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Full Length Research Paper

Soil dynamic of agricultural landscape in East Siang District of Arunachal Pradesh, Eastern Himalaya

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The study aims to evaluate the effect of altitude on soil properties in agricultural landscape of East Siang, Eastern Himalaya. Four study sites along the altitude namely, Ruksin (<150 m asl), Pasighat (150 to 300 m asl), Mebo (300 to 450 m asl) and Pangin (>450 m asl) were selected. Soil samples were collected on seasonal basis during 2009 to 2011 for analysis of physico-chemical properties. The results obtained were statistically analyzed using STATISTICA 6. Study revealed that soil texture was loamy sand to sandy loam. Bulk density, soil porosity and available Phosphorous were higher in lower altitude study sites; however soil moisture and available Potassium showed reverse trend. Water holding capacity was lower in upper soil surface except in sites at Pangin. Soil was slightly acidic in nature at all sites. Soil organic carbon (SOC), soil organic matter (SOM) and Total Kjeldahl Nitrogen were higher in mid altitude. All the study sites showed low C:N ratio. Differences in parameter of soil properties at different years, sites, seasons, soil depths and in combination of these factors were significantly different except in moisture, SOC and SOM in year and soil depth combination. Based on the result, it can be concluded that soil fertility was better in mid altitude.

Key words: Agricultural landscape, east Siang, eastern Himalaya, soil dynamic, soil physico-chemical properties.

INTRODUCTION

Soil is dynamic natural body comprising unconsolidated mineral and organic matter including water and air on the upper most layers of earth surface and play an important role in maintaining the ecosystem functioning on which all life depends (Agyemang et al., 2011). It varies greatly in space and time, a single agricultural field may contain many identifiably different types of soil and the nutrient contents (Clark et al., 2005) owing to many processes and their chemical and biological properties (Milne et al., 2004). Added to these, variation in the weather, specifically rainfall and temperature, and the changing nutrient requirements of crop plants as they grow (Barraclough, 1986), make soil nutrients more dynamic. The physico-chemical properties of soils govern the biological activities and interchanges of molecules/ions between the solids, liquid and gaseous phases which influence nutrient cycling, plant growth and decomposition of organic materials.

The parameters of soil quality are frequently used to make comparative assessments in agricultural management practices to determine their sustainability (Regnold and Palmer, 1995; Islam and Well, 2000). The problems of soil quality deterioration and fertility decline are prevalent throughout the world (Harden, 2001; Lal, 2001). Cropping intensification without adequate restoration of soil fertility may threaten the sustainability of agriculture (Roy et al., 2003). Under similar agroecological environments, land use and cultural practices become the dominant factors that affect soil properties and crop production (Nnaji et al., 2002). People through their crop production practices influence course of the formation and the physico-chemical status of the soil at any given time (Asadu and Enete, 1997). It was observed that soils formed over the same parent

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material and under the same climate and relief had dissimilar soil physico-chemical properties due to different land use types (Ogunkunle and Egghaghara, 1992; Akamigbo, 1999). Unsuitable land use often leads to sub-optimal use of land and agricultural investments and this triggers processes such as soil degradation (Onweremadu, 2007). Landscape position creates differences in soil formation through runoff, drainage, temperature and soil erosion and consequently difference in soil properties along a hill slope (Brubaker et al., 1993). All these affect local carbon and nitrogen processes (Hobbie, 1996) and the variability of soil properties in complex hills (Miller et al., 1988; Bhatti et al., 1991). High yields and good product can be achieved only when the right type of soil is used for a certain crop. However, for areas in which suitable soil is not available, soil amendment may be done to facilitate the crop growth and optimum yield.

The ability to produce food is the fundamental factors in societal development therefore need to know the kind of element or nutrient for a better production (Saidou et al., 2004). The study of the soil has been foster by people's interest in plant growth and food production (Hinrich et al., 1985). A proper evaluation of the fertility of a soil before planting a crop helps in adopting appropriate measures to make up for the shortcomings and ensuring a good crop production. However, soil fertility decline is less visible and less spectacular and more difficult to assess (Belachew and Abera, 2010). The present study was undertaken to evaluate the effect of altitude on soil properties in agricultural landscape of East Siang district - Arunachal Pradesh, Eastern Himalaya. The finding of the study will help in taking up or formulating measures for enhancing and restoring soil fertility which will lead to increase in crop productivity.

MATERIALS AND METHODS

Study site

East Siang district, Arunachal Pradesh where the present study is carried out lies between 27º 43' to 29º 20' N latitude and 94º 42' to 95º 35' E longitude covering a geographical area of about 4005 km^2. The district is characterized by undulating topography. The topography of valley gradually changes to foot hills and hills from south to north. In between the hills, there exist narrow, deep or shallow valleys due to undulating topography and flow of Siang River and its tributaries. About 41,574 ha of the total geographical area are under agricultural practices including 11,510 ha in net irrigated area in the study site. Forest (62%) is the most dominant land use in the district followed by the land under miscellaneous use (13%), agricultural practices (9%), fallow land (2%), etc (Anonymous, 2007). Majority of cultivation are rain–fed, however, some agricultural farm are irrigated by channeling streams and rivers. The district is blessed with many small streams and rivers (Siang River and its many tributaries). On higher reaches of the district bamboo drip irrigation is widely used. However, majority of the uplands remain fallow during rabi season because of water stress. The major crops in the district include paddy, maize, millet, pulses, oilseeds, potato, turmeric, ginger, chilly, etc. As the land cover of the study area is dominated by forests hence topography does not have much effect on erosion. However, settled agricultural practices are prevalent in plain to gentle slope area hence runoff from the hilly area further enriches the soil. During the monsoon period farmers do avoid slashing of forest crops hence soil erosion may be minimal on the hilly area where shifting cultivation practices is prevalent. This may be further reduces the erosion through vegetal growth before the monsoon period.

Keeping physiography and climatic conditions in consideration, four study sites namely, Ruksin (<150 m asl), Pasighat (150 to 300 m asl), Mebo (300 to 450 m asl) and Pangin (>450 m asl) were selected in the present study. The climate of major part of the district falls under humid sub-tropical with wet summer and winter and other remaining part falls under tropical condition (Kaul and Haridasan, 1987). The climatic condition of the district is monsoonic. The year may be divided into four seasons that is, winter (January to February), pre-monsoon (March to May), monsoon (June to September) and post-monsoon (October to December). The climatic data of Pasighat for the year 2009 and 2010 were collected from Regional metrological office, LGBI Airport, Guwahati. Monthly average maximum and minimum temperature ranges between 24.4 and 32.8°C, and between 12.1 and 24.6°C, respectively. Both the monthly average temperature was lower between November and February, and higher between March and October. Monthly average rainfall ranges from nil to 1013.9 mm, of that maximum was received during April and September while minimum between October and March. Relative humidity of the district is high and ranges between 62 and 98%. It was high during March and October and slightly lower between November and February. As there were no other metrological station in other study sites, it was difficult to compare the climatic variation among the sites. However, based on the field survey experience there was slight variation in climatic condition among the sites which might be due to topographic variation, land use practices etc.

Soil sample

Soil samples were randomly collected from all the four selected study sites on seasonal basis that is, pre-monsoon, monsoon, post-monsoon and winter season during 2009 to 2011. For each study sites, 10 random soil samples each from the 10 agricultural fields were collected in a zigzag manner at two different soil depth that is, 0 to 15 cm and 15 to 30 cm. The soil samples were taken in such a way that the soils collected represent the whole sampling area adequately. The random soil samples of respective soil depth from respective study site were thoroughly mixed to obtain a composite soil sample. The composite soil samples at two different soil depths for each site were brought to laboratory in air tight polythene bags. Coarse woody debris, roots, stone particles, gravels etc., were removed from the soil samples. Soil moisture and soil pH were determined using fresh soil samples. Then, the soil samples were air dried, crushed using mortar and pestle, sieved through a 2 mm mesh sieve to remove any coarse particles. Finally, these soils were passed through 0.5 mm mesh screen for analysis of physical and chemical properties of soil.

Soil texture and bulk density were determined by Bouyoucos hydrometer and gravimetric method, respectively (Allen et al., 1974). Soil porosity was determined using the bulk density and particle density (Allen et al., 1974). Water holding capacity (WHC) was determined by Keen's box method (Piper, 1942) and soil moisture content through gravimetrically (Allen et al., 1974). pH was determined electrometrically by digital pH meter (EUTECH – pH Testr 10) in 1: 2.5 suspension of soil in distilled water (Anderson and Ingram, 1993). Soil organic carbon was determined by rapid titration method (Walkley and Black, 1934). Soil organic matter was estimated by multiplying the organic carbon content by 1.72, assuming that the soil organic matter contains 58% carbon (Allen et al., 1974). Total Kjeldahl nitrogen (TKN) was determined by

Table 1. Soil physical properties of the selected study sites along the altitudinal gradient in two soil depths.

Study site	Depth (cm)	Bulk density (g cm^{-3})	Porosity (%)	Water holding capacity (WHC) (%)	% of soil particles			Texture class
					Sand	Clay	Silt	
Ruksin(<150 m asl)	0-15	0.78±0.01	70.57±0.22	68.50±0.67	72	4	24	Loamy sand
	15-30	0.80±0.00	69.56±0.13	70.08±0.95	68	4	28	Sandy Loam
Pasighat (150-300 m asl)	0-15	0.71±0.01	73.08±0.33	54.55±0.42	80	2	18	Loamy sand
	15-30	0.72±0.02	72.70±0.77	63.04±0.28	72	2	26	Loamy sand
Mebo (300 – 450 m asl)	0-15	0.68±0.01	74.21±0.33	82.94±0.61	52	8	40	Sandy loam
	15-30	0.76±0.01	71.32±0.44	83.56±0.04	40	8	52	Silt loam
Pangin (>450 m asl)	0-15	0.69±0.01	73.96±0.22	78.52±0.73	48	8	44	Silt loam
	15-30	0.72±0.01	72.83±0.44	76.50±0.53	72	4	24	Loamy sand

± indicates SE (n = 3).

Table 2. Correlation coefficients among various soil physical properties (data taken once) of all the study sites.

Soil physical properties	Bulk density	Porosity	WHC
Bulk density	1.000		
Porosity	-1.000*	1.000	
WHC	-0.124	0.124	1.000

N = 24; *values are significant at P < 0.01 probability level.

digestion and distillation method (Allen et al., 1974). Available potassium was determined using flame photometer (SYSTRONICS – Flame Photometer 130 and FPM Compressor 126) (Allen et al., 1974). Available phosphorus was determined by molybdenum blue method (Anderson and Ingram, 1993).

Physical character of soil such as texture, bulk density, water holding capacity, and soil porosity were analyzed once for all the selected four sites. Whereas, other soil physico-chemical properties such as soil moisture, pH, soil organic carbon, soil organic matter and soil nutrients (N, P and K) were analyzed on seasonal basis for two year that is, 2009 to 2010 and 2010 to 2011 for all the selected sites. The data collected were statistically analyzed using STATISTICA 6. The relationships between different physico-chemical properties/characteristics of the soil from the four study sites were analyzed using Pearson's correlation coefficient values (r). Two-way and Multi-factorial analysis of variance (ANOVA) was also conducted to determine the pattern of variations in different soil properties along the years, sites, sampling seasons, soil depths and their interaction effect on various soil properties/characteristics. The level of significance (P) in all the cases was held at 0.01 and 0.05.

RESULTS AND DISCUSSION

Texture of the soil was loamy sand to sandy loam (Table 1). The higher sand particles observed in Ruksin and Pasighat than Mebo and Pangin may be presumed that the undulating topography and slope leading to erosion caused by the long period of intensive cultivation. The lower proportion of silt particles in Ruksin and Pasighat suggested that cultivation of crops especially under continuous mono-cropping reduces silt particles in soil. This may also be attributed due to erosion, which removes finer particles of soil due to less vegetative cover that could reduce the impact of raindrops on soil in Ruksin and Pasighat. There was not much variation in proportion of clay particle between the study sites; this suggested that the soils are similar with respect to textural composition since the soils are derived from the same parent materials.

Bulk density ranges from 0.68±0.01 to 0.80±0.001 g cm^{-3}. It was maximum (0.80±0.00 g cm^{-3}) in lower soil surface of lowest altitude (Ruksin) and it decreases with increase in altitude. Upper soil surface had comparatively lower bulk density than the lower soil surface in all the study sites (Table 1). Bulk density difference may be attributed to differences in soil organic matter content (Ghosh and Dhyani, 2005). Upper surface of soil contain more organic matter due to rapid decomposition of crop residues thus, had lower bulk density. Bulk density level for ideal plant growth is < 1.60 g cm^{-3} (Arshad et al., 1996). Bulk density of all the study sites was within the threshold limit. It had negative significant correlation with porosity (r = -1.000, P < 0.01) (Table 2). It varied significantly along the sites (F = 27.85, P < 0.01), soil depths (F = 22.55, P < 0.01) and in combination of both the factors that is, site x soil depth (F = 3.59, P < 0.05) (Table 3).

Soil porosity ranges between 69.56±0.13 and 74.21±0.33% and was maximum (74.21±0.33%) in Mebo and minimum (69.56±0.13%) in Ruksin. It was higher in upper soil surface than the lower soil surface in all the study sites even though difference is very low (Table 1). It had negative significant correlation with bulk density (r = -1.000, P < 0.01) (Table 2). It varied significantly along the sites (F = 27. 9, P < 0.01) soil depths (F = 22.5, P < 0.01)

Table 3. Summary of Two - way ANOVA for effect of site and soil depth on soil physical properties (data taken once) of all the study sites.

Source of variance	df (Degree of freedom)	Soil physical properties/F values		
		Bulk density	Porosity	WHC
Site	3	27.85*	27.88*	640.58*
Soil depth	1	22.55*	22.55*	26.67*
Site*Soil depth	3	3.59**	3.58**	28.53*

* and** values are significant at P < 0.01 and P < 0.05 probability level respectively.

and in combination of both the factors i.e., site x soil depth (F = 3.6, P < 0.05) (Table 3).

WHC ranges from 54.55±0.42 to 83.56±0.04%. It was highest (83.56±0.04%) in lower soil surface of Mebo block and lowest (54.55±0.42%) in upper soil surface of Pasighat. WHC was lower in upper soil surface than the lower soil surface except in Pangin (Table 1). This may be due to presence of low amount of humus in upper surface of the soil. Hot and humid condition of the region allows rapid decomposition of organic matter and does not allow its accumulation; however, in Pangin there may be accumulation of organic matter on the surface due to low rate of decomposition on the upper surface than the lower surface due to lower temperature (there is slight decrease in temperature in Pangin than the other study sites). WHC had negative correlation with bulk density and positive correlation with porosity but the values are not significant (Table 2). It varied significantly along the sites (F = 640.6, P < 0.01), soil depths (F = 26.7, P < 0.01) and in combination of both the factors that is, site x soil depth (F = 28.5, P <0.01) (Table 3).

Soil at all the study sites was slightly acidic in nature (4.87±0.03 to 6.90±0.00) (Figure 1) hence, there is high possibility of aluminium and other heavy metal toxicity (Muya et al., 2011). Acidity of the soil could be due to leaching of bases from the exchange complex under the prevailing heavy rainfall and undulating topography. At all the study sites, soil pH tends to be slightly more acidic in post-monsoon and winter than pre-monsoon and monsoon. Soil pH was comparatively more acidic in lower soil depth than the upper soil depths. It was more acidic in Ruksin and Pasighat than Mebo and Pangin (Figure 1). This might be because of burning of crop residues in the agricultural field which is more frequent in higher altitude sites that is, Mebo and Pangin. Burning increases the soil pH (Roder et al., 1993; Bird et al., 2000; Badia and Marti, 2003; Snyman, 2004) due to ash deposit from the burnt plant biomass (Oluwole et al., 2008). Threshold limit range of pH for optimum plant growth is 5.5 to 7.0 (Kamoni and Wanjogu, 2006). Mean values of pH of all the study sites were within the threshold limit except at Ruksin. Soil pH had positive significant correlation with moisture, SOC and SOM (r = 0.456, 0.213 and 0.213, respectively, P <0.01) and negative significant correlation with available P and K (r = -0.212 and -0.209, respectively, P < 0.01) (Table 4). Soil pH was significantly different among the years, sites, seasons, soil depth and combination of these factors (F = 848, 565, 489, 23 etc., respectively, P < 0.01) (Table 5).

Soil moisture content was low and ranges between 14.60±0.12 and 29.47±0.07% (Figure 1). In general, it was higher at Mebo and Pangin at both the depths compared to Ruksin and Pasighat, which might be due to more ground cover in the former sites (higher altitude) than the later. Maximum soil moisture was observed during pre-monsoon and monsoon months and minimum during post-monsoon and winter that is, dry period (Figure 1). Soil moisture had positive significant correlation with soil pH and available K (r = 0.456, P < 0.01 and r = 0.150, P < 0.05) and negative significant correlation with available P (r = -0.186, P < 0.01) (Table 4). Differences in soil moisture content at different years, study sites, sampling periods, soil depths and in combination of these factors were significantly different at P < 0.01 (F = 41.6, 2326.9, 989, 8.8, etc., respectively) and combination of year, season and soil depth; site, season and soil depth; and year, site, season and soil depth were significant at P < 0.05 (F = 3.02, 16.66 and 9.17, respectively). While the combination of year and soil depth was not significant at both the level (Table 5).

Soil organic carbon (SOC) ranges from 0.32±0.03 to 3.06±0.02% (Figure 1). It was higher in upper surface of the soil than the lower surface in all the study sites. Such variation was also reported by Sevgi and Tecimen (2009) from Kazdagi mountainous uplands. It was high in monsoon and post monsoon in all the study sites (Figure 1) which might be because of decomposition and accumulation of death and decay of plants grown in rainy season. The SOC were highest in Pasighat followed by Mebo, Pangin and Ruksin (Figure 1). This could be due to tillage and site clearance before cultivation which is more common practice in Ruksin than the other sites. Removal of crop residue from the fields is known to hasten SOC decline especially when coupled with conventional tillage (Yang and Wander, 1999; Mann et al., 2002). Threshold limit range of SOC (%) for optimum plant growth is 2 to 4% (Kamoni and Wanjogu, 2006). Mean values of SOC at Pasighat and Mebo were within the limit while, it was slightly lower in Pangin (1.95%) and quite low in Ruksin (1.13%). SOC had positive significant

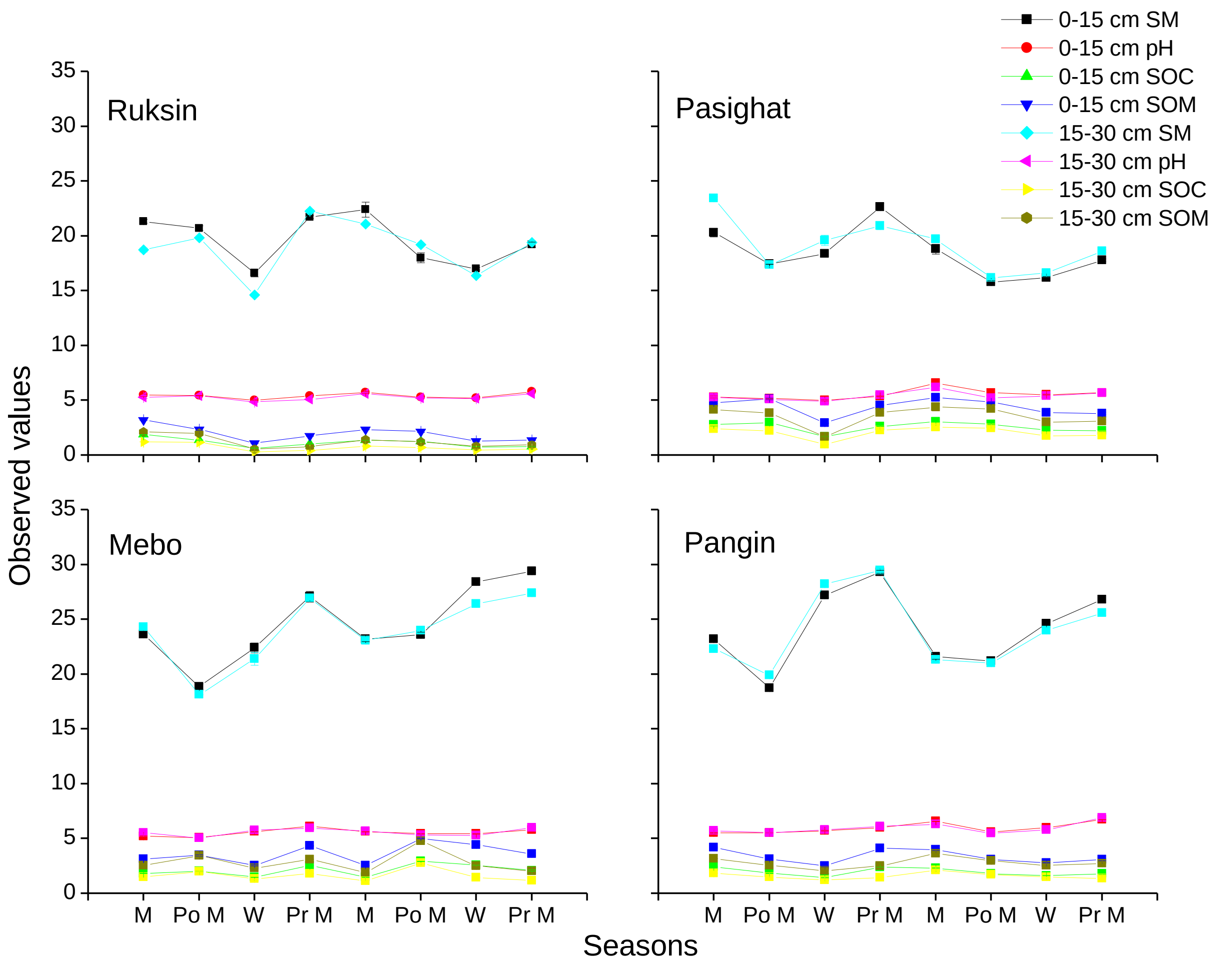

Figure 1. Variation in soil properties - pH, Soil moisture (SM %), Soil Organic Carbon (SOC %) and Soil Organic Matter (SOM %) at Ruksin, Pasighat, Mebo and Pangin in different seasons (M=Monsoon, PoM=Post-monsoon, W=Winter, PrM=Pre-monsoon) for two consecutive years (2009-2010 and 2010-2011) at two soil depth (0-15 cm and 15-30 cm). Vertical line bar indicates ± SE.

Table 4. Correlation coefficients among various soil physico-chemical properties at all the study sites.

Soil physico-chemical properties	pH	Moisture	SOC	SOM	N	P	K
pH	1.000						
Moisture	0.456*	1.000					
SOC	0.213*	0.109	1.000				
SOM	0.213*	0.110	1.000*	1.000			
N	-0.058	-0.018	0.520*	0.519*	1.000		
P	-0.212*	-0.186*	0.162**	0.162**	-0.152*	1.000	
K	-0.209*	0.150**	-0.097	-0.096	0.318*	-0.368*	1.000

N = 192; * and ** values are significant at P < 0.01and P < 0.05 probability level respectively.

correlation with pH, TKN (r = 0.213 and 0.520, respectively, P < 0.01) and available P (r = 0.162, P < 0.05) (Table 4). It varied significantly among the years (F = 4.93, P < 0.05); study sites, sampling periods, soil depths and in combination of these factors (F = 2594.26, 647.84, 1478.89 etc., respectively, P < 0.01). While the combination of year and soil depth was not significant at both the level (Table 5).

Table 5. Summary of Multi-factorial ANOVA for effect of year, site, sampling season and soil depth on physico-chemical properties (data taken seasonally) of all the study sites.

Source of variances	df (Degree of freedom)	Soil physico-chemical properties/F values						
		pH	Moisture	SOC	SOM	N	P	K
Year	1	848*	41.58*	4.93**	4.74**	11.50*	390.36*	4700.64*
Site	3	565*	2326.91*	2594.26*	2619.90*	333.71*	148.84*	2338.43*
Season	3	489*	989.04*	647.84*	652.07*	146.85*	852.87*	2702.69*
Soil depth	1	23*	8.77*	1478.89*	1487.33*	470.72*	12.34*	2898.36*
year*site	3	127*	366.90*	36.98*	37.41*	8.30*	144.55*	921.76*
year*season	3	104*	113.23*	208.13*	209.53*	81.42*	9.57*	162.43*
site*season	9	76*	282.27*	177.56*	179.29*	61.36*	54.42*	416.43*
year*soil depth	1	18*	1.21^{NS}	2.80^{NS}	2.74^{NS}	10.95*	5.83**	57.12*
site*soil depth	3	15*	23.68*	6.40*	6.58*	8.76*	2.92**	58.55*
season*soil depth	3	4*	6.55*	23.42*	23.53*	11.25*	2.96**	15.48*
year*site*season	9	51*	77.26*	58.38*	59.00*	31.89*	35.87*	239.15*
year*site*soil depth	3	6*	13.78*	34.08*	34.01*	15.94*	8.05*	10.34*
year*season*soil depth	3	12*	3.02**	9.06*	9.36*	17.64*	9.94*	14.94*
site*season*soil depth	9	9*	16.66**	21.48*	21.85*	12.26*	9.39*	25.03*
year*site*season*soil depth	9	6*	9.17**	11.37*	11.45*	19.66*	9.59*	54.03*

*and ** values are significant at P < 0.01and P < 0.05 probability level respectively; ^{NS} values are not significant.

The SOM ranges between 0.55±0.05 and 5.26±0.03% (Figure 1). Organic matter content was high as a result of luxuriant growth of vegetation, high rainfall and low decomposition rate in the acidic soil environment. On contrary to other ecosystem, soil organic matter is lower in winter season than the other seasons mainly because of poor crop growth due to water scarcity (dry season) and thus no accumulation of organic matter. SOM was higher in upper surface of the soil than the lower surface in all the study sites. It was higher in monsoon and post monsoon (Figure 1) because of decomposition and accumulation of death and decay rainy season plants. It was maximum in Pasighat block followed by Mebo, Pangin and Ruksin (Figure 1). This could be associated with the land use system (tillage and site clearance before cultivation is more common practices in Ruksin block than the other sites) since it affects the amount and quality of litter input, the litter decomposition rates and the processes of organic matter stabilization in soils (Romkens et al., 1999; Six et al., 1999; 2002). SOM had positive significant correlation with pH, total Kjeldalh N (r = 0.213 and 0.519, respectively, P < 0.01) and available P (r = 0.162, P < 0.05) (Table 4). It varied significantly at different years (F = 41.6, P < 0.05); study sites, sampling periods, soil depths and in combination of these factors (F = 2326.9, 989, 8.8, etc., respectively, P < 0.05). While the combination of year and soil depth was not significant at both the level (Table 5).

The soils of the region are rich in TKN content due to presence of high amount of organic matter. TKN ranges from 0.07±0.01 to 0.40±0.01% (Figure 2). Concentration of TKN was higher in upper surface of the soil than the lower surface in all the study sites (Figure 2). This could be due to declining humus content with the depth of the soil (Malo et al., 2005). It was higher in winter and post monsoon than monsoon and pre-monsoon (Figure 2) and this trend might be due to decrease in the rate of mobilization and uptake by the plant (Singh et al., 2000). TKN was lowest at Ruksin. It increased at Pasighat and again decreased with the rise in altitude (Figure 2). This might be due to the removal of nitrogen by precipitation through the downward movements of the mountainous organic mass (Hood et al., 2003). Threshold limit of total N is 0.2% (Kamoni and Wanjogu, 2006). Mean values of N at Ruksin (0.2%) was within the limit while it was above the limit in all other study sites. TKN had positive significant correlation with SOC, SOM and available K (r = 0.520, 0.519 and 0.318, respectively, P < 0.01) and negative significant correlation with available P (r = -0.152, P < 0.05) (Table 4). Differences in TKN content at different years, study sites, sampling periods, soil depths and in combination of these factors were significantly different (F = 11.50, 333.71, 146.85, 470.72 etc., respectively, P < 0.01) (Table 5).

Available P content in the soil ranges from 0.008±0.001 to 0.019±0.001% (Figure 2). Concentration of soil available P was more or less similar in the two depth of the soil in all the study sites (Figure 2). Concentration of available P tend to increase during monsoon and pre-monsoon season (Figure 2) when precipitation was high; and decreases in post-monsoon and winter seasons when precipitation was low. Such result was also

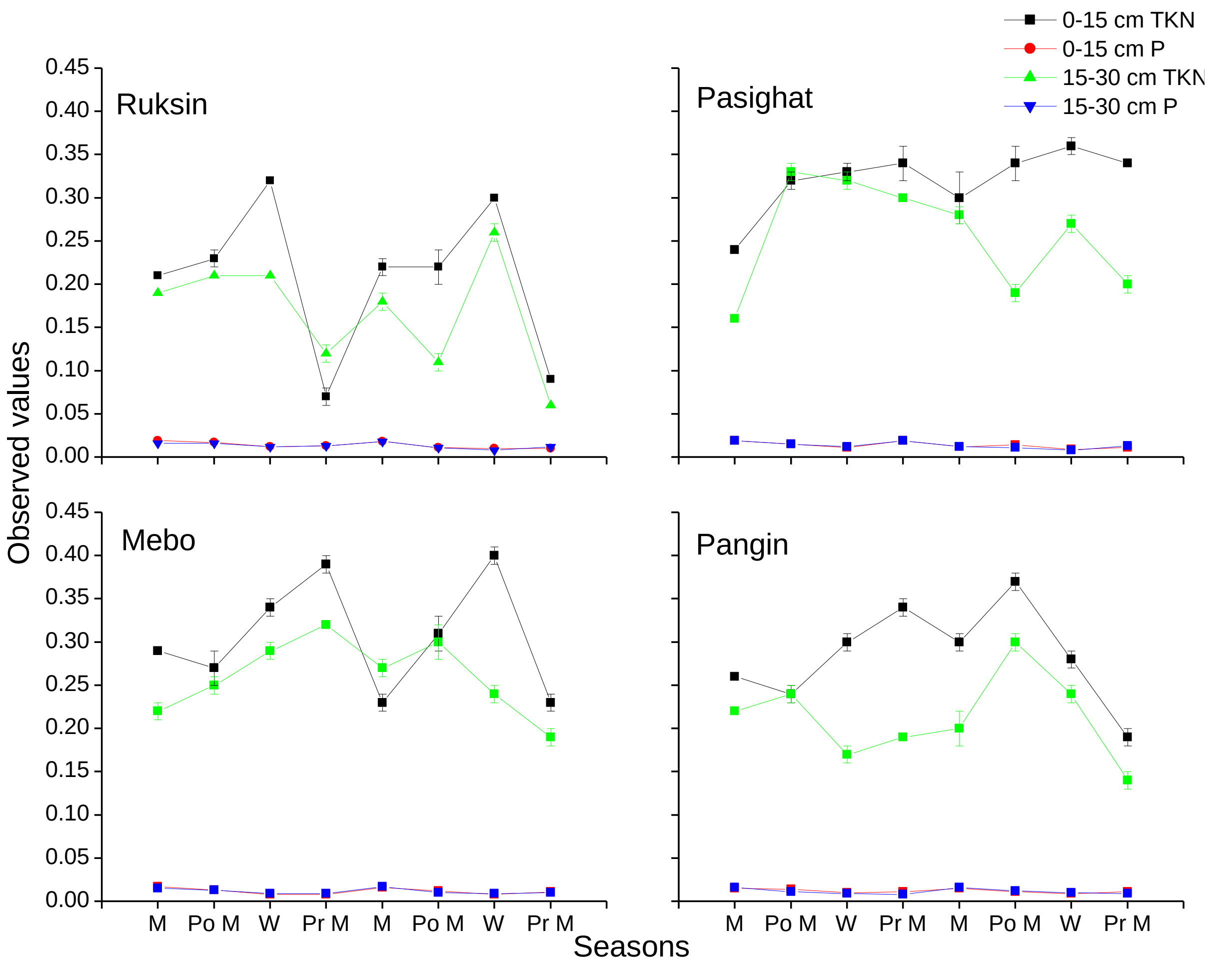

Figure 2. Variation in soil properties – total Kjeldalh Nitrogen (TKN %) and available Phosphorous (P %) at Ruksin, Pasighat, Mebo and Pangin in different seasons (M=Monsoon, PoM=Post-monsoon, W=Winter, PrM=Pre-monsoon) for two consecutive years (2009-2010 and 2010-2011) at two soil depth (0-15 cm and 15-30 cm). Vertical line bar indicates ± SE.

reported by Cameron (1996) from Australian soil. This finding was however in contradiction to the result of Perrott et al. (1990) and Ross et al. (1995). Concentration of available P was higher in lower altitude study sites (Ruksin and Pasighat) than the higher altitude study sites (Mebo and Pangin) (Figure 2) which might be due to more acidic soil in the former study sites than the latter study sites. Low P content in acidic soil was also reported from other upland agricultural fields (Patiram et al., 1990). Threshold limit of available P for optimum plant growth is 7.6 ppm (= 1.9%) (Aune and Lal, 1997). Mean values of P (%) in all the study sites were very low as compared to the threshold limit. This might be due to the interference of aluminium ions under acidic conditions of the soils in all the study sites. Available P had positive significant correlation with SOC and SOM (r = 0.162 and 0.162, respectively, $P < 0.05$) and negative significant correlation with pH, moisture, TKN and available K (r = -0.212, -0.186, -0.152 and -0.368, respectively, $P < 0.01$) (Table 4). It varied significantly at years, study sites, sampling periods, soil depths, in combination of these factors (F = 390.36, 148.84, 852.87, 12.34 etc., respectively, $P < 0.01$) and in combination of year and soil depth, site and soil depth, and season and soil depth (F = 5.83, 2.92 and 2.96, respectively, $P < 0.05$) (Table 5).

Available K content in the soil of the district ranges between 20.15±1.09 and 255.03±1.90 Kg ha^{-1} (Figure 3). Upper surface of the soil have more K content than the lower surface of the soil in all the study sites (Figure 3). Similar to the TKN, K content tends to increase in post-monsoon and winter; and decreases in pre-monsoon and monsoon in all the study sites (Figure 3). Available soil K was more in Mebo and Pangin than the Ruksin and Pasighat (Figure 3) mainly because of burning of plant residues in the agricultural fields which are more frequent in the former sites than the later sites. The ash deposited from the burnt plant biomass is known to be rich source

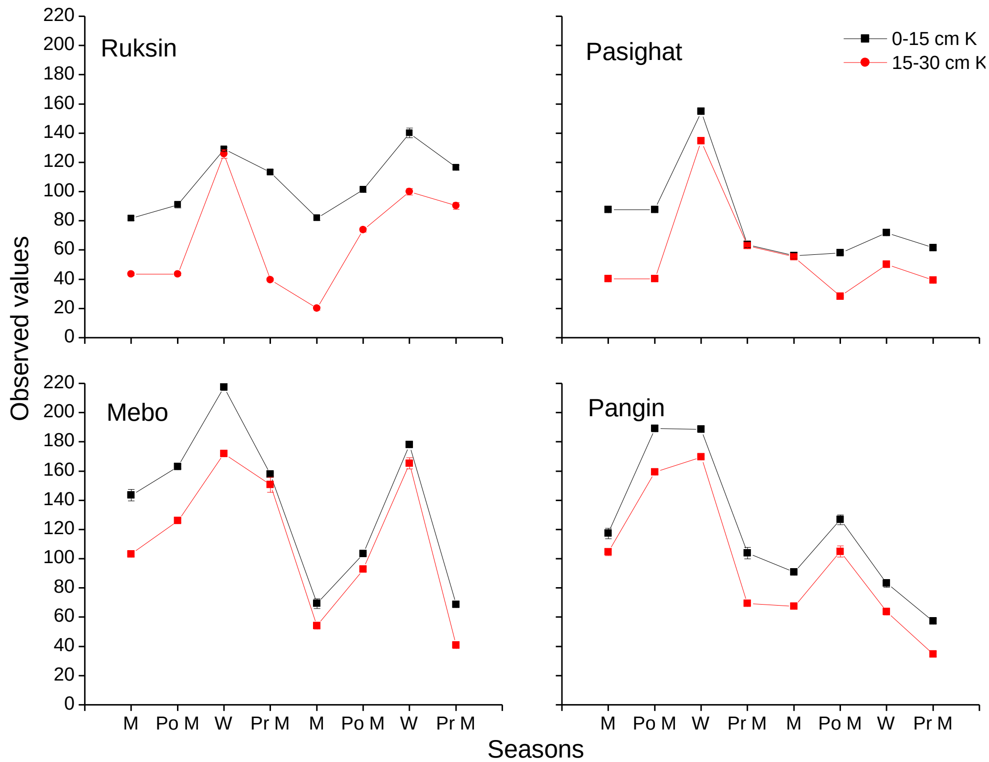

Figure 3. Variation in available Potassium (K kg ha^{-1}) at Ruksin, Pasighat, Mebo and Pangin in different seasons (M=Monsoon, PoM=Post-monsoon, W=Winter, PrM=Pre-monsoon) for two consecutive years (2009-2010 and 2010-2011) at two soil depth (0-15 cm and 15-30 cm). Vertical line bar indicates ± SE.

of cation such as K (Clapham and Zibilske, 1992). Available K had positive significant correlation with moisture ($r = 0.150$, $P < 0.05$) and TKN ($r = 0.318$, $P < 0.01$) and negative significant correlation with pH and available P ($r = -0.209$ and -0.368, respectively, $P < 0.01$) (Table 4). Available K was significantly different among the years, sites, seasons, soil depth and combination of these factors (F = 4700.64, 2338.43, 2702.69, 2898.36 etc., respectively, $P < 0.01$) (Table 5).

C: N ratio was calculated from the mean values of SOC and TKN for each block at two depths and the values ranges from 4.43 to 8.24 (Figure 4). C: N ratio was lowest at Ruksin at both soil depths, suddenly increased at Pasighat and then decreases with increase in altitude that is, Mebo and Pangin (Figure 4). It is considered that greater the C: N ratio, lower would be the N content in the soil (Mishra, 2011) and thus, lower N availability to the plants (Maithani et al., 1998). Lower C: N ratio shows nutrient rich soil (Arunachalam and Pandey, 2003). All the study sites showed low C: N ratio. C: N ratio close to 10 signifies nutrient balance that a fertile soil could maintain (Myers et al., 1994). C: N ratio at Pasighat is more close to 10 followed by Mebo, Pangin and Ruksin (Figure 4). For fertility of their lands they rely on mixed cropping, crop rotation, green manuring, etc. Crops residues are generally kept in the field for natural decomposition; burnt in the agricultural/jhum field itself or directly ploughed back into the soil. In doing so, different plants leave different amounts of nitrogen, potentially aiding synchronization. Retention of crop residues on the soil surface enhanced Carbon-sequestration and water conservation.

Conclusion

Considering the result of foregoing pages, it can be concluded that soil fertility was better in Pasighat and Mebo than Ruksin and Pangin. Pasighat being district headquarter, has better advantage in using and implementing fertilizer and advanced agricultural technology to maintain and conserve soil fertility. Mebo (300 to 450 m asl) which represent foot hill to mid-hill has milder climatic variation coupled with traditional agricultural system resulted into better conservation and maintenance of soil fertility. While Ruksin (<150 m asl) and Pangin (>450 m asl) which represent plain and mid-hill to top hill, respectively are exposed to severe climatic condition which hamper natural processes of soil fertility restoration. Further, Ruksin having porous border with

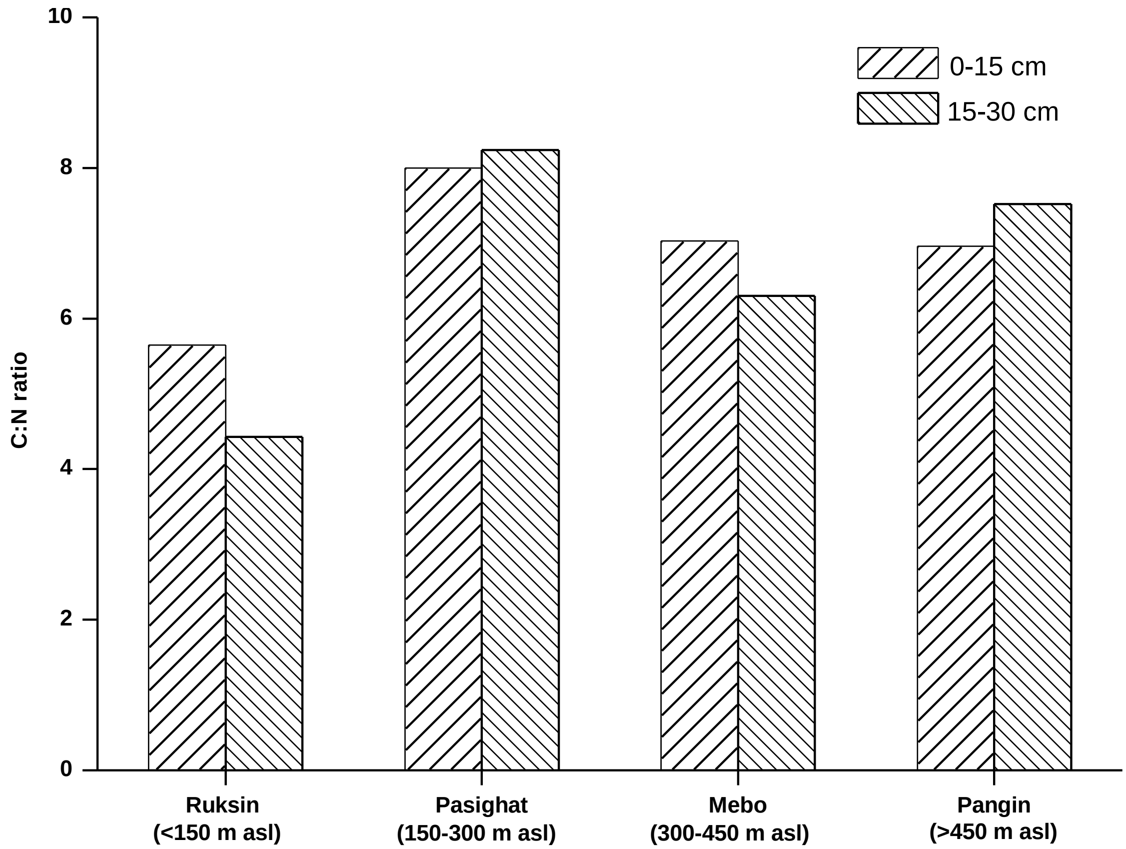

Figure 4. Mean Carbon: Nitrogen (C: N) ratio for two years (2009-2010 and 2010-2011) at Ruksin, Pasighat, Mebo and Pangin at two soil depth (0-15 cm and 15-30 cm).

Assam, farmers are extensively practicing intensive monoculture farming with less fallow period. Short fallow period fails to restore soil fertility (Giller et al., 1997) and monoculture farming results to nutrient poor land (Mishra and Laloo, 2006; Mishra, 2010). On the other hand, Pangin being in higher altitude, there are downward movements of mountainous organic mass resulting to poor soil nutrient. In general, in all the study sites, soil erosion through runoff is main agent of land degradation in the area devoid of vegetable cover. The loss of top fertile soil from the limited cultivated lands has forced many farmers to abandon their traditionally cultivated land and to move on to other marginal lands. Thus, better management and increasing in cropping intensities with regular recuperative periods for enhancing and restoring soil fertility is need of the time.

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