Journal of Plantation Crops, 2014, 42(1): 117-123

Climatic and terrain influence on acidity, exchangeable bases and cation exchange capacity in soils of coffee plantations of Karnataka

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(Manuscript Received: 24-10-13, Revised: 06-11-13, Accepted: 02-12-13)

Keywords: Acidity, cation exchange capacity, climate, coffee-growing soils, exchangeable bases, Karnataka terrain

Coffee or 'brown gold' is the most traded commodity in the world which has a net output of 8.4 million tons. Global output of *Arabica* is 5.3 million tons and *Robusta* is 3.1 million tons. Brazil is the top producer of *Arabica* coffee, while Vietnam tops in *Robusta* coffee production. India is the sixth largest producer of coffee after Brazil, Vietnam, Columbia, Indonesia and Ethiopia. Seventy per cent of Indian coffee is commercially grown in the Kodagu, Chickmagalore and Hassan districts of Karnataka. Coffee productivity in a given situation is dependent on agro- climatic factors, physiological attributes of species, terrain and soil properties, production technologies employed and managerial practices adopted.

Coffee is an exhaustive crop and gives away a lot of photosynthates and nutrients through beans even at the level that may cause exhaustion of the plant. Roelofsen and Coolhaas (1940) reported that one ton of green beans of *Robusta* coffee removes 4 kg CaO, where as Alwar *et al.* (1991) found out that the removal of CaO by *Arabica* coffee as 9.7 kg ha^{-1} y^{-1} and that of MgO by *Arabica* coffee was 5.8 kg ha^{-1} y^{-1}. One ton of *Robusta* green beans removed 4 kg of MgO (Roelofsen and Coolhaas, 1940). Catani and de Moraes (1958) reported that single *Arabica* plant during its fifth year removed 23.4 g of MgO.

Characterization of soils of coffee growing areas were carried out and contents of exchangeable calcium and magnesium were assessed in *Arabica* and *Robusta* coffee plantations under different climates and terrains in Chickmagalore, Kodagu and Hassan districts of Karnataka. Twenty-four soil profiles were studied and horizon-wise soil samples

Table 1. Climatic Parameters

Station	Total rainfall (mm)	Length of dryseason (months)	Temp. (°C)	Relative humidity (%)	Elevation (m) MSL	Potential evapotranspiration (mm)	Moisture index (%)
Madikeri	3311.0	4	20.4	82.3	1380	1264	162
Balehonnur	2791.9	4	22.3	86.0	900	1009	177
Sakleshpur	2349.3	4	22.2	75.0	1047	1200	96
Mudigere	2338.4	4	22.7	75.0	900	1200	88
Chethalli	1607.0	4	22.9	69.0	900	1415	14
Arasinguppe	1591.6	5	22.6	85.7	1160	1405	13
Belur	1045.4	4	23.2	69.0	1100	1405	-14

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Table 2. Depth wise distribution of selected morphological, physical and chemical properties

Depth (cm)	Horizon	Moist colour	Clay (%)	Texture	Coarse fragments (Vol. %)	Organic carbon (%)	Extr. iron % (CBD)
Perhumid: Madikeri soil: Clayey, kaolinitic, isohyperthermic Ustic Kandihumult							
0-24	Ap	7.5YR 3/4	34.7	gcl	15	2.03	1.10
24-45	Bt1	7.5YR 3/4	43.5	gc	20	1.21	2.11
45-72	Bt2	7.5YR 4/4	42.3	gc	25	0.92	2.17
72-109	Bt3	7.5YR 4/4	45.1	gc	35	0.50	1.76
109-133	Bt4	7.5YR 4/6	44.5	gc	25	0.44	1.83
133-165	BC	7.5YR 4/6	36.3	gcl	35	0.36	1.24
Perhumid: Balehonnur soil: Loamy-skeletal, mixed, isohyperthermic Oxic Dystrustept							
0-24	AP	10YR 3/3	26.4	gscl	25	2.08	1.58
24-42	BW1	10YR 4/4	24.8	vgscl	40	0.89	1.26
42-73	BW2	7.5YR 4/4	25.3	vgscl	45	0.55	1.02
73-102	BW3	7.5YR 4/4	26.6	vgscl	50	0.27	0.77
102-151	BW4	7.5YR 5/4	18.4	vgsl	60	0.14	0.54
Humid: Sakleshpur soil: Fine-loamy, mixed, isohyperthermic Ustic Palehumult							
0-18	Ap	7.5YR 3/2	30.2	scl	-	2.27	1.95
18-47	BA	5YR 3/3	33.3	scl	-	1.00	2.28
47-79	Bt1	5YR 3/4	32.9	scl	-	0.79	2.34
79-115	Bt2	5YR 4/4	37.6	sc	-	0.49	2.81
115-151	Bt3	5YR 4/4	38.2	sc	-	0.15	2.71
Humid: Mudigere soil: Loamy-skeletal, mixed, isohyperthermic Pachic Haplustoll							
0-24	Ap	10YR 3/2	21.6	gscl	35	4.81	0.60
24-45	Bw1	7.5YR 3/2	22.5	vgscl	40	2.59	0.58
45-75	Bw2	7.5YR 4/4	17.5	vgsl	45	0.70	0.40
75-112	Bw3	7.5YR 4/6	16.7	vgsl	50	0.62	0.38
112-151	Bw4	7.5YR 4/6	15.4	vgsl	60	0.34	0.36
Moist subhumid: Chethalli soil: Fine-loamy, mixed, isohyperthermic Pachic Argiustoll							
0-23	Ap	10YR 2/2	26.1	scl	-	2.46	1.46
23-50	Bt1	10YR 3/2	29.2	scl	-	2.05	2.30
50-83	Bt2	7.5YR 3/2	32.2	scl	-	1.07	2.47
83-117	Bt3	5YR 3/3	30.6	gscl	30	0.42	3.98
117-154	Bt4	5YR 4/4	31.8	gscl	35	0.38	2.86
Moist subhumid: Arasinguppe soil: Fine-loamy, mixed, isohyperthermic Dystric Haplustept							
0-19	Ap	10YR 3/3	39.3	gcl	20	2.63	3.18
19-42	Bw	10YR 4/3	33.8	gcl	25	1.29	2.83
42-68	BC1	10YR 4/4	16.9	gsl	35	0.54	1.92
68-85	BC2	10YR 4/4	18.2	vgl	40	0.36	2.07
85+	Cr						
Dry subhumid: Belur soil: Loamy-skeletal, mixed, isohyperthermic Typic Argiustoll							
0-26	Ap	10YR 3/2	29.9	scl	-	1.82	3.06
26-39	Bt1	10YR3/3	33.2	gscl	-	1.60	3.54
39-75	Bt2	7.5YR3/4	34.7	vgscl	45	1.03	5.81
75-103	Bt3	5YR 4/4	33.2	vgscl	55	0.60	4.84
103-151	BC	2.5YR 3/6	29.7	gscl	25	0.43	3.77

Table 3. Types of acidity and related factors and its distribution in soil profile

Depth (cm)	Horizon	pH (Water)	pH (KCl)	$BaCl_2$-TEA Acidity (cmol (p+) kg^{-1})	KCl Acidity (Al) (cmol (p+) kg^{-1})	CEC (cmol (p+) kg^{-1})	ECEC (cmol (p+) kg^{-1})	BS (%)	CEC / Clay Ratio	ECEC / Clay Ratio
Perhumid: Madikeri soil: Clayey, kaolinitic, isohyperthermic Ustic Kandihumult										
0-24	Ap	5.1	4.1	12.6	0.65	8.3	3.3	32	0.24	0.10
24-45	Bt1	5.0	4.2	13.2	0.57	7.4	3.3	37	0.17	0.08
45-72	Bt2	5.2	4.2	10.6	0.28	6.5	2.7	37	0.15	0.06
72-109	Bt3	5.2	4.3	6.7	0.23	6.4	3.1	45	0.14	0.07
109-133	Bt4	5.3	4.2	8.5	0.30	6.0	3.1	47	0.13	0.07
133-165	BC	5.3	4.1	5.3	0.67	5.9	2.3	36	0.16	0.06
Perhumid Balehonnur soil: Loamy-skeletal, mixed, isohyperthermic Oxic Dystrustept										
0-24	AP	4.9	4.2	11.8	0.52	8.4	3.4	34	0.31	0.13
24-42	BW1	4.8	4.0	8.4	1.18	4.4	2.1	22	0.18	0.09
42-73	BW2	4.8	4.0	6.8	1.18	3.9	2.1	24	0.15	0.08
73-102	BW3	4.6	3.9	5.8	1.41	2.9	2.2	26	0.11	0.08
102-151	BW4	4.8	4.0	4.7	0.81	1.7	1.5	43	0.09	0.08
Humid: Sakleshpur soil: Fine-loamy, mixed, isohyperthermic Ustic Palehumult										
0-18	Ap	6.2	5.5	15.7	-	11.0	9.1	83	0.54	0.45
18-47	BA	5.1	4.9	12.5	-	8.2	6.9	84	0.25	0.21
47-79	Bt1	5.4	4.5	11.3	-	6.7	5.6	84	0.20	0.17
79-115	Bt2	5.2	4.3	9.0	-	6.9	4.6	68	0.18	0.14
115-151	Bt3	5.3	4.5	9.8	-	6.7	4.9	73	0.18	0.13
Humid: Mudigere soil: Loamy-skeletal, mixed, isohyperthermic Pachic Haplustoll										
0-24	Ap	6.0	5.4	21.9	-	16.1	14.5	91	0.74	0.67
24-45	Bw1	5.9	5.0	17.1	-	9.8	8.0	82	0.44	0.36
45-75	Bw2	6.0	4.8	9.3	-	4.1	3.5	87	0.23	0.20
75-112	Bw3	5.8	4.6	9.9	-	4.8	3.0	62	0.29	0.18
112-151	Bw4	5.6	4.4	9.9	-	4.4	2.7	62	0.28	0.17
Moist subhumid: Chethalli soil: Fine-loamy, mixed, isohyperthermic Pachic Argiustoll										
0-23	Ap	5.4	4.9	21.3	1.0	13.4	8.5	57	0.51	0.33
23-50	Bt1	5.6	5.2	14.1	-	12.6	11.4	90	0.43	0.39
50-83	Bt2	5.9	5.6	12.5	-	10.8	10.4	96	0.35	0.32
83-117	Bt3	6.1	5.5	9.9	-	7.9	7.8	99	0.26	0.26
117-154	Bt4	6.2	5.4	9.4	-	8.7	7.4	86	0.27	0.23
Moist subhumid: Arasinguppe soil: Fine-loamy, mixed, isohyperthermic Dystric Haplustept										
0-19	Ap	5.6	4.5	16.0	0.12	24.5	21.4	87	0.62	0.54
19-42	Bw	5.4	3.7	19.8	0.68	24.1	18.9	76	0.71	0.56
42-68	BC1	6.0	3.7	20.2	0.64	19.5	18.2	90	1.15	1.08
68-85	BC2	6.2	3.7	13.8	0.31	22.8	20.3	88	1.26	1.12
85+	Cr									
Dry subhumid: Belur soil: Loamy-skeletal, mixed, isohyperthermic Typic Argiustoll										
0-26	Ap	6.2	5.1	11.6	-	14.3	13.3	93	0.48	0.45
26-39	Bt1	6.3	5.6	7.9	-	17.1	12.8	75	0.51	0.38
39-75	Bt2	6.7	5.8	9.5	-	14.9	11.5	77	0.43	0.33
75-103	Bt3	6.9	5.7	5.8	-	12.3	11.0	89	0.37	0.33
103-151	BC	6.7	5.6	7.9	-	17.0	15.2	90	0.57	0.51

Table 4. Exchangeable bases and base saturation and its distribution

Depth (cm)	Horizon	Exchangeable bases					$BaCl_2$-TEA	CEC	BSSum
		Ca	Mg	Na	K	Total	Acidity	Sum of	of cations
		(cmol (p+)kg^{-1})						cations	(%)
Perhumid: Madikeri soil: Clayey, kaolinitic, isohyperthermic Ustic Kandihumult									
0-24	Ap	1.9	0.33	0.17	0.22	2.7	12.6	15.3	17
24-45	Bt1	2.0	0.33	0.14	0.21	2.7	13.2	15.9	17
45-72	Bt2	1.6	0.39	0.15	0.29	2.4	10.6	13.0	18
72-109	Bt3	1.8	0.55	0.15	0.39	2.9	6.7	9.6	30
109-133	Bt4	1.7	0.61	0.15	0.31	2.8	8.5	11.3	25
133-165	BC	1.3	0.50	0.16	0.21	2.2	5.3	7.4	29
Perhumid Balehonnur soil: Loamy-skeletal, mixed, isohyperthermic Oxic Dystrustept									
0-24	AP	2.1	0.38	0.19	0.23	2.9	11.8	14.7	19
24-42	BW1	0.5	0.16	0.15	0.13	1.0	8.4	9.4	10
42-73	BW2	0.4	0.11	0.15	0.27	0.9	6.8	7.7	12
73-102	BW3	0.3	0.11	0.14	0.23	0.7	5.8	6.5	11
102-151	BW4	0.2	0.11	0.14	0.25	0.7	4.7	5.4	13
Humid: Sakleshpur soil: Fine-loamy, mixed, isohyperthermic Ustic Palehumult									
0-18	Ap	7.3	1.21	0.15	0.48	9.1	15.7	24.8	37
18-47	BA	5.0	1.20	0.15	0.53	6.9	12.5	19.4	36
47-79	Bt1	4.0	1.17	0.14	0.30	5.6	11.3	16.9	33
79-115	Bt2	3.0	1.13	0.13	0.35	4.6	9.0	13.7	34
115-151	Bt3	3.6	0.82	0.15	0.37	4.9	9.8	14.7	33
Humid: Mudigere soil: Loamy-skeletal, mixed, isohyperthermic Pachic Haplustoll									
0-24	Ap	13.0	1.03	0.19	0.37	14.5	21.9	36.4	40
24-45	Bw1	7.2	0.43	0.15	0.26	8.0	17.1	25.1	32
45-75	Bw2	3.0	0.26	0.14	0.16	3.5	9.3	12.8	27
75-112	Bw3	2.4	0.29	0.14	0.13	3.0	9.9	12.9	23
112-151	Bw4	2.0	0.38	0.16	0.13	2.7	9.9	12.6	21
Moist subhumid: Chethalli soil: Fine-loamy, mixed, isohyperthermic Pachic Argiustoll									
0-23	Ap	6.5	0.61	0.13	0.33	7.6	21.3	28.9	26
23-50	Bt1	5.2	1.02	0.14	0.24	11.4	14.1	25.5	45
50-83	Bt2	5.6	0.84	0.14	0.29	10.4	12.5	22.9	45
83-117	Bt3	5.5	0.85	0.14	0.31	7.8	9.9	17.7	44
117-154	Bt4	5.4	1.09	0.13	0.25	7.4	9.4	16.8	44
Moist subhumid: Arasinguppe soil: Fine-loamy, mixed, isohyperthermic Dystric Haplustept									
0-19	Ap	17.5	3.17	0.21	0.37	21.2	16.0	37.2	57
19-42	Bw	14.2	3.67	0.21	0.08	18.2	19.8	38.0	48
42-68	BC1	13.2	4.04	0.23	0.04	17.6	20.2	37.8	47
68-85	BC2	14.0	5.69	0.27	0.03	20.0	13.8	33.8	59
85+	Cr								
Dry subhumid: Belur soil: Loamy-skeletal, mixed, isohyperthermic Typic Argiustoll									
0-26	Ap	10.5	2.00	0.19	0.61	13.3	11.6	24.9	54
26-39	Bt1	10.2	1.96	0.20	0.35	12.8	7.9	20.7	62
39-75	Bt2	9.4	1.62	0.18	0.28	11.5	9.5	21.0	55
75-103	Bt3	9.5	1.19	0.16	0.10	11.0	5.8	16.8	66
103-151	BC	13.4	1.40	0.20	0.17	15.2	7.9	23.1	66

analyzed using standard procedure for soil morphological, physical and chemical parameters. Cation exchange capacity (CEC) of soil samples was determined by the NH_4OAc method (Jackson, 1958; Sarma *et al*., 1987). The ammonium acetate extract obtained from CEC estimation was used to determine the exchangeable Ca and Mg by atomic absorption spectrophotometry.

Soils of the perhumid zone (Table 1) were very deep, strongly acid, reddish brown, moderately rich in organic carbon, low in CEC and base saturation (BS) and were classified as Kandihumults, Kanhaplohumults, Kandiustults or Kanhaplustults under Ustic, Rhodic or Typic subgroups (Table 2-4).

These soils had either a kandic horizon or an argillic horizon having kandic properties. The

Table 5. Exchangeable calcium and magnesium in different climatic zones of tropical coffee soils

Pedon	Surface Ca (cmol (p+) kg^{-1}	Surface Mg (cmol (p+) kg^{-1}	Sub-surface Ca (cmol (p+) kg^{-1})	Sub-surface Mg (cmol (p+) kg^{-1})
		Per-humid climate		
Koppa 1	5.46	0.93	3.22	0.38
Koppa 2	5.07	0.85	2.58	0.62
Koppa 3	2.06	0.27	1.38	0.44
Balehonnur 1	5.36	0.70	2.31	0.40
Balehonnur 2	2.05	0.38	0.37	0.12
Balehonnur 3	5.5	0.47	2.08	0.32
Madikeri 1	1.94	0.33	1.77	0.43
Madikeri 2	2.32	0.49	2.32	0.49
Mean	3.72	0.55	2.00	0.40
		Humid climate		
Kalasa 1	18.42	3.79	8.88	1.56
Kalasa 2	13.87	2.59	7.90	1.19
Kalasa 3	9.40	3.72	10.20	1.12
Mudigere 1	12.95	1.03	3.90	0.32
Mudigere 2	15.79	1.76	5.14	0.52
Mudigere 3	12.13	0.85	6.93	0.64
Sakleshpur 1	8.37	2.38	2.78	1.32
Sakleshpur 2	11.95	2.88	11.65	2.22
Sakleshpur 3	7.26	1.21	4.02	1.17
Mean	12.24	2.25	6.82	1.12
		Moist sub-humid climate		
Arasinguppe 1	17.48	3.17	10.98	3.52
Arasinguppe 2	14.72	3.75	14.07	4.30
Chethalli 1	6.49	3.01	8.80	0.90
Chethalli 2	21.02	3.58	15.95	4.04
Chethalli 3	12.41	2.25	6.67	1.38
Mean	14.42	3.47	11.29	2.83
		Dry sub-humid climate		
Belur 1	10.52	2.00	9.59	1.54
Belur 2	2.31	1.36	2.33	0.44
Mean	6.42	1.68	5.96	0.99
Overall Mean	9.37	1.82	7.85	1.23

associated soils had a cambic horizon with a CEC per kg clay less than 24 cmol (p+) kg^{-1} and were classified under Oxic Dystrustepts and Oxic Haplustepts. Very high total rainfall and little low mean temperature under high elevation with extended dry period of nearly 4 months makes the organic carbon to accumulate, allowing more microflora to act upon, which helps the formation of very deep soil profiles with strong or very strong acidity, very low cation exchange capacity and base saturation with high sesquioxides and iron oxide concentrations giving reddish colour. These soils in turn showed acute deficiencies of exchangeable Ca and Mg. These soils have very low concentration (Table 5) of exchangeable Ca and Mg both in surface (3.7and 0.6 cmol (p+) kg^{-1}) as well as control section (2.0 and 0.4 cmol (p+) kg^{-1}). Ananthanarayana *et al.* (1986) reported the critical limit of exchangeable Ca in acid soils as 1000 ppm or 5 cmol (p+) kg^{-1} and for Mg it is 375 ppm or 3.125 cmol (p+) kg^{-1}.

Major soils of the humid zone (Table 1) were deep or very deep, moderately acid, dark (reddish) brown, rich in organic carbon, medium in CEC and medium to high in base saturation and were classified as Haplohumults, Palehumults, Haplustolls, Argiustolls or Paleustolls under Ustic, Pachic or Typic sub-groups. These soils showed an increase in clay content with depth and had an argillic horizon or cambic horizon overlain by mollic or umbric epipedon (Table 2-4). These soils had low concentration of exchangeable Ca and Mg (Table 5) both in surface (12.2 and 2.3 cmol (p+) kg^{-1}) as well as control section (6.8 and 1.1 cmol (p+) kg^{-1}).

Major soils of the moist sub-humid zone (Table 1) were deep to very deep, slightly acid, dark brown, rich in organic carbon, high in CEC and base saturation and were classified under Argiustolls with Pachic or Typic subgroups. These soils had an argillic horizon with more than fifty per cent base saturation overlain by a thick mollic epipedon. The associated soils were Dystric Haplustepts with a cambic horizon having a base saturation less than sixty per cent in at least one layer of B horizon (Table 2-4). These soils have higher concentration of exchangeable Ca and Mg (Table 5) both in surface (14.4 and 3.5 cmol (p+) kg^{-1}) as well as control section (11.3 and 2.8 cmol (p+) kg^{-1}). Magnesium deficiency may also arise due to excess application of K fertilizer or other materials which are rich in K. Magnesium deficiency is also reported in Central and South American coffee soils due to repeated mulching with napier grass, which has a high K content (Willson, 1985).

Soils of the dry sub-humid zone (Table 1) were very deep, neutral, dark brown, medium to rich in organic carbon, medium in CEC and base saturation and are classified under Typic Argiustolls. These soils have an argillic horizon with base saturation more than fifty per cent overlain by a mollic epipedon. The associated soils were having a cambic horizon with a CEC per kg clay of less than 24 cmol (p+) kg^{-1} and were classified under Oxic Haplustepts (Table 2-4). These soils have low concentration of exchangeable Ca and Mg (Table 5) both in surface (9.4 and 1.8 cmol (p+) kg^{-1}) as well as control section (7.9 and 1.2 cmol (p+) kg^{-1}).

Low to medium but distributed rainfall of 1000-2500 mm and high mean temperature under high elevation with dry period of 4 to 5 months favour high biomass production, make the organic carbon to decompose and accumulate, allowing more microflora to act upon and assist in formation of deep soil profiles with slight to moderate acidity, medium cation exchange capacity and base saturation with high sesquioxides giving dominance of reddish colour. The soils of humid, moist sub-humid and dry sub-humid zones showed much higher exchangeable calcium and magnesium than per-humid zone and at the same time expressed seasonal deficiencies of both owing to more porous nature of soil, dominated with low activity clays.

Mean exchangeable Ca of the surface horizon (Table 5) studied was 9.4 cmol (p+) kg^{-1} and that of control section was 7.9 cmol (p+) kg^{-1} while, exchangeable Mg remained at 1.8 cmol (p+) kg^{-1} and that of control section it was 1.2 cmol (p+) kg^{-1}. The results indicated very strong acidity, extremely low CEC, base saturation and a very low content of exchangeable Ca and Mg in soils of the plantations of per-humid tropical climate in surface (3.7 and 0.6 cmol (p+) kg^{-1}) as well as subsurface (2.0 and 0.4 cmol (p+) kg^{-1}) compared to other climates *viz.* humid, moist sub-humid and dry sub-humid remained higher.

From this study, there is a clear indication that in per-humid zone exchangeable Ca and Mg were very low coupled with very strong acidity, extremely low CEC and BS compared to other zones. Both these exchangeable cations have been leached away beyond root zone or replaced by hydrogen, aluminium, iron or manganese ions in the exchange complex as well as adsorbent surfaces favoured by strongly acidic soil reaction. This is a result of heavy rainfall associated with high temperature in the per-humid zones and high plant uptake and removal from the system. Exchangeable Ca as well as Mg showed an increasing trend from per-humid to humid and sub-humid zones in surface as well as control section owing to low rainfall, high dry period and high temperature but low leaching beyond root zone. Exchangeable Mg is deficient in all the climatic zones in both surface as well as control section except the surface soils of moist sub-humid zone. Liming of coffee plantations has to be given high priority to correct strongly acid soil reaction and deficiencies of exchangeable Ca and Mg as well to provide constant high coffee output.

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