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SOIL PHYSICAL, CHEMICAL AND BIOLOGICAL PROPERTIES UNDER DIFFERENT FODDER CROP BASED SYSTEMS IN GOLAGHAT DISTRICT OF UPPER ASSAM BRAHMAPUTRA VALLEY ZONE OF INDIA

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ABSTRACT

Very little information is available on the effects of long-term fodder crop cultivation on soil properties in India, mainly because organized fodder production has not yet been widely adopted. Therefore, the present study was conducted to evaluate the changes in soil physical, chemical and biological properties under different fodder crop-based systems in Golaghat district of Upper Brahmaputra Valley Zone of Assam. Continuous cultivation of fodder crops improved several soil properties compared with virgin soil. Soil pH increased with fodder cultivation, resulting in a relatively less acidic soil reaction. Soil organic carbon increased under continuous fodder cultivation, with napier grass recording the highest content. Available nitrogen, phosphorus, potassium, calcium and magnesium also increased, with napier and setaria showing comparatively higher nutrient contents. Continuous fodder cultivation improved hydraulic conductivity through increased soil porosity and reduced bulk density, with five years of continuous hybrid napier cultivation recording the lowest bulk density. Available water content increased under fodder crops. Soil aggregation and mean weight diameter were higher under continuous cultivation of napier and setaria than under other fodder crops and virgin soil. Biological properties were also improved, as indicated by higher microbial biomass carbon, phosphomonoesterase activity and dehydrogenase activity under fodder crops. The highest microbial biomass carbon was recorded under six years of continuous napier cultivation, while five years of continuous hybrid napier cultivation recorded the highest phosphomonoesterase and dehydrogenase activities. Overall, continuous fodder crop cultivation improved the physical, chemical and biological properties of soil and demonstrated its potential for sustainable soil management in the Upper Brahmaputra Valley Zone of Assam.

Key words: Fodder crops, virgin Soil, soil physico-chemical properties, soil biological properties.

Introduction

Agriculture and animal husbandry in India are closely integrated into the socio-economic and cultural fabric of rural communities, particularly through mixed farming systems. Livestock provides an important source of income for small and subsistence farmers and serves as a form of economic security during crop failures. Adequate availability of quality fodder is therefore essential for sustaining livestock production. In addition to providing feed, fodder crops, particularly perennial

grasses, can contribute substantially to the improvement of soil quality and the sustainability of agricultural systems.

Perennial fodder grasses have extensive and fibrous root systems that contribute to soil aggregation, improve soil structure, enhance water infiltration and increase soil water retention. Ghosh *et al.*, (2009) reported that soils under perennial grasses showed increases of 30% in soil organic carbon (SOC), 70% in mean weight diameter, 20% in available soil water, 40% in hydraulic conductivity, 63% in infiltration rate and 10% in soil microbial biomass

carbon. Among the grasses, *Setaria*, *Congosignal* and *Makunia* recorded comparatively higher values of these soil quality attributes, which were attributed to their extensive root systems and better soil binding capacity. The improved soil physical properties and continuous ground cover provided by perennial grasses also reduced soil erosion by about 33%, indicating their potential contribution to ecological sustainability and carbon sequestration (Ghosh *et al.*, 2009).

The extensive root systems of forage grasses facilitate water infiltration and transmission, particularly in soils with poor structural stability. Perennial grasses have also been reported to improve soil quality and conserve soil moisture (Dalal *et al.*, 1991; Carter *et al.*, 1994). Continuous addition and decomposition of root biomass contribute to the accumulation of organic matter and SOC, which subsequently influence several soil physical properties and processes, including aggregate formation and stability, water-holding capacity, hydraulic conductivity and resistance to water and wind erosion (Zebarth *et al.*, 1999; Franzluebbers, 2002; Celik *et al.*, 2004). Improvements in infiltration rate, hydraulic conductivity and available water content under perennial grasses are closely associated with changes in soil pore characteristics. The water-holding capacity of soil is primarily governed by the number and size distribution of pores and the specific surface area of soil particles (Haynes and Naidu, 1998).

Besides improving physical properties, continuous cultivation of fodder crops can influence soil chemical and biological properties through the regular addition of plant residues and root-derived organic matter. Soil microbial biomass carbon is considered an important and sensitive indicator of changes in soil quality under different land-use and management systems (Sheng *et al.*, 2015). Enhanced microbial activity under perennial vegetation may also stimulate the production and activity of soil enzymes involved in nutrient cycling and organic matter decomposition (Duchene *et al.*, 2017; Veres *et al.*, 2015). Thus, long-term cultivation of fodder crops has the potential to improve the overall physical, chemical and biological functioning of soil.

Despite these potential benefits, relatively limited information is available on the long-term effects of different fodder crop-based systems on soil quality under the agro-climatic conditions of Assam. Therefore, the present study was undertaken to quantify the effects of continuous cultivation of different fodder crops on the physical, chemical and biological properties of soil in Golaghat district of the Upper Brahmaputra Valley Zone of Assam. The specific objectives were (i) to assess the

changes in soil physical properties under continuous cultivation of different fodder crops, (ii) to evaluate their effects on soil chemical properties, and (iii) to assess the changes in soil biological properties under different fodder crop-based systems. The study was intended to determine the extent to which continuous fodder cultivation improved soil quality and to identify fodder crops with greater potential for maintaining or enhancing soil health under the conditions of Assam.

Materials and Methods

A field and laboratory study was conducted during 2019–2023 to assess the physical, chemical and biological properties of soil under different fodder crop-based systems at Bokakhat, Golaghat district, Assam. The district lies in the Upper Brahmaputra Valley agro-climatic zone between 25°50′–26°47′ N and 93°16′–94°10′ E, with a mean annual rainfall of 138.04 cm. The study site, located on the old Brahmaputra floodplain at 72.2 m above mean sea level (26°38′ 24″ N, 93°36′ 02″ E), experiences a humid subtropical climate with temperatures ranging from 11.6°C to 31.78°C and relative humidity of 52.34–96.5%.

Soil samples were collected from seven fodder crop-based systems from farmer's field of Bokakahat. The systems included 3 years' continuous cultivation of Napier (*Cenchrus purpureus*) followed by 4 years of Maize (*Zea mays*), 6 years' continuous cultivation of Napier (*Cenchrus purpureus*), 6 years' continuous cultivation of *Setaria* (*Setaria sphacelata*), 4 years' continuous cultivation of Bajra (*Pennisetum glaucum* L.), 5 years' continuous cultivation of Hybrid Napier (*Pennisetum purpureum* × *Pennisetum glaucum*), 4 years' continuous cultivation of Oat (*Avena sativa*) and Virgin soil. The virgin soil was an uncultivated and undisturbed soil that had remained free from crop cultivation throughout the study period. Only organic sources of nutrients, namely farmyard manure (FYM), compost and crop residues, were applied to the fodder crop-based systems. Soil samples were collected from five depths, viz., 0–20, 20–40, 40–60, 60–80 and 80–100 cm, from each fodder crop system and the virgin soil. The collected soil samples were analyzed in the laboratory for various physical, chemical and biological properties.

All physical and chemical properties of soil were analysed by using standard laboratory procedures. Estimation of soil microbial biomass carbon was done through fumigation-extraction method described by Jenkinson and Powlson (1976). Estimation of phosphomonoesterase activities was done colorimetrically following the method of Tabatabai and Bremner (1969)

Table 1: Distribution of soil pH under fodder crops and virgin soil.

Depth (cm)	Napier (3 Y) followed by Maize (4 Y)	Napier (6 Y)	Setaria (6 Y)	Bajra (4 Y)	Hybrid napier (5 Y)	Oat (4 Y)	Mean	Virgin soil	SE	SD (0.05)	CV %
0-20	5.23	5.63	5.41	5.23	5.63	5.46	5.43	4.67	0.13	0.33	6.22
20-40	5.12	5.79	5.38	5.69	6.24	5.84	5.68	5.19	0.15	0.40	7.13
40-60	4.78	5.12	5.93	5.84	5.46	6.21	5.56	4.67	0.22	0.59	10.96
60-80	5.36	5.94	5.70	6.2	5.78	5.97	5.83	5.42	0.11	0.30	5.25
80-100	5.89	6.23	6.48	6.14	6.32	6.1	6.19	5.32	0.14	0.38	6.23

Table 2: Distribution of electrical conductivity (dSm⁻¹) of soils under different fodder crops.

Depth (cm)	Napier (3 Y) followed by Maize (4 Y)	Napier (6 Y)	Setaria (6 Y)	Bajra (4 Y)	Hybrid napier (5 Y)	Oat (4 Y)	Mean	Virgin soil	SE	SD (0.05)	CV %
0-20	0.029	0.018	0.019	0.019	0.023	0.020	0.022	0.013	0.002	0.005	24.390
20-40	0.019	0.017	0.018	0.018	0.020	0.012	0.017	0.012	0.001	0.003	19.664
40-60	0.018	0.016	0.014	0.014	0.018	0.017	0.016	0.012	0.001	0.002	14.760
60-80	0.014	0.008	0.014	0.014	0.017	0.018	0.014	0.009	0.001	0.004	27.820
80-100	0.011	0.008	0.011	0.011	0.013	0.015	0.012	0.006	0.001	0.003	27.850

Table 3: Distribution of hydraulic conductivity (cm sec⁻¹) of soils under different fodder crops.

Depth (cm)	Napier (3 Y) followed by Maize (4 Y)	Napier (6 Y)	Setaria (6 Y)	Bajra (4 Y)	Hybrid napier (5 Y)	Oat (4 Y)	Mean	Virgin soil	SE	SD (0.05)	CV %
0-20	0.036	0.119	0.065	0.085	0.003	0.014	0.054	0.004	0.017	0.045	95.81
20-40	0.005	0.010	0.042	0.007	0.003	0.002	0.011	0.003	0.005	0.014	138.60
40-60	0.002	0.006	0.009	0.002	0.001	0.001	0.004	0.003	0.001	0.003	87.27
60-80	0.001	0.003	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.001	62.10
80-100	0.001	0.001	0.002	0.001	0.003	0.001	0.001	0.001	0.001	0.001	33.07

Table 4: Distribution of bulk density (Mg m⁻³) of soils under different fodder crops.

Depth (cm)	Napier (3 Y) followed by Maize (4 Y)	Napier (6 Y)	Setaria (6 Y)	Bajra (4 Y)	Hybrid napier (5 Y)	Oat (4 Y)	Mean	Virgin soil	SE	SD (0.05)	CV %
0-20	1.34	1.30	1.31	1.37	1.30	1.39	1.34	1.44	0.02	0.05	3.92
20-40	1.36	1.33	1.34	1.39	1.39	1.43	1.37	1.55	0.03	0.07	5.36
40-60	1.47	1.41	1.35	1.43	1.42	1.45	1.42	1.70	0.04	0.11	7.64
60-80	1.50	1.51	1.51	1.54	1.48	1.47	1.50	1.77	0.04	0.10	6.75
80-100	1.56	1.55	1.62	1.57	1.54	1.60	1.57	1.86	0.04	0.11	6.93

and expressed as $\mu\text{g p-nitrophenol/gm dry soil/ha}$. Estimation of Dehydrogenase activities which represents the total oxidative activities of soil microorganisms during organic matter breakdown was done following the method of Casida *et al.*, (1964).

Result and Discussion

Effect of fodder crops on soil physico-chemical properties

Inclusion of any crops in a cropping system is always associated with its effect on the soil physico-chemical properties. It is this effect through which any crop influences the soil quality and health and ultimately effect

agricultural production.

Soil pH is a property of soil that has a tremendous influence on the soil behavior and thus availability of nutrients in soils by effecting chemical environment. The mean value of soil pH for fodder crops ranged from 5.43 to 6.19 with a mean of 5.74 and for virgin soil, pH values ranged from 4.67 to 5.32 with a mean of 5.05 (Table 1).

Soil electrical conductivity (EC) is a measure of the salt content in the soil and it is an important indicator of soil health. Soil EC is affected by cropping, irrigating, land use, and history of application of fertilizer, manure, and compost. Variations in EC values down the profile

Table 5: Distribution of particle density (Mg m^{-3}) of soils under different fodder crops.

Depth (cm)	Napier (3 Y) followed by Maize (4 Y)	Napier (6 Y)	Setaria (6 Y)	Bajra (4 Y)	Hybrid napier (5 Y)	Oat (4 Y)	Mean	Virgin soil	SE	SD (0.05)	CV %
0-20	2.01	2.00	2.03	2.11	2.02	2.19	2.06	2.21	0.03	0.09	4.27
20-40	2.22	2.13	2.19	2.27	2.14	2.21	2.19	2.32	0.03	0.07	3.06
40-60	2.27	2.25	2.27	2.35	2.28	2.28	2.28	2.39	0.02	0.05	2.22
60-80	2.37	2.34	2.38	2.56	2.33	2.37	2.39	2.41	0.03	0.08	3.24
80-100	2.68	2.51	2.43	2.63	2.48	2.54	2.55	2.59	0.03	0.09	3.43

Table 6: Distribution of water content of soils at field capacity (%) under different fodder crops.

Depth (cm)	Napier (3 Y) followed by Maize (4 Y)	Napier (6 Y)	Setaria (6 Y)	Bajra (4 Y)	Hybrid napier (5 Y)	Oat (4 Y)	Mean	Virgin soil	SE	SD (0.05)	CV %
0-20	22.39	22.46	22.27	19.19	22.94	20.19	21.57	20.01	0.57	1.50	7.02
20-40	21.28	21.14	21.1	18.41	22.31	19.67	20.65	19.87	0.49	1.29	6.32
40-60	19.68	20.69	20.07	16.58	20.12	18.16	19.22	18.86	0.54	1.42	7.41
60-80	16.94	19.17	19.08	14.73	18.06	16.49	17.41	15.31	0.66	1.75	10.22
80-100	14.32	14.56	15.39	12.96	15.69	14.21	14.52	13.12	0.39	1.03	7.20

Table 7: Distribution of water content of soils at permanent wilting point (%) under different fodder crops and virgin soil.

Depth (cm)	Napier (3 Y) followed by Maize (4 Y)	Napier (6 Y)	Setaria (6 Y)	Bajra (4 Y)	Hybrid napier (5 Y)	Oat (4 Y)	Mean	Virgin soil	SE	SD (0.05)	CV %
0-20	10.09	10.2	10.05	9.07	9.58	9.96	9.83	9.52	0.15	0.41	4.15
20-40	10.65	10.9	10.91	8.55	9.4	9.86	10.05	9.93	0.33	0.87	8.68
40-60	9.91	10.86	10.13	8.19	9.25	9.37	9.62	9.63	0.31	0.83	8.62
60-80	8.03	10.91	9.91	8.61	8.83	8.93	9.20	8.52	0.37	0.98	10.76
80-100	7.93	8.43	9.46	7.29	8.27	8.77	8.36	7.76	0.27	0.71	8.59

Table 8: Distribution of mean weight diameter (mm) of soils under different fodder crops and virgin soil.

Depth (cm)	Napier (3 Y) followed by Maize (4 Y)	Napier (6 Y)	Setaria (6 Y)	Bajra (4 Y)	Hybrid napier (5 Y)	Oat (4 Y)	Mean	Virgin soil	SE	SD (0.05)	CV %
0-20	1.72	3.85	2.43	2.46	3.46	1.39	2.55	1.21	0.38	1.00	42.79
20-40	1.48	2.39	1.55	1.61	2.59	1.09	1.79	1.01	0.23	0.60	36.09
40-60	1.44	1.30	1.07	1.07	1.37	0.92	1.20	0.72	0.10	0.26	22.96
60-80	0.84	1.09	0.91	0.83	1.04	0.73	0.91	0.68	0.06	0.15	17.28
80-100	0.63	0.83	0.73	0.51	0.79	0.52	0.67	0.51	0.05	0.14	21.42

also found in both fodder crops and virgin soil. With the increase in depth the EC values decreases (Table 2).

Hydraulic conductivity, an indicator of the soil's capacity to transmit water under saturated conditions, decreased with increasing soil depth across all locations (Table 3). Hydraulic conductivity was higher under fodder crops ($0.054\text{--}0.001\text{ cm s}^{-1}$; mean 0.014 cm s^{-1}) than under virgin soil ($0.004\text{--}0.001\text{ cm s}^{-1}$; mean 0.002 cm s^{-1}). Six years of continuous Napier cultivation recorded the highest mean hydraulic conductivity (0.028 cm s^{-1}), followed by Setaria (0.024 cm s^{-1}).

Higher hydraulic conductivity under fodder crops was associated with lower bulk density, greater porosity and

improved root development. Vegetation can enhance hydraulic properties by modifying soil structure, aggregation and root characteristics (Hao *et al.*, 2019; Cercioglu *et al.*, 2019). The decline with depth was mainly due to increased bulk density and reduced porosity.

Bulk density (BD) as an essential soil physical parameter is found to increase down the profile indicating increase in soil compaction (Table 4). Highest bulk density was observed in virgin soil ranging from 1.44 Mg m^{-3} to 1.86 Mg m^{-3} down the profile with a mean value of 1.66 Mg m^{-3} . Continuous cultivation of napier grass for six years showed lowest mean value (1.42 Mg m^{-3}) of bulk density ranged from 1.30 Mg m^{-3} to 1.55 Mg m^{-3} .

Table 9: Distribution of organic carbon content (%) of soils under different fodder crops and virgin soil.

Depth (cm)	Napier (3 Y) followed by Maize (4 Y)	Napier (6 Y)	Setaria (6 Y)	Bajra (4 Y)	Hybrid napier (5 Y)	Oat (4 Y)	Mean	Virgin soil	SE	SD (0.05)	CV %
0-20	1.37	1.21	1.31	1.30	1.36	1.33	1.31	1.12	0.03	0.09	7.00
20-40	1.04	1.31	1.38	1.14	1.26	1.24	1.23	1.06	0.05	0.13	10.63
40-60	0.89	1.09	1.21	1.11	1.22	1.31	1.14	0.78	0.07	0.19	17.46
60-80	0.89	0.64	0.86	0.67	0.79	0.52	0.73	0.61	0.05	0.14	19.37
80-100	0.61	0.48	0.52	0.59	0.74	0.47	0.57	0.46	0.04	0.10	18.32

Table 10: Distribution of organic carbon content (%) of soils under different fodder crops and virgin soil.

Depth (cm)	Napier (3 Y) followed by Maize (4 Y)	Napier (6 Y)	Setaria (6 Y)	Bajra (4 Y)	Hybrid napier (5 Y)	Oat (4 Y)	Mean	Virgin soil	SE	SD (0.05)	CV %
0-20	491.1	482.7	509.3	427.6	459.8	462.5	472.2	382.0	16.22	42.91	9.34
20-40	382.0	438.2	454.7	394.5	426.6	384.7	413.5	363.8	12.70	33.60	8.27
40-60	363.8	419.9	345.6	348.1	398.7	328.1	367.4	291.0	16.29	43.09	12.09
60-80	254.6	268.8	291.0	246.5	297.4	231.0	264.9	244.6	9.38	24.83	9.48
80-100	200.1	215.7	218.3	202.4	210.3	179.2	204.3	178.3	6.16	16.30	8.13

Table 11: Distribution of available phosphorus (kg ha⁻¹) of soils under different fodder crops and virgin soil.

Depth (cm)	Napier (3 Y) followed by Maize (4 Y)	Napier (6 Y)	Setaria (6 Y)	Bajra (4 Y)	Hybrid napier (5 Y)	Oat (4 Y)	Mean	Virgin soil	SE	SD (0.05)	CV %
0-20	28.67	30.43	26.91	26.16	31.02	28.60	28.63	27.77	0.67	1.76	6.18
20-40	37.25	38.40	30.64	27.78	35.02	25.61	32.45	25.09	2.09	5.53	17.61
40-60	33.72	35.66	28.01	25.30	33.79	26.44	30.49	25.82	1.66	4.40	14.76
60-80	26.03	29.30	22.95	23.74	29.39	29.58	26.83	23.39	1.15	3.04	11.56
80-100	29.10	21.14	31.30	21.28	25.76	27.82	26.07	22.74	1.52	4.01	15.66

Table 12: Distribution of available potassium (kg ha⁻¹) of soils under different fodder crops and virgin soil.

Depth (cm)	Napier (3 Y) followed by Maize (4 Y)	Napier (6 Y)	Setaria (6 Y)	Bajra (4 Y)	Hybrid napier (5 Y)	Oat (4 Y)	Mean	Virgin soil	SE	SD (0.05)	CV %
0-20	212.4	204.4	161.2	143.7	167.9	121.3	168.5	87.0	16.76	44.35	28.28
20-40	300.4	135.7	180.7	97.0	121.1	85.4	153.4	98.3	28.50	75.40	51.82
40-60	234.5	88.5	89.7	101.7	126.2	60.7	116.9	117.6	21.19	56.04	47.92
60-80	128.9	71.5	66.1	62.7	70.2	44.2	73.9	80.9	9.95	26.31	35.12
80-100	97.3	40.1	27.9	34.7	43.7	36.0	46.6	68.4	9.30	24.60	49.47

Particle density increased with soil depth and was higher in virgin soil than in fodder-cropped soils, mainly due to the lower organic matter content of virgin soil (Table 5). Continuous fodder cultivation increased organic matter addition and consequently reduced particle density. Six years of Napier and five years of hybrid Napier cultivation recorded comparatively lower particle density, with mean values of 2.25 and 2.25 Mg m⁻³, respectively. Overall, the lower particle density under fodder crops reflected the beneficial effect of continuous organic matter addition.

The highest percentage of field capacity water content range were found in case of five years continuous

cultivation of hybrid napier (22.94% to 15.69% with a mean of 19.82%) followed by six years continuous cultivation of napier (22.46% to 14.56% with a mean of 19.60%). The mean percent water content of soils at field capacity under fodder crops was higher than the virgin soil and decreased with the increase in soil depth down the profile (Table 6). As reported by Ghosh *et al.*, (2009) the saturated water content under grasses was 20% higher than the control. The results of the present investigation also indicate similar trend. This is basically due to increased organic matter content, leading to alteration of pore structure and geometry and also its role in soil aggregate formation.

Table 13: Distribution of cation exchange capacity (c mole (p+) kg⁻¹) of soils under different fodder crops and virgin soil.

Depth (cm)	Napier (3 Y) followed by Maize (4 Y)	Napier (6 Y)	Setaria (6 Y)	Bajra (4 Y)	Hybrid napier (5 Y)	Oat (4 Y)	Mean	Virgin soil	SE	SD (0.05)	CV %
0-20	12.68	15.67	13.60	12.17	14.44	13.14	13.62	9.99	0.68	1.80	13.72
20-40	12.51	14.44	13.18	11.13	13.93	12.12	12.89	6.01	1.07	2.83	23.74
40-60	10.92	13.93	11.00	9.69	11.03	10.92	11.25	4.72	1.05	2.78	26.98
60-80	8.88	11.03	7.22	9.00	10.03	9.40	9.26	4.41	0.82	2.17	25.34
80-100	6.59	10.03	6.72	5.87	8.18	6.88	7.38	4.01	0.71	1.87	27.11

Table 16: Distribution of microbial biomass carbon (µgm gm⁻¹) in soils under different fodder crops and virgin soil.

Depth (cm)	Napier (3 Y) followed by Maize (4 Y)	Napier (6 Y)	Setaria (6 Y)	Bajra (4 Y)	Hybrid napier (5 Y)	Oat (4 Y)	Mean	Virgin soil	SE	SD (0.05)	CV %
0-20	484.0	561.6	518.3	436.9	469.3	494.2	494.1	281.0	33.82	89.48	19.30
20-40	313.3	435.6	316.8	357.6	382.8	239.5	340.9	163.1	34.41	91.04	28.85
40-60	224.0	299.1	264	223.1	260.3	213.3	247.3	113.7	22.21	58.76	25.75
60-80	157.0	197.6	89.9	72.1	101.0	79.2	116.1	61.0	18.98	50.22	46.39
80-100	82.0	78.7	50.3	49.5	80.7	67.4	68.1	35.6	6.95	18.40	29.01

Table 17: Distribution of phosphomonoesterase (µgm gm⁻¹ hr⁻¹) activity in soils under different fodder crops and virgin soil.

Depth (cm)	Napier (3 Y) followed by Maize (4 Y)	Napier (6 Y)	Setaria (6 Y)	Bajra (4 Y)	Hybrid napier (5 Y)	Oat (4 Y)	Mean	Virgin soil	SE	SD (0.05)	CV %
0-20	205.3	271.3	239.2	97.4	289.6	169.4	212.0	153.1	25.93	68.61	33.70
20-40	142.4	230.7	140.4	172.4	181.3	120.4	164.6	69.0	19.25	50.95	33.75
40-60	187.8	132.3	113.5	78.9	164.2	94.2	128.5	60.5	17.34	45.88	38.63
60-80	91.9	57.0	89.2	64.3	79.1	67.1	74.8	41.7	6.80	17.99	25.68
80-100	52.2	32.6	67.2	19.5	33.1	27.0	38.6	31.2	6.20	16.41	43.71

The water content of soils at permanent wilting point under fodder crops and virgin soil decreased with the increase in soil depth of soil profile (Table 7). But with the increase in soil depth the per cent water content of soils at permanent wilting point of fodder crops were higher than the virgin soil.

Available water capacity, which represents the water readily available to crops, was higher under continuous cultivation of perennial fodder crops. This improvement was mainly attributed to increased organic matter and root biomass from root decay and crop residue incorporation, which reduced bulk density and enhanced soil water-holding capacity, infiltration, hydraulic conductivity, and available water content.

The ranges of mean weight diameter under fodder crops were higher than the virgin soils and it decreased down the profile with increase in soil depths (Table 8). the highest range of mean weight diameter was found in six years' continuous cultivation of napier (3.85mm to 0.83mm with a mean of 1.89mm) followed by five years' continuous cultivation of hybrid napier (3.46mm to 0.79mm with a mean of 1.85mm).

According to Coskun Gulser (2006) forage cropping increased mean weight diameter by increasing the proportion of macro-aggregation over the control due to different root mechanisms. Soil aggregation represented by mean weight diameter (MWD) and percentage of water stable aggregate (WSA) was significantly ($p < 0.05$) affected by long-term pasture (Ghosh *et al.*, 2009). Similar type of results was observed in the present study.

Organic carbon content decreased with the increase in soil depth (Table 9). Fodder crops showed high per cent of soil organic carbon content than virgin soil and the percent organic carbon is high in case of napier than other fodder crops. Das *et al.*, (2016) also observed highest soil organic carbon stock under napier followed by congosignal grass. The increase in soil organic carbon under forage compared to the initial value may be due to high root biomass, and addition of organic matter to the soil through decaying of large volume of dead roots (Fissore *et al.*, 2008; Ghosh *et al.*, 2009; Bonnin and Lal, 2012; Kristina *et al.*, 2009).

Nitrogen being the most important nutrient element responsible for vegetative growth is essentially the most important parameter for success of forage crops. With

Table 18: Distribution of Dehydrogenase activity ($\mu\text{gm gm}^{-1}\text{hr}^{-1}$) in soils under different fodder crops and virgin soil.

Depth (cm)	Napier (3 Y) followed by Maize (4 Y)	Napier (6 Y)	Setaria (6 Y)	Bajra (4 Y)	Hybrid napier (5 Y)	Oat (4 Y)	Mean	Virgin soil	SE	SD (0.05)	CV %
0-20	22.39	22.46	22.27	19.19	22.94	20.19	21.57	20.01	0.57	1.50	7.02
20-40	21.28	21.14	21.1	18.41	22.31	19.67	20.65	19.87	0.49	1.30	6.32
40-60	19.68	20.69	20.07	16.58	20.12	18.16	19.22	11.86	1.18	3.12	17.17
60-80	6.94	9.17	9.08	4.73	8.06	6.49	7.41	5.31	0.66	1.75	24.59
80-100	4.32	4.56	5.39	2.96	5.69	4.21	4.52	3.12	0.39	1.03	23.86

the increase in soil depths available nitrogen content decreases down the profile (Table 10). Six years continuous cultivation of napier grass showed highest range of available nitrogen content of 482.6 kg ha^{-1} to 215.7 kg ha^{-1} with a mean of 365.1 kg ha^{-1} .

Soil available phosphorus decreased with increasing soil depth but remained higher under fodder crops than in virgin soil (Table 11). Hybrid napier recorded the highest phosphorus content ($25.76\text{--}31.02 \text{ kg ha}^{-1}$; mean 31.00 kg ha^{-1}), followed by napier ($21.14\text{--}30.43 \text{ kg ha}^{-1}$; mean 30.99 kg ha^{-1}). The higher phosphorus availability under napier may be attributed to enhanced phosphomonoesterase activity and greater organic matter accumulation.

Available potassium content was higher under fodder crops than in virgin soil and decreased with increasing soil depth (Table 12). The highest range of available potassium content was found in continuous cultivation of three years napier and four years maize (212.4 kg ha^{-1} to 97.3 kg ha^{-1} with a mean of 194.7 kg ha^{-1}), followed by six years continuous cultivation of napier (204.4 kg ha^{-1} to 40.1 kg ha^{-1} with a mean of 108.0 kg ha^{-1}).

Cation exchange capacity of soil in fodder crops were higher than virgin soil and decreased with the increase in soil depth down the profile (Table 13).

Soil calcium concentration and availability to crops is influenced by pH, cation exchange capacity, soil type, and the concentration of other minerals in the soil. The soil calcium and magnesium contents decreased with the

increase in soil depth down the profile and fodder crops showed higher range of calcium and magnesium contents in soil than virgin soil (Fig. 1).

Effect of fodder crops on soil biological properties

The microbial biomass carbon of fodder crops was much higher than the virgin soil and biomass carbon decreased down the profile with increase in soil depth (Table 16). Highest microbial biomass carbon range was found in case of six years continuous cultivation of napier ($561.6 \mu\text{gm gm}^{-1}$ to $78.7 \mu\text{gm gm}^{-1}$ with a mean of $314.5 \mu\text{gm gm}^{-1}$). Ghosh *et al.* (2009) observed maximum soil microbial biomass carbon under setaria. They also found that soil microbial biomass carbon was 10% higher under perennial grass than under cultivated cropland (control).

The phosphomonoesterase (PME) activity decreased with increasing soil depth (Table 17) and was higher under fodder crops than virgin soil, with the highest activity recorded under five years of continuous hybrid Napier cultivation. Zhang *et al.*, (2021) reported that forage cultivation and organic phosphorus addition can enhance PME activity, particularly in plant roots and rhizosphere soil.

Several factors such as soil moisture, oxygen availability, redox potential, pH, organic matter content, depth of the soil profile, temperature, and season of the year, heavy metal contamination and soil fertilization or pesticide use can effect significantly the dehydrogenase activity of soil. The dehydrogenase activities of fodder crops were higher than the virgin soils and in most of the cases it decreased down the profile (Table 18.).

Conclusion

Continuous cultivation of fodder crops improves soil physico- chemical and biological properties, soil aggregation and mean weight diameter of soil. Cultivation of napier grass and also setaria, seemed to have greater influence on soil physico- chemical and biological properties as compared to other fodder crops. Besides napier, continuous cultivation of setaria as well as congosignal also showed high improvement of these properties than other fodder crops. This study reveals

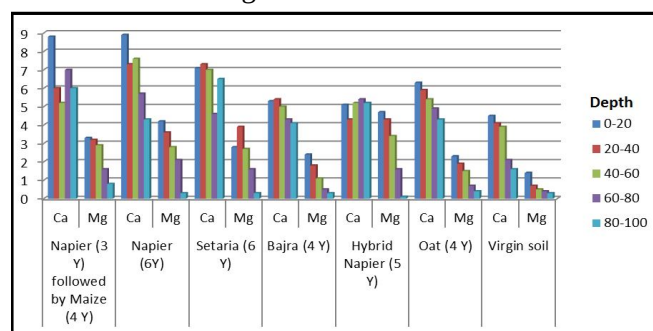


Fig. 1: Distribution of calcium (c mole (p+) kg^{-1}) and magnesium (c mole (p+) kg^{-1}) of soils under different fodder crops and virgin soil.

that incorporation of fodder crop in any cropping system should be mandatory to maintain soil quality and ensure higher soil carbon sequestration. With more and emphasis on organic/ natural farming, inclusion of fodder crop will also help the animal component in the farming system.

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