger/finger millet/and chilli based systems are also adopted in very small land area. Livelihood of the farmers is largely dependent on *jhum* cultivation as most of the agricultural produces for household comes from *jhum* area (Ramakrishna, 1984). Fallow also represents a time when the soil is susceptible to water erosion which is another major loss mechanism for soil organic matter. The fallow period represents a time of high microbial activity and decomposition of soil organic matter (SOM) with no input of crop residue. Tillage practice in *jhum* have not been found in the EHR and only dibbling of seeds are done can be considered as zero tillage. One crop of rice along with mixture of other household requiring crops is grown during April-September and the land kept fallow after harvesting the first crop (Mantal et al., 2006). Intensive intercultural practices are not followed in *jhum* land, this leads to high soil erosion and deteriorate the soil quality. The burning of biomass on *jhum* land releases huge CO_2 in to the atmosphere which is the major component in green house gas and/or cause for climate change (Rastogi et al., 2002). As the availability of biomass on *jhum* land directly depends to the fallow period of site, short *jhuming* cycle reduced the soil fertility. Similarly alternatives to field burning are needed to reduce smoke emissions and maintain air quality (Doran and Mielke, 1984). Minimum care along with low cost water conservation technologies can certainly intensify the frequency of cropping as compared to traditional crop-fallow system (Schillinger et al., 2010).

The fertilizer consumption of the state is hardly 2.5 kg/ha, which is the least in the country and give enough scope for organic growing of various crops. Growing hedge row crops and residues incorporation into the soil are the two low cost techniques, certainly prevent the loss of soil organic carbon (SOC) and improve the range of microbial activity, which not only improve the overall soil health but also supply the wide range of nutrients to crops (Campbell et al., 2000). As the amount of crop residue returned to the soil is increased, SOC sequestration is expected to increase if the residue C is not lost as CO_2 to the atmosphere. More intensive cropping system along with reduced tillage is needed to prevent the loss of SOC than crop-fallow. Keeping the above in mind, the present investigation was carried out to study the traditional and improved method of cropping system in *jhum* land and their effect on soil.

2. Materials and Methods

2.1 Experimental Site

The daily temperature during a year varies widely between minimum 6.5^0C and maximum 37.5^0C. The study area receives average rainfall of 2930 mm with high degree of temporal and spatial variations. The field experiment was carried out during 2008, 2009 and 2010 at two villages *viz* Digbak and Belo with two sites for both the years at each village on Dumporijo circle district Daporijo. The experiment was laid out in such a way that farmers practice was considered as control (T_1); T_2: T_1 + Mulching with crop residues; T_3: Improved crop management (includes plant population, application of fertilizer, pesticides, weed management, hedge row incorporation); T_4: T_3 + mulching with crop residues. Soil sample of the experimental site at 15 cm depth was collected after slashing, burning and cleaning in the *jhum* site and analyzed. Bulk density (BD: 1.37 g/cm^3) and porosity (46.0%) were measured according to Majumdar and Singh (2000). The soils are silty clay loam in texture, pH (4.97), organic carbon (Walkaley and Black, 1.32 %), available N (alkaline permanganate N, 194.5 kg/ha), available phosphorus (Olsen P, 10.1 kg/ha) and available K (Neutral normal ammonium acetate K, 190.2 kg/ha) was recorded.

2.2 Cultivation Details

Hedge row plants like *Crotoleria*, *Tephrosia* and *Flemengia* were grown across the slope on improved practice. The height of 1.0 m was maintained for all the hedge row plants and rest of the biomass was incorporated in soil for improving the soil health (Table 1). The biomass was chopped in to small pieces and incorporated for better microbial decomposition. Residues of rice and maize were used as mulching material during the experiment. After harvesting the rainy season crop seeds of pea and soybean were sown by dibbling and later residues were completely spread on ground surface. Weed biomass of the cropping period of treatment plots were also incorporated on ground. The improved model is explained in fig. 1. Yield and economics were recorded besides analyzing the soil health.

2.3 Observations Recorded

Rice equivalent yield (REY: kg/ha): REY of the various crops are calculated as suggested by Saha and Ghosh (2010). The duration of rice was about 150 days (dibbling to harvest) and duration of other treatments was calculated by adding the duration of sequential crops with the base crop. Production efficiency (PE) was measured on the basis of yield on per day basis (Azam et al., 2008); similarly land use efficiency (LUE) was measured by comparing the percentage increased in land use after imposing treatments with control (Herbert, 2005). Increase in income and employment were also expressed in percentage by calculating the additional income and employment generated after executing various treatments.

2.4 Statistical Analysis

Statistical analysis was carried out to know the variance for different parameters, effect of treatments, using standard statistical package (SAS, 9.2) and significance was identified in both 1 and 5% level while non-significant results were denoted as NS.

3. Results and Discussion

3.1 Yield

Among the various imposed treatments the yield of all the crops was higher on T_4 followed by T_3 (Table 2). The yield of sequential crops like pea and soybean were better on T_4 followed by T_2. This might be due to the availability of soil moisture was better on mulched treatment, which not only supplied the optimum moisture but also helped to uptake more nutrients. However, the least yield of all the crops was recorded on traditional *jhum* cultivation. This was due to unscientific cultivation which caused soil degradation, fertility loss and least microbial activity. Growing of sequential crops was also not possible due to unavailability of water and poor resource on the site (Ramakrishna, 1984). T_4 recorded higher yield of rice, maize, chilli, tomato, French bean, okra (69, 107, 163, 211, 98.6 and 126% respectively) over T_1 (Table 2), whereas, pea and soybean were additional crop harvested from T_2, T_3 and T_4. Similarly the biomass (crop, hedge row plants and weeds) was recorded 225.8, 208.5 and 19.9% higher on T_4, T_3 and T_2, respectively over T_1 (Table 3). Improved practices provide the opportunity to plant for better growth and development, which led to better accumulation of dry matter production. The improved practice may also included the activity of enzymes like amylase, lipase, cellulase and chitinase, which continued to break down organic matter in the soil (to release the nutrients and make it available to the plant roots) even after they have been excreted and hold more water for easy availability to plants (Tiwari et al., 1989, Lunt and Jacobson, 1994, Chaoui et al., 2003).

3.2 Equivalent Yield, Production and Land-use Efficiency

Traditional *jhum* cultivation recorded the least REY over the improved one. However, the highest REY was recorded from the T_4 followed by T_3 (Table 4). T_4 took maximum time to reap the sequential crops, this might be due to the improved management practices and availability of soil moisture prolonged the vegetative stage. The PE was recorded 42.8% higher on T_4 followed by T_3 (27.4%). However, least PE recorded on T_1. These findings are in agreement with Sharma et al. (2000), Azam et al. (2008), Saha and Ghosh (2010). Similarly, LUE was recorded 44.4% higher on T_4 followed by T_3 (41.85%). This was due to the fact that land was with standing crop for longer time than the traditional method of *jhum* cultivation (Herbert, 2005). The increment in income and employment was recorded higher on T_4.

3.3 Economics

The economic parameters like cost of cultivation (CoC), gross return (GR), net return (NR), B: C, marginal return (MR), marginal cost (MC) and MR: MC was recorded during the study (Table 5 and 6). It was observed that all the economic parameters was recorded higher when crops were grown under the T_4 followed by T_3 except B: C and MC: MR. This might be due to the fact that the CoC was relatively higher on T_3 which reduces the ratio of income, but the overall return was always higher on T_3 than T_2. However the lowest economic parameters were noticed on traditional practice.

3.4 Mulching and Recycling of Crop Residues

Weed biomass was recorded low in mulched plot than the no mulch. This might be due to the mulching of various crop residues on sequential crops reduced the germination and emergence of weed seeds from the seed bank by preventing the solar radiation interception (Table 3). Soybean and pea are also having smothering effect, soil binding, increase infiltration rate, N fixing and improving the microbial activity in soil (Singh and Yadav, 2006). Improved practices recycled the crop residues in better manner, even mulched material also get incorporated on surface which led to build up of soil organic matter. Similarly, hedge row materials incorporation improves the overall soil health than control which resulted to poor microbial population due to burning of biomass after harvesting the economic part of the crops.

3.5 Weed Biomass

Grasses, sedges and broad leaved weeds threatens to traditional *jhum* cultivation. Some of the common weeds of *jhum* land are- *Eleusine indica, Cyanodon dactylon, Cyperus rotundus, Ageratum conyzoides, Euphorbia hirta, Eupatorium odoratum* and *Borreria hispida* (Hazarika et al., 2001). The weed biomass of 1.5 t/ha was harvested on T_1 and T_2 which was higher than improved method of *jhum* cultivation like T_4 and T_3 (Table 3). This was due to the fact that mulch restricted the penetration of light which restricted the germination and emergence of weed seeds. However, the weed biomass was higher on T_3 on sequential crop followed by T_4. The least was recorded on T_2. The weed biomass of fallow period was not measured for traditional *jhum* cultivation.

3.6 Carbon Sequestration

Soil organic carbon is the important indicator of soil fertility status. Improved method of *jhum* cultivation (T_4, T_3 and T_2) returns all the biomass to the soil which improve the SOC (43.3, 39.2 and 21.6%, respectively) over traditional *jhum* practice (Fig. 2). Increasing SOC density is by increasing carbon (C) input through intensification of agriculture and recycling of crop residues and biomass. Higher crop productivity under intensive agriculture increases plant residue input into the soils and thus has the potential of increasing SOC level (Lal, 2004, Franzluebbers, 2005). Conservation practices increases SOC sequestration by improving micro-aggregation and placement of SOC in the soil horizons (Lal and Kimble, 1997). Eventually, the increase levels of crop residues returned to the soil with improved practice are more common. This led to build up of SOC sequestration (Doran and Mielke, 1984). Surface residue management systems improve soil quality by increasing SOC, fungal biomass, earthworm populations, and microbial enzyme activity (Kennedy et al., 2004).

3.7 Soil Health

The final status of porosity was recorded 7.6, 6.7 and 2.4% respectively higher for T_4, T_3 and T_2 over traditional *jhum* cultivation (Fig. 3a). BD was improved when residues are incorporated and mulched with various crop residues in sequential crop (Fig. 3b). Similarly the chemical parameters like N (25.4, 19.6 and 6.7% respectively), P (45.2, 39.8 and 12.9% respectively) and K (31.3, 25.9, and 5.0% respectively) were recorded higher on T_4, T_3 and T_2 over traditional *jhum* cultivation (Fig. 3c, d, e). Disturbances of soil in *jhum* land were not advised unless it is very necessary. The exposure of SOC is minimum to environment with improved practice. This reduced the oxidative soil environment resulting in least decomposition of crop residues and SOC. Recycling of crop residues has been suggested to improve overall soil fertility by increasing the available N, P and K to support sustainable crop production. The benefits of incorporating un-decomposed straw have also been recognized in tropical environments. Kumar and Goh (2000) reported that incorporation of crop residues is essential for sustaining soil productivity through replenishing SOM. SOM is not only a key indicator of soil quality, but it also supplied essential nutrients upon mineralization (N, P, and S) and improves soil physical, chemical, and biological properties (Kumar et al., 2001, Goh et al., 2001). Hamman et al. (2007) found the intensity of the burning of residue affects soil characteristics, and that soil pH decreased with burning. The pH in the burn treatment was often lower than the minimum intercultural treatments. In improved *jhum* cultivation practices, pH of all the treatments increased to a max 5.5 in T_4 (Fig. 3f). SOC may be one of the best indicators of soil health, although measurable changes in SOC do not occur until huge biomasses are incorporated to the soil. As seen in this study, improved *jhum* cultivation eventually led to increased SOC, improved bulk density and porosity in the cropping systems (Campbell et al., 2000, Schillinger et al., 2007).

4. Conclusions

The improved practice of *jhum* cultivation recorded direct positive effect on soil health which led to improvement in productivity, enhances the water holding capacity, accelerate microbial activity, lower weed infestation, and reduces environmental problem and increment in yield. Therefore it is suggested for the region to adopt such practices for reaping the maximum with sustainability.

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Table 1. Green, dry and total biomass yield of hedge row crops and their nutrient status (mean of 2008- 2010)

Hedge row (running length)	Green Biomass (1 m running length)	Dry biomass (1 m running length)	Total biomass (dry weight basis)	N (%)
Tephrosia (80 m)	5.8	1.9	152.0	1.74
Crotoleria (104 m)	9.8	2.4	249.6	1.50
Flemengia (52 m)	3.6	1.1	57.2	2.86

Table 2. Crop yield (q/ha/year) of different crops on *jhum* land (mean of 2008- 2010)

Treatments	Rice	Pea	Chilli	Tomato	Maize	Soybean	French bean	Okra
T_1	5.80^a	0.00^c	0.97^d	1.62^d	3.25^d	0.00^c	2.68^d	1.80^d
T_2	6.83^c	5.41^b	1.13^c	2.47^c	3.77^c	4.06^b	3.18^c	2.45^c
T_3	9.07^b	5.57^b	1.54^b	3.65^b	5.20^b	4.23^b	4.23^b	3.34^b
T_4	10.15^d	6.75^a	2.25^a	5.18^a	6.06^a	6.45^a	5.71^a	4.35^a
CD	**	**	**	**	**	**	**	**
R^2	0.94	0.99	0.92	0.97	0.92	0.98	0.93	0.95
CV	10.0	7.0	11.0	8.0	8.0	9.5	8.6	8.0

*, **: Significant at the level of $p< 0.05$ and 0.01, R^2: Regression efficiency, CV: Coefficient of variation, Different letters denote that they are differed significantly and same letter were statistically similar with each other

T_1: Control; T_2: T_1 + Mulching with crop residues; T_3: Improved crop management (includes plant population, application of fertilizer, pesticides, weed management, hedge row incorporation); T_4: T_3 + mulching with crop residues.

Table 3. Biomass yield of different residues (q/ha/year) of different crops on *jhum* land (mean of 2008- 2010)

Treatments	Crop residues		Hedge rows	Weed biomass
	Cereals	Pulses		
T_1	19.80^d	0.50^d	0.00	15.55^d
T_2	30.10^c	27.00^c	0.00	17.78^c
T_3	41.50^b	37.20^b	4.60^a	22.22^b
T_4	43.60^a	43.40^a	4.68^a	18.53^a
CD	**	**	**	**
R^2	0.95	0.96	0.99	0.89
CV	11.0	13.7	12.7	10.0

*, **: Significant at the level of $p< 0.05$ and 0.01, R^2: Regression efficiency, CV: Coefficient of variation, Different letters denote that they are differed significantly and same letter were statistically similar with each other

T_1: Control; T_2: T_1 + Mulching with crop residues; T_3: Improved crop management (includes plant population, application of fertilizer, pesticides, weed management, hedge row incorporation); T_4: T_3 + mulching with crop residues.

Table 4. Analysis on various production and economic parameters on *jhum* land (mean of 2008- 2010)

Treatments	Rice equivalent yield (kg/ha)	Duration (days)	Production efficiency (kg/ha/day)	Land use efficiency (%)	Income (%)	Employment (%)
T_1	2011.7^d	150	13.41^d	41.10^d	-	-
T_2	3835.5^c	(150+100†) =250	15.34^c	68.49^c	61.18^c	40.00^c
T_3	4764.9^b	(150+108†) =258	18.47^b	70.68^b	66.56^b	41.86^b
T_4	6324.9^a	(150+120†) =270	23.43^a	73.97^a	78.73^a	44.44^a
CD	**		**	**	*	*

*, **: Significant at the level of $p< 0.05$ and 0.01, †time taken to harvest sequential crops, different letters denote that they are differed significantly and same letter were statistically similar with each other

T_1: Control; T_2: T_1 + Mulching with crop residues; T_3: Improved crop management (includes plant population, application of fertilizer, pesticides, weed management, hedge row incorporation); T_4: T_3 + mulching with crop residues.

Table 5. Monitory return of different crops on *jhum* land (mean of 2008- 2010)

Treatments	Rice	Maize	Pea	Soybean	Chilli	Tomato	French bean	Okra	Total
T_1	4640	2100	-	-	2100	2004	3360	1890	16094
T_2	5520	2520	4400	6450	2700	2904	3840	2350	30684
T_3	7200	3619	4256	6120	4100	4440	5064	3320	38119
T_4	7840	4340	5512	10200	5525	6240	6672	4270	50599
Additional income over control									
T_2	880	420	4400	6450	600	900	480	460	14590
T_3	2650	1519	4256	6120	2000	2346	1704	1430	22025
T_4	3200	2200	5512	10200	3425	4236	3312	2380	34505

Price Rs. /kg: Rice 8; Maize 7; Pea 8, Soybean 15; Chilli 25, Tomato 12; French bean 12; Okra 10

T_1: Control; T_2: T_1 + Mulching with crop residues; T_3: Improved crop management (includes plant population, application of fertilizer, pesticides, weed management, hedge row incorporation); T_4: T_3 + mulching with crop residues.

Table 6. Economics analysis (Rs/ha) of various treatments on jhum land (mean of 2008- 2010)

Treatments	Cost of cultivation	Gross return	Net return	B:C	Marginal returns (MR)	Marginal cost (MC)	MR:MC
T_1	9500	16094	6594	0.69[d]	-	-	-
T_2	13700	30684	16984	1.24[b]	10390	4200	2.47[a]
T_3	18400	38119	19719	1.07[c]	13125	8900	1.47[b]
T_4	19600	50599	30999	1.58[a]	24405	10100	2.42[a]

Different letters denote that they are differed significantly and same letter were statistically similar with each other

T_1: Control; T_2: T_1 + Mulching with crop residues; T_3: Improved crop management (includes plant population, application of fertilizer, pesticides, weed management, hedge row incorporation); T_4: T_3 + mulching with crop residues.

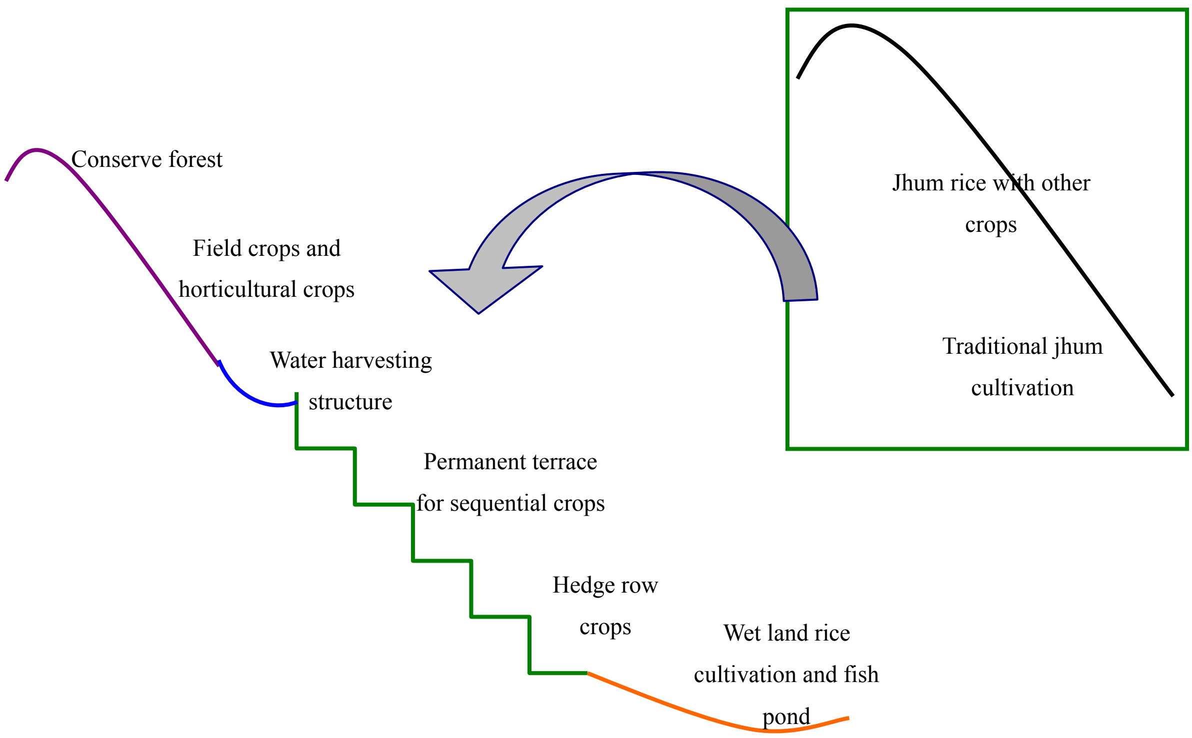

Figure 1. Proposed schematic model for *jhum* improvement

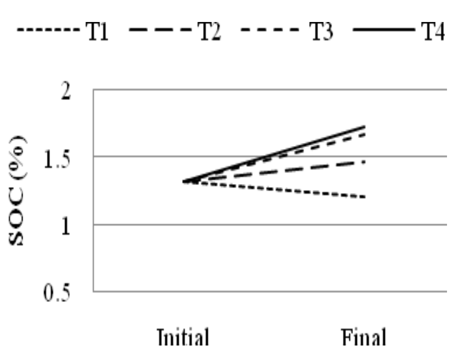

Figure 2. Soil organic carbon (%) as inflenced by imposed treatments (mean of 2008- 2010)

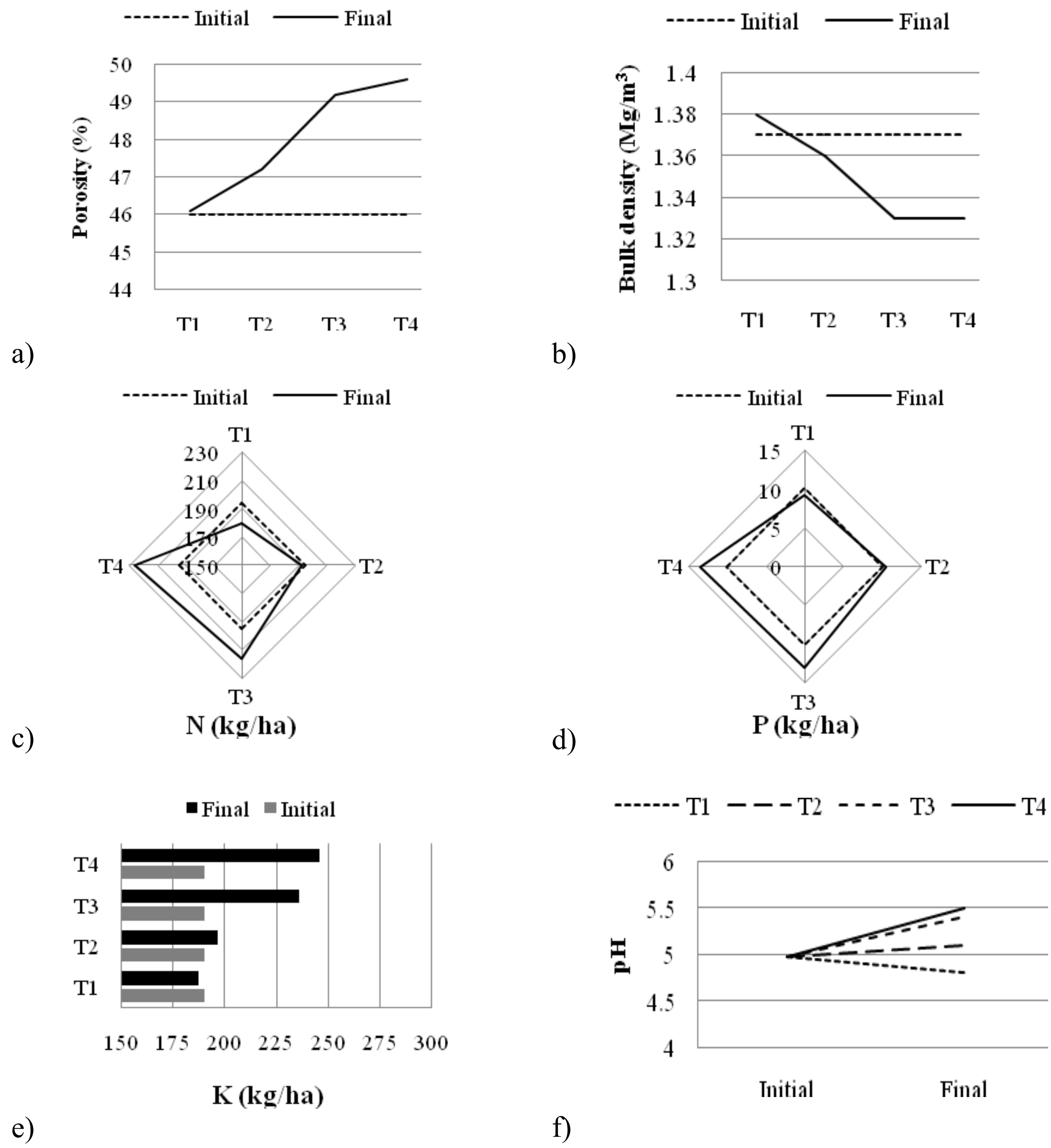

Figure 3. Physical and chemical properties of soil influenced by treatments (mean of 2008- 2010) a) porosity (%), b) bulk density (Mg/m^3), c) nitrogen (kg/ha), d) phosphorus (kg/ha), e) potassium (kg/ha), f) pH