Characterization of available major nutrients in dominant soils of rainfed crop production systems of India

Srinivasrao Ch.
National Academy of Agricultural Research Management

Pravin N. Gajbhiye
Mahatma Phule Krishi Vidyapeeth

Bandi Venkateswarlu
Vasant Rao Naik Maratwada Krishi Vidya Peeth , Parbhani , India

Indian J.Dryland agric. Res. & Dev. 2006 21(2) : 105-113

Characterization of Available Major Nutrients in Dominant Soils of Rainfed Crop Production Systems of India

Ch.Srinivasa Rao, K.P.R.Vittal, G.Ravindra Chary, P.N.Gajbhiye and B.Venkateswarlu

Central Research Institute for Dryland Agriculture, Santosh Nagar, Hyderabad, 500 059, A.P.

ABSTRACT: Nineteen representative soil profiles from arid, semi arid (moist and dry) and subhumid regions across eight major rainfed crop based production systems were characterized for available macronutrient status and distribution. Except in surface layers (0-15 cm) at few locations, most soil profiles were low in organic carbon. Profile mean (0-105 cm) of organic carbon content was less than 0.50 per cent in all the 19 soil profiles studied. Available N was low in all the profiles except of Vertisol at Indore. Other Vertisols at Rajkot, Kovilpatti, Bellary, Bijapur and Solapur showed extremely low available N. Surface soils of Rajkot, Akola, Solapur and Bellary were P deficient and that of Agra, S.K.Nagar, Bangalore, Hoshiarpur and Rakh Dhiansar were K deficient. Sulphur was deficient in surface layers of Faizabad, Rajkot, Akola, S.K.Nagar and Hoshiarpur. Light textured acidic soils at Phulbani, Anantapur, S.K.Nagar and Bangalore were Ca deficient. Magnesium deficiency was widespread among rainfed soils and Alfisols at Bangalore showed extremely low available Mg (0.07 me 100 g^{-1}). Correlation coefficients between various soil properties and available nutrients indicated that correlation coefficients varied from significantly negative to positive. Organic carbon showed significantly positive correlation with available N, P and K in most of the profiles and with S in many profiles.

Key Words: Macronutrients, soil properties, soil types, rainfed production systems

Out of the estimated 143 m.ha net cultivated land in India, 97 m.ha (68%) is rainfed which produces 41 per cent of the food grains in the country. Low and erratic rainfall, high temperature, degraded soils with low available water and multi-nutrient deficiencies are important factors contributing to low crop yields in these regions. The dominant soil orders in rainfed production systems are: Inceptisols, Alfisols, Aridisols, Vertisols and associated soils. Land productivity in irrigated areas is reaching a plateau and the bulk of the increasing food demand has to be met by improving land productivity in rainfed production systems. Such higher productivity levels have to be supported by already degraded and less fertile soils in rainfed regions. Moreover, fertilizer application in dryland agriculture is low (Singh *et al.* 1999) and continuous cultivation of improved varieties results in depletion of native soil reserves. Soils of rainfed regions have not been characterized systematically for their nutrient availability and distribution albeit some past studies generated limited data on specific nutrients with regard to surface soils only. Present study examines the availability and distribution of major nutrients in various soil types spreading across eight diverse rainfed production systems.

Materials and Methods

Depth-wise soil samples (15 cm interval) up to 105 cm were collected from representative soil pedons under various rainfed crop based production systems viz., rainfed rice (Faizabad, Phulbani and Ranchi), groundnut (Rajkot and Anantapur), soybean (Indore and Rewa), cotton (Akola and Kovilpatti), rabi sorghum (Bellary, Bijapur and Solapur), pearlmillet (Agra, Hisar and S.K.Nagar), fingermillet (Bangalore) and maize (Arjia, Hoshiarpur and Rakh Dhiansar). Three pedons were collected to represent each location at respective research stations. Details of locations, climate, soil type, mean annual rainfall and length of growing period are given in Table 1. These rainfed production systems represent diverse climate viz., arid, semi arid and subhumid, with shallow, medium to deep and very deep Aridisols, Alfisols, Inceptisols, Vertic Inceptisols and Vertisols (Velayutham *et al*. 1999). Length of growing period varied from 60 to 210 days and mean annual rainfall varied from 412 mm at Hisar to 1378 mm at Phulbani.

Soil samples were processed and analysed for particle size, organic carbon, pH, EC, $CaCO_3$ and CEC (Jackson, 1973). Available N (Subbaiah and Asija, 1956), P (Olsen et.al. 1954) for neutral and alkaline soils and Bray's (Bray and Kurtz, 1945) for acid soils, potassium (Hanway and Heidel, 1952), calcium and magnesium (Jackson, 1973) and sulphur (Williams and Steinbergs, 1959). Soil P was estimated colorimetrically, K by flame photometry, Ca and Mg by atomic absorption spectrophotometer and sulphur by turbidimetry. Details of soil properties are presented in Table 2. Relationships between key soil properties and nutrient contents were examined by simple correlations.

Table 1. Locations, climate, soil type, rainfall and production systems of the study areas

Rainfed crop production system/ Location/ State	Agro-ecological sub region (AESR)	Climate	Soil type	Mean annual rainfall (mm)	Length of growing period (days)
Rice based production system					
1. Faizabad (Uttar Pradesh)	9.2	Subhumid	Alluvial-deep Inceptisols	1057	150-180
2. Phulbani (Orissa)	12.1	Subhumid	Red/yellow-deep Alfisols	1378	180-210
3. Ranchi (Jharkhand)	12.3	Subhumid	Red-shallow Alfisols	1299	180-210
Groundnut based production system					
4. Rajkot (Gujarat)	2.4	Arid	Black-medium deep Vertisols	615	60-120
5. Anantapur (Andhra Pradesh)	3.0	Arid	Red-shallow Alfisols	590	90-120
Soybean based production system					
6. Indore (Madhya Pradesh)	5.2	Semi arid	Black-deep Vertisols	944	120-150
7. Rewa (Madhya Pradesh)	10.3	Subhumid	Black-medium deep-deep Vertisols	1087	150-180
Cotton based production system					
8. Akola (Maharashtra)	6.3	Semi arid	Black-medium deep-deep Vertic Inceptisols/ Vertisols	825	120-150
9. Kovilpatti (Tamil Nadu)	8.1	Semi arid	Black-deep Vertisols	743	90-120
Rabi sorghum based production system					
10. Bellary (Karnataka)	3.0	Semi arid	Black-medium deep-very deep Vertisols	500	90-120
11. Bijapur (Karnataka)	3.0	Semi arid	Black-medium deep-deep Vertisols	680	90-120
12. Solapur (Maharashtra)	6.1	Semi arid	Black-medium deep-deep Vertic/ Vertisols	723	90-120

Pearlmillet based production system					
13. Agra (Uttar Pradesh)	4.1	Semi arid	Alluvial-very deep Inceptisols	665	90-120
14. Hisar (Haryana)	2.3	Arid	Alluvial-very deep Aridsols	412	60-90
15. Sardar Krishinagar (Gujarat)	2.3	Arid	Desert-very deep Aridisols	550	60-90
Fingermillet based production system					
16. Bangalore (Karnataka)	8.2	Semi arid	Red-very deep Alfisols	926	120-150
Maize based production system					
17. Arjia (Rajasthan)	4.2	Semi arid	Black-medium deep Vertic Inceptisols/ Vertisols	656	90-120
18. Hoshiarpur (Punjab)	9.1	Semi arid	Alluvial-deep- Inceptisols	1000	120-150
19. Rakh Dhiansar (Jammu & Kashmir)	14.2	Subhumid	Alluvial-deep Inceptisols	1180	150-210

Results and Discussion

Soil properties: Various soil properties in terms of mean and range of each profile are presented in Table 2. Soils of Phulbani, Anantapur and Bangalore were slightly to moderately acidic and remaining sixteen profiles were neutral to alkaline. Electrical conductivity of most of the soil profiles under different production systems was normal except at Hisar, Agra and Bijapur where higher salinity levels were observed. Soils of Akola, Kovilpatti, Bellary, Bijapur, Rajkot and Indore were calcareous where as soils at other locations showed less than 5 per cent $CaCO_3$. Majority of the soils in these rainfed regions were low in organic carbon except surface layers (0-15 cm) of Indore (0.68%), Ranchi (0.62%), Rakh Dhiansar (0.56%), Faizabad and Hoshiarpur (0.52%). All other profiles showed less than 0.5 per cent organic carbon. Profile mean organic carbon content at all 19 locations was less than 0.50 per cent (Table 2).

In rainfed rice based production system, all the three profiles at Faizabad, Phulbani and Ranchi showed mean clay content above 30 per cent. In groundnut system, Vertisol of Rajkot showed profile mean about 60 per cent. Similarly under pearlmillet and maize production systems, profile mean clay content was above 30 per cent except in the soils at Hisar, S.K.Nagar, Arjia, Hoshiarpur and Rakh Dhiansar. Wide variations were observed in CEC amongst soils under each production system. Generally higher CEC was observed in black soils than other soil types. In most of the profiles, CEC followed the trend similar to clay content. Among locations studied, Akola soils showed the highest CEC followed by Indore and Solapur.

Available Nutrients

Macronutirents

Nitrogen: Ranges and means of available nutrients (Table 3) indicated that available N status of all the soil profiles except surface layer of Indore was low (Fig.1a). However, profile mean values of available N were low at all the 19 locations. Vertisols of Rajkot, Kovilpatti, Bellary, Bijapur, Solapur and Entisols at S.K.Nagar showed available N below 100 kg ha^{-1} indicating the severe deficiency of available nitrogen in these soils. Organic matter is the major source of N in soils and as most soils in rainfed regions were very low in organic matter. Available nitrogen was also low. Low level of soil N is primarily attributed to climate, soil temperature regime and cropping systems prevalent in the area. Jenny and Raychaudhari (1960) observed that N and carbon losses were more pronounced in areas having dry climates/hot temperature. In most of the profiles, surface soils showed higher available N and decreased with depth. About 63 per cent of the total districts surveyed in India were low in available N while 33 per cent were

Table 2. Physio chemical properties of soil profiles under diverse rainfed crop production systems

Production system/ location	pH (1:2)	EC (dSm^{-1})	$CaCO_3$ (%)	OC (%)	Particle size (%)			CEC cmol (p^+) kg^{-1}
					Sand	Silt	Clay	
Rice based production system								
Faizabad	7.5-8.3* (8.1)**	0.10-0.61 (0.29)	0.46-1.88 (1.10)	0.08-0.52 (0.18)	26.1-32.1 (28.5)	28.0-38.0 (32.0)	29.9-43.9 (39.3)	21.7-29.3 (25.9)
Phubani	5.2-6.5 (6.0)	0.02-0.07 (0.02)	0.11-0.62 (0.38)	0.06-0.24 (0.12)	46.6-66.6 (55.4)	10.0-14.0 (11.1)	19.4-43.4 (33.4)	8.6-15.6 (13.2)
Ranchi	6.1-7.6 (6.9)	0.04-0.05 (0.05)	0.30-1.76 (1.09)	0.13-0.62 (0.28)	35.4-61.4 (43.5)	17.0-20.0 (18.4)	20.6-46.6 (38.0)	18.9-31.7 (28.8)
Groundnut based production system								
Rajkot	7.8-8.5 (8.1)	0.08-0.12 (0.10)	5.82-12.96 (8.45)	0.10-0.52 (0.38)	19.3-33.5 (26.5)	10.0-14.0 (12.1)	56.5-66.7 (61.3)	21.1-34.7 (28.5)
Anantapur	6.5-6.9 (6.8)	0.03-0.13 (0.09)	0.98-4.90 (3.19)	0.16-0.19 (0.17)	55.6-69.6 (60.5)	6.0-12.0 (9.1)	24.6-37.3 (30.3)	10.8-13.7 (13.0)
Soybean based production system								
Indore	7.8-8.0 (7.9)	0.19-0.39 (0.24)	4.30-4.91 (4.64)	0.57-0.68 (0.61)	2.9-12.0 (7.5)	24.0-32.5 (30.1)	60.0-66.2 (62.6)	51.0-55.8 (53.5)
Rewa	7.3-7.6 (7.4)	0.05-0.18 (0.10)	0.57-1.06 (0.78)	0.11-0.23 (0.17)	26.7-29.6 (28.0)	22.8-24.0 (23.2)	47.4-49.4 (48.7)	20.8-22.1 (21.4)
Cotton based production system								
Akola	8.2-8.5 (8.3)	0.11-0.14 (0.13)	18.1-20.3 (19.0)	0.12-0.25 (0.18)	18.1-20.8 (18.8)	16.0-20.0 (19.1)	60.2-65.9 (62.2)	59.3-61.4 (60.4)
Kovilpatii	7.9-8.1 (8.01)	0.26-2.60 (0.80)	9.70-12.5 (11.25)	0.26-0.45 (0.36)	28.0-32.1 (29.81)	5.0-6.0 (5.85)	61.9-66.0 (64.38)	52.2-55.4 (53.6)
Rabi sorghum based production system								
Bellary	8.2-8.9 (8.7)	0.21-0.72 (0.33)	14.5-17.9 (15.8)	0.18-0.30 (0.22)	15.9-23.5 (20.4)	10.0-16.0 (13.1)	61.5-70.1 (66.4)	27.4-30.0 (29.2)
Bijapur	8.5-8.8 (8.64)	0.24-2.85 (1.40)	18.5-20.9 (19.9)	0.14-0.37 (0.27)	7.3-32.4 (20.40)	12.0-26.0 (17.7)	55.6-66.7 (61.9)	29.4-37.7 (33.90)
Solapur	8.0-8.2 (8.1)	0.08-0.15 (0.12)	3.7-6.2 (5.37)	0.30-0.31 (0.30)	10.4-13.3 (11.47)	12.0-14.0 (13.57)	74.5-75.6 (74.86)	36.7-41.5 (39.53)
Pearlmillet based production system								
Agra	8.1-9.2 (8.7)	0.34-1.08 (0.68)	0.5-2.1 (1.6)	0.12-0.36 (0.19)	41.8-52.1 (45.5)	14.0-20.0 (17.4)	33.9-39.9 (37.0)	19.4-27.2 (25.1)
Hisar	7.1-7.9 (7.4)	0.25-3.60 (1.79)	0.5-1.2 (0.91)	0.11-0.19 (0.15)	42.1-66.1 (55.9)	14.0-24.0 (17.5)	19.9-33.9 (26.6)	12.7-22.8 (18.2)
S.K.Nagar	7.9-8.2 (8.0)	0.03-0.06 (0.04)	0.24-1.34 (1.09)	0.16-1.06 (0.43)	82.2-85.8 (84.1)	4.0-5.0 (4.1)	10.2-12.8 (11.7)	7.3-9.3 (8.3)

Finger millet based production system								
Bangalore	5.5-6.2 (5.81)	0.05-0.08 (0.07)	0.20-1.48 (0.93)	0.12-0.22 (0.16)	51.1-75.0 (57.5)	1.0-4.0 (3.3)	24.9-44.9 (39.2)	7.7-15.9 (11.76)
Maize based production system								
Arjia	8.1-8.6 (8.31)	0.12-0.18 (0.14)	2.15-4.70 (3.37)	0.14-0.47 (0.24)	50.9-78.9 (63.6)	8.0-16.0 (13.1)	13.1-33.1 (23.2)	10.0-27.4 (18.7)
Hoshiarpur	7.2-8.4 (7.8)	0.10-0.21 (0.13)	3.11-4.84 (3.94)	0.20-0.52 (0.36)	65.0-84.1 (72.1)	13.0-17.0 (14.2)	15.9-17.9 (16.8)	8.20-10.0 (9.46)
Rakh Dhiansar	6.9-7.6 (7.2)	0.03-0.11 (0.04)	2.20-2.85 (2.43)	0.32-0.56 (0.38)	77.1-82.1 (79.5)	5.0-8.0 (7.14)	11.9-18.1 (14.0)	5.25-7.28 (6.34)

* Range in the profile ** Profile mean

Table 3. Macronutrient status of various soil profiles under diverse rainfed production system

Production system/ Location	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Ca (me/100g)	Mg (me/100g)
Rice based production system						
Faizabad	102.2 – 151.5* (125.7)**	5.3 – 17.7 (8.4)	140.2 – 183.7 (160.3)	22.4 – 41.4 (32.5)	3.10 – 4.70 (3.71)	1.00 – 1.14 (1.09)
Phulbani	93.5 – 117.8 (104.8)	11.8 – 22.8 (14.5)	152.3 – 237.4 (195.1)	12.7 – 23.5 (19.0)	0.31 – 3.93 (2.02)	0.15 – 0.77 (0.40)
Ranchi	161.8 – 264.7 (215.5)	11.7 – 24.5 (17.4)	125.4 – 156.8 (138.8)	16.5 – 22.8 (19.3)	1.54 – 3.22 (2.77)	0.24 – 0.80 (0.65)
Groundnut based production system						
Rajkot	30.2 – 161.2 (93.5)	7.7 – 8.4 (8.0)	49.3 – 367.4 (188.8)	7.6 – 12.9 (9.6)	5.17 – 6.12 (5.69)	2.31 – 2.99 (2.83)
Anantapur	73.1 – 125.9 (103.6)	15.6 – 29.8 (19.6)	120.8 – 143.3 (129.2)	5.3 – 47.9 (23.1)	4.43 – 5.94 (5.33)	0.66 – 0.84 (0.74)
Soybean based production system						
Indore	193.2 – 288.4 (243.9)	7.8 – 12.4 (9.0)	248.2 – 362.8 (322.3)	16.5 – 34.2 (22.7)	6.59 – 6.98 (6.72)	1.14 – 1.19 (1.17)
Rewa	60.1 – 166.6 (113.9)	7.7 – 10.5 (9.0)	336.0 – 506.2 (407.5)	28.0 – 50.4 (40.2)	5.44 – 5.86 (5.70)	2.22 – 2.75 (2.60)
Cotton based production system						
Akola	96.6– 125.8 (116.2)	5.3 – 7.4 (6.3)	35.8 – 161.3 (76.7)	16.1 – 19.0 (17.5)	6.60 – 6.84 (6.76)	1.14 – 1.19 (1.17)
Kovilpatti	58.9 – 144.2 (86.3)	4.9 – 7.4 (6.7)	210.5 – 474.8 (272.3)	77.2 – 92.2 (87.4)	6.28 – 7.05 (6.72)	1.11 – 1.19 (1.16)

Rabi sorghum based production system						
Bellary	32.5 – 60.9 (44.0)	8.1 – 8.7 (8.3)	304.6 – 483.8 (365.4)	16.8 – 32.4 (24.3)	5.47 – 5.90 (5.78)	2.56 – 2.82 (2.76)
Bijapur	52.8 – 66.4 (58.2)	8.2 – 11.8 (9.4)	318.1 – 488.3 (378.2)	52.6 – 88.4 (70.6)	5.66 – 6.09 (5.80)	2.94 – 3.03 (2.99)
Solapur	59.2 – 102.9 (73.7)	7.6 – 9.6 (8.0)	456.9 – 595.8 (500.4)	31.3 – 82.6 (41.2)	5.37 – 6.02 (5.73)	2.90 – 3.03 (2.94)
Pearlmillet based production system						
Agra	102.9 – 144.2 (123.6)	7.1 – 18.7 (10.4)	94.1 – 116.8 (103.1)	103.0 – 137.0 (127.7)	2.32 – 4.51 (3.46)	0.91 – 1.10 (1.02)
Hisar	68.9 – 191.9 (150.3)	8.5 – 32.4 (10.9)	143.3 – 206.1 (163.1)	57.5 – 172.0 (124.1)	1.62 – 7.40 (4.81)	0.33 – 0.64 (0.36)
S.K.Nagar	86.6 – 114.2 (98.4)	7.8 – 18.4 (11.6)	58.2 – 107.5 (85.1)	18.14 – 21.2 (19.6)	1.45 – 2.16 (1.85)	0.15 – 0.42 (0.32)
Fingermillet based production system						
Bangalore	82.8 – 120.5 (102.0)	48.6 – 145.2 (65.2)	40.3 – 98.1 (53.0)	40.5 – 66.7 (56.0)	0.97 – 1.53 (1.36)	0.07 – 0.46 (0.26)
Maize based production system						
Arjia	96.5 – 288.5 (182.6)	6.1 – 14.5 (8.5)	62.7 – 201.6 (109.4)	9.4 – 22.8 (16.0)	4.29 – 6.22 (5.41)	0.16 – 0.81 (0.44)
Hoshiarpur	65.2 – 215.7 (124.1)	9.6 – 18.1 (12.6)	35.8 – 134.4 (81.24)	2.3– 9.1 (4.7)	4.32 – 5.42 (4.99)	0.18 – 0.28 (0.22)
Rakh Dhiansar	94.1 – 154.3 (114.9)	10.3 – 15.9 (12.4)	44.8 – 71.6 (55.6)	17.9 – 23.5 (20.8)	0.93 – 1.44 (1.06)	0.13 – 0.24 (0.18)

* Range in the profile, ** Profile mean

under medium category (Ghosh and Hassan, 1980). Profile means of available N ranged from 104.6 to 215.5 kg ha^{-1} under rice based production system, 93.5 to 103.6 kg ha^{-1} under groundnut, 113.9 to 243.9 kg ha^{-1} under soybean, 86.3 to 116.2 kg ha^{-1} under rabi sorghum, 98.4 to 150.3 kg ha^{-1} under pearlmillet, 102.0 kg ha^{-1} under fingermillet and 114.9 to 182.6 kg ha^{-1} under maize based based production system.

Phosphorus: Phosphorus deficiency is widespread in soils of rainfed region. Surface soils of Rajkot, Akola, Solapur and Bellary showed deficiency in available P status (Fib.1b). Soils of Faizabad, Phulbani, Ranchi, Indore, Rewa, Kovilpatti, Bijapur, Agra, S.K.Nagar, Arjia, Hoshiarpur and Rakh Dhiansar were medium in available P and remaining soils had above 20 kg ha^{-1} available P. Alfisols of Bangalore showed exceptionally high buildup of available P. A wide variation in available P among soil types could be attributed to parent material, organic carbon content and management practices such as addition of P containing fertilizers. Profile mean

Fig. 1a. Available N status in surface layers (0-15 cm) at different locations under diverse rainfed production systems

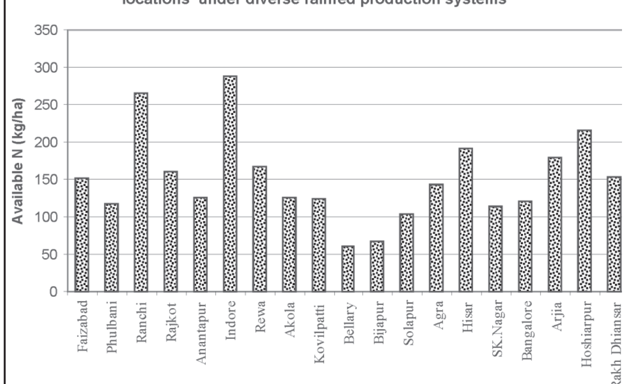
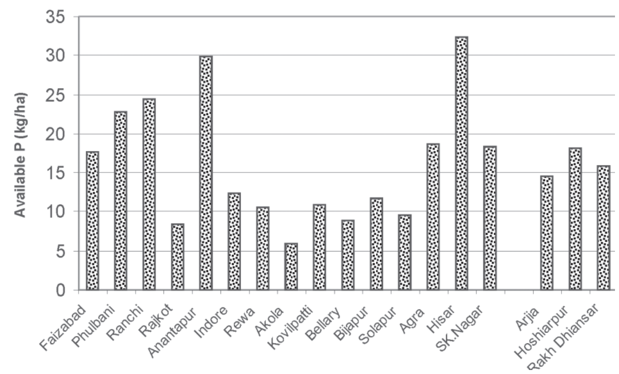


Fig. 1b. Available P status in surface layers (0-15 cm) at different locations under diverse production systems (Bangalore: 145 kg/ha)



available P content in all profiles except Bangalore was either low or medium. Mean available P status in the soil profile varied from 8.4 to 17.4 kg ha^{-1} under rice system, 8.0 to 19.6 kg ha^{-1} under groundnut system, 9 kg ha^{-1} under soybean system, 6.3 to 6.7 kg ha^{-1} under cotton system, 8.0 to 9.4 kg ha^{-1} under rabi sorghum system, 10.4 to 11.6 kg ha^{-1} under pearlmillet system, 65.2 kg ha^{-1} under fingermillet system and from 8.5 to 12.6 kg ha^{-1} under maize production. While reporting the P deficiency areas in India, Ghosh and Hassan (1979) stated that P deficiency was widespread, as soils in 98 per cent of the districts tested either low or medium in available P. An analysis of data from 24 districts, which account for 50 per cent of the total production of sorghum – a dryland crop, showed that 15 districts were low and 9 districts were medium in available P (Singh and Venkateswarlu, 1985).

Potassium: In rainfed agro ecosystems, the soils were characterized by low to high available K status. Surface soils of Agra, S.K.Nagar, Bangalore, Hoshiarpur and Rakh Dhiansar were low in K, Faizabad, Phulbani, Ranchi, Anantapur, Akola, Hisar and Arjia were medium and Rajkot, Indore, Rewa, Kovilpatti, Bellary, Bijapur and Solapur were high in avialable K (Fig. 2a). Potassium deficiency was noticed in coarse textured alluvial soils, red and lateritic and shallow soils and soils which supported continuous high yields without K addition (Srinivasarao, 2000). Vertisols and Vertic intergrades showed relatively high available K as compared to Inceptisols and Alfisols because of higher clay content and smectitic clay. Potassium status of different rainfed agroecological sub-regions of India (Subbarao and Srinivasarao, 1996) indicated that available K of rainfed regions varied from low to high depending upon soil type, parent material, texture, mineralogy and maneagement practices. Profile mean of available K varied from 138.8 to 195.1 kg ha^{-1} under rice based production system, 129.2 to 188.8 kg ha^{-1} under groundnut system, 322.3 to 407.5 kg ha^{-1} under soybean system, 76.7 to 272.3 kg ha^{-1} under cotton system, 365.4 to 500.4 kg ha^{-1} under rabi sorghm system, 85.1 to 163.1 kg ha^{-1} under pearlmillet system, 53.0 kg ha^{-1} under fingermillet and 55.6 to 109.4 kg ha^{-1} under maize based production system.

Secondary Nutrients

Sulphur: Surface soils of Faizabad, Rajkot, Akola, S.K.Nagar and Hoshiarpur were low and Phulbani, Ranchi, Indore, Bellary, Arjia and Rakh Dhiansar were medium in available S and remaining soils were high (Fig.2b). Profiles of Kovilpatti, Bijapur, Agra, Hisar, S.K.Nagar, Bangalore showed an increasing trend in available S with depth whereas in remaining profiles, there was decrease with depth. Because of low and medium status of sulphur in some of these regions, response of various crops to S application has been recorded (Srinivasa rao *et al*. 2001). Profile mean

Fig. 2a. Available K status in surface layers (0-15 cm) at different locations under diverse rainfed production systems

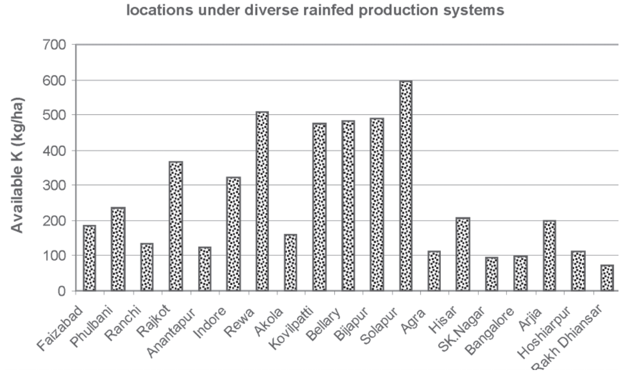
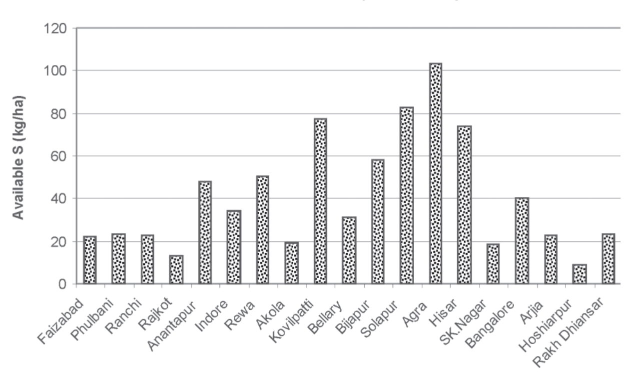


Fig. 2b. Available S status in surface layers (0-15cm) at different locations under diverse rainfed production systems



available sulphur varied 19.0 to 32.5 kg ha^{-1} under rice based production system, 9.6 to 23.1 kg ha^{-1} under groundnut, 22.7 to 40.2 kg ha^{-1} under soybean system 17.5 to 87.4 kg ha^{-1} under cotton system, 24.3 to 70.6 kg ha^{-1} under rabi sorghum, 19.6 to 127.7 kg ha^{-1} under pearlmillet, 56 kg ha^{-1} under fingermillet and from 4.7 to 20.8 kg ha^{-1} under maize based production system.

Calcium: Available Ca (exchangeable) status of dryland soils varied widely. Surface layers of several soil profiles were deficient in available Ca (< 1.5 me 100 g^{-1}) (Tiwari 1990) such as Phulbani, Anantapur, S.K.Nagar and Bangalore. Profile mean available Ca status varied from 2.02 to 3.71 me 100 g^{-1} under rice based production system, 5.33 to 5.69 me 100 g^{-1} under groundnut, 5.70 to 6.72 me 100 g^{-1} under soybean, 6.72 to 6.76 me 100 g^{-1} under cotton, 5.73 to 5.80 me 100 g^{-1} under rabi sorghum, 1.85 to 4.81 me 100 g^{-1} under pearlmillet, 1.36 me 100 g^{-1} under fingermillet and from 1.06 to 5.41 me 100 g^{-1} under maize based production systems.

Magnesium: Surface layers of soils at Phulbani, Ranchi, Anantapur, Agra, Hisar, S.K. Nagar, Bangalore, Arjia, Hoshiarpur and Rakh Dhiansar were Mg deficient (<1.0 me 100 g^{-1}). All these soils are light textured and leaching of exchangeable Mg is very common. Extreme Mg deficiency was observed at Alfisols of Bangalore (0.07 me 100 g^{-1}), Phulbani and Entisols of S.K.Nagar (0.15 me 100 g^{-1}), Rakh Dhiansar (0.13 me 100 g^{-1}) and Hoshiarpur (0.18 me 100 g^{-1}). Available Mg status (profile mean) varied from 0.40 to 1.09 me 100 g^{-1} under rainfed rice based production system, 0.74 to 2.83 me 100 g^{-1} under groundnut, 1.17-2.60 me 100 g^{-1} under soybean, 1.16 to 1.17 me 100 g^{-1} under cotton, 2.76 to 2.99 me 100 g^{-1} under rabi sorghum, 0.32 to 1.02 me 100 g^{-1} under pearlmillet, 0.26 me 100 g^{-1} under finger millet, and from 0.18 to 0.44 me 100 g^{-1} under maize based production system.

Relationship of available nutrients with soil properties: Relationship between various soil properties and available nutrient status in different soil types varied between significantly negative to significantly positive depending upon soil type, production system and also due to crop management practices being followed (Table 4). There was positive correlation of available N with organic carbon in all the soils and negative correlation with soil pH. Similarly P and K showed positive correlation with organic carbon in most of the profiles. Relationship between available K and clay and CEC varied from negative to positive. Calcium status showed positive correlation with clay and CEC.

Table 4. Coefficient of correlation(r) between available macronutrients and properties of soils under rainfed crop production systems

Soil property	Available nutrient					
	N	P	K	S	Ca	Mg
pH	-0.97 to +0.48*	-0.93 to +0.54	-0.96 to +0.42	-0.89 to +0.77	-0.90 to +0.83	-0.90 to 0.96
EC	-0.93 to +0.98	-0.84 to +0.93	-0.91 to +0.97	-0.89 to +0.93	-0.77 to +0.96	-0.88 to 0.86
$CaCO_3$	-0.98 to +0.90	-0.85 to +0.80	-0.97 to +0.92	-0.98 to +0.98	-0.94 to +0.98	-0.95 to 0.95
OC	+0.09 to +0.97	-0.25 to +0.99	-0.15 to +0.99	-0.92 to +0.98	-0.94 to +0.58	-0.95 to 0.92
Sand	-0.94 to +0.98	-0.76 to +0.90	-0.94 to +0.96	-0.96 to +0.87	-0.98 to +0.55	-0.94 to 0.84
Silt	-0.89 to +0.98	-0.95 to +0.98	-0.93 to +0.90	-0.97 to +0.99	-0.87 to +0.99	-0.96 to 0.86
Clay	-0.87 to +0.97	-0.96 to +0.94	-0.93 to +0.93	-0.78 to +0.96	-0.51 to +0.98	-0.75 to 0.96
CEC	-0.89 to +0.84	-0.97 to +0.78	-0.88 to +0.89	-0.88 to +0.98	-0.65 to +0.96	-0.87 to 0.98

Critical r value for significance at P(0.05)=0.75

***** Ranges are made based on r values obtained for individual profile

Acknowledgements

Authors are thankful to Chief Scientists and Scientists at different centers of AICRPDA and for their help in collecting soil samples.

References

Bray, R.H and L.T. Kurtz., 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Science, 59:39-45.

Ghosh.AB and R. Hasan, 1979. Phosphorus fertility status of soils of India. In "Phosphorus in soils , crops and fertilizers". Bulletin no.12, Indian Society of Soil Science,New Delhi .1-8.

Ghosh, A.B. and R. Hasan, 1980. Nitrogen fertility status of soils of India. Bulletin No.10. Indian Society of Soil Science, New Delhi.

Hanway, J.J., and H. Heidel, 1952. Soil analysis methods as used in Iowa State College Soil Testing Laboratory. Iowa. Agric., 27:1-13.

Jackso, M.L., 1973. Soil Chemical Analysis (Reprint). Prentice Hall of India Pvt. Ltd. New Delhi.

Jenny, H. and S.P. Raychaudhuri, 1960. Effect of climate and cultivation on nitrogen and organic matter resources in Indian soils. Indian Council of Agricultural Research, New Delhi.

Olsen,S R., C.V. Cole, F.S.Watanabe, and L A Dean, 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Circular, USDA.939.

Singh H.P., K.L. Sharma and B. Venkateswarlu, 1999. Fertilizer use in rainfed areas. Fertilizer News, 44 (5): 27- 30 & 33-38.

Singh, R.P. and J. Venkateswarlu, 1985. Fertilizer News, 30(4): 67-80.

Srinivasarao,Ch., K.K. Singh, and M. Ali, 2001. Sulphur: A key nutrient for higher pulse production. Fertilizer News, 46(10): 37-48.

Srinivasarao, Ch., A. Subba Rao and S.K. Bansal, 2000. Relationship of some forms of potassium with neutral normal ammonium acetate extractable K in mineralogically different benchmark soil series of India. Journal of Indian Society of Soil Science, 48:27-32.

Subbaiah, B.V. and G.L Asija 1956. A rapid procedure for the determination of available nitrogen in soils. Current Science. 25: 259-260.

Subba Rao, A., and Ch. Srinivasa Rao, 1996. *Potassium Status and Crop Response to Potassium in the Soils of Agro-ecological Regions of India*. IPI Research Topics No.20. International Potash Institute, Basel, Switzerland. pp 1-57.

Tiwari, K.N. 1990. Secondary nutrients-Scope in 90's In: Soil Fertility and Fertilizer Use Vol. IV, IFFCO, New Delhi. P.95.

Velayutham, M., D.K. Mandal, C. Mandal and J. Sehgal, 1999. Agroecological sub regions of India for planning and development. NBSS Publication 35, 372 p. NBSS & LUP, Nagpur.

Williams, C.H. and A.Steinbergs, 1959. Soil sulphur fractions as chemical indices of available sulphur in some Australian soils. Australian Journal of Agricultural Research.10: 342-352.