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Tea yield and soil properties as affected by slope position and aspect in Lahijan area, Iran

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Abstract

Soil genesis, physico-chemical properties and tea yield were investigated along different hillslope positions in the major tea cultivation area of Iran, i.e. Lahijan, Gilan Province. Land suitability was also determined for the tea production in this hilly region. Four different slope positions i.e., summit, shoulder, backslope and toeslope were sampled on three slope aspects following the profile description. Tea leaf was also sampled in those positions as an index of tea yield. The results of the soil genesis studies presented a catenary evolution in which the well developed Cambisols (Hapludepts) were formed mainly on summit positions and non-developed Regosols (Udorthents) were formed on less stable segments of shoulder and backslope. In toeslope, where the groundwater saturates the soil profile, hydromorphic properties were dominant and Gleysols (Endoaquepts) were formed. Some soil physico-chemical and morphological properties such as solum thickness, thickness of the epipedons, clay content, organic carbon, total nitrogen, carbonate, and exchangeable magnesium were significantly different on different slope positions in the near surface layers. However the differences were not reflected in the tea yield. Land suitability evaluation in different landforms in the three aspects showed that the soils were marginally suitable and non-suitable for tea production. The most limiting factors were climatic factors especially the mean minimum temperature during the coldest month of the year. Shoulder and backslope positions showed the lowest suitability due to higher slope gradient and lower organic carbon and soil depth. Tea yield as determined by leaf dry weight showed no significant differences in different slope positions. Moreover, different aspects had also a non-significant role regarding the soil properties and tea production. It is believed that in this humid region the effects of slope aspect and position are rather annihilated due to the uniform density of the vegetation and soil moisture.

Keywords: Tea cultivation; Slope positions; Aspect; Soil property.

Introduction

Lahijan region in Gilan Province is considered as the major tea producing area in Iran. Understanding the soil limiting factors for the production of this important plant would help policy makers for the sustainable planning and management of the soils. Tea is mainly cultivated in the hill slopes in Lahijan area. Stability of the landform directly influences the soil properties and consequently the soil productivity. Among many landform parameters, effect of slope position and aspect on the variability of soil quality attributes and yield were little studied. There are many studies carried out on the relationship of soils and geomorphic surfaces. Pierson and Mulla (1990) studied the soil properties on different slope positions and concluded that soils formed on footslope and toeslope positions contained higher organic carbon and aggregate stability compared to summit position. Walia and Chamuah (1990), investigated some soil parameters e.g. soil texture, organic matter content , pH, kind and the presence of surface and subsurface horizons in four pedons formed on flood plains, piedmont plains, hillslopes and lowlands and showed that soils of piedmont plains were the most suitable for tea production due to higher acidic conditions and Al^{3+} activity. Floodplains and lowlands were shown to be non-suitable due to their poor drainage conditions. Brubaker et al., (1993), studied the soil properties highly related to landform position and found significant differences among 13 properties. Sand, silt, pH, calcium carbonate content, and exchangeable Ca^{2+} and Mg^{2+} mostly decreased down the slope. Young and Hammer (2000) found that most of the soil properties were similar between ridge and shoulder positions. Differences were minimal within the backslope. Backslopes differed from ridges and shoulders, with more argillic horizon clay, thinner epipedons, and less organic C, lower pH and base saturation, and less silt on a clay-free basis. Color patterns suggest that backslopes are wetter than ridges and shoulders, with more redoximorphic activity and organic matter accumulation on ped faces. Tsui et al., (2004) reported that the slope aspect and gradient can control the movement of water and soil material on a hillslope and hence contribute to the spatial differences of soil properties. The studied transect was divided into three slope positions: summit, backslope and footslope, each with a different floristic composition and structure. Their results showed that organic carbon, available N, available K, extractable Fe and exchangeable Na were highest on the summit, while pH, available P, exchangeable Ca and Mg were significantly higher on the footslope at 0–5 cm soils. Similar patterns were observed at subsurface 5–15 cm depth soils. Soils were reported to have properties such as redder color, moderate to high acidity, lower than 50% base saturation in the argillic horizon, in the sloping landscapes (Bhaskar et al., 2004). Soils of the upper slope positions had higher available Fe, Mn, Cu and Zn. These soils were classified as Ultisols and Entisols while soils of valleys were of Inceptisols order. Soils particles 0.5 mm in diameter decreased downslope, and those of 0.05 and 0.5 mm formed a larger soil fraction in the midslope position other than summit or footslope. Total organic C, N and P in the middleslope soil were the lowest among the soils in the three topographic positions (Chen et al., 2002).

The term of land evaluation has been used to describe many concepts and analytical procedures, but most frequently its main objective is to appraise the potential of land for alternative kinds of use by comparison of the requirement of land use with the resources offered by the land (Dent and Young, 1981). Land evaluation is now well established as an important component of the broader field of resource assessment (Messing et al., 2003). Physical land evaluation is concerned with assessing whether a particular use of a group of uses could be supported by the land resource. In the agricultural context, it involves comparing a crop's physical requirements for growth with the land's inherent or managed properties and provides a performance index such as suitability index (Bouma, 1999). Three adjacent hillsopes with different aspects in the Lahijan area were considered to study some selected soil quality attributes, soil development and land suitability for tea production and relate the effects of slope aspect and position on the spatial variability of soils properties and tea yield.

Methods and Materials

Site setting and sampling

The study area is a hilly region of Kate Chal, 2 Km from Lahijan, lying between 37° 10´ 59" northern latitude and 50° 2´ 44" eastern longitude (Figure 1). The climate of the region is humid with the mean annual precipitation of 1312 mm and mean minimum and maximum temperatures of 19.5 and 2.8 °C, respectively. The mean humidity is 77.5% and the annual evapotranspiration is 884 mm. The soil moisture and temperature regimes are udic and thermic, respectively. The major geological formations are composed of thick sedimentary and metamorphic rocks of Tertiary and Quaternary periods. The coastal plain lying between Alborz mountain ranges and Caspian Sea is composed of marine, river and aeolian deposits of varying thicknesses. Three adjacent north, south and east slope aspects were selected and summit, shoulder, backslope and toeslope positions were sampled after describing the soil profiles (Figure 1). The soils were then classified according to Soil Taxonomy and World Reference Base for Soil Resources (Soil Survey Staff, 2006; WRB 2006).

Figure 1. Study area and the slope positions sampled (SU: Summit, SH: Shoulder, BS: Backslope, TS: Toeslope)

Laboratory analyses

Particle-size distribution was determined after dissolution of $CaCO_3$ with 2N HCl and decomposition of organic matter with 30% H_2O_2. After repeated washing to remove salts, samples were dispersed using sodium hexametaphosphate for determination of sand, silt and clay fractions by the pipette method (Day, 1965). Alkaline-earth carbonate was measured by acid neutralisation (Salinity Laboratory Staff, 1954). Organic carbon was measured by wet oxidation with chromic acid and back titration with ferrous ammonium sulphate (Nelson, 1982). Soil pH was measured in a saturation paste and electrical conductivity (total soluble salts) was determined in a saturation extract (Salinity Laboratory Staff, 1954). Cation exchange capacity (CEC) was determined using sodium acetate (NaOAc) at pH 8.2 (Chapman, 1965). Basic cations were determined using ammonium acetate at pH 7 (Salinity Laboratory Staff 1954). Total N and available P were determined by Kjeldahl and Olsen (Olsen, 1953) methods. The soluble K and Na were measured by flame photometer and soluble Ca and Mg were determined by titration with EDTA (Salinity Laboratory Staff, 1954).

In order to study the tea green leaf production, leaves were sampled in $1.5m^2$ areas with three replications in each slope position. The samples were put in bags and taken to the lab for oven dry weight determinations. For land suitability evaluation, soils located in different positions were physically evaluated for tea production by comparison of the tea production requirements with land characteristics using three different comparison methods including (i) simple limitation method, (ii) number and intensity of limitations and (iii) parametric method. Parametric methods included Storie and Square root methods (Sys et al, 1991a). The FAO guidelines for land evaluation (FAO, 1976) and land evaluation procedure constructed by Sys et al., (1991a) were used. Tea production requirements were prepared in literature cited (Sys et al., 1993) integrated with farmer's communications. Statistical analyses were carried out on the data after the test of normality done by Kolmogorov-Smirnov using SPSS software (SPSS Inc, 1999) through analyses of variance. The means of soil quality parameters, in different slope positions were compared with their tea yield.

Results and Discussions

Table 1 presents the classification of the soils formed on different slope positions and aspects according to the Soil Taxonomy (Soil Survey Staff, 2006) which is based mainly on the presence of diagnostic horizons and soil moisture regimes. Soils are mostly classified as Inceptisols and Entisols. As seen, soils are all well drained except the toeslope position, which shows gley patterns and therefore classified as Endoaquepts. Due to the high slope gradient, cambic horizons are the most developed ones and there is not a significant difference among different slope positions and aspects with regard to the development of the soils. This similarity could mainly be explained by the fact that the whole study area receives high precipitation and there is no significant difference among different aspects and slope positions regarding the moisture content which is considered as a main soil forming factor. Moreover, the effect of erosion on different slope positions is highly reduced due to the dense anchorage made by tea roots.

Table 2 shows some physical, chemical and morphological properties of the soils. The most important feature observed, is the clay illuviation process shown as Bt horizon mainly in the summit positions. The higher stability and consequently higher infiltration in this position have provided favourable conditions for the downward leaching of clay. The clay content differences with the upper horizon however, do not meet the requirements for the argillic horizon and therefore considered as cambic horizon. Majority of the studied soils are acidic and pH increases with depth due to the leaching of bases from upper horizons. Organic carbon is highest in the surface layers and decreases regularly with depth. The soils are poor in N and K. The texture is mainly sandy loam and sandy clay loam. The calcium carbonate content of the soils shows it's high depletion from upper horizons evidenced by having no effervescence with dilute HCl. There is no salinity or sodicity in the area. The drainage condition of the soils is well drained except the toeslope position which is poorly drained.

Table 1. Classification of the soils according to the Soil Taxonomy.

Soil Classification (Soil Taxonomy, 2006)	Slope Position	Slope Aspect
Coarse-loamy, mixed, superactive, acid, thermic, Typic Hapludepts	Summit	North
Fine-loamy, mixed, superactive, acid, thermic, Typic Hapludepts	Shoulder	North
Coarse- loamy, mixed, superactive, acid, thermic, Typic Udorthents	Backslope	North
Coarse- loamy, mixed, superactive, acid, thermic, Typic Udorthents	Summit	East
Fine- loamy, mixed, superactive, acid, thermic, Typic Hapludepts	Shoulder	East
Coarse- loamy, mixed, superactive, nonacid, thermic, Typic Hapludepts	Backslope	East
Fine- loamy, mixed, superactive, nonacid, thermic, Typic Hapludepts	Summit	South
Coarse- loamy, mixed, superactive, acid, thermic, Typic Hapludepts	Shoulder	South
Fine- loamy, mixed, superactive, acid, thermic, Typic Udorthents	Backslope	South
Fine- loamy, mixed, superactive, nonacid, thermic, Typic Endoaquepts	Toeslope	-

Effect of slope positions on the solum thickness, physico-chemical properties of the surface horizons and tea yield

Analyses of the variance of the solum thickness and soil physico-chemical properties of the different slope positions are shown in Table 3. The results revealed that slope position had significant effects on properties such as solum thickness, thickness of the epipedons, saturated soil moisture, clay content, total N, calcium carbonate content, and exchangeable Mg at 5% level of confidence. Differences in CEC, pH, available K, and basic cations were nonsignificant mainly due to high leaching conditions. Comparison of the means of different physico-chemical properties and tea yield by Duncan test on summit, shoulder, backslope and toeslope positions are presented in Table 4. There was not any significant difference between the tea yield and slope positions. The thickness of the epipedon increased downward on different slope positions. The investigations made by Ovalles and Collins (1986) confirmed that there was a decrease in the thickness of the surface horizons from summit to backslope with 10% slope gradient. Moreover, Young and Hammer (2000) relate the differences of the soil properties on backslope compared to summit and shoulder to the thinner surface horizon of the backslope. In the present study the solum thickness is highest on toeslope position. Khaier and Khademi (2001) found the thickest surface horizon on the toeslope and footslope positions. This is mainly explained by the higher deposition on these slope positions.

Table 2. Selected physico-chemical and morphpological properties of the soils studied

H*	Depth	SP	Sand	Silt	Clay	ECe	pH	OC	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CEC	N	P	K	CCE	Color moist	Soil Structure
			%			dSm^{-1}		%	Exchangeable (meq $100g^{-1}$)					% Total	mg kg^{-1} (available)		%		
									Summit-Northern aspect										
Ap	0-15	55	52.2	27.8	20	0.2	4.4	3.6	6.4	3.2	0.48	0.12	26	0.28	1.33	42	1.75	10YR4/6	gr
Bt	15-50	41	60	26.6	13.4	0.2	4.8	0.5	6.4	1.6	0.44	0.06	14	0.05	2.8	18	2.75	10YR4/6	m-c2abk
Crt	50-85	42	58	30.6	11.4	0.1	5.1	0.1	7.2	6.3	0.44	0.06	17	0.02	1.75	20	3.25	10YR4/6	m
									Shoulder-Northern aspect										
Ap	0-12	57	48	28.6	23.4	0.2	4.8	2.2	6.4	1.6	0.42	0.18	20	3.5	6.4	3	1.75	10YR4/6	gr
Bt	12-43	53	54.7	25.9	19.4	0.1	5.4	0.1	8	3.2	0.44	0.1	17	0.05	1.75	34	2.25	10YR5/6	m-c2abk
Crt	43-85	50	56.7	25.5	17.4	0.1	5.2	0.3	5.6	4	0.5	0.08	17	0.03	1.4	22	3.25	10YR5/8	m
									Backslope-Northern aspect										
Ap	0-18	66	50.7	25.9	23.4	1.6	3.9	3.8	4	4.8	0.6	0.2	24	0.44	11.2	74	1.25	10YR3/4	gr
C1	18-50	43	64.7	23.3	12	1.2	4.2	0.7	3.2	1.6	0.54	0.06	13	0.1	2.8	16	3.75	7.5YR3/4	m
C2	50-75	44	62.7	25.3	12	1.8	4.7	0.2	11.2	4.8	0.4	0.06	20	0.06	2.45	16	3.25	10YR4/6	m
									Summit-Eastern aspect										
Ap	0-15	59	44.7	37.3	18	0.2	4.7	3.1	6.4	4	0.54	0.28	22	0.26	7.7	18	2.25	10YR4/6	gr
Crt	15-40	44	54.7	33.3	12	0.1	5	0.4	8.8	4.8	0.6	0.06	18	0.04	7.7	18	2.25	10YR4/6	m
Cr	40-60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	m

* H: Horizon; SP: Saturated Moisture Percentage; OC: Organic Carbon; CEC: Cation Exchange Capacity; CCE: Calcium Carbonate Equivalent

Table 2. Continued…

H*	depth	SP	Sand	Silt	Clay	ECe	pH	OC	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CEC	N	P	K	CCE	Color Moist	Soil Structure
	cm		%			dSm^{-1}		%	Exchangeable (meq $100g^{-1}$)					%	mg kg^{-1} available		%		
Shoulder-Eastern aspect																			
Ap	0-16	64	50.7	31.3	18	0.2	4.7	3.6	5.6	1.6	0.54	0.42	23	0.3	3.5	170	2.25	10YR3/4	gr
AB	16-28	64	44.7	37.3	28	0.1	4.6	1	7.2	4	0.54	0.14	19	0.1	2.45	46	2	10YR4/4	c2abk
Bt	28-60	72	49.4	20	30.6	0.07	5.2	0.5	8	4.8	0.64	0.05	22	0.06	1.4	42	2.25	10YR5/8	m2abk
C	60-100	51	61.4	22	16.6	0.06	5.1	0.2	4.8	4	0.52	0.10	13	0.03	2.1	22	3.25	10YR4/6	c1abk
Backslope-Eastern aspect																			
Ap	0-15	56	47.4	30	22.6	0.3	5.5	2.5	6.4	3	0.58	0.24	20	0.23	5.6	80	1.75	10YR6/4	gr
Bw1	15-35	47	53.4	26	20.6	0.2	5.8	1.1	5.6	4.8	0.52	0.10	13	0.11	2.1	30	2	10YR4/4	m2abk
Bw2	35-60	42	57.4	24	18.6	0.1	5.9	0.6	5.6	1.6	0.52	0.08	10	0.06	1.4	22	1.5	10YR4/6	c1abk
C	60-80	38	53.4	34	12.6	0.1	5.8	0.2	4	1.6	0.44	0.06	8	0.03	2.1	18	1	10YR6/4	m
Summit-southern aspect																			
Ap	0-12	60	56.9	25.3	17.8	0.3	4.7	3.2	5.6	4.8	0.44	0.46	21	0.28	3.5	168	1	10YR4/6	gr
Bt	12-40	60	54.9	27.3	17.8	0.09	5.9	0.4	8.8	4.8	0.5	0.14	18	0.06	1.4	44	1	10YR5/6	c1abk
BC	40-60	61	52.9	25.3	21.8	0.08	5.8	0.2	8.8	6.4	0.6	0.14	19	0.04	0.7	42	1	10YR4/6	m/c1abk
C	+60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	m

* H: Horizon; SP: Saturated Moisture Percentage; OC: Organic Carbon; CEC: Cation Exchange Capacity; CCE: Calcium Carbonate Equivalent

Table 2. Continued…

H*	Depth	SP	Sand	Silt	Clay	ECe	pH	OC	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CEC	N	P	K	CCE	Color (moist)	Soil Structure
	cm		%			dSm^{-1}		%	Exchangeable (meq $100g^{-1}$)					% Total	mg kg^{-1} (available)		%		
									Shoulder-southern aspect										
Ap	0-15	60	54.9	27.3	17.8	0.3	4.9	0.8	5.6	3.2	0.54	0.34	19	0.24	4.2	134	1.5	7.5YR5/4	gr
Bw	15-30	48	62.9	21.3	15.8	0.1	5.5	0.4	5.6	4.	0.46	0.16	14	0.06	2.1	52	1.5	10YR6/4	c1abk
BCt	30-60	48	52.9	29.3	17.8	0.1	5.3	0.3	7.2	4.8	0.54	0.1	15	0.03	3.1	28	1.5	7.5YR5/8	m/c1abk
Cg	60-100	58	58.9	25.3	15.8	0.1	5	0.2	8.8	8	0.6	0.14	22	0.02	0	38	1.5	7.5YR6/6	m
									Backslope-southern aspect										
Ap	0-25	59	48.9	31.3	19.8	0.2	4.8	2.7	5.6	3.2	0.32	0.14	19	0.22	3.5	50	1.5	7.5YR3/4	gr
C	25-50	44	54.9	27.3	17.8	0.1	5.2	0.2	6.4	4	0.56	0.08	16	0.06	0.7	22	1.5	10YR5/8	m
Ab	50-85	55	50.9	25.3	23.8	0.1	5.2	0.8	7.2	4	0.46	0.1	20	0.12	1.4	28	2	10YR3/3	abk
Cb	85-100	56	50.9	27.3	21.8	0.1	5.1	0.2	5.6	4	0.56	0.1	15	0.06	1.4	26	1.5	10YR4/6	m
									Toeslope										
Ap	0-25	50	52.9	27.3	19.8	0.1	4.7	1	6.4	4	0.56	0.12	19	0.15	3.5	44	1	7.5YR5/4	gr
Bw	25-35	43	60.9	23.3	15.8	0.1	5	0.4	8.8	2.4	0.24	0.12	17	0.1	11.9	40	2	10YR3/4	abk
Cg	35-150	54	44.9	31.3	23.8	0.1	5.8	0.6	10.4	4	0.2	0.12	19	0.11	2.8	40	2	2.5YR5/3	m

* H: Horizon; SP: Saturated Moisture Percentage; OC: Organic Carbon; CEC: Cation Exchange Capacity; CCE: Calcium Carbonate Equivalent

Table 3. Analyses of variance of some soil properties on different slope positions.

Property	unit	Sum of Squares	df	Mean Square	F	Sig.
Solum thickness	cm	2606.25	3	868.75	4.58	0.038
Thickness of the surface horizon	cm	240.33	3	80.11	9.52	0.005
Saturated moisture content		198.81	3	66.27	5.34	0.026
Clay		23.69	3	7.90	5.43	0.025
Organic carbon		9.50	3	3.17	5.03	0.030
Total N	%	0.037	3	0.01	2.59	0.050
CCE*		2.39	3	0.80	3.12	0.050
Exchangeable Mg	meq/100g	7.16	3	2.39	3.69	0.050

*Calcium Carbonate Equivalent

The saturated moisture content of the soils on the toeslope position was lowest comparing the other slope positions. This is mainly attributed to the lower clay and organic matter. The highest saturated moisture was found on the backslope position. The investigations done on the variation of the organic carbon on the different slope positions showed that the toeslope positions are mostly high in organic carbon even compared to the summit position. Wilding et al. (1982) explains the higher organic carbon of the lower slope positions by the finer soil texture and therefore higher moisture reserved in the soil which promotes vegetative growth and reduces the oxidation of organic matter. Another reason for the higher organic carbon content of the lower slope positions is the depositions from upper positions. Malo et al. (1974) also reported an increase in the organic carbon level and the solum thickness from shoulder to summit positions. Brubaker et al. (1993) showed the decrease in the clay, organic carbon, CEC and available K in the lower slope positions. Cheng (1987) however, reports that erosion of the material from upper positions and their subsequent deposition in the lower positions is responsible for the higher organic matter in the lower positions. The high amorphous iron and clay remains in the surface layers of the upper positions. In the present study however, the organic matter in the toeslope position was lower mainly due to the poor drainage conditions, lower vegetative growth and deposition from upper sections. The results of the tea yield in the toeslope position supports the above hypothesis. Jones et al. (1989) related the higher organic matter and yield of the upper slope position to the more dense rooting systems and plant residue in this position. The lower organic carbon of the shoulder position is consistent with the findings of Khaier and Khademi (2001), Khormali et al. (2006), Murali et al. (1978), and Pierson and Mulla (1990).

Total nitrogen is lowest in the toeslope position. This is explained in a same way as for the organic carbon. The near surface water table and the hydromorphic properties reduced the yield and consequently the organic matter which is responsible for the reduction in total N. The highest calcium carbonate was detected in the soils of shoulder position and is significantly different from toeslope position. The higher surface erosion and the subsequent outcropping of the underneath calcium carbonate rich layer is mainly responsible for the higher quantity of lime in the shoulder position. Eghbal and Southard (1993) and Matzek (1955) reported the similar findings. Matzek (1955) believes by increasing the slope gradient, and the higher runoff, downward leaching of the carbonate reduces.

Table 4. Comparison of the means of soil properties and tea yield on different slope positions by Duncan test.

Slope position	Yield*	Na^+	K^+	Mg^{2+}	Ca^{2+}	CCE$	K	P*	N	CEC	OC	pH	ECe*	clay	silt	sand	SP	TH$	soil depth
	$tonh^{-1}$		$meq100g^{-1}$			%	$mgkg^{-1}$		%	$cmolkg^{-1}$	%		dSm^{-1}			%		cm	cm
Summit	1.52a	0.48a	0.28a	4a	1.8a	1.6ab	109a	1.1a	0.27^{ab}	23a	3.3a	4.6a	-1.4a	18.6a	30.1a	51.2a	57.8a	14a	61.6a
Shoulder	0.88a	0.5a	0.31a	2.1a	1.7a	2.2a	123a	0.93a	0.24^{ab}	21a	2.2ab	4.8a	-1.4a	18.4a	29a	51.2a	60.2a	14.3a	95b
Backslope	1.1a	0.5a	0.19a	3.6a	1.6a	1.5ab	68a	1.2a	0.29^{ab}	21a	3a	4.7a	-0.76a	21.9b	29a	49a	60.4a	19.3a	85ab
Toeslope	0.91a	0.56a	0.12a	4a	1.8a	1b	44a	1.4a	0.15^{ab}	19a	1b	4.7a	-1.8a	19.8^{ab}	27.3a	52.9a	50.4b	25b	100b

Means in each column with similar letters are not statistically significant at 5% level of confidence
* normalized data
$TH: Thickness of the surface horizon; CCE: Calcium Carbonate Equivalent

Table 5. Comparison of the means of soil properties and tea yield on different slope aspects by Duncan test.

Slope aspect	Yield*	Na^+	K^+	Mg^{2+}	Ca^{2+}	CCE$	K	P*	N	CEC	OC	pH	ECe*	clay	silt	sand	SP	TH$	soil depth
	$tonh^{-1}$		$meq100g^{-1}$			%	$mgkg^{-1}$		%	$cmolkg^{-1}$	%		dSm^{-1}			%		cm	cm
North	3.4a	0.51a	0.19a	3.2a	5.2a	2.1a	69a	1.83a	0.31a	22a	3a	4.3a	-0.53a	21.4a	27.2a	49.3a	61.5a	15a	80a
East	2.3a	0.56a	0.33a	2.3a	6.0a	2.0a	125a	1.5a	0.26a	21.5a	3a	5.1a	-1.3b	20.3a	30.6a	49a	60a	15.5a	90a
South	2.6a	0.43a	0.24a	3.2a	5.6a	1.5a	92a	1.3a	0.23a	22a	1.7a	4.8a	-1.44a	18.8a	29.3a	51.9a	59.5a	20a	100a

Means in each column with similar letters are not statistically significant at 5% level of confidence
* normalized data
$TH: Thickness of the surface horizon; CCE: Calcium Carbonate Equivalent

Slope aspect and the soil properties and yield variations

The slope aspect indirectly affects the surface runoff and erosion. Slopes of the same gradient but with different aspects are not under the same risk of soil erosion. The main effect of the slope aspect on the surface runoff and erosion is through differences in the microclimate. The solar radiation received by a sloping landform is highly related to the aspect. The role of slope aspect is highly visible in the dryer regions than the humid areas (Zaiden et al., 1982). Daniel et al., (1987), reported that topography causes rapid evapotranspiration on southern aspects by changing the microclimate of the area, and in the meantime increases the rate of soil forming processes in the north facing slopes which results in a thicker solum with higher organic matter and denser vegetation.

As seen in Table 5, slope aspect had no significant effect on the soil properties mainly due to the high rainfall which compensates the radiation differences among aspects. In other words, the humid climate of the area lowers the importance of the radiation difference received on different aspects.

Land suitability evaluation

A summary of physical land suitability evaluation in different land forms in three aspects done by three comparison methods are given in Table 6. According to Sys *et al* (1991) guideline for physical land evaluation, the area was marginally suitable (S3) and non-suitable (N1 or N2) for tea production. The physical suitability classes determined by simple and number and intensity limitations methods had identical limitation degrees, whereas parametric methods (including storie and square root) showed lower classes for tea production in all landscape positions due to the interaction among ratings of land characteristics. This conclusion is in accordance with the findings of Ayoubi (1996) and Manrique and Vehera (1984). The results of square root method (e.g Khidir procedure) indicated that using root square equation instead of simple multiplication provided realistic results. Mandal et al. (2002) reported that land index calculated by khidir method (square root) was highly correlated with actual cotton yield in Nagpur district in India. The most limiting physical factors are climatic factors especially mean of minimum temperature during the coldest month of the year. Other limiting factors of the lower importance are the soil and land properties which control the suitability class of land forms for tea production. Shoulder position showed the lowest suitability due to higher slope gradient and lower soil organic carbon and depth. The similar results were also found for backslope position.

Conclusion

The results of this study showed that thickness of the solum and surface horizons and properties such as organic carbon content, total N, clay, carbonate and exchangeable Mg varied significantly on different slope positions. The tea yield however, was not significantly different on different slope positions. Organic carbon and total N were significantly low in the toeslope position. The field observations confirmed the presence of shallow water table and poor drainage conditions which are responsible for the reduction of tea yield. The slope aspect did not significantly affect the soil properties and tea production mainly due to the almost uniform and high precipitation in the area. The most physical limitation factors are climatic factors especially mean of minimum temperature during the coldest month of year. Investigations on the soil-landform relationship revealed that there is a strong link between the soil properties and the slope positions. More detailed studies would be helpful for the management of the sloping geomorphic surfaces.

Table 6. Physical Land suitability subclasses of tea production in different slope positions using three comparison methods.

Aspect	Position	Simple limitation method	Number and Intensity of limitations	Parametric	
				Storie	Square root
Northern	Summit	S3c	S3c	N1c	S3c
Northern	Shoulder	N1t	N1t	N2c	N2t
Northern	Backslope	S3c	S3tc	N2c	N1t
Eastern	Summit	S3cs	S3cs	N1c	S3c
Eastern	Shoulder	N1t	N1t	N2c	N1t
Eastern	Backslope	S3ct	S3ct	N2c	N1t
Southern	Summit	S3c	S3c	N1c	S3c
Southern	Shoulder	N1t	N1t	N2c	N2t
Southern	Backslope	S3c	S3c	N2c	S3c

*c, t and s subscripts stand for climate, topography and soil limitations respectively.

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