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Long-term effect of pastures on soil quality in acid soil of North-East India

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Abstract. North-East India is known for its complex, diverse, risk-prone, and fragile hilly ecosystem. Natural resources in terms of soil, water, vegetation, and soil organic carbon (SOC) are much degraded. Effects of long-term perennial grasses maintained at a permanent fodder block of the ICAR Research Complex, Meghalaya, on soil quality were examined after 15 cropping cycles. The aims were (*i*) to ascertain whether perennial grass primarily maintained as fodder source for ruminants could conserve resources and improve soil quality in the hilly ecosystem of North-East India, and (*ii*) to select a suitable perennial grass to minimise land degradation, restore SOC, and improve the soil quality. Soil samples were collected in 2007–08 (dry season) from plots of 8 perennial grasses [*Setaria sphacelata* (setaria), *Brachieria rosenesis* (congosignal), *Thysanolaena maxima* (broom), *Penicum maximum* var. Makunia and var. Hamil (guinea), *Pennisetum purpureum* (napier), *Paspalum conjugalum* (paspalam), *Arachis pintoi* (wild groundnut)] and analysed for physical, chemical, and biological properties. A control plot had no grass cover.

Hamil and Makunia produced a large amount of green fodder, while Makunia, paspalam, setaria, and congosignal had greatest root biomass. Relative to the control, soil under perennial grasses showed increases of ~30% SOC, 70% mean weight diameter, 20% available soil water, 40% hydraulic conductivity, 63% infiltration rate, and 10% soil microbial biomass carbon. Among grasses, soil under setaria, congosignal, and Makunia had higher values of these attributes than under other species because of better soil binding through an extensive root system. Improvement of soil physical properties and processes under these grasses, coupled with complete ground cover, reduced soil erosion by ~33% and also signified ecological benefits through C-sequestration. Soil quality management in the fragile ecosystem of North-East India should include permanent pastural grasses, particularly, setaria, congosignal, and Makunia.

Additional keywords: pastural effect, soil quality, fodder crops, North-East India.

Introduction

The north-eastern region of India comprising 8 States (Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura) represents a distinct geophysical region. It has 8.30% (27.49 Mha) of the country's area and 3.90% (39.96 million) of the population. The region is characterised by fragility, marginality, inaccessibility, ethnic heterogeneity, and ecosystem diversity. It has also been identified as one of 18 mega-biodiversity zones of the country. Around 77% of the region's area is hilly and eroded plateau, with only 12% area under net cultivation.

The predominantly tribal population is agrarian and practices ecosystem-specific farming systems, raising both crops and animals. Agriculture and animal husbandry in the region are complementary. Due to the monocropping system practiced, animal husbandry is vital. Animals had been raised under free-range conditions with little supplementary feed; as a result, productivity was not satisfactory (NEC 2003). Farmers have started semi-intensive husbandry practices and seek cheap, nutritionally rich feed resources; meanwhile, demand for quality animal products is increasing. Local native pastures contain only 3.15–3.43% crude protein (dry matter (DM) basis) (Varma 1988), which is far below the level in improved fodder grasses. Some perennial improved grasses and legume fodders, e.g. setaria (*Setaria sphacelata*), congosignal (*Brachieria rosenesis*), and guinea (*Penicum maximum*) perform well at mid altitude in the north-eastern region and were identified for livestock feeding, needing little supplementation of energy and protein requirements for growing calves (Yadav *et al*. 1991). Similarly, Hamil (*Penicum maximum* var. Hamil), broom (*Thysanolaena maxima*), napier (*Pennisetum purpureum*), and wild groundnut (*Arachis pintoi*) fodder are suitable for rabbits (Gupta *et al*. 1993; Gupta 2004; Gupta and Bujarbaruah 2005). For large-scale fodder production, a permanent fodder block was developed at the research farm of the Indian Council of Agricultural Research (ICAR) Research Complex, Umiam, Meghalaya, with 8 perennial grasses.

Almost 88.3 Mt of soil is estimated to be lost annually as a result of shifting cultivation in the North-Eastern Hill (NEH) Region (Prasad and Sharma 1993), with the rate of loss ranging from 30 to 170 t/ha.year (Singh and Singh 1980), compared with

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the national average of 16.35 t/ha.year (Narayana and Ram Babu 1983). Such high rates of soil erosion result in considerable leaching of nutrients from the topsoil, ultimately leading to poor productivity of crops. Prasad *et al*. (1981) estimated that 18.1 Mt of soil eroded annually from the land subjected to shifting cultivation would lead to losses of 603 t of organic carbon, 97 t of available P_2O_5, and 5690 t of available K_2O. Engineering measures to check soil erosion are available but are not cost-effective. Biological methods of soil water conservation, especially grass/vegetation-based are reported to be suitable for hilly ecosystems and cost-effective. Perennial grasses provide year-round ground cover, the most important measure in reducing run-off and soil erosion particularly from hill slopes. Permanent ground cover reduces runoff by maintaining an open surface soil structure that enhances infiltration (Hairsine and Prosser 1997), and grass stems absorb the impact of rain drops and provide surface roughness (Grewal and Abrol 1986). Perennial grass also improves soil quality (Dalal *et al*. 1991; Carter *et al*. 1994) and conserves soil moisture, as well as being used as a source of fodder.

The present study examined whether perennial grasses primarily maintained at the ICAR research station as a source of fodder for ruminants could conserve nutrients and improve soil quality in hilly ecosystem of North-East India. The objectives of the study were: (*i*) to determine various physical, chemical, and biological attributes of soil quality under different perennial grasses, (*ii*) to compare soil quality attributes under grasses with a no-grass control, and (*iii*) to select suitable perennial grass species which improve the soil quality best in a fragile and degraded ecosystem.

Materials and methods

Experimental site

The study was conducted at the fodder block of the ICAR Complex for the North-East Hill (NEH) Region, Umiam, 25°41′21″N and 91°55′25″E, and at an altitude of 980 m above mean sea level. The station, in central Meghalaya, has annual mean rainfall of 2439 mm (coefficient of variation 15.96%); average rainfall of the area is 2349 mm (Fig. 1), mostly confined to May–November. Mean daily temperature varies between 2.5°C (January) and 32.5°C (August). Soils are *Typic Paleudalf*, highly acidic (pH 4.5–6.5) in reaction, and high in organic carbon content (2.97%), with an average slope of 32–53% (Bhattacharyya *et al*. 1994).

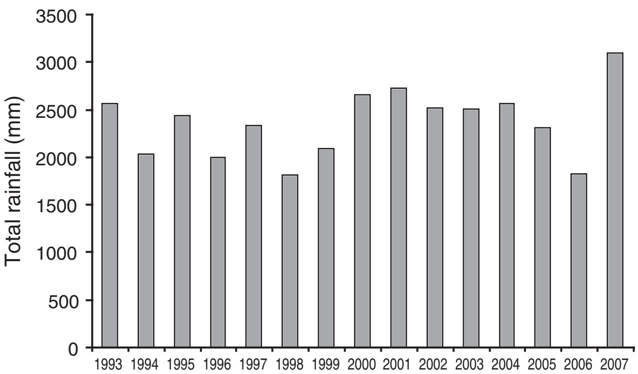

Fig. 1. Rainfall distribution of the experimental area during 1993–2007.

Treatments and description of grasses

Eight perennial grass species planted in 1993–94 and maintained in the block for 15 years for fodder requirements of ruminants were selected for study. These were broom grass, setaria, wild groundnut, congosignal, guinea var. Hamil and var. Makunia, napier, and paspalam (*Paspalam conjugalum*). A control plot from nearby had continuous cultivation for 15 years without any grass cover. Treatments consisting of 8 grasses and 1 control were tested in a randomised complete block design and replicated 3 times.

Characteristics of the fodder species are given in Table 1. Except for wild groundnut all the species are erect type. Only broom and groundnut grow year-round; the others are confined to rainy season. The climate of the region is favourable for growth of all 8 species. These species grow well in cultivated land, degraded land, and also under trees. Wild groundnut has the highest protein content; in other species it varies from 6.41 to 8.72 g/100 DM. The palatability of these fodders for cattle, goat, and rabbit are good and they are recommended for feeding. These fodder species easily survive in extreme cold weather and moisture stress during December–January. However, during this period, fodder cutting is not possible due to slow and stunted growth.

Cultural practice

Eight permanent plots of 1225 m^2 were made to accommodate the grasses in 1993–94. Raised beds (bunds) 35 m in length and 15 cm high were made in each plot to avoid water stagnation, with a distance of 1 m from bund to bund. Two or 3 root slips (20–25 cm) of the species were transplanted on bunds/hills by the end of May (after receiving 3–4 good rain showers), maintaining a distance of 50 cm from plant (hills) to plant (hills). Soils were treated with lime at 2 t/ha and FYM at 10 t/ha and mixed thoroughly before planting. First year-rhizome roots and canopy coverage were only 50–60%; however, full canopy coverage was observed from the second year onwards. Three or 4 weedings followed every year. The weeds were put back into the bunds and incorporated with interculture operations. With this practice, the soil is enriched with an annual addition of 2.5–3.5 t/ha of organic matter, reducing the use of FYM. Four cuttings of fodder were taken from the second year onward at intervals of 50–70 days for all species except broom. The first cut was in May, the second after 50 days, the third and fourth after 70-day intervals.

Soil analysis

Soil samples in the dry season were collected in 2007–08 after 15 cropping cycles from each plot under grass and the control, from 0–0.15, 0.15–0.30, and 0.30–0.45 m soil depth. For all treatments, soil samples were collected randomly from 3 locations. Samples were brought to the laboratory and ~250 g (oven-dry basis) of each sample was taken for determining aggregate size distribution. The remaining portion was air-dried at room temperature and passed through a 2-mm sieve

Table 1. Characteristics of the various grass species used in the study
All of the species favour medium to high rainfall. Values for protein content and fodder yield are mean ± s.d.

Species	Growth habit	Branches	Preferred growth sites	Growing season	Cuttings per year	Protein content (g/100 DM)	Fodder yield (t/ha) Green	Dry
Broom grass (*Thysanolaena maxima*)	Erect	25–145	Cultivated land, terrace land	Year round	Single	8.72 ± 1.56	28.67 ± 3.17	10.03 ± 1.11
Setaria (*Setaria sphacelata*)	Erect	35–40	Cultivated land, degraded land, under trees etc.	Rainy season	4–5	7.47 ± 1.02	20.08 ± 0.55	11.87 ± 3.10
Perennial groundnut (*Arachis pintoi*)	Creeper	–	Wasteland, under trees	Year round	4–5	15.10 ± 1.36	30.4 ± 0.63	8 ± 0.16
Congosignal (*Brachieria rosenesis*)	Erect & bushy	65–72	Cultivated field terrace, river side	Rainy season	4–5	8.33 ± 1.05	113.7 ± 2.15	20.75 ± 0.40
Guinea var. Makunia (*Penicum maximum*)	Erect	31–40	As above	Rainy season	4–5	8.45 ± 1.15	121.2 ± 2.06	23.87 ± 0.41
Guinea var. Hamil (*P. maximum*)	Erect	8–10	As above	Rainy season	4–5	6.41 ± 1.39	125.7 ± 2.60	26 ± 0.54
Paspalam (*Paspalam conjugalum*)	Erect	20–30	As above	Rainy season	4–5	9.71 ± 1.63	5.3 ± 0.49	0.91 ± 1.32
Napier (*Pennisetum purpureum*)	Erect	30–40	Cultivated land	Rainy season	4–5	9.82 ± 1.79	259.8 ± 3.12	36.12 ± 0.61

for analysis of physical properties such as organic carbon and particle size distribution. Bulk density and hydraulic conductivity were measured on the basis of undisturbed core samples collected from treatments.

The SOC was determined by the wet digestion method of Walkley and Black (Nelson and Sommers 1982). The size distribution of the water-stable aggregates was estimated by the wet sieving method (Yoder 1936), using a set of sieves of 4, 2, 1, 0.5, 0.25, and 0.125 mm diameter. Aggregates of 4.8 mm size were first separated from the bulk soil by dry sieving. About 50 g of the aggregate was put on the first sieve of the set and gently moistened from below to avoid a sudden rupture of aggregates. After soaking the soil for 10 min the set was shaken in the water for 10 min at 30 oscillations/min. The amount of soil retained on each size sieve, after correction for sand content, was used to calculate the mean weight diameter (MWD) of the water-stable aggregates following van Bavel (1949). The percentage weight of water-stable aggregates retained on sieves >0.25 mm diameter was expressed as water-stable macro-aggregates (WSA). The soil water characteristic curves were determined by pressure plate apparatus (Black 1965). Water retention at –0.01, –0.033, –0.05, and –0.1 MPa was measured using undisturbed core samples, while retention at –0.5, –1.0, and –1.5 MPa suction was measured using disturbed samples. Available soil water content was estimated as the difference between the volumetric water retention at –0.033 and –1.5 MPa, multiplied by depth of the soil. Saturated hydraulic conductivity (Ks) was estimated following the constant head method (Klute 1965). Soil infiltration rate was determined using double-ring infiltrometer on a pre-wetted soil for 48 h (Richards 1954). Moisture equivalent of the soils was measured as outlined by Piper (1950). Erosion ratio was computed using the expressions given by Middleton (1930): erosion ratio = dispersion ratio/ (clay/moisture equivalent ratio).

For analysis of soil microbial biomass content (SMBC), a 40-g moist sample (2 mm) was kept for 3 days of pre-incubation at 25°C before attaining basal respiration condition. SMBC was determined by the ethanol-free chloroform fumigation extraction method (Vance *et al*. 1987) using a *K*c value of 0.45 (Jerkinson and Ladd 1981). The earthworm population was counted following a physical procedure (excavating and hand sorting) as described by Kooch *et al*. (2008). One quadrate 0.5 by 0.5 m (0.25 m^2) was placed on the surface of the soil and the plough layer (0–0.15 m) inside the quadrate was completely excavated. The excavated soil was kept in a gunny bag and the population of earthworms was counted by hand-sorting. The number was then converted to per ha basis. Average bodyweight of earthworms under different grass cultivation was taken after repeated washing with distilled water until the ingested soils were washed out. Thereafter, earthworms were placed on the filter paper for drying and the weight was recorded.

Root sampling and analysis

Root samples were collected using root-sampling cores (6 cm height, 8.6 cm diameter) up to a depth of 0.30 m. After thorough washing and staining with methyl violet, roots were dried at 65°C to a constant weight and weighed. Carbon analysis was done by the method of Anderson and Ingram (1993). Total N was determined by the standard method as described by Bremner and Mulvaney (1982). Lignin and cellulose were determined by the method of Rowland and Roberts (1994).

Statistical analysis

Analysis of variance (ANOVA) was carried out using the randomised complete block design. Least significant difference (l.s.d.) at $P = 0.05$ was used to test the difference between means of individual treatments (Gomez and Gomez 1984).

Results and discussion

Biomass production

The production potential of the perennial grasses is presented in Table 1. These perennial grasses have better nutrient contents than native grasses (Gupta and Bujarbaruah 2005). Guinea varieties Hamil and Makunia, as well as napier, had the highest green fodder yield, whereas groundnut and paspalum had the lowest (Table 1). Makunia, paspalam, setaria, and congosignal had significantly higher root biomass than the other species (Fig. 2). Perennial grasses differ in the relative abundance of roots; root distribution and density within the soil profile are genetically determined and vary with soil type, moisture, nutrient availability, organic matter distribution, and soil management (Myers *et al*. 1994).

Chemical properties

Many factors influence the complex chemical, physical and biological processes that govern soil quality and crop productivity. Changes in soil quality caused by inappropriate agricultural practices, acidification, salinity, and decline in soil organic matter may take several years to appear. Long-term experiments provide the best means of studying changes in soil properties and processes over time and are important for obtaining information on long-term sustainability of agricultural systems to formulate strategies for maintaining soil health (Swarup 1998).

The retention of SOC depends on the quantity as well as quality of the chemical composition (lignin/nitrogen ratio, carbon/nitrogen ratio, cellulose, hemi-cellulose, etc.; Table 2) of grass root and litter, and varies widely as a function of climate and soil type (Parton *et al*. 1987). In general, soil under perennial grass maintained ~30% higher SOC ($P < 0.05$) than the control and initial value; significantly higher SOC at 0–0.15 m depth ($P < 0.05$) was observed under most fodder species, the highest being setaria, congosignal, and Makunia, compared with the control (Table 3). The superiority of these grasses was mainly due to concomitant higher root biomass generation (Fig. 2), constant addition of organic matter to the soil through decaying of large volume of dead roots (Balkrishnan and Toky 1993), and high return of leftover surface plant residue (Christensen 1988) leading to improvement in C-status of the soil. Broom grass generally had no significant effect on SOC compared with the control and initial value. The average C/N and lignin/N ratios in roots of broom grass were lower than those in the other fodder species (Table 2). In general, the decomposition rate is much faster in materials with narrow C/N ratio than with wider ratios. This is one reason why the SOC storage was not higher in broom grass plots. There was a trend to decline of SOC in the control plot (intensive cropping) from initial SOC status, although this was not significant (Table 3). Repeated ploughing, little coverage of soil surface, and no regular addition of organic matter were practiced under traditional cultivation over a long period of time; therefore, traditional cultivation tended to deplete the SOC level in the control plot. Available N was highest under setaria (Table 3); paspalum, while producing the lowest fodder biomass, had highest P, S, Fe, and Zn with moderate level of organic carbon and N. There was no consistency in N, P, K, S, Fe, and Zn contents in soil among other species at 0.15–0.30 and 0.30–0.45 m depth.

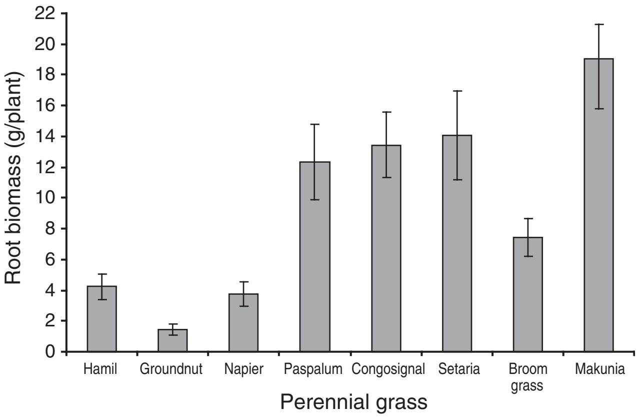

Fig. 2. Root biomass of perennial grasses at 0–0.30 m soil depth.

Physical properties

Data in Tables 4 and 5 reveal that all the grasses improved soil aggregation and soil water transmission considerably. The perennial grasses had varied root biomass, which is the continuous source of organic matter. Addition of organic matter through root decay enhances SOC, which directly or indirectly affects soil physical properties and processes such as aggregation, water-holding capacity, hydraulic conductivity, and resistance of soil to water and wind erosion (Zebarth *et al*. 1999; Franzluebbers 2002; Celik *et al*. 2004). Hudson (1994) reported that soils high in organic matter had greater

Table 2. Chemical composition of roots of the different fodder grasses

Fodder grass	N (%)	C (%)	Lignin (%)	Cellulose (%)	C : N ratio	Lignin : N ratio
Broom grass	2.20	35.54	14.81	35.80	16.15	6.73
Setaria	1.62	42.77	17.32	36.97	26.40	10.69
Perennial groundnut	1.75	38.20	16.04	37.54	21.83	9.17
Congosignal	1.42	40.54	18.09	39.78	28.55	12.74
Guinea var. Makunia	1.56	39.81	16.34	36.63	25.39	10.47
Guinea var. Hamil	1.80	38.45	17.30	35.06	21.36	9.61
Napier	2.03	36.28	16.22	37.70	17.87	7.99
Paspalum	2.03	36.93	17.08	36.04	18.19	8.41
s.d.	0.27	2.40	1.01	1.45	4.47	1.86

Table 3. Soil nutrient status after 15 years of planting of the different perennial fodder grasses

Fodder species	Organic C (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	Available S (kg/ha)	Fe (μg/g)	Zn (μg/g)
0–0.15 m soil depth							
Broom grass	1.75	293.03	16.3	222.1	49.03	184.80	3.81
Setaria	2.40	416.87	23.7	149.7	52.13	166.00	1.19
Perennial groundnut	2.30	288.47	5.1	129.9	34.83	91.90	0.46
Congosignal	2.55	252.37	14.3	103.8	52.27	215.93	2.64
Guinea var. Makunia	2.54	265.27	6.5	110.0	54.43	147.00	1.01
Guinea var. Hamil	2.25	275.77	7.1	103.8	34.30	144.97	0.95
Napier	1.93	241.17	12.1	123.1	46.43	272.93	3.35
Paspalum	2.21	268.97	24.1	96.8	54.27	281.10	4.18
Control (no fodder)	1.63	255.31	4.8	98.1	32.7	95.3	0.45
s.d.	0.11	4.65	4.25	4.88	2.06	4.94	0.16
l.s.d. ($P = 0.05$)	0.19	8.14	3.2	7.1	3.61	8.66	0.28
Sample size (*n*)	27	27	27	27	27	27	27
Initial value	1.69	247.7	5.1	102.5	35.9	95.8	0.46
0.15–0.30 m soil depth							
Broom grass	1.33	214.90	16.8	212.5	22.53	141.73	1.29
Setaria	2.31	381.70	21.1	177.2	30.80	161.97	1.18
Perennial groundnut	1.99	254.37	4.1	122.8	35.60	85.70	0.43
Congosignal	1.96	241.03	7.2	119.4	45.67	170.73	1.08
Guinea var. Makunia	2.23	255.13	4.6	103.6	41.60	144.93	0.83
Guinea var. Hamil	1.89	261.10	6.1	83.5	32.43	120.03	0.66
Napier	1.77	229.20	7.5	107.6	57.47	172.20	2.86
Paspalum	1.97	242.00	27.2	85.7	35.93	292.07	4.02
Control (no fodder)	1.12	235.1	4.8	84.1	20.3	81.7	0.54
s.d.	0.04	3.30	2.71	2.94	3.78	3.71	0.03
l.s.d. ($P = 0.05$)	0.08	5.78	2.0	4.3	6.61	6.49	0.06
Sample size (*n*)	27	27	27	27	27	27	27
0.30–0.45 m soil depth							
Broom grass	1.42	274.67	8.8	134.9	30.20	115.07	0.99
Setaria	2.15	333.00	11.7	162.2	25.50	137.37	1.16
Perennial groundnut	2.08	247.63	6.7	110.9	25.33	95.07	0.35
Congosignal	2.20	237.07	6.4	89.0	26.70	165.23	0.93
Guinea var. Makunia	1.92	222.67	4.3	86.5	57.67	127.57	0.66
Guinea var. Hamil	1.83	248.40	5.3	79.7	23.93	111.27	0.52
Napier	2.05	199.77	5.2	111.9	28.23	167.17	2.27
Paspalum	1.49	234.27	20.3	40.8	37.53	272.97	3.62
Control (no fodder)	1.38	178.0	4.3	82.5	24.9	98.1	0.61
s.d.	0.04	4.53	3.18	3.29	1.84	5.66	0.09
l.s.d. ($P = 0.05$)	0.08	7.93	2.4	4.8	3.23	9.91	0.16
Sample size (*n*)	27	27	27	27	27	27	27

Table 4. Effect of the various fodder species on soil aggregation

Fodder species	Water stable aggregates (%)			Per cent aggregate stability			MWD (mm)		
Depth (m):	0–0.15	0.15–0.30	0.30–0.45	0–0.15	0.15–0.30	0.30–0.45	0–0.15	0.15–0.30	0.30–0.45
Broom grass	59.4	51.07	44.25	48.27	43.52	37.06	1.04	0.94	0.98
Setaria	72.55	63.23	57.44	62.55	54.2	43.12	1.93	1.84	1.6
Perennial groundnut	65.48	57.08	60.31	57.64	47.23	55.24	1.56	1.42	1.5
Congosignal	76.11	60.15	59.7	65.87	52.14	44.21	1.96	1.55	1.62
Guinea var. Makunia	75.05	62.09	48.65	64.9	53.07	39.69	2.01	1.73	1.62
Guinea var. Hamil	72.86	60.33	56.14	65.55	51.27	43.58	1.72	1.48	1.44
Napier	58.61	52.2	60.25	46.92	40.07	47.25	1.44	1.3	1.52
Paspalum	63.33	56.5	47.12	56.49	42.35	37.2	1.74	1.58	1.32
Control (no fodder)	50.22	42.75	36.57	40.96	34.51	30.08	0.97	0.93	0.86
s.d.	2.67	2.27	2.30	2.98	2.03	1.78	0.13	0.17	0.13
l.s.d. ($P = 0.05$)	4.68	3.97	4.03	5.22	3.56	3.11	0.22	0.29	0.23
Sample size (*n*)	27	27	27	27	27	27	27	27	27

available water holding capacity than soils of similar texture with less organic matter.

Soil aggregation represented by mean weight diameter (MWD) and % water stable aggregate (WSA) was significantly ($P < 0.05$) affected by long-term pasture (Table 4). The MWD and %WSA at all the soil depths under setaria, congosignal, and Makunia was generally significantly higher than the other treatments; Hamil also had high % WSA. Improved soil aggregation under setaria is due to a large root system and root biomass, accumulation of higher SOC, proliferation of rhizosphere and micro floral and fungal activities, and root exudation below ground (Arunachalam *et al*. 1997), which ultimately results in better movement of soil water within the soil profile. The role of SOC in improving aggregation in the present study was also apparent from the significant correlation ($P < 0.01$) between SOC and physical properties (Table 6). The percent aggregate stability across soil depths did not follow a definite trend, although setaria, congosignal, and Makunia had higher values. The beneficial effects of such grasses and continuous addition of organic matter on formation of large aggregates was reported by Andersen and Coleman (1985). Haynes and Francis (1993) also reported that perennial ryegrass and perennial white clover had high root mass, and that root length and density had the greatest effect on increasing MWD. This addition of organic matter might have increased the microbial activity of soil, which helped micro-aggregates to bind together to form water stable macro-aggregates, as macro-aggregates are mainly held together by fungal hyphae, fibrous roots, and polysaccharides (Tisdall and Oades 1982).

Table 5. Effect of the various fodder crops on soil water transmission

Fodder species	Infiltration rate (cm/h)	Hydraulic conductivity (mm/h)	Available water (%)
Broom grass	14.42	2.21	31.64
Setaria	22.60	3.88	46.25
Perennial groundnut	19.36	2.76	41.22
Congosignal	20.06	3.17	43.58
Guinea var. Makunia	18.48	2.55	37.30
Guinea var. Hamil	17.25	2.44	34.63
Napier	18.80	2.65	35.29
Paspalum	17.44	2.30	36.54
Control (no fodder)	11.33	1.96	30.85
s.d.	1.28	0.31	1.87
l.s.d. ($P = 0.05$)	2.24	0.55	3.28
Sample size (n)	27	27	27

Table 6. Correlation matrix ($n = 27$) for soil organic carbon and physical properties of the soil

SOC, Soil organic carbon; MWD, mean weight diameter; WSA, water stable aggregate; ASM, Available soil moisture. * $P < 0.05$; ** $P < 0.01$

	SOC	MWD	WSA (>2 mm)	Aggregate stability
SOC	1.00			
MWD	0.94**	1.00		
WSA (>2 mm)	0.90**	0.84**	1.00	
Aggregate stability	0.85**	0.78**	0.96**	1.00
ASM	0.68**	0.72**	0.58**	0.54**

The high above-ground biomass of the grasses, particularly napier, congosignal, Hamil, and Makunia (Table 1), covered the soil surface and reduced the velocity of direct rain drops, which otherwise lead to heavy run off. Improved soil physical parameters as a result of continuous growing of perennial grasses, coupled with complete ground cover, reduced susceptibility to soil erosion, as evident from erosion ratio data (Fig. 3). Grewal and Abrol (1986) reported that surface vegetation protected soil directly against erosive forces of raindrops and surface run-off by improving soil physical and hydrological parameters. Similarly, these grasses resulted in greater water transmission in terms of infiltration rate, hydraulic conductivity, and available water content (Table 5). This might be ascribed to higher SOC and higher root biomass. The saturated water content under grasses was 20% higher than the control. Water-holding capacity is controlled primarily by number of pores, their size distribution, and specific surface area of soils (Haynes and Naidu 1998). Following addition of organic matter through continuous root decay of these grasses, the specific surface area increases and results in increased water-holding capacity. Evrendilek *et al*. (2004) also reported that soil available water increased as the amount of organic materials increased. As with water content, grasses resulted in a 63% increase in soil infiltrability over control. The general trend observed in the present study was highest infiltration rate under setaria and least under the control. Within an established fodder block, macropores dominate the pore space and facilitate rapid movement of water through the soil profile (Humbel 1975). The greatest improvement in saturated hydraulic conductivity was apparent in soils under setaria followed by congosignal.

Biological properties

On average, SMBC was 10% higher under perennial grass than under cultivated cropland (control). Karlen *et al*. (1994) reported 17–64% higher SMBC at conservation reserve program sites than cropland or fallow sites. SMBC was maximum under setaria, with the highest population and bodyweight of earthworms (Table 7), followed by paspalum. Though paspalam had the lowest fodder biomass and lower level

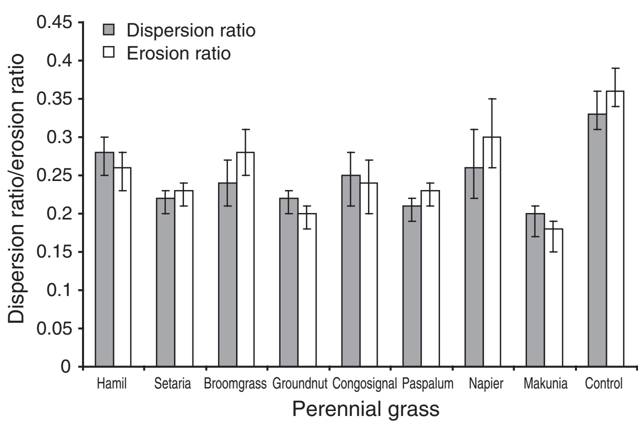

Fig. 3. Effect of grasses on soil dispersibility and erodibility.

Table 7. Biological activity after 15 years of planting under different perennial fodder grasses

Fodder species	SMBC (mg/kg soil)	Worm population/ha	Bodyweight (g)
Broom grass	164.40	358 333	1.82
Setaria	271.06	556 667	2.13
Perennial groundnut	124.95	316 667	1.52
Congosignal	216.99	455 000	1.97
Guinea var. Makunia	175.32	361 667	1.75
Guinea var. Hamil	108.58	203 333	1.37
Napier	104.45	195 000	1.34
Paspalum	255.60	516 667	2.11
Control (no fodder)	156.1	18 752	1.38
s.d.	5.83	14 905	0.04
l.s.d. ($P = 0.05$)	10.21	26 105	0.08
Sample size (n)	27	27	27

of organic carbon compared with setaria, congosignal, and Makunia, interestingly it contained higher SMBC than these grasses. Higher root biomass and high available P, S and micronutrient contents in the case of paspalam perhaps stimulated microbial activity and may be the reason for higher SMBC. These parameters were lowest under napier. The SMBC and earthwarm count were moderate under congosignal. Haynes and Francis (1993) highlighted that in comparison with arable crop species, perennial grasses such as Italian ryegrass and white clover have higher root mass and root length density and therefore higher SMBC and greater production of carbohydrate extract in hot water. As a result they have a greater effect on improving soil aggregate stability.

Conclusion

The study indicated a long-term effect of pastures in significantly improving soil hydro-physical characteristics and biological activity particularly, increasing SOC by 30%, water-stable aggregate by 40%, MWD by 70%, available soil moisture by 20%, SMBC by 10%, and decreasing the erosion ratio by 33%. Such improvements in soil properties have a direct bearing on long-term sustainability, soil erosion, and soil quality in a complex, diverse, risk-prone, fragile hilly ecosystem. Among perennial grasses, setaria, congosignal, and guinea var. Makunia minimised erosion as a result of better binding through extensive root system and improved soil conservation through constant surface cover with large above-ground biomass, and also demonstrated ecological importance through C-sequestration. The study clearly suggests that several soil quality indicators are improved by placing highly erodible cropland under perennial grass. Those indicators can be used to assess long-term impacts of agricultural management practices. The soil quality management in this fragile ecosystem should include growing of these grasses, particularly setaria, congosignal, and guinea on a permanent basis, which would not only fulfil the fodder requirement of ruminants but also address the problem of land degradation, and help in mitigating the effect of climate change and global warming.

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