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Impact of fodder grasses and organic amendments on productivity and soil and crop quality in a subtropical region of eastern Himalayas, India

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ABSTRACT

Agriculture in the Eastern Indian Himalayas is characterized by fragility and marginality with about 77% of the geographical area under hills and degraded plateau. Thus, field experiments were conducted for three consecutive years during 2008–2011 to assess the impact of perennial fodder grasses and sources of nutrient supply on productivity and quality of soil and fodder under terrace conditions in a subtropical degraded hill soil of Meghalaya, India (980 m above sea level). The treatment consisted of four fodder crops and three sources of nutrients. Fodder crops were broom grass (*Thysanolaena maxima*), congosignal grass (*Brachieria rosenesis*), hybrid napier (*Pennisetum typhoides* x *P. purpureum*) and guinea grass (*Panicum maximum*). Three sources of nutrient supply were organic, inorganic and control (inherent soil fertility conditions). Farmyard manure (FYM) was used as organic source of nutrient supply on N equivalent basis and P nutrition was supplemented through rock-phosphate. Fertilizer urea, single super phosphate and muriate of potash were used as inorganic source of nutrients. The dry fodder yield increased in each successive year and three year average dry fodder yield was significantly higher with hybrid napier (28.1 Mg ha^{-1}) than other grasses. Among nutrient sources, the average dry fodder yield under organic amendment (22.9 Mg ha^{-1}) was 27.5 and 64.4% higher than that under inorganic fertilizer (17.9 Mg ha^{-1}) and control (13.9 Mg ha^{-1}), respectively. Crude fibre (35.9%) and lignin (7.02%) concentrations were the maximum in hybrid napier whereas, cellulose (39.1%) was the highest in congosignal grass. On the contrary, crude protein concentration was the maximum in broom grass (8.27%), and it was at par with that in hybrid napier. The available N, P, K and soil organic carbon (SOC) contents were significantly higher ($P = 0.05$) under organic compared to those under other nutrient sources. The SOC concentration (17.2 g kg^{-1}) and stock (32.2 Mg ha^{-1}) after three years under organic treatment was 5.3 and 2.1% and 13.3 and 8.1% higher than that recorded under inorganic and control, respectively. The study indicated suitability of fodder grasses and organic amendments in improving quality of marginal degraded hill soils.

1. Introduction

In the eastern Indian Himalayas, ‘slash and burn’ agriculture (widely known as *jhuming* or shifting cultivation) is practiced on ~0.88 million hectare (M ha) area (Choudhury et al., 2013). Deforestation by ‘slash and burn’ exacerbates soil erosion and ecosystem degradation (Saha et al., 2007). *Bun* cultivation; involving raised beds of 0.15–0.30 m height, 0.75–1 m width with almost equal width under sunken area made along the slopes; is a modified form of shifting cultivation. In this system, biomass is

Abbreviation: a.s.l, above sea level; CO_2, carbon dioxide; CEC, cation exchange capacity; DHA, dehydrogenase activity; DTPA, diethylene tetramine penta acetic acid; Fe, iron; FYM, farmyard manure; ICAR, Indian Council of Agricultural Research; Cu, copper; CD, critical difference; NS, not significant; Mn, manganese; M ha, million hectare; Mg, mega gram; $NaHCO_3$, sodium bicarbonate; NH_4OAC, ammonium acetate; NEH, Northeastern Hill; OM, organic matter; ρb, bulk density; SEm, standard error of mean; SMBC, soil microbial biomass carbon; SOC, soil organic carbon; TEA, tri ethanol amine; Zn, zinc.

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burnt under the *bun* (raised beds) and area is abandoned after two or three years. The system is widely used in the Meghalaya plateau and it aggravates soil erosion and degradation (Saha et al., 2012a). Adverse effects of shifting cultivation, *bun* cultivation and deforestation on plant and animal genetic resources, desertification, soil erosion inducing nutrient loss, and siltation of water bodies have been widely reported (Ramakrishnan, 1993; Marafa and Chau, 1999). Soil loss on steep slopes (44–53%) by shifting cultivation in North Eastern Hill (NEH) region of India has been reported as 40.9 Mg ha^{-1} yr^{-1} and the corresponding losses of soil organic carbon (SOC) and plant nutrients (kg ha^{-1}) are 702.9 of SOC, 63.5 of P and 5.9 of K (Singh and Singh, 1981). Soil erosion under first and second years, and on abandoned shifting cultivation area have been estimated at 147, 170 and 30 Mg ha^{-1} yr^{-1}, respectively (Singh and Singh, 1981). Soil erosion, due to inappropriate cultural practices and burning of biomass, results in significant loss of SOC and carbon dioxide (CO_2) emission (Brown, 1997). Steep slopes, cultivation along the slope, low input, minimal nutrient replacement and high rainfall are among major causes of soil degradation in the NEH region of India (Ghosh et al., 2009).

Maintaining and enhancing soil quality are crucial to sustaining agricultural productivity and environmental quality (Lal, 2004). Continuous cropping, without use of conservation-effective measures, has negative effects on the soil and environment (e.g., loss of SOC, soil erosion, water pollution). Thus, soil management methods are needed that enhance use efficiency of inputs, reduce losses and minimize adverse impacts on the environment. Biological methods of soil and water conservation, especially grass/vegetation covers are suitable for hilly ecosystems, and are also cost-effective. Soil quality management in the fragile hill ecosystems under humid conditions should include permanent pastoral grasses (Saha et al., 2012a). Perennial grasses provide year-round ground cover, which reduces run-off and soil erosion from sloping land (Ghosh et al., 2009). Perennial grass cover improves physico-chemical properties of the soil by adding organic matter (OM) (Bonnin and Lal, 2012). The contribution of soil organic matter (SOM) from grasses can increase water stable aggregates (WSA), mean weight diameter (MWD), and soil moisture retention (Ekwue, 1990). Larger root mass, root exudates, and the presence of fungal hyphae in soils under grasses improve the stability of macro-aggregates (Tisdall and Oades, 1982).

Forages are integral component of any farming system suitable for the hill ecosystem to supply green fodders for livestock (Ghosh et al., 2009), reduce runoff (Saha et al., 2012b) and improve soil quality (Choudhury et al., 2013). Lack of good quality fodder reduces milk yield and increases cost of dairying. Diverse range of perennial forages {broom grass (*Thysanolaena maxima*), congosignal grass (*Brachieria rosenesis*), napier grass (*Pennisetum typhoides* x *P. purpureum*), guinea grass (*Panicum maximum*), setaria (*Setaria sphacelata*), etc.} are suitable for cultivation on degraded soils of the NEH region (Gupta, 2004) and have better fodder quality compared to native grasses.

Cultivation of forages in degraded and sloping lands not only supplies green palatable fodders to livestocks but also rehabilitates the degraded soils by improving physico-chemical properties (Ghosh et al., 2009). Forages have strong root systems compared to field crops (such as rice, maize etc.), protect soil and improve aggregation. A geospatial study in NEH region of India covering about 10.1 M ha, reported high SOC concentration from grassland and second only to forest land use. The SOC stock under perennial grassland was 47 Mg ha^{-1} vs. 23 Mg ha^{-1} under degraded and abandoned *jhum* (shifting cultivation) land (Choudhury et al., 2013).

Mechanically disturbed soil is a source of CO_2 through mineralization of OM by microbes, while undisturbed soils can be a sink for C (Al-Kaisi et al., 2005). Most degraded and depleted soils contain a lower SOC pool than in those under natural ecosystems (Bonin and Lal, 2014). Decline in SOC creates an array of negative effects on land productivity (Saha et al., 2012b). Thus, restoring SOC pool is essential for improving soil quality, crop productivity, and enhancing numerous ecosystem services (Sundaram et al., 2012). Soils under perennial grasses and those which are undisturbed for a long time are potential C sinks because the grasses add OM to soils through root growth, and decline in OM mineralization because of lack of tillage (Conant et al., 2001; Gentile et al., 2005). Further, conversion of degraded cropland soils to forage and perennial grasses lead to C sequestration (Grandy and Robertson, 2007). Grasslands have high inherent SOM concentration that supplies plant nutrients; increases soil aggregation, limits soil erosion, and also increases cation exchange capacity (CEC) and water storage. Thus, establishing perennial grasses and forages is a good measure for improving soil quality in degraded lands (Bonin and Lal, 2012).

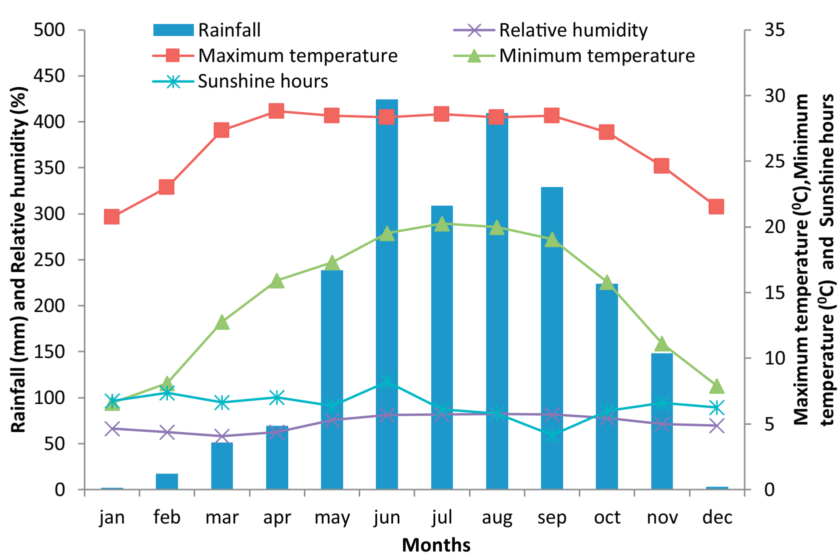

Fig. 1. Mean monthly weather parameters during 2008–11.

Organic manure application has the potential to improve quality of degraded soils. Higher levels of total SOC, total N, soluble P, microbial activity and soil microbial biomass carbon (SMBC) are observed from organic compared to mineral soils (Mader et al., 2002). Organic manures influence soil productivity through their effects on soil physical, chemical and biological properties. Organic manure increases SMBC (Peacock et al., 2001), soil respiration (Ajwa and Tabatabai, 1994), and enzyme activities (Crecchio et al., 2001) along with SOC and concentration of N and other nutrients (Crecchio et al., 2001). On the other hand, inorganic fertilizers have relatively less effect on SMBC (Plaza et al., 2004). However, there may be little difference in bacterial biodiversity (Lawlor et al., 2000) or in fungal communities (Franke-Snyder et al., 2001) between organically or conventionally managed soils.

Thus, present investigation was conducted with the objective to assess the impact of perennial forage grasses and organic amendments on soil properties and fodder productivity. It was designed to test the hypothesis "establishment of perennial grasses on degraded soils using organic amendments improves soil properties and sustains productivity".

2. Materials and methods

2.1. Study site

A field experiment was conducted at the experimental farm of Indian Council of Agricultural Research (ICAR) Research Complex for NEH region, Umiam, India for three consecutive years (2008–11). The experiment was sited at 25°41′21″N and 91°55′25″E, with an altitude of 980 m above sea level. The site receives an average annual rainfall of 2349 mm. The minimum and maximum monthly temperature varies between 2.5 °C (January) and 32.5 °C (August). Three years mean monthly weather parameters and monthly rainfall during the experimental period are depicted in Fig. 1.

Soil of the experimental site is well drained, and classified as *Typic Paleudalf* (silty clay loam). The site was previously used for cultivation of turmeric (*Curcuma longa*) for three years, with an average rhizome yield of about 10 Mg ha^{-1}. The soil was severely degraded as evidenced by the presence of gravels on the surface. The available nutrients in terms of alkaline permanganate oxidizable N, 0.5 M $NaHCO_3$ extractable P and 1 N NH_4OAC exchangeable K contents at initiation of the present study were 218.6, 16.27 and 235.5 kg ha^{-1}, respectively. The initial pH and SOC concentrations were 5.4 and 15.2 g kg^{-1}, respectively. Soil bulk density (ρb) of 0–15 and 15–30 cm depths was 1.28 and 1.33 Mg m^{-3}, respectively.

The experiment was laid out in a factorial Randomized Block Design with treatment combinations of four grasses and three nutrient sources. Four forage grasses included broom grass, congosignal grass, hybrid napier and guinea grass. Three nutrient sources were control (grown with inherent soil fertility), organic manure and inorganic fertilizers. The treatments were replicated three times. The plot size was 5 m length × 3 m breadth. Forage grasses were planted at a spacing of 90 × 50 cm for broom grass and 75 × 50 cm for other three grasses. Recommended doses of nutrients were 80:60: 40 kg ha^{-1} N, P_2O_5 and K_2O, respectively. Equivalent quantity of only N and P_2O_5 was applied through organic and inorganic sources. Whereas, in the case of control, grasses were raised under inherent soil fertility without any external nutrient application (farmers' practice). Inorganic nutrient sources were urea, single super phosphate and muriate of potash for supplying N, P and K, respectively. During the first year, full dose of P and K along with 50% N was applied in pits (30 cm width × 20 cm depth) and mixed with the soil before planting the grass slips in first week of May. The remaining 50% applied in two equal splits in the first week of July and mid-August. During second and third year, 30% N along with full P and K, were side dressed during mid-May after a weeding before onset of monsoon. The remaining 70% of N was applied in three equal splits (for broom in two splits) after each cutting. Farmyard manure (FYM) was applied on the basis of N-equivalent, and the P requirement was supplemented through the input of rock-phosphate in case of organic sources of nutrient supply. The FYM was obtained from an adjacent dairy unit in the farm, and contained 9.1 ± 0.6, 2.7 ± 0.3 and 9.4 ± 0.6 g kg^{-1} total N, P and K, respectively. The Fe, Cu, Zn and Mn concentrations in FYM were 3520 ± 17.50, 57 ± 6.90, 315 ± 7.16 and 281 ± 9.25 ppm, respectively. The average moisture content in FYM was about 40%. The average C-concentration in FYM was 228 ± 9.5 g kg^{-1} with a C:N ratio of 24:1. The P_20_5 content in rock-phosphate was 18.5 ± 1.81 g kg^{-1}. Thus, ~8.8 Mg ha^{-1} FYM (dry weight basis) was applied for nutrition of forages each year under organic treatment. As rock-phosphate is allowed in organic production system, it was used as P source under organic treatment. In first year FYM along with rock-phosphate was applied in pits, 20 days before planting the slips. From second year onwards, FYM and rock-phosphate were side dressed around the grass hills after weeding during mid-May. Four cuttings of forages were taken each year beginning in May, and at an interval of 50–60 days, and the green fodder yields were recorded. In case of broom grass, only 3 cuttings were taken annually. Thus, the grasses were planted in first year and regrowth were managed every year as these are perennial in nature. Two hand weedings were done every year; one before onset of monsoon in May (after first cutting) and another in August. The weed biomass was retained as in-*situ* mulch. Soil disturbance was minimal and limited only to the placement of fertilizer and manure as per the specific treatment. Some characteristics of grasses used in the study are presented in Table 1.

2.2. Proximate analysis

The dry matter content was determined by drying the forage samples at 60 °C till constant weight (Rangana, 1997). Dry fodder yield was estimated on the basis of oven dry weight. Percentage crude protein was determined by the modified 'micro-Kjeldhal Method' (Bremner and Mulvaney, 1982). P concentration of plant tissues, digested in HNO_3 and $HClO_4$ was determined by the ammonium molybdate method (Olsen and Sommers, 1982). Lignin

Table 1
Characteristics of the various grass species used in the study.

Species	Growth habit	No. of tillers clump^{-1}	No. of cuttings yr^{-1}	Protein content (g 100 g^{-1} DM)	Uses
Broom	Erect	29–75	3	8.47 ± 1.17	Broom sticks, soil conservation, fodder for cattles
Congo-signal	Erect and bushy	65–72	4	8.02 ± 1.19	Soil conservation, fodder for cattles
Guinea	Erect	35–47	4	8.21 ± 1.33	Soil conservation, fodder for cattles
Napier	Erect	30–48	4	8.96 ± 1.42	Soil conservation, fodder for cattles

DM: dry matter, ±: standard deviation from mean.

and cellulose contents were determined by the method of Rowland and Roberts (1994) and the crude fibre content by the A.O.A.C (1984) procedure.

2.3. Soil sampling and analysis

Soil samples were obtained from each plot for 0–15 cm and 15–30 cm depths for ρb and 0–15 cm for other parameters every year during the month of May. Soil ρb was determined by the core method (Blake and Hartge, 1986) using cores of 5.8 cm in height and 5.4 cm in diameter. Bulk samples were air dried, grinded and passed through a 2 mm sieve and used for analysis of chemical parameters. The SOC concentration was determined on finely ground samples passed through a 250 μ sieve. Total C was determined by the dry combustion method (Nelson and Sommers, 2005) using a TOC analyzer (Elementar, Vario TOC select, Germany). Concentration of SOC was assumed to be equal to the total C, because of the negligible inorganic C concentrations since soil pH was <7 (Jagadamma and Lal, 2010).

Soil pH was determined by potentiometric method using a pH meter. Soil available N was determined by the alkaline permanganate method (Subbiah and Asija, 1956); available P by $NaHCO_3$ extraction (Olsen and Sommers, 1982) and available K by neutral 1-normal NH_4OAC extraction (Knudsen et al., 1982). Concentration of Fe, Mn, Zn and Cu were determined by DTPA-TEA extraction method (Lindsay and Norvell, 1978). The SMBC was determined by the chloroform fumigation method of Vance et al. (1987) using a Kc (constant) value of 0.45 (Jerkinson and Ladd, 1981). Soil dehydrogenase activity (DHA) was estimated by the procedures described by Tabatabai (1982) by reducing 2, 3, 5-triphenyl tetrazolium chloride (Casida et al., 1964).

The SOC stock was calculated using ρb for the corresponding soil depth, as follows (Lal et al., 1998):

$$\text{SOC stock}(\text{Mg ha}^{-1}) = \text{SOC concentration}(\text{g kg}^{-1}) \times \text{bulk concentration}(\text{Mg m}^{-3}) \times \text{depth}(\text{m}) \times 10^{-3}\,\text{Mg kg}^{-1} \times 10^{4}\,\text{m}^2\,\text{ha}^{-1}$$

C-sequestration was estimated using following equation:

$$\text{C sequestered}(\text{Mg C ha}^{-1}\,\text{soil}) = \text{SCO stock current} - \text{SOC stock initial}$$

2.4. Statistical analysis

The analysis of variance method (Gomez and Gomez, 1984) was followed to statistically analyze all parameters. The significance of different sources of variations was tested by error mean square of Fisher Snedecor's '*F*' test at probability level (P = 0.05). Summary table compiled include the standard error mean (SEm±) and critical difference (CD) to compare the difference between the means. Three years data were pooled and mean value also presented along with individual years. Significant interactions of a forage and nutrient sources are presented. Year *x* treatments interactions presented wherever found significant.

3. Results and Discussion

3.1. Fodder productivity

Irrespective of sources of nutrient supply, fodder yields increased over the years and the maximum biomass was produced during 2010–11. Among forages, hybrid napier produced significantly higher green (Supplementary Table 1) and dry fodder yields (Table 2) in 2009–10, 2010–11 as well as the three years average yield compared with other forage grasses. Guinea grass was the next best species which produced significantly higher fodder yield compared to those of congosignal and broom grasses. The green and dry fodder yields were significantly higher with organic sources of nutrient supply during all three years of experimentation as well as for average yield compared to those receiving inorganic sources of nutrients and control (Table 2). However, green and dry fodder yields under inorganic source of nutrient supply remained significantly superior to that of the control during all three years. Organic sources of nutrient supply produced

Table 2
Dry fodder yield (Mg ha^{-1}) as influenced by year species and nutrient source interactions.

1. Year × nutrient interaction					4. Year × forage × nutrient source interactions				
Treatments	Control (C1)	Organic (C2)	Inorganic (C3)	Mean	Treatments	Y1	Y2	Y3	Mean
2008–09 (Y1)	7.2	13.3	9.9	10.2	C1M1	6.2	11.1	10.8	9.4
2009–10 (Y2)	17.5	26.4	20.7	21.5	C2M1	14.0	14.2	15.0	14.4
2010-11 (Y3)	17.1	28.9	23.2	23.1	C3M1	12.1	12.6	13.5	12.7
Mean	13.9	22.9	17.9	18.2	C1M2	26.9	58.5	60.1	48.5
SEm (±)		0.49			C2M2	46.0	70.0	71.9	62.6
CD (P = 0.05)		1.50			C3M2	36.3	62.5	65.5	54.8
					C1M3	28.3	72.8	75.6	58.9
2. Year × forage interaction	C2M3	54.7	131.3	141.6	109.2				
Treatments	Y1	Y2	Y3	Mean	C3M3	39.8	96.9	118.3	85.0
Broom (M1)	3.6	4.2	4.4	4.1	C1M4	24.5	67.0	58.8	50.1
Congo (M2)	12.1	21.2	21.9	18.4	C2M4	44.4	101.6	118.7	88.2
Hybrid napier (M3)	13.6	33.5	37.3	28.1	C3M4	30.9	76.5	80.8	62.8
Guinea (M4)	11.1	27.2	28.7	22.4	Mean	30.4	64.6	69.2	–
Mean	10.1	21.5	23.1	18.2	SEm (±)		1.36		
SEm (±)		0.79			CD (P = 0.05)	3.87			
CD (P = 0.05)		2.24							
3. Nutrient source × forage interaction									
Treatments	Control	Organic	Inorganic	Mean					
Broom	3.1	4.8	4.2	4.1					
Congo	16.2	20.9	18.3	18.4					
Hybrid napier	19.6	36.4	28.3	28.1					
Guinea	16.7	29.4	20.9	22.4					
Mean	13.9	22.9	17.9	18.2					
SEm (±)		0.78							
CD (P = 0.05)		2.23							

27.5 and 64.4% higher dry fodder yield (pooled) than that under inorganic and control, respectively. The interaction effect between year, forage species and sources of nutrient supply were also significant on dry fodder yields (Table 2). Year *x* forage species and year *x* nutrient source interactions revealed that dry fodder yields were the highest in 2009–10 being at par with 2010–11 and productivity in both of these years were significantly higher than those recorded in 2008–09. Similarly, year *x* nutrient source *x* forage species interaction indicated that dry fodder productivity was significantly higher in 2009–10 which was at par with 2010–11 than 2008–09 for most of the treatments. The productivity of hybrid napier was significantly higher under organic sources of nutrient supply during all three years compared to other treatments but was similar to that of the hybrid napier with inorganic (2010–11) source, and congosignal grass with organic (2008–09) source of nutrient supply (Table 2).

The higher yields in case of continuous application of organic manure compared to conventional farming was attributed to improvement in physico-chemical and biological properties of the soil and nutrient uptake by diverse forage crops as evident from the post-harvest soil and plant analysis data. Improvement in soil health and subsequent increase in productivity of field crops (Das et al., 2004) including forage grasses (Ghosh et al., 2009) due to application of organic manure have been reported by numerous researchers. Perennial grasses differ in production of above and below-ground biomass. Both guinea and napier grasses have higher biomass productivity than those of other grasses (Ghosh et al., 2009). The relative abundance of roots; and root distribution and density within the soil profile are genetically determined and vary with soil type, moisture regime, nutrient availability, organic matter distribution, and soil management (Myers et al., 1994).

3.2. Fodder quality

Quality of biomass (above and below ground) affects the feed value, digestibility, decomposition rate and SOC retention capacity (Ghosh et al., 2009). Broom grass had the maximum dry matter content followed by hybrid napier (Table 3). In the present study, the maximum crude protein concentration was observed in broom grass followed by that in hybrid napier. Sources of nutrient supply did not have significant effect on crude protein concentration in fodder, which was 8.32, 8.62 and 8.91% in broom grass and 7.57, 8.42 and 8.91% in napier grass during the year 2008–09, 2009–10 and 2010–11, respectively (Table 3). Average chlorophyll index was the highest in guinea grass (39.52) followed by that in hybrid napier (38.95) (Table 3). In 2008–09, crude fibre content was the highest in congosignal grass. However, from second year onwards, crude fiber content was the maximum in hybrid napier followed by that in congosignal grass. Average crude fibre content was also the maximum in hybrid napier followed by that in congosignal grass. Among the sources of nutrients, organic source produced significantly higher crude fiber content in all three years and the average compared to that under inorganic and control, which were at par with each other. Average lignin and cellulose contents were also the maximum under organic followed by that in inorganic source. Among forages, lignin content was the highest under hybrid napier, whereas cellulose percentage was the maximum under congosignal grass. The lowest lignin content was observed in congosignal grass (Table 4).

The N content in roots of forage species ranged from 15.2 to 21.1 g kg^{-1}, the highest being in broom grass (Table 5). Further, C-content was the maximum in roots of congosignal followed by that in guinea grass. The lignin and cellulose contents were also more in congosignal than in other grasses. Accordingly, C:N and lignin: N ratios of roots were more in congosignal grass followed by that in guinea grass and other grasses. The average C:N and lignin:N ratios in roots of broom grass were lower than those observed in roots of other forages.

The produce quality is specific to the crops and controlled by a complex interaction of factors, including soil type and the mineral composition of the manures used (Warman and Harvard, 1998). Parray et al. (2007) reported that phenol, chlorophyll, ascorbic acid, oxalic acid, acidity, lycopene and carotenoid contents were enhanced by the application of FYM compared to that of the control. The digestibility of plants is influenced by the fibre, lignin and cellulose contents. The lignin content of a plant is the most indigestible component of the fibre fractions (Gillespie, 1998). Thus, a lower lignin content of the plants is considered good for better digestibility. The crude fibre, cellulose and lignin contents were not influenced by sources of nutrients except in 2010–11, when crude fibre content was significantly higher under organic sources than in control. Significant increase in plant height, crude protein and decrease in crude fibre contents with increasing levels of FYM application have been reported by others (Ahmed et al., 2012). Sodeinde et al. (2009) reported that application of poultry droppings produced higher crude protein content in the leaves of guinea grass and also enhanced the forage quality. Higher C:N and lignin:N ratios for the roots of setaria (*Setaria italica*) and congosignal compared to other grass species have been reported by Ghosh et al. (2009).

3.3. Nutrient uptake by fodders

Among major plant nutrients supplied through external sources, N is required in higher quantity and hence, it is the

Table 3
Dry matter, crude protein content and chlorophyll index of fodder crops under different nutrient sources.

Fodder crops	Dry matter content (%)				Crude protein (%)				Chlorophyll index			
	Y1	Y2	Y3	Mean	A	B	C	Average	A	B	C	Average
Broom grass	21.2	21.1	21.2	21.2	8.19	8.29	8.34	8.27	34.2	40.3	41.1	38.5
Congosignal grass	19.1	19.0	19.2	19.1	7.65	7.72	7.73	7.70	31.1	34.4	36.7	34.1
Hybrid napier	20.9	20.8	20.9	20.8	8.01	8.02	8.10	8.04	36.3	39.5	41.1	38.9
Guinea grass	21.1	21.0	21.0	21.0	7.48	7.55	7.67	7.57	37.3	40.3	41.0	39.5
SEm (±)	0.43	0.32	0.33	0.20	0.09	0.10	0.15	0.11	0.91	0.91	0.72	0.78
CD (P = 0.05)	1.27	0.94	1.00	0.79	0.27	0.30	0.45	0.32	2.70	2.71	2.13	2.32
Nutrient sources												
Control	19.4	19.4	19.4	19.4	7.47	7.41	7.41	7.43	32.8	36.2	38.2	35.8
Organic	21.7	21.7	21.9	21.8	8.24	8.51	8.74	8.50	36.6	41.1	42.9	40.2
Inorganic	20.5	20.4	20.4	20.4	7.78	7.77	7.73	7.76	34.7	38.5	38.8	37.3
SEm (±)	0.32	0.28	0.16	0.21	0.05	0.11	0.08	0.09	0.75	1.02	1.03	0.84
CD (P = 0.05)	1.24	1.12	0.63	0.82	0.20	0.44	0.31	0.35	NS	NS	NS	NS

Y1-2008–2009, Y2-2009–10, Y3-2010–2011, CD: critical difference, SEm: standard error of mean.

Table 4
Crude fibre, lignin and cellulose contents of fodder crops under different nutrient sources.

Fodder crops	Crude fibre (%)				Lignin (%)				Cellulose (%)			
	Y1	Y2	Y3	Mean	Y1	Y2	Y3	Mean	Y1	Y2	Y3	Mean
Broom grass	34.3	32.9	34.1	33.8	6.95	6.93	6.88	6.92	34.6	35.0	35.2	34.9
Congosignal grass	34.9	34.7	34.6	34.7	6.33	6.26	6.17	6.25	38.4	39.4	39.6	39.1
Hybrid napier	34.2	35.7	37.9	35.9	7.11	7.00	6.96	7.02	37.7	38.2	37.9	37.9
Guinea grass	33.1	34.0	31.0	32.7	7.04	6.97	6.92	6.98	36.5	36.6	36.4	36.5
SEm (±)	0.56	0.66	1.09	0.70	0.04	0.03	0.03	0.02	0.46	0.88	0.84	0.67
CD (P = 0.05)	1.66	1.96	3.24	2.13	0.11	0.09	0.09	0.07	1.35	2.62	2.50	2.00
Nutrient sources												
Control	33.3	32.1	30.4	31.9	6.96	6.91	6.84	6.90	36.4	37.0	37.0	36.8
Organic	35.5	36.8	37.7	36.7	6.79	6.71	6.68	6.73	37.0	37.5	37.5	37.3
Inorganic	33.6	34.1	35.1	34.3	6.83	6.76	6.68	6.76	36.9	37.4	37.4	37.2
SEm (±)	1.75	1.09	1.43	1.29	0.21	0.04	0.04	0.03	0.33	1.14	0.51	0.48
CD (P = 0.05)	NS	NS	5.72	NS	NS	NS	NS	NS	NS	NS	NS	NS

Y1-2008–2009, Y2-2009–10, Y3-2010–2011, CD: critical difference, SEm: standard error of mean, NS: not significant.

Table 5
Chemical composition of roots of the different forage species.

Fodder grass	N ($g\,kg^{-1}$)	C ($g\,kg^{-1}$)	Lignin ($g\,kg^{-1}$)	Cellulose ($g\,kg^{-1}$)	C:N ratio	Lignin:N ratio
Broom grass	21.1	357.4	152.0	347.0	16.94	7.20
Congosignal grass	15.2	386.3	192.0	378.0	25.41	12.63
Hybrid napier	19.5	360.8	158.0	372.0	18.50	8.10
Guinea grass	15.7	376.8	174.0	361.0	24.00	11.08
s.d.	2.88	13.6	17.93	13.6	4.12	2.54

s.d.: standard deviation, C:N: carbon nitrogen ratio.

primary focus among all nutrients (Magar, 2004). The soils of the NEH are highly acidic and deficient in P (Das et al., 2008). Thus, N and P uptake of fodder grasses were assessed under different treatments. Sources of nutrient supply and fodder grasses had significant effect on N and P uptake of forages (Supplementary Table 2). Fodder nutrient (N and P) uptake was the highest under organic followed by that under inorganic fertilizers for all three years. Among forage species, hybrid napier had significantly higher N and P uptake than by other grasses for all three years. Average nutrient uptake was the maximum under organic followed by that under inorganic fertilizers and control. The average N and P uptake under organic manure was 38 and 58% higher than that under inorganic and 90 and 125% higher than that in control, respectively. Greater biomass production under organic manures also increased the nutrient uptake compared to that under inorganic and control treatments. The increase in nutrient uptake of crops under organic sources may be due to improvement in soil available N and P contents because of favourable soil quality compared to inorganic fertilizers and control treatments (Manna et al., 2001). Increase in nutrient uptake due to concomitant increase in biomass has also been reported by Das et al. (2013) and Ghosh et al. (2009).

3.4. Soil quality and SOC stocks

Soil available N, P, K status and that of SOC concentrations were not significantly influenced by the forage species. However, fertilizer treatment had significant effect on these parameters in all three years including average nutrient concentrations (Table 6). There was a marked improvement in concentrations of available N, P, K and that of SOC compared to the antecedent level in soil under all forages irrespective of fertilizer type, indicating the importance of forages to improving soil quality.

Concentrations of available N, P, K and that of SOC after three years were significantly higher under organic manure compared to those under inorganic fertilizer and control treatment. Average concentrations of N, P, K and SOC were also the maximum in soil receiving organic manure followed by those under inorganic sources of nutrient supply. Average concentrations of N, P, K and SOC under organic and inorganic sources of nutrient supply were 8.4, 31.7, 4.7 and 12.2% and 2.3, 15.0, 2.0 and 7.7%, respectively, higher than those under control.

Soil ρb decreased with successive cropping cycles and the lowest values were observed in 2010–11 in 0–15 cm and 15–30 cm layers compared to the antecedent values (Table 7). Forages and

Table 6
Soil available nitrogen, phosphorus, potassium and organic carbon contents as influenced by fodder crops and sources of nutrient supply.

Nutrient sources	N ($kg\,ha^{-1}$)				P ($kg\,ha^{-1}$)				K ($kg\,ha^{-1}$)				SOC ($g\,kg^{-1}$)			
	Y1	Y2	Y3	Mean	Y1	Y2	Y3	Mean	Y1	Y2	Y3	Mean	Y1	Y2	Y3	Mean
Control	224.7	225.4	228.7	226.3	16.1	16.4	17.3	16.7	234.5	236.5	238.9	236.6	15.3	15.5	15.8	15.5
Organic	240.5	245.1	250.1	245.3	20.9	22.0	23.0	22.0	243.3	247.9	252.0	247.7	16.3	17.3	17.9	17.2
Inorganic	230.5	233.3	231.1	231.6	18.6	18.7	20.1	19.2	240.9	241.9	241.3	241.4	16.0	16.8	17.0	16.6
SEm (±)	0.77	1.71	1.11	1.14	0.18	0.33	0.49	0.29	1.37	1.44	2.11	1.52	0.1	0.3	0.20	0.21
CD (P = 0.05)	3.01	6.72	4.36	4.47	0.70	1.29	1.94	1.13	5.37	5.66	8.29	5.97	0.32	1.0	0.70	0.72
Initial	218.6	16.27	235.5	1.52												

Y1-2008–2009, Y2-2009–10, Y3-2010–2011, SOC: soil organic carbon, CD: critical difference, SEm: standard error of mean, NS: not significant.

Table 7
Physical and biological properties soil as influenced by fodder crop and sources of nutrient supply.

Nutrient sources	Bulk density ($Mg\,m^{-3}$)								Soil microbial biomass carbon ($\mu g\,g^{-1}$ dry soil)				Dehydrogenase activity ($\mu g\,g^{-1}$ dry soil)			
	0–15 cm				15–30 cm											
	Y1	Y2	Y3	Mean	Y1	Y2	Y3	Mean	Y1	Y2	Y3	Mean	Y1	Y2	Y3	Mean
Control	1.28	1.27	1.26	1.27	1.34	1.33	1.31	1.33	204	208	199	204	6.58	7.91	7.59	7.41
Organic	1.25	1.22	1.2	1.22	1.32	1.30	1.29	1.30	227	239	254	240	7.26	8.24	8.12	7.87
Inorganic	1.27	1.25	1.24	1.25	1.32	1.32	1.31	1.32	220	228	233	227	7.21	8.06	7.97	7.70
SEm (±)	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.01	3.44	4.95	9.61	5.42	0.08	0.06	0.09	0.04
CD (P = 0.05)	0.04	0.07	0.04	0.05	NS	NS	NS	NS	13.52	19.45	37.73	21.29	0.30	0.23	0.35	0.14
Initial	1.28				1.33				–				–			

Y1-2008–2009, Y2-2009–10, Y3-2010–2011, CD: critical difference, SEm: standard error of mean, NS: not significant.

nutrient sources had no effect on ρb at 15–30 cm, but that in 0–15 cm depth was significantly affected by fertilizer type with the maximum under inorganic and minimum under organic manures. However, soil ρb under control and inorganic fertilizers were statistically similar throughout the sampling periods. Average ρb was also lower with organic source at 0–15 cm (1.22 $Mg\,m^{-3}$) and 15–30 cm (1.29 $Mg\,m^{-3}$) depths compared to that under other treatments.

The SMBC and DHA activity were significantly higher under organic manure compared to that under control, though the SMBC was similar under organic and inorganic fertilizers. The average SMBC and DHA under organic manure was 17.9 and 6.21% higher than that under control, respectively. Forage species had no effect on SMBC and DHA. Relatively more SMBC and DHA were observed under hybrid napier than that under other species.

Neither forage species nor fertilizer type affected soil micronutrient concentrations (Fe, Mn, Cu). However, there existed a trend of improvement in micronutrient concentration over the years compared to initial level (Supplementary Table 3). None-the-less, concentration of Zn was significantly influenced by the fertilizer type, and it was higher under organic manure than in other treatments. Broom grass had relatively higher concentrations of Fe, Zn and Cu than those in other species. However, concentration of Mn was higher under congosignal grass than in other forages. In general, concentrations of Mn, Zn and Cu were higher with organic, while that of Fe was more under inorganic fertilizers than under other treatments.

The SOC stock (0–15 cm) after third year was 5.4–7.5% higher under forages and 2.3–10.4% higher under fertilizer types compared to the antecedent stock. Among forages, the highest SOC stock was observed under napier followed by that under congosignal grass. Among the fertilizers, the maximum SOC stock was observed under organic followed by that under inorganic fertilizers. The SOC stock in the third year under organic fertilizer was 8.1 and 2.1 $Mg\,ha^{-1}$ higher than that under control and inorganic fertilizers, respectively (Fig. 2). The average SOC stock levels also followed a similar trend. Approximately 5.8 Mg-C was added through FYM under organic source of nutrient supply. Thus, the rest 2.3 Mg SOC may be the contributions from detritus and root biomass. The increase in SOC under forages compared to the initial values may be due to concomitant high root biomass, and addition of OM to the soil through decaying of large volume of dead roots (Fissore et al., 2008), and return of detritus materials (Ghosh et al., 2009). Perennial grasses have a high root biomass, which is the continuous source of OM to the soil (Kristina et al., 2009). Further, perennial grasses also have higher SMBC and greater production of carbohydrate extract in hot water (Haynes and Francis, 1993). Thus, grasses improve soil aggregation, water transmission properties (Ghosh et al., 2009) and SOC concentrations (Conant et al., 2001). Increase in SOC concentration over time may be attributed to the minimal disturbance of soil under perennial grasses and to extensive root systems (Gentile et al., 2005). However, the retention of SOC depends on the quantity of root biomass and its quality (lignin/nitrogen ratio, carbon/nitrogen ratio, cellulose, hemi-cellulose, etc.) which can vary widely as a

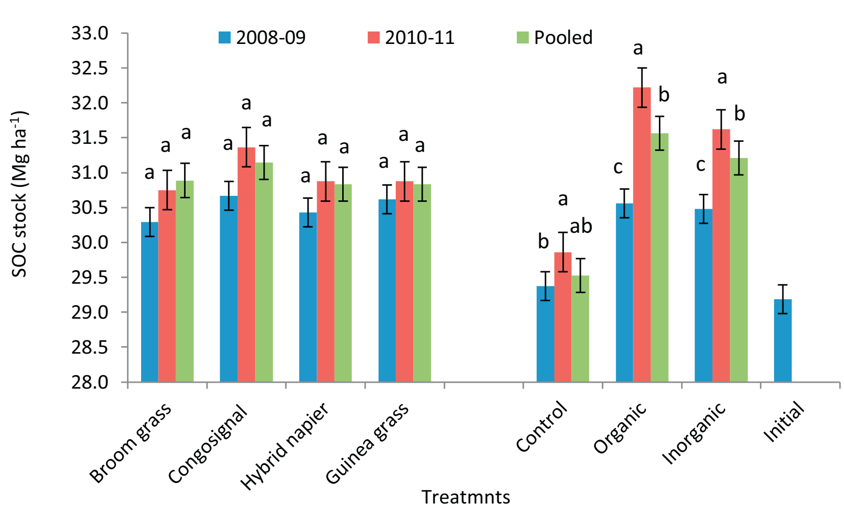

Fig. 2. SOC stocks under different treatment vs. initial at final harvest during 2008–09, 2010–11 and 3-years pooled (vertical bars indicate standard error from mean; bars with different letters are significantly different within a year).

function of climate and soil type (Fissore et al., 2008; Ghosh et al., 2009). In general, the decomposition rate is faster in materials with narrow than with wider C:N ratios. Relatively high SOC storage under congosignal grass and comparatively lower under broom grass may be due to differences in the C:N ratio. Therefore, conversion of crop lands to hybrid napier can increase C-sequestration in agricultural ecosystems (Sundaram et al., 2012; Nishanth et al., 2013).

In present study SOC concentrations and stock was the highest under organic followed by inorganic. Continuous applications of organic amendments can enhance SOC concentration (Jiang et al., 2006; Patel et al., 2015), available P and K and improve soil quality (Das et al., 2013). Consistently higher SOC, total N, SMBC, microbial biomass N and available water holding capacity and, lower ρb have been observed in organic compared to those in soils of conventional farms in Nebraska (Liebig and Doran, 1999). In general, FYM is more effective than inorganic fertilizers in increasing the SOC stock (Sundaram et al., 2012).

Decrease in ρb, increase in water retention characteristics; and concentrations of SOC, N, P, K, Ca and Mg owing to application of organic manure have been reported by other researchers (Ahmed et al., 2012). The increase in available P may be attributed to organic acids which are released during microbial decomposition of OM which helps in solubility of native phosphates (Bhardwaj and Omanwar, 1994). The higher availability of K is attributed to beneficial effects of OM on the reduction of K fixation and interaction of OM with clay to release K from non-exchange fraction to the available pool (Das et al., 2013).

4. Conclusions

The data supports following conclusions

- Perennial forages improved soil quality and SOC stocks over the years compared to antecedent level, thus, exhibiting their suitability for rehabilitation of degraded hill soils.
- Napier grass is the most suitable species for fodder productivity, improving soil fertility and SOC concentrations.
- Organic sources of fertilizers improved soil properties and enhanced SOC stock by ~10% over initial level after three years of forage crops cultivation.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agee.2015.10.011.

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