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# Categorisation of Districts Based on Nonexchangeable Potassium Implications in Efficient K Fertility Management in Indian Agriculture

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It has been well established that a significant proportion of plant needs of potassium (K) are met from nonexchangeable fraction of soil K (19, 21, 22, 23, 24, 42). Under intensive cropping, in the absence of K fertilisation, initially exchangeable K in soil contributes to plant K nutrition, but with further cropping exchangeable K attains a certain minimal level and thereafter, plant K removal from soil and contribution of nonexchangeable K to K uptake are almost synonymous and accounts for up to 90-95% of the total plant K uptake (26, 30, 36, 49, 55, 62). Due to larger contribution of nonexchangeable K to plant K needs, lack of crop responses to applied K have been reported even in soils with low exchangeable K. The major sources of nonexchangeable K in soils are K rich 2:1 clay minerals such as micas and vermiculite (3, 4, 5, 13, 14, 20). However, the release of K from the interlayer of these minerals may be very slow process depending upon the weathering stage of these minerals, and therefore, whether the K release rates of soils under cropping are in tune with plant K needs becomes the most important aspect as far as K nutrition of crop plants is concerned (25, 37, 42, 47).

India has 182 million ha cultivable land with 142.1 million ha net area sown and 121 million farmers. Among the states, Rajasthan has the largest portion of cultivable land followed by Maharashtra, Uttar Pradesh, Madhya Pradesh, Andhra

Pradesh, Karnataka and Gujarat. The earlier estimates of soil fertility for K based on data generated from soil testing laboratories in the country indicated discrepancies in the percentage of samples testing high, though the overall soil K fertility of soils declined (1, 8, 11, 58). Besides, existing categorization of soils based on available K status is not able to explain the crop response pattern in many regions of India. Therefore, it has become essential to look into soil dynamics under intensive production systems and confirm which K fraction in soil is predominantly contributing to crop K nutrition (15, 16, 56, 59, 60). It was also essential to examine whether imported K fertiliser is efficiently used in Indian agriculture and whether it is applied to right crop on right soil, where K application is a must.

It is worthwhile to note that even the most progressive and productive states like Punjab and Haryana, have most skewed  $N:P_2O_5:K_2O$  ratios. The focus has been on nitrogen followed by phosphorus and very little use of potassium resulting in a huge imbalance. In the year 2020, the deficit of K in Indian agriculture is projected to be around 10 million tonnes/annum while the estimates of N and P balances are positive (26, 28, 29, 31, 35, 52). There is obviously an urgent need for delineating the K deficient regions of the country district wise and assess the expected responses to applied K so that the K fertiliser management can

Recommendations of potassic fertiliser are made based on available (exchangeable + water soluble) K status of soils in different soil testing laboratories in India. However, recent studies employing a variety of measures of nonexchangeable K indicated a very substantial contribution of nonexchangeable fraction of soil K to crop K uptake. Present paper examines the information generated in the last 30 years on the status of nonexchangeable K in Indian soils, its contribution to crop K needs, categorization of Indian soils based on exchangeable and nonexchangeable K fractions and K recommendations considering both the fractions of soil K. Inclusion of nonexchangeable K in the soil testing aids in predicting immediate K needs of crop plants as well as long term K needs of intensive cropping systems. Based on published information on Indian soils, district wise maps were prepared for both exchangeable and nonexchangeable K and K deficient districts of the country were identified where K application is a must. Some maintenance dose of K is required in some districts where, exchangeable K is high but nonexchangeable K is low or medium. These maps and suggested recommendations help to prioritize the K efficient zones where K application is essential and higher possibility exists for improving the K use efficiency. Special care should be taken on K fertilisation on high K requirement crops like banana, sugarcane, potato, cotton, several cereals, tobacco, intensive fodder systems, vegetables and fruit crops. Therefore, inclusion of nonexchangeable K as a soil test in the soil testing laboratories for assessing long term K supplying capacity of Indian soils under intensive cropping systems and arriving at reliable K fertiliser recommendations is essential.

be taken up with emphasis on efficient use of K and the consequent economy in K use (23).

#### Scenario of K Fertiliser Use in India

Two most important K fertilisers are potassium chloride or muriate of potash (MOP) containing 60%  $K_2O$  and sulphate of potash (SOP) containing 50%  $K_2O$ . India has no deposits of K fertilisers and all of it has to be imported. During 2008-09, 2.6 million tonnes (mt) of  $K_2O$  (equivalent to 4.4 mt MOP) was consumed in India and by 2025 the amount of  $K_2O$  consumption may double to meet the foodgrain needs of the country. However, the major concern is the spiraling international price of MOP; it was US\$ 172 per tonne (fob Vancouver) in January 2007 and rose to US \$405-625 per

tonne in June 2008. Huge amount of foreign exchange is being used to import K fertiliser. This scenario underlines the need for using the costly K fertiliser judiciously and most economically considering the crop K needs and the soil K reserves (17, 18, 27, 39, 41).

#### Interpretation of Available K in Relation to Nonexchangeable K in Soil

Usually soils analysing less than 120  $kg\ ha^{-1}\ K$  (144  $kg\ K_2O$ ) are rated low in available K, between 120 and 280  $kg\ ha^{-1}\ K$  (144-336  $kg\ K_2O$ ) medium and above 280  $kg\ ha^{-1}\ K$  (336  $kg\ K_2O$ ) as high in available K (6). Unfortunately, these rating limits are irrespective of crops or soils. Solankey et al. (12) studied the response of two wheat varieties to potassium on farmers' fields in

swell-shrink soils. Though these soils were adequate in available K, crop responded to 30  $kg\ ha^{-1}\ K_2O$ . They have established a critical limit of 14.4  $kg\ K$  water-soluble K but failed to establish a critical limit based on ammonium acetate K. For delineation of fertility status, to isolate responsive soils from non-responsive ones and to recommend fertiliser K, critical limits for different crops in soils of various agroecological regions are needed. Information is provided about critical limits of available K in different crops on some well-defined soils (Table 1) (35). The data show a great diversity in the critical limits ranging from 48 to 137  $mg\ kg^{-1}$  soil. These results also indicate that for single crop, there is wide range of critical limits. For example, for rice, the critical limits based on available K varied from 58

**Table 1 - Critical levels of available (NH<sub>4</sub>OAc) K in different soils for different crops**

Crop	Soil and state	Critical level (mg kg <sup>-1</sup> )
Rice	Medium black soil (A.P.)	100
	Red soils (A.P.) Dubba & Chalka	75
	Light soils of Kodad (A.P.)	67.5
	Alluvial soils (A.P.)	190
	Rarha series, alluvial soil (U.P.)	117
	Uttari series, alluvial soils (U.P.)	120
	Calcareous soils (Bihar)	58
	Phondaghat series, lateritic soils (Maharashtra)	76
	Udic Ustochrepts, Uttari series (U.P.)	110
	Lateritic soils, Kumbhave series (Maharashtra)	86.6
	Fluventic Ustochrept (Orissa)	64
	Khaki series Typic Haplustalf (U.P.)	71
Wheat	Belar series, Vertic Haplaquept (West Bengal)	112
	Bankati series, Aeric Ochraqualf (West Bengal)	110
	Uttari series, Typic Ustochrepts (U.P.)	100
	Rarha series, alluvial soil (U.P.)	95
	Jagdishpur Bagha, calcareous soil (Bihar)	60
	Umendanda soil series (Bihar)	50
Maize	Puto series, Alfisol (Bihar)	48
	Khaki series, Typic Haplustalf (U.P.)	71
	Haplustalfs, Rajasthan	47
	Valuthalakudi series (Tamil Nadu)	71
Sorghum	Jagdishpur Bagha, calcareous soil (Bihar)	81
	Islamnagar series 3 & 4 (M.P.)	240
Pearl millet	Typic Chromusterts (Maharashtra)	335
	Medium black soil (A.P.)	95
	Black calcareous soils (Gujarat)	60
	Alluvial soils (A.P.)	160
Groundnut	Light soils of Kodad (A.P.)	60
	Black calcareous soils (Gujarat)	65
Potato	Sub montane soils (H.P.)	120
Cotton	Tulewal and Samana series, alluvial soils (Punjab)	50
Chickpea	Rarha series, alluvial soil (U.P.)	137
	Uttari series, Typic Ustochrepts (U.P.)	105

Source: Compiled from different sources

to 190 mg kg<sup>-1</sup> and for sorghum from 240 to 335 mg kg<sup>-1</sup>. Though crop requirements are fairly uniform across the regions but critical limits changed among soil types. It means, crop K requirement are fulfilled from not only available K but also soil reserve K (Tables 2 and 3), which is not accounted now in soil test based K recommendations (15, 33, 38, 43, 44, 48).

#### Substantial Contribution of Nonexchangeable K to Plant K Uptake

The contribution of nonexchangeable K to plant K uptake was worked out in both green house studies as well as in field experiments. It was indicated that the crops particularly cereals with well branched root system draw K from soil, majorly from nonexchangeable source. The contribution of nonexchangeable K from eight illitic soils (2, 9, 19, 22, 54, 57) during 245 days of exhaustive cropping with sudangrass was 70% in first harvest (during initial 35 days) and it reached the highest level of 90% between 2<sup>nd</sup> and 4<sup>th</sup> harvests

when exchangeable K attained minimal level. After reaching the minimal level of exchangeable K (Table 4), the pattern of crop K uptake and release of nonexchangeable K was almost identical (22, 57). Sachdeva and Khera (9) reported substantial contribution of nonexchangeable K to crop nutrition in illite dominant alluvial soils to the extent of 80-90%. In a field experiment, Talukdar and Khera (19, 50, 53, 63) showed that if only contribution from surface soils (0-15 cm) was taken into account the contribution of nonexchangeable K in plant K uptake by maize and pearl millet varied from 77.5-88.9%, whereas, if the contribution from 60 cm of soil was included, the nonexchangeable K contribution came down to the range to 54-76%. However, when the same soil was employed in a green house study, the contribution extended to 89% in both maize and bajra. Studies also showed that contribution of nonexchangeable K to crop removal decreased with increase in the level of applied K in wheat-sorghum (fodder) system on an alluvial soil.

Krishna Kumari et al. (2, 22) reported that wheat crop utilised about 86% of the total K uptake from nonexchangeable source. But this contribution was negligible when K fertiliser was applied. At higher levels of K application, there was a build up in the nonexchangeable K. In the case of pearl millet, when no K was applied, the crop utilized about 95% of the K from nonexchangeable source and it decreased to 59% at 53.5 mg K kg<sup>-1</sup> soil and to 13 and 22% at 107 and 160.5 mg K kg<sup>-1</sup> levels, respectively. The nonexchangeable K utilized by

**Table 2 - Some forms of nonexchangeable K in smectitic soils (mg kg<sup>-1</sup>)**

Soil Samples (30)	Form of K				Plant mobilisation rate of soil reserved K (kg ha <sup>-1</sup> day <sup>-1</sup> )
	6N H <sub>2</sub> SO <sub>4</sub>	NaTPB	Boiling 1N HNO <sub>3</sub>	EUf 30-35K	
Mean	273	658	842	144	1.20
Range	161-652	390-1720	500-1875	56-382	0.34-4.21
S.D.	141	338	391	97	1.01

**Table 3 - Cumulative nonexchangeable K released in different media of extraction (mg kg<sup>-1</sup>)**

Soil Series	0.01 M CaCl <sub>2</sub>		0.01 M Citric acid		0.01 M HCl	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
<i>Smectitic soils</i>						
Kamliakheri	165	131	152	135	142	120
Noyyal	518	392	668	616	473	380
Mean	342	262	410	376	308	250
<i>Illitic soils</i>						
Lukhi	105	84	163	135	94	77
Rarha	138	97	289	195	118	82
Mean	122	91	226	165	106	80
<i>Kaolinitic soils</i>						
Kodad	101	102	126	165	72	117
Vijayapura	66	62	71	80	35	39
Mean	83	82	99	123	54	78
Mean of six series	182	144	245	221	156	136

the rice plant grown in pots in the green house ranged from 40.8 to 95.2% under exhaustive cropping and when K fertiliser was applied the K utilized by rice from nonexchangeable source was found reduced (22). To an alfalfa crop when more potassium was applied through fertilisers, less potassium was released from nonexchangeable source. The literature cited above clearly brought out that especially in soils containing good amounts of micaceous minerals, the nonexchangeable content of the soils should duly be taken into account while recommending K fertiliser rates. The fertiliser rates to be applied get reduced in proportion to the amount of nonexchangeable K in micaceous minerals.

#### Geographical Information System (GIS) Based Maps for Exchangeable K and Nonexchangeable K

Geographic information systems (GIS) was used for categorising Indian districts into low, medium and high in terms of exchangeable and nonexchangeable K based on published information on K status in Indian soils during last 30 years, across districts and tried to derive the patterns or relation of the same with reference to AERS, AESR maps (NBSS& LUP, Nagpur)(10). Using Arcview 3.1, district wise maps of exchangeable and nonexchangeable K and boundaries of agroecological regions on these maps were imposed.

#### Categorisation of Districts as per their K Reserves and Availability

Data for exchangeable and nonexchangeable potassium (K) (mg kg<sup>-1</sup>) of different soil groups of various regions in India are obtained in excel tabular format. A new field "District id" for each region is added to the tables and converted into "dbf format" compatible for Arcview GIS and saved. The resulting tables were added to Arcview tables and linked to the table of districts shapefile using common field "Districts id". Using "Legend Editor" property districts shapefile is classified into three categories, low, medium and high by taking exchangeable K and nonexchangeable K as fields of classification. For deriving the maps for AESR and AERS for exchangeable K and nonexchangeable K, weighted average approach was followed for deriving a single unit value for the whole sub region, region as the case may be by unioning the maps of districts with sub region/region. For categorising soils for exchangeable K three levels were used viz., low (<50 mg kg<sup>-1</sup>), medium (50-120 mg kg<sup>-1</sup>) and high (>120 mg kg<sup>-1</sup>). For nonexchangeable K, the categories used were low (<300 mg kg<sup>-1</sup>), medium (300-600 mg kg<sup>-1</sup>) and high

**Table 4 - Effect of amount of clay and its relative illite content on total release of nonexchangeable K and K replenishment rate in eight soil series**

Soil Series	Clay (%)	Illite (%)	Boiling HNO <sub>3</sub> K (mg kg <sup>-1</sup> )	Total release of nonexchangeable K (mg kg <sup>-1</sup> )	K replenishment rate (kg ha <sup>-1</sup> day <sup>-1</sup> )	Contribution of Nonexchangeable K to total K uptake
Hamidpur	8.3	61.7	2030	314	2.98	73
Hissar	20.2	60.9	2040	352	3.36	77
Kakra	5.7	59.2	970	307	2.93	84
Thaska	6.2	50.9	1710	293	2.89	76
Manesar	10.0	53.7	1665	301	2.89	83
Khoh	10.3	53.7	1399	280	2.53	81
Palam	9.7	34.0	789	182	1.81	94
Mehrauli	13.2	53.4	1842	337	3.11	78



**Table 5 - Categorization of Indian soils based on exchangeable and nonexchangeable K reserves of soils**

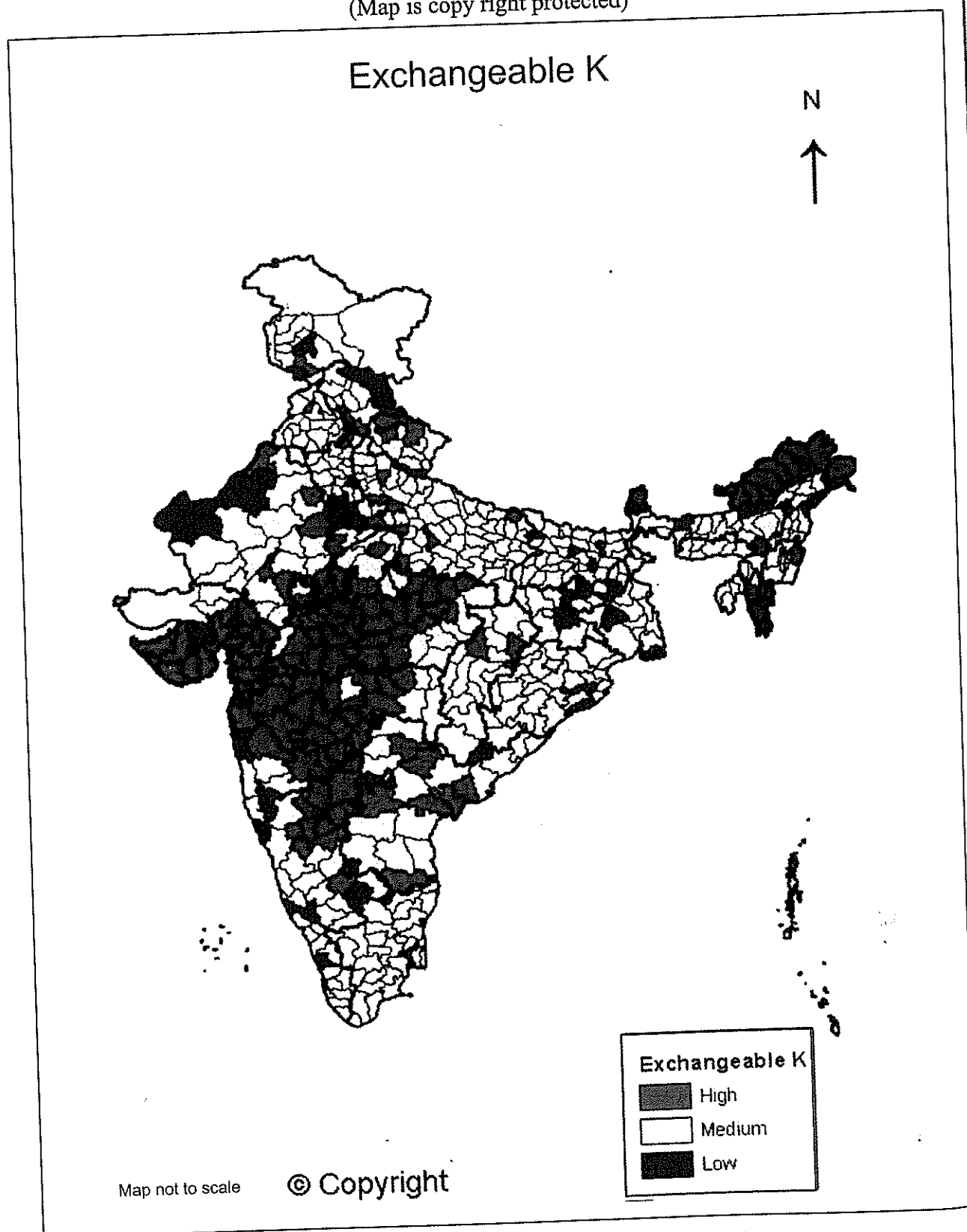
Cate gory	Ex K	Non Ex K	No of districts	Status (districts)	Recommen dations
I	L	L	15	GUJARAT (Surendranagar), JHARKHAND (Giridhi, Dumka, Hazaribagh, Ranchi), KARNATAKA (Bangalore(u), Bangalore), KERALA (Kasaragod, Thrissur), MAHARASTRA (Raigad), ORISSA (Cuttack, Puri), RAJASTHAN (Bikaner, Jaisalmer, Bharatpur)	K fertilization is must
II	L	M	18	ANDHRA PRADESH (Ranga Reddy), ASSAM (Jorhat, Sonipur, Kokrajhar), BIHAR (Gopalganj, Samastipur, Munger), HIMACHAL PRADESH (Lahul & Spiti), JAMMU AND KASHMIR (Anantnag, Pulwama, Jammu), KARNATAKA (KODAGU), ORISSA (Malkangiri), RAJASTHAN (Alwar, Dausa), WEST BENGAL (Bankura)	K fertilization is essential
III	L	H	2	BIHAR (Madhupura), Uttarakhand (Udhamsingh Nagar),	K additions at critical stages of crops improve yield levels.
IV	M	L	58	ANDHRA PRADESH (Nalgonda, Srikakulam, Vizianagaram), BIHAR (Araria, Champaran(East), Champaran(West), Nawadah, Saharsa), JHARKHAND (Sahebganj, Godda, Pashchimi Singhbhum, Purbi Singhbhum), KERALA (Kannur, Wayanad, Kozhikode, Mallapuram, Ernakulam, Idukki, Alappuzha, Pathanamthitta, Kollam), MAHARASTRA (Satara, Ratnagiri, Sindhudurg), NAGALAND (Tuensang, Mokokchung, Wokha, Kohima, Phek, Dimapur), ORISSA (Sundargarh, Mayurbhanj, Kendujhar, Jharsuguda, Baleswar, Debagarh, Anugul, Bhadrak, Dhenkanal, Jajapur, Bolangir, Naupada, Boudh, Kandhamal, Nayagarh, Khordha, Jaghatsinghapur, Kalahandi, Ganjam, Rayagada, Gajapati), RAJASTHAN (Siker, Barmer), WEST BENGAL (Birbhum, Purulia, Midnapur(West), South 24 Paraganas),	Continuous cropping needs K addition at critical stages as nonexchangeable K fraction does not contribute to plant K nutrition substantially.
V	M	M	115	ANDHRA PRADESH (Ananthapur, Nellore), ASSAM (Tinsukla, Dhemaji, Dibrugarh, N.Lakhimpur, Barpeta, Bongaigaon, Cachar, Darrang, Dhubri, Goalpara, Golaghat, Hailakandi, K. Anglong, Kamrup, Karimganji, Nagaon), BIHAR (Aurangabad, Banke, Begusarai, Bhagalpur, Buxar, Darbhanga, Gaya, Jahanabad, Jamui, Kaimur, Katihar, Khagaria, Kishan Ganj, Lakhai sarai, Madhubani, Muzaffarpur, Patna, Sheikh pura, Sitamarhi, Vaishali), CHATTISGARH (Bastar, Dantiwada, Janjigirchampa), DADRA&NAGAR HAVELI (Silvassa), DAMAN & DIU (Diu, Daman), GUJARAT (Kutch, Basantkanta, Patan), HARYANA (Rewari), HIMACHAL PRADESH (Chamba, Kangra, Kullu, Mandi, Una), JAMMU AND KASHMIR (Badgam, Baramala, Doda, Kargil, Kathua, Kupwara, Leh, Poonch, Rajauri), JHARKHAND (Bokarao, Chatra, Deoghar, Dhanbad, Garhwa, Gumla, Kodarma, Lohardaga, Pakaur), KARNATAKA (Belgaum, Chamerajanagar, Chikmagalur, Dhakshin Kannad, Hassan, Kolar, Mandya, Mysore, Shimoga, Udupi, Uttarkannada), KERALA (Palakkad, Kottayam, Trivandrum), LAKSHADWEEP (Lakshadweep), MADHYA PRADESH (Balaghat, Datia, Dindori, Mandla, Seoni, Shahdol, Sidhi, Tikamgarh), MAHARASTRA (Akola), MANIPUR (Bishnupur, Chandel, Churachandapur, Imphal(East), Imphal(West), Senapathi, Tamenglong, Thoubal), MEGHALAYA (Ribhoi, West Garo Hills, East Garo Hills, West Khasi Hill, Jaintia Hills, East Khasi Hill, South Garo Hills), MIZORAM (Kolasib), NAGALAND (Zunheboto), ORISSA (Sambalpur, Bargarh, Sonapur, Kendrapara, Nabarangapur, Koraput), PONDICHERRY (Yanam, Pondicherry, Karaikal), PUNJAB (Roopnagar, Chandigarh), RAJASTHAN (Ajmer, Bhilwara, Bundi, Churu, Dholpur, Dungarpur, Jalore, Udaipur), TAMILNADU (Thiruvallur, Madras, Vellore, Kancheepuram, Dharmapuri, Tiruvannamalai, Viluppuram, Erode, Cuddalore, Perambalur, Ariyalur, Nagapattinam, Namakkal, Pudukkottai, Sivaganga, Madurai, Theni, Virudhunagar, Toothukudi), UTTAR PRADESH (Gonda, Gorakhpur, Jaunpur), UTTARAKHAND (Garhwal, Almora), WEST BENGAL (Calcutta, Burdwan)	Maintenance doses of K may be required for intensive cropping systems

VI	M	H	172	<p>ANDHRA PRADESH (Adilabad, Cuddapah, East Godavari, Khammam, Kurnool, Medak, Nizamabad, Prakasam, Visakhapatnam), ASSAM (Sibsagar, Nalbari, Morigaon), BIHAR (Supaul, Sheohar, Saran, Siwan, Purnea, Bhojpur, Nalanda, Rohtas), CHATTISGARH (Dhamrati, Durg, Jashpur, Kanker, Kawardha, Korba, Koriya, Mahasamund, Raipur, Rajnandgaon, Sarguja), HARYANA (Bhiwani, Faridabad, Fatehabad, Gurgaon, Hissar, Jhajjar, Kaithal, Karnal, Mohindergarh, Panipat, Rohatak, Sirsa, Sonapat, Yamunanagar), HIMACHAL PRADESH (Hamirpur, Shimla), JAMMU AND KASHMIR (Srinagar), JHARKHAND (Palamau), KARNATAKA (Chitradurga, Devanagari), MADHYA PRADESH (Bhind, Jhabua, Morena, Neemurch, Sheopur, Shivpuri), MAHARASTRA (Bhandara, Chandrapur, Gadchiroli, Gandiya, Sangli), PUNJAB (Amritsar, Bhatinda, Faridkot, Fatehgarhsahib, Ferozepur, Gurdaspur, Hoshiarpur, Jullundur, Ludhiana, Mansa, Moga, Musktsar, Nawanshahr, Patiala, Sangrur), RAJASTHAN (Banswara, Hanumangarh, Jodhpur, Karauli, Nagaur, Pali, Sirohi, Tonk), TAMILNADU (Anna Dindigul, Coimbatore, Ramanathapuram, Salem, The Nilgiris, Thiruvavur, Tiruchirapalli, Tirunelveli), TRIPURA (North Tripura, Dhalai, West Tripura, South Tripura), UTTAR PRADESH (Allahabad, Ambedkar Nagar, Auraya, Azamgarh, Badaun, Bahraich, Bal, Ballia, Banda, Barabanki, Bareilly, Basti, Bhagpat, Bijnor, Bullandshahr, Chandauli, Chitrakut, Deoria, Faizabad, Farrukhabad, Fatehpur, Ghaziabad, Ghazipur, Goutambudda Nagar, Hamirpur, Hardoi, Hatraspur, Jalaun, Kanno, Kanpur Dehat, Kaushambi, Kheri, Kushi Nagar, Lalitpur, Lucknow, Mahoba, Mainpuri, Mathura, Mau, Meerut, Mirzapur, Moradabad, Muzaffarnagar, Pilibhit, Pratapgarh, Rae Bareilly, Rampur, Saharanpur, Sant Kabir Nagar, Sant Ravidas Nagar, Shahjahanpur, Shrawasti, Sidharth Nagar, Sitapur, Sonbhadra, Sultanpur, Unnao), UTTARAKHAND (Bageswar, Champawat, Dehradun, Haridwar, Nainital, Pithoragarh, Rudrapur), WEST BENGAL (24 Paraganas (North), Cooch Behar, Darjeeling, Haora, Hooghly, Jalpaiguri, Malda, Murshidabad, Nadia, Uttar Dinagpur)</p>	Crops may not need immediate K additions.
VII	H	L	1	RAJASTHAN (Jaipur)	Long term cropping would need K additions after few years
VIII	H	M	24	<p>ANDHRA PRADESH (Chittoor, Mehbubnagar, Warangal), ASSAM (N.C.Hills), CHATTISGARH (Bilaspur), GUJARAT (Ahmedabad, Amreli, Rajkot, Valasad), KARNATAKA (Bijapur, Tumkur), MADHYA PRADESH (Indore, Panna, Umaria), MAHARASTRA (Amaravati), MIZORAM (Aizawl, Chhimiup, Lawangtlai, Lunglei, Mamit, Saina, Serchhip), NAGALAND (Mon), SIKKIM (Sikkim East),</p>	K application is not required immediately.
IX	H	H	129	<p>ANDHRA PRADESH (Guntur, Karimnagar, Krishna, West Godavari), ARUNACHAL PRADESH (Changuang, Dibang Valley, East Kameng, East Siang, Lohit, Lower Subansiri, Papum Pari, Taksang, Tirap, Upper Siang, Upper Subansiri, West Kameng, West Siang), CHATTISGARH (Raigarh), GOA (North Goa, South Goa), GUJARAT (Amreli, Anand, Bhavanagar, Broach/Bharuch, Dhod, Gandhi Nagar, Jamnagar, Junagad, Kheda, Mehsana, Narmada, Panchmahal, Porbandar, Sabarkanta, Surat, The Dangs, Vadodara), HARYANA (Panchakula, Ambala, Kurukshetra), HIMACHAL PRADESH (Bilaspur, Solan, Sirmour), JAMMU AND KASHMIR (Udhampur), KARNATAKA (Bagalkot, Bellary, Bidar, Dharwad, Gadage, Gulbarga, Haveri, Koppal, Raichur), MADHYA PRADESH (Barwani, Betul, Bhopal, Chhatarpur, Chhindwara, Damoh, Dewas, Dhar, East Nimar, Guna, Gwalior, Harda, Hoshangabad, Jabalpur, Katni, Mandsaur, Narsimhpur, Raisen, Rajgarh, Ratlam, Rewa, Sagar, Satna, Sehore, Shajapur, Ujjain, Vidisha, West Nimar), MAHARASTRA (Ahmednagar, Amaravati, Aurangabad, Beed, Buldhana, Dhule, Hingoli, Jalgaon, Jalna, Latur, Mumbai, Nagpur, Nanded, Nandurbar, Nasik, Osmanabad, Parbhani, Pune, Solapur, Thane, Wardha, Washim, Yavatmal), MANIPUR (UKHRUL), PUNJAB (Kapurthala), RAJASTHAN (Baran, Chittorgarh, Ganganagar, Jhalawar, Jhunjhunu, Kota, Rajsmand, Sawai Madhopur), SIKKIM (Sikkim North, Sikkim West, Sikkim South), TAMILNADU (Thanjavur), UTTAR PRADESH (Agra, Aligarh, Etah, Etawah, Jhansi, Jyotibaphulenagar, Kanpur Nagar, Maharajgunj), UTTARAKHAND (Uttar Kashi, Chamoli, Tehri Garhwal),</p>	K application is not required.

Exchangeable K: Low=<50 mg kg<sup>-1</sup>, Medium= 50-120 mg kg<sup>-1</sup>, High=>120 mg kg<sup>-1</sup>  
Nonexchangeable K: Low=<300 mg kg<sup>-1</sup>, Medium= 300-600 mg kg<sup>-1</sup>, High=>600 mg kg<sup>-1</sup>

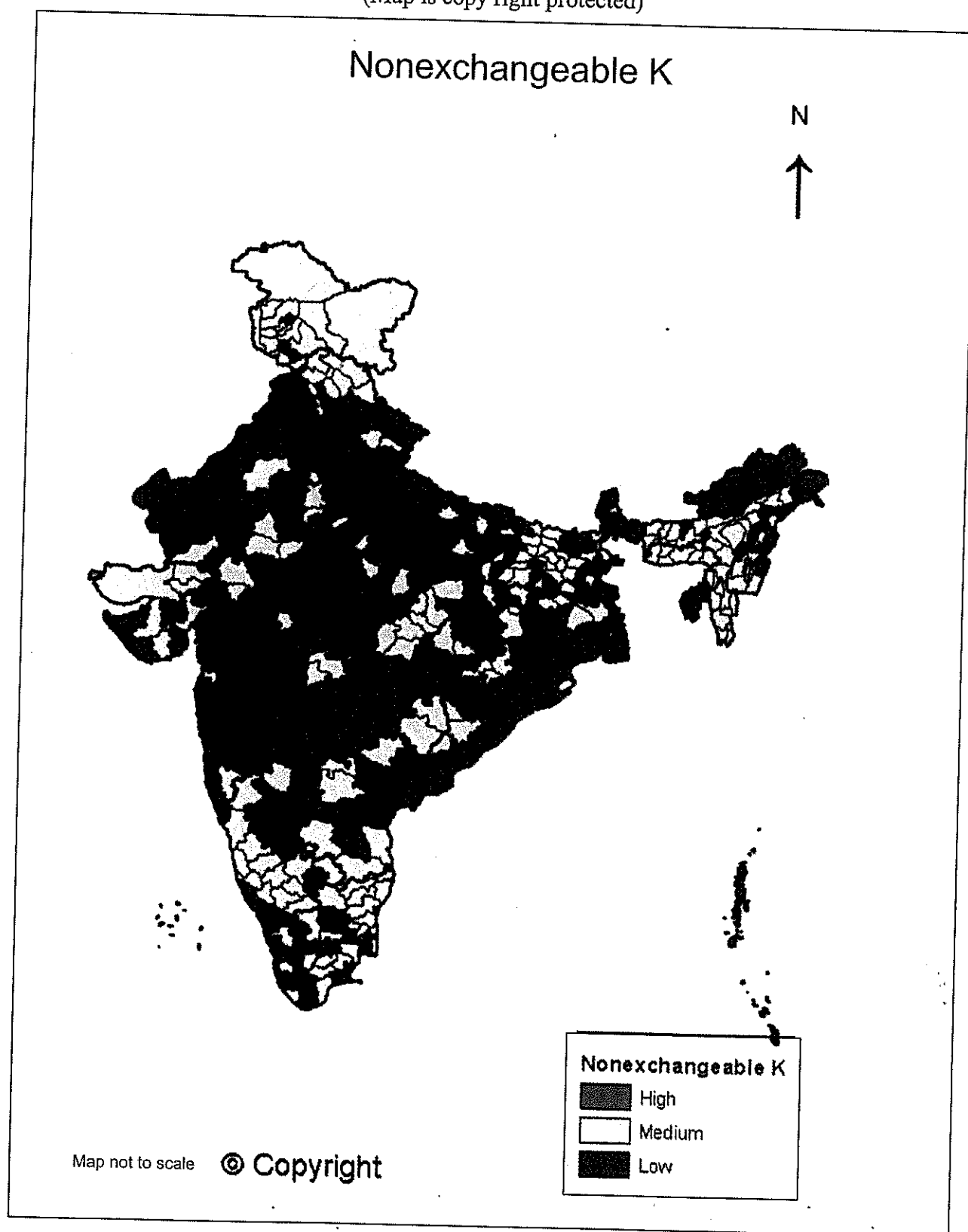


Map 1. District wise exchangeable K status of Indian soils  
(Map is copy right protected)



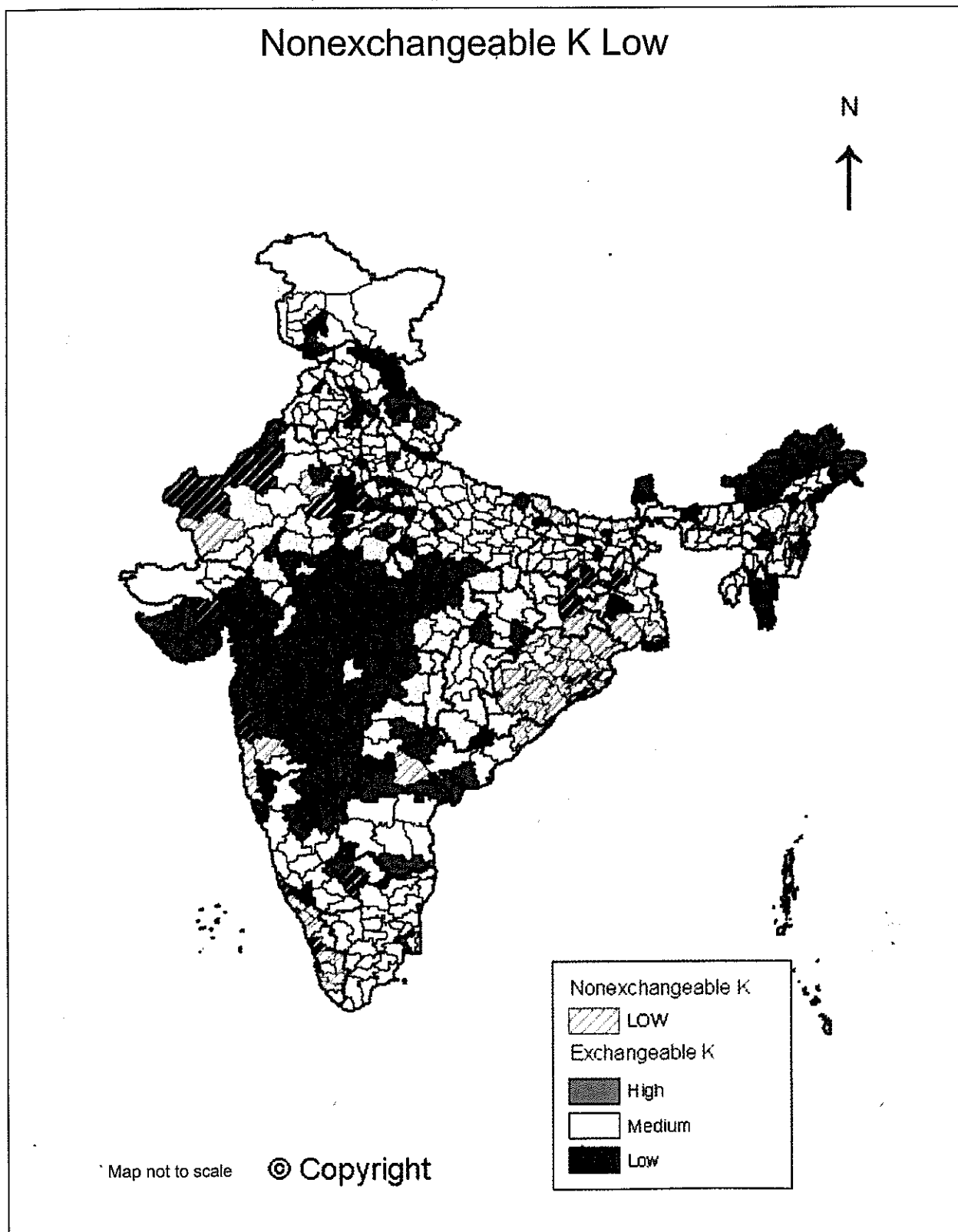


Map 2. District wise nonexchangeable K status of Indian soils  
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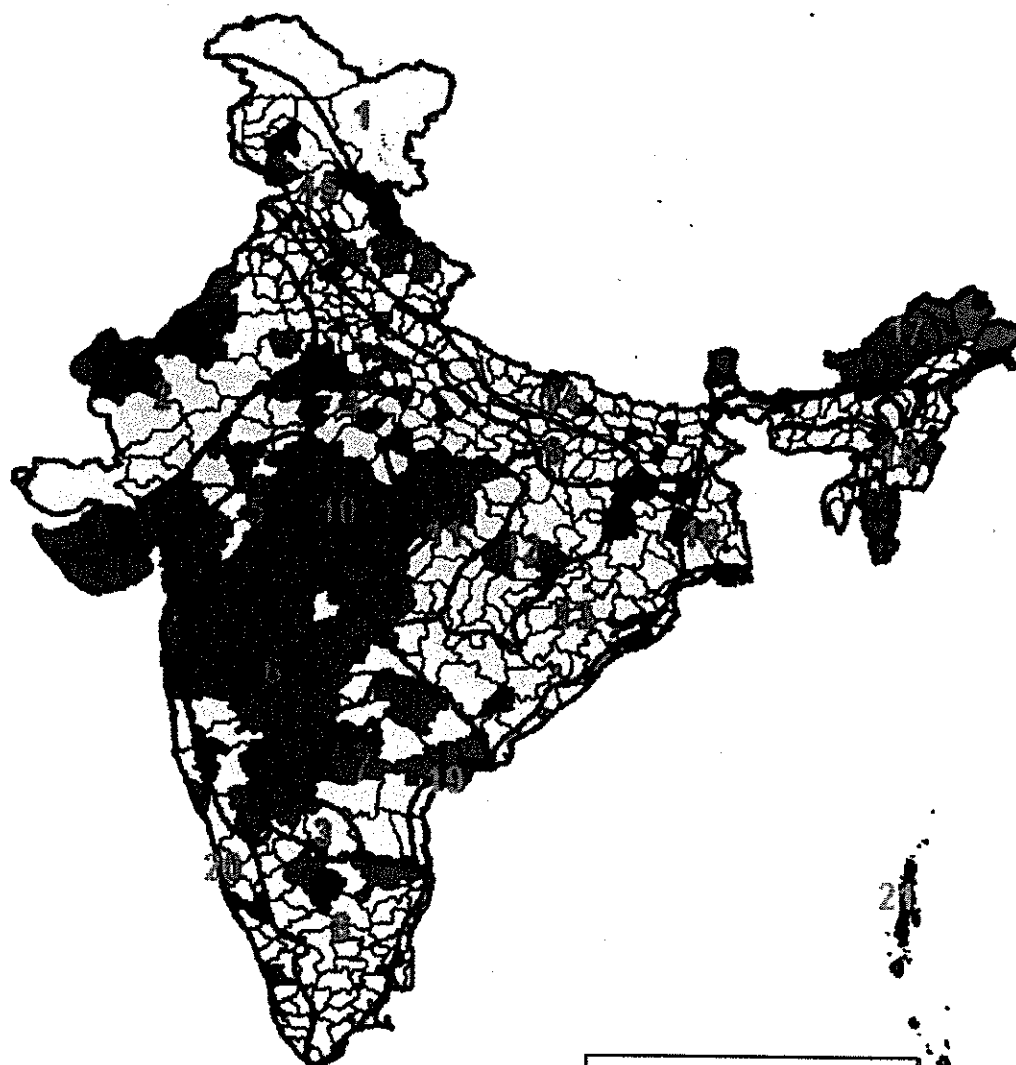
Map 3. Districts with low nonexchangeable K super imposed on exchangeable K map (Map is copy right protected)



Map 4. Exchangeable K status in different agroecological regions of India  
(Map is copy right protected)

# Exchangeable K and Agro Ecological Region

N  
↑



## Agro Ecological Region

AEZ Region

## Exchangeable K

High

Medium

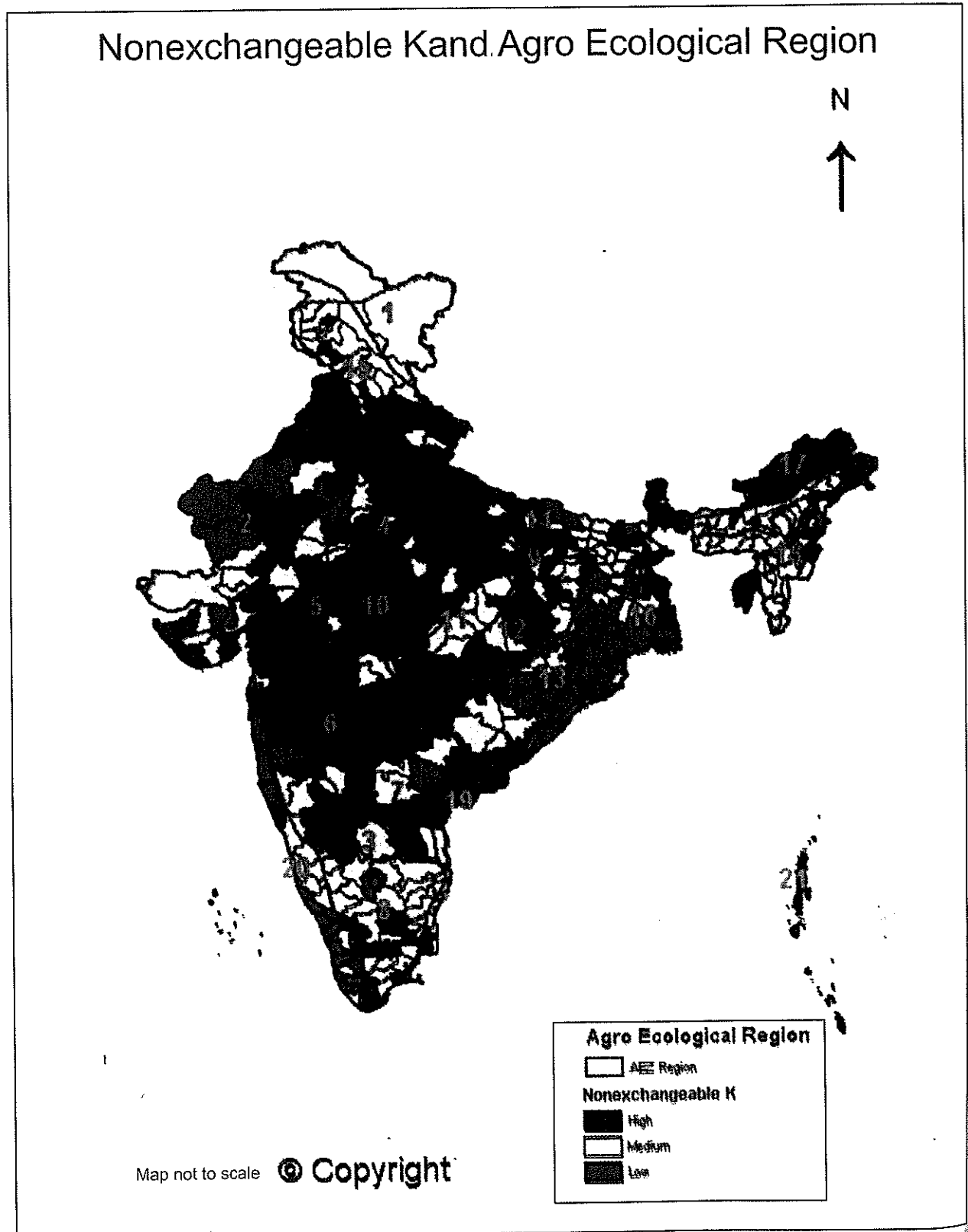
Low

Map not to scale

© Copyright



Map 5. Nonexchangeable K status in different agroecological regions of India  
(Map is copy right protected)





(>600 mg kg<sup>-1</sup>).

### Identification of K Efficient Districts for K Fertiliser Use

Based on above maps, districts were identified with low, medium and high in exchangeable as well as nonexchangeable K fractions (**Maps 1, 2, 3, 4 and 5**). Nine categories of districts were identified in combination of exchangeable and nonexchangeable K fractions (32, 34, 38, 45, 46, 55). Fifteen districts were identified where both exchangeable and nonexchangeable K status was low (Category I) (**Table 5**). These districts represent mostly red, lateritic soils, light textured and shallow soils. Since both the K fractions were low, K supply to crops grown on these soils is a must and therefore regular K fertilisation should be done considering crop K removal and the recommendations generated in the local university or ICAR institutes. Another 18 districts are categorized under Category II where exchangeable K was low while nonexchangeable K was medium. These soils also represent light textured and acidic alluvial soils. As exchangeable K was low and medium K reserves, regular K application is essential. Two districts under Category III, where exchangeable was low and nonexchangeable K was high, K addition at critical stages is required to improve the crop yields. Category IV covers 58 districts where exchangeable K medium and nonexchangeable low. These districts represent light textured alluvial, red and lateritic, acid sulfate and sandy soils. These soils need considerable attention from K management point of view. Continuous cropping on these soils result in depletion of soil reserve K, therefore, K addition at critical stages is required. If K demanding cropping systems like rice-wheat, rice-wheat-fodder, sunflower based, potato and other tuber crops, banana, intensive fodder and vegetables based systems are grown, regular additions of K is essential. Category V covers 115

districts of India, where both exchangeable and nonexchangeable K fractions were medium. These regions represent various types of soils from acid to alkaline, red, medium to deep black and alluvial. As both the fractions were medium, K additions are required for high value, quality (tobacco) and K exhaustive crops (sugarcane, potato etc.). Another 172 districts fall under Category VI, where exchangeable K was medium and nonexchangeable K was high. These districts represent variety of soils starting from heavy textured red soils, medium to deep black soils, heavy textured alluvial soils, high organic carbon Mollisols. Crops may not need immediate application of K unless specific K loving crops like banana and potato are grown. One district (Jaipur) falls under Category VII, where exchangeable K was high and nonexchangeable K was low. This district represents medium deep alluvial soils with less K bearing minerals. Long term intensive cropping would need some maintenance level of K. Category VIII covers 24 districts where exchangeable K was high and medium nonexchangeable K. These districts represent medium to deep black soils, fine textured alluvial and red soils with sufficient K rich mica. Potassium application is not required immediately. Category IX represents 129 districts where both exchangeable and nonexchangeable K was high. These soils represent deep black and fine textured alluvial soils and show higher long term K supplying power and do not require K application.

### Verification of the Categorisation of K Availability with Crop Responses

Above recommendations have been verified with existing crop response data published in these regions. Bangalore rural where both exchangeable and nonexchangeable K reserves were low (category I)

showed significant response to K in groundnut and ragi crops (7, 17, 51). Under long-term cropping at Bangalore rural, the decrease in exchangeable K was from 123 kg ha<sup>-1</sup> to 66 kg<sup>-1</sup> under NP treatment, observed severe yield decline in ragi and maize in subsequent years under 100 % N and 100 % NP with drastic depletion of soil reserve K (61). Similarly, in light textured alluvial soils where exchangeable K was low and nonexchangeable K was medium (category II), significant yield responses of various field crops were obtained due to K application (57, 64). In light textured Alfisols of Rangareddy district of Andhra Pradesh, sorghum responded significantly to added K (64). In soils of category III, while exchangeable K was low and nonexchangeable K was high, response of field crops to moderate amounts of K was obtained (64). In category IV soils where medium exchangeable K and low nonexchangeable K, crop response to K application was significant in later years of long term cropping (17). Similarly in several districts of Orissa, where nonexchangeable K is low, continuous rice-rice cultivation resulted in the significant response to K (17). Deep black and alluvial soils under category VIII and IX where high exchangeable K and medium to high nonexchangeable K, applied K to field crops was rare (35, 58).

### CONCLUSIONS

Above results suggest that soils of India vary widely in their K status as reflected by variations in readily available K and nonexchangeable K reserves. This exercise is first of its kind where two distinct fractions of K were involved in categorizing Indian soils for K fertility management and identified some districts as priority regions where regular K application is a must. However, the maps generated with available information using GIS technique, should be interpreted with some caution. At many locations, high levels of K reserves



in deeper layers indicate their substantial potential to supply K from sub-soil K to crop K nutrition under intensive systems of production. Alfisols and Oxisols and light textured Inceptisols were definitely low in soil K reserves. Inceptisols with higher ratio of nonexchangeable to exchangeable K, have larger reserves but lower readily available K and so need maintenance doses of K. Vertisols and associated soils with relatively low levels of this ratio have higher available K but low to medium nonexchangeable K which under long-term cropping, may get depleted faster. Soils were categorised by including nonexchangeable K along with exchangeable K, as contribution of nonexchangeable is substantial in K removals by different production systems. In soils with low levels of both exchangeable and nonexchangeable K, K application must be done to realise full yield potential of different cropping systems. Similarly, for different categories, K recommendations have been suggested based on soil K reserve status. This categorization of soils into different groups provides a comprehensive assessment of K supply for plant uptake and better recommendation of potash application. Fertiliser recommendations evolved on the basis of soil test calibration including both exchangeable and nonexchangeable K reserves and crop response studies carried out on soils classified should be extended immediately for crop K advisory purposes. This work resulted in the identification of the Indian districts where both the readily available and soil reserve K sources are low and where K application is essential. Where nonexchangeable K is low and medium in several districts, continuous cultivation of crops gradually results in soil K depletion and reduction in crop yields. Potassium fertiliser is not produced in India and its use is therefore completely import dependent. Government of India is spending a huge amount of foreign

exchange on importing K fertilisers. These costly imported K fertilisers should therefore be used more rationally, judiciously and efficiently. The K fertiliser material should be made available in the regions or districts where soil K reserves are low and high K requirement crops are grown during crop season at the village level.

#### FUTURE NEEDS OF WORK

- Use the maps generated and districts identified in the present study in prioritizing regions for K fertiliser use.
- Need to link up these maps with predominant crops/cropping systems being followed in the different districts or regions, so that further fine tuning to K recommendations can be evolved.
- Introduce the new methodology for estimating nonexchangeable K in all soil testing laboratories in India (40).
- Continuous monitoring of both K fractions (exchangeable and nonexchangeable) in different soil types under predominant cropping systems.
- Prepare balance sheets of soil potassium in different production systems and zones at least after every decade.
- For monitoring of K status/dynamics, and crop yield sustainability, new long term fertiliser experiments may be initiated in each of nine categories of soils suggested in the present paper considering predominant soil types and cropping systems.

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# Categorisation of Districts Based on Nonexchangeable Potassium Implications in Efficient K Fertility Management in Indian Agriculture

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It has been well established that a significant proportion of plant needs of potassium (K) are met from nonexchangeable fraction of soil K (19,21,22,23,24,42). Under intensive cropping, in the absence of K fertilisation, initially exchangeable K in soil contributes to plant K nutrition, but with further cropping exchangeable K attains a certain minimal level and thereafter, plant K removal from soil and contribution of nonexchangeable K to K uptake are almost synonymous and accounts for up to 90-95% of the total plant K uptake (26, 30, 36, 49, 55, 62). Due to larger contribution of nonexchangeable K to plant K needs, lack of crop responses to applied K have been reported even in soils with low exchangeable K. The major sources of nonexchangeable K in soils are K rich 2:1 clay minerals such as micas and vermiculite (3, 4, 5, 13, 14, 20). However, the release of K from the interlayer of these minerals may be very slow process depending upon the weathering stage of these minerals, and therefore, whether the K release rates of soils under cropping are in tune with plant K needs becomes the most important aspect as far as K nutrition of crop plants is concerned (25, 37, 42, 47).

India has 182 million ha cultivable land with 142.1 million ha net area sown and 121 million farmers. Among the states, Rajasthan has the largest portion of cultivable land followed by Maharashtra, Uttar Pradesh, Madhya Pradesh, Andhra

Pradesh, Karnataka and Gujarat. The earlier estimates of soil fertility for K based on data generated from soil testing laboratories in the country indicated discrepancies in the percentage of samples testing high, though the overall soil K fertility of soils declined (1, 8, 11, 58). Besides, existing categorization of soils based on available K status is not able to explain the crop response pattern in many regions of India. Therefore, it has become essential to look into soil dynamics under intensive production systems and confirm which K fraction in soil is predominantly contributing to crop K nutrition (15, 16, 56, 59, 60). It was also essential to examine whether imported K fertiliser is efficiently used in Indian agriculture and whether it is applied to right crop on right soil, where K application is a must.

It is worthwhile to note that even the most progressive and productive states like Punjab and Haryana, have most skewed N:P:O<sub>2</sub>:K<sub>2</sub>O ratios. The focus has been on nitrogen followed by phosphorus and very little use of potassium resulting in a huge imbalance. In the year 2020, the deficit of K in Indian agriculture is projected to be around 10 million tonnes/annum while the estimates of N and P balances are positive (26, 28, 31, 35, 52). There is obviously an urgent need for delineating the K deficient regions of the country district wise and assess the expected responses to applied K so that the K fertiliser management

Recommendations of potassic fertiliser are made based on available (exchangeable + water soluble) K status of soils in different soil testing laboratories in India. However, recent studies employing a variety of measures of nonexchangeable K indicated a very substantial contribution of nonexchangeable fraction of soil K to crop K uptake. Present paper examines the information generated in the last 30 years on the status of nonexchangeable K in Indian soils, its contribution to crop K needs, categorization of Indian soils based on exchangeable and nonexchangeable K fractions and K recommendations considering both the fractions of soil K. Inclusion of nonexchangeable K in the soil testing aids in predicting immediate K needs of crop plants as well as long term K needs of intensive cropping systems. Based on published information on Indian soils, district wise maps were prepared for both exchangeable and nonexchangeable K and K deficient districts of the country were identified where K application is a must. Some maintenance dose of K is required in some districts where, exchangeable K is high but nonexchangeable K is low or medium. These maps and suggested recommendations help to prioritize the K efficient zones where K application is essential and higher possibility exists for improving the K use efficiency. Special care should be taken on K fertilisation on high K requirement crops like banana, sugarcane, potato, cotton, several cereals, tobacco, intensive fodder systems, vegetables and fruit crops. Therefore, inclusion of nonexchangeable K as a soil test in the soil testing laboratories for assessing long term K supplying capacity of Indian soils under intensive cropping systems and arriving at reliable K fertiliser recommendations is essential.

be taken up with emphasis on efficient use of K and the consequent economy in K use (23).

#### **Scenario of K Fertiliser Use in India**

Two most important K fertilisers are potassium chloride or muriate of potash (MOP) containing 60%  $K_2O$  and sulphate of potash (SOP) containing 50%  $K_2O$ . India has no deposits of K fertilisers and all of it has to be imported. During 2008-09, 2.6 million tonnes (mt) of  $K_2O$  (equivalent to 4.4 mt MOP) was consumed in India and by 2025 the amount of  $K_2O$  consumption may double to meet the foodgrain needs of the country. However, the major concern is the spiraling international price of MOP; it was US\$ 172 per tonne (fob Vancouver) in January 2007 and rose to US \$405-625 per

tonne in June 2008. Huge amount of foreign exchange is being used to import K fertiliser. This scenario underlines the need for using the costly K fertiliser judiciously and most economically considering the crop K needs and the soil K reserves (17, 18, 27, 39, 41).

#### **Interpretation of Available K in Relation to Nonexchangeable K in Soil**

Usually soils analysing less than 120  $kg\ ha^{-1}\ K$  (144  $kg\ K_2O$ ) are rated low in available K, between 120 and 280  $kg\ ha^{-1}\ K$  (144-336  $kg\ K_2O$ ) medium and above 280  $kg\ ha^{-1}\ K$  (336  $kg\ K_2O$ ) as high in available K (6). Unfortunately, these rating limits are irrespective of crops or soils. Solankey et al. (12) studied the response of two wheat varieties to potassium on farmers' fields in

swell-shrink soils. Though these soils were adequate in available K, crop responded to 30  $kg\ ha^{-1}\ K_2O$ . They have established a critical limit of 14.4  $kg^{-1}\ K$  water-soluble K but failed to establish a critical limit based on ammonium acetate K. For delineation of fertility status, to isolate responsive soils from non-responsive ones and to recommend fertiliser K, critical limits for different crops in soils of various agroecological regions are needed. Information is provided about critical limits of available K in different crops on some well-defined soils (Table 1) (35). The data show a great diversity in the critical limits ranging from 48 to 137  $mg\ kg^{-1}$  soil. These results also indicate that for single crop, there is wide range of critical limits. For example, for rice, the critical limits based on available K varied from 58



**Table 1 - Critical levels of available (NH<sub>4</sub>OAc) K in different soils for different crops**

Crop	Soil and state	Critical level (mg kg <sup>-1</sup> )
Rice	Medium black soil (A.P.)	100
	Red soils (A.P.) Dubba & Chalka	75
	Light soils of Kodad (A.P.)	69.5
	Alluvial soils (A.P.)	190
	Rarha series, alluvial soil (U.P.)	117
	Uttari series, alluvial soils (U.P.)	120
	Calcareous soils (Bihar)	58
	Phondaghat series, lateritic soils (Maharashtra)	76
	Udic Ustochrepts, Uttari series (U.P.)	110
	Lateritic soils, Kumbhave series (Maharashtra)	86.6
	Fluventic Ustochrept (Orissa)	64
	Khatki series Typic Haplustalf (U.P.)	71
Wheat	Belar series, Vertic Haplaquept (West Bengal)	112
	Bankati series, Aeric Ochraqualf (West Bengal)	110
	Uttari series, Typic Ustochrepts (U.P.)	100
	Rarha series, alluvial soil (U.P.)	95
	Jagdishpur Bagha, calcareous soil (Bihar)	60
Maize	Umendanda soil series (Bihar)	50
	Puto series, Alfisol (Bihar)	48
	Khatki series, Typic Haplustalf (U.P.)	71
	Haplustalfs, Rajasthan	47
	Valuthalakudi series (Tamil Nadu)	71
Sorghum	Jagdishpur Bagha, calcareous soil (Bihar)	81
	Islamnagar series 3 & 4 (M.P.)	240
Pearl millet	Typic Chromusteris (Maharashtra)	335
	Medium black soil (A.P.)	95
	Black calcareous soils (Gujarat)	60
Groundnut	Alluvial soils (A.P.)	160
	Light soils of Kodad (A.P.)	60
Potato	Black calcareous soils (Gujarat)	65
	Sub montane soils (H.P.)	120
Cotton	Tulewal and Samana series, alluvial soils (Punjab)	50
Chickpea	Rarha series, alluvial soil (U.P.)	137
	Uttari series, Typic Ustochrepts (U.P.)	105

Source: Compiled from different sources

to 190 mg kg<sup>-1</sup> and for sorghum from 240 to 335 mg kg<sup>-1</sup>. Though crop requirements are fairly uniform across the regions but critical limits changed among soil types. It means, crop K requirement are fulfilled from not only available K but also soil reserve K (Tables 2 and 3), which is not accounted now in soil test based K recommendations (15, 33, 38, 43, 44, 48).

#### Substantial Contribution of Nonexchangeable K to Plant K Uptake

The contribution of nonexchangeable K to plant K uptake was worked out in both green house studies as well as in field experiments. It was indicated that the crops particularly cereals with well branched root system draw K from soil, majorly from nonexchangeable source. The contribution of nonexchangeable K from eight illitic soils (2, 9, 19, 22, 54, 57) during 245 days of exhaustive cropping with sudangrass was 70% in first harvest (during initial 35 days) and it reached the highest level of 90% between 2<sup>nd</sup> and 4<sup>th</sup> harvests

when exchangeable K attained minimal level. After reaching the minimal level of exchangeable K (Table 4), the pattern of crop K uptake and release of nonexchangeable K was almost identical (22, 57). Sachdeva and Khera (9) reported substantial contribution of nonexchangeable K to crop nutrition in illite dominant alluvial soils to the extent of 80-90%. In a field experiment, Talukdar and Khera (19, 50, 53, 63) showed that if only contribution from surface soils (0-15 cm) was taken into account the contribution of nonexchangeable K in plant K uptake by maize and pearl millet varied from 77.5-88.9%, whereas, if the contribution from 60 cm of soil was included, the nonexchangeable K contribution came down to the range to 54-76%. However, when the same soil was employed in a green house study, the contribution extended to 89% in both maize and bajra. Studies also showed that contribution of nonexchangeable K to crop removal decreased with increase in the level of applied K in wheat-sorghum (fodder) system on an alluvial soil.

Krishna Kumari et al. (2, 22) reported that wheat crop utilised about 86% of the total K uptake from nonexchangeable source. But this contribution was negligible when K fertiliser was applied. At higher levels of K application, there was a build up in the nonexchangeable K. In the case of pearl millet, when no K was applied, the crop utilized about 95% of the K from nonexchangeable source and it decreased to 59% at 53.5 mg K kg<sup>-1</sup> soil and to 13 and 22% at 107 and 160.5 mg K kg<sup>-1</sup> levels, respectively. The nonexchangeable K utilized by

**Table 2 - Some forms of nonexchangeable K in smectitic soils (mg kg<sup>-1</sup>)**

Soil Samples (30)	Form of K				Plant mobilisation rate of soil reserved K (kg ha <sup>-1</sup> day <sup>-1</sup> )
	6N H <sub>2</sub> SO <sub>4</sub>	NaTPB	Boiling 1N HNO <sub>3</sub>	EUF 30-35K	
Mean	273	658	842	144	1.20
Range	161-652	390-1720	500-1875	56-382	0.34-4.21
S.D.	141	338	391	97	1.01



**Table 3 - Cumulative nonexchangeable K released in different media of extraction (mg kg<sup>-1</sup>)**

Soil Series	0.01 M CaCl <sub>2</sub>		0.01 M Citric acid		0.01 M HCl	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
<i>Smectitic soils</i>						
Kamliakheri	165	131	152	135	142	120
Noyyal	518	392	668	616	473	380
Mean	342	262	410	376	308	250
<i>Illitic soils</i>						
Lukhi	105	84	163	135	94	77
Rarha	138	97	289	195	118	82
Mean	122	91	226	165	106	80
<i>Kaolinitic soils</i>						
Kodad	101	102	126	165	72	117
Vijayapura	66	62	71	80	35	39
Mean	83	82	99	123	54	78
Mean of six series	182	144	245	221	156	136

the rice plant grown in pots in the green house ranged from 40.8 to 95.2% under exhaustive cropping and when K fertiliser was applied the K utilized by rice from nonexchangeable source was found reduced (22). To an alfalfa crop when more potassium was applied through fertilisers, less potassium was released from nonexchangeable source. The literature cited above clearly brought out that especially in soils containing good amounts of micaceous minerals, the nonexchangeable content of the soils should duly be taken into account while recommending K fertiliser rates. The fertiliser rates to be applied get reduced in proportion to the amount of nonexchangeable K in micaceous minerals.

#### Geographical Information System (GIS) Based Maps for Exchangeable K and Nonexchangeable K

Geographic information systems (GIS) was used for categorising Indian districts into low, medium and high in terms of exchangeable and nonexchangeable K based on published information on K status in Indian soils during last 30 years, across districts and tried to derive the patterns or relation of the same with reference to AERs, AESR maps (NBSS& LUP, Nagpur)(10). Using Arcview 3.1, district wise maps of exchangeable and nonexchangeable K and boundaries of agroecological regions on these maps were imposed.

#### Categorisation of Districts as per their K Reserves and Availability

Data for exchangeable and nonexchangeable potassium (K) (mg kg<sup>-1</sup>) of different soil groups of various regions in India are obtained in excel tabular format. A new field "District id" for each region is added to the tables and converted into "dbf format" compatible for Arcview GIS and saved. The resulting tables were added to Arcview tables and linked to the table of districts shapefile using common field "Districts id". Using "Legend Editor" property districts shapefile is classified into three categories, low, medium and high by taking exchangeable K and nonexchangeable K as fields of classification. For deriving the maps for AESR and AERs for exchangeable K and nonexchangeable K, weighted average approach was followed for deriving a single unit value for the whole sub region, region as the case may be by unioning the maps of districts with sub region/region. For categorising soils for exchangeable K three levels were used viz., low (<50 mg kg<sup>-1</sup>), medium (50-120 mg kg<sup>-1</sup>) and high (>120 mg kg<sup>-1</sup>). For nonexchangeable K, the categories used were low (<300 mg kg<sup>-1</sup>), medium (300-600 mg kg<sup>-1</sup>) and high

**Table 4 - Effect of amount of clay and its relative illite content on total release of nonexchangeable K and K replenishment rate in eight soil series**

Soil Series	Clay (%)	Illite (%)	Boiling HNO <sub>3</sub> K (mg kg <sup>-1</sup> )	Total release of nonexchangeable K (mg kg <sup>-1</sup> )	K replenishment rate (kg ha <sup>-1</sup> day <sup>-1</sup> )	Contribution of Nonexchangeable K to total K uptake
Hamidpur	8.3	61.7	2030	314	2.98	73
Hissar	20.2	60.9	2040	352	3.36	77
Kakra	5.7	59.2	970	307	2.93	84
Thaska	6.2	50.9	1710	293	2.89	76
Manesar	10.0	53.7	1665	301	2.89	83
Khoh	10.3	53.7	1399	280	2.53	81
Palam	9.7	34.0	789	182	1.81	94
Mehrauli	13.2	53.4	1842	337	3.11	78

**Table 5 - Categorization of Indian soils based on exchangeable and nonexchangeable K reserves of soils**

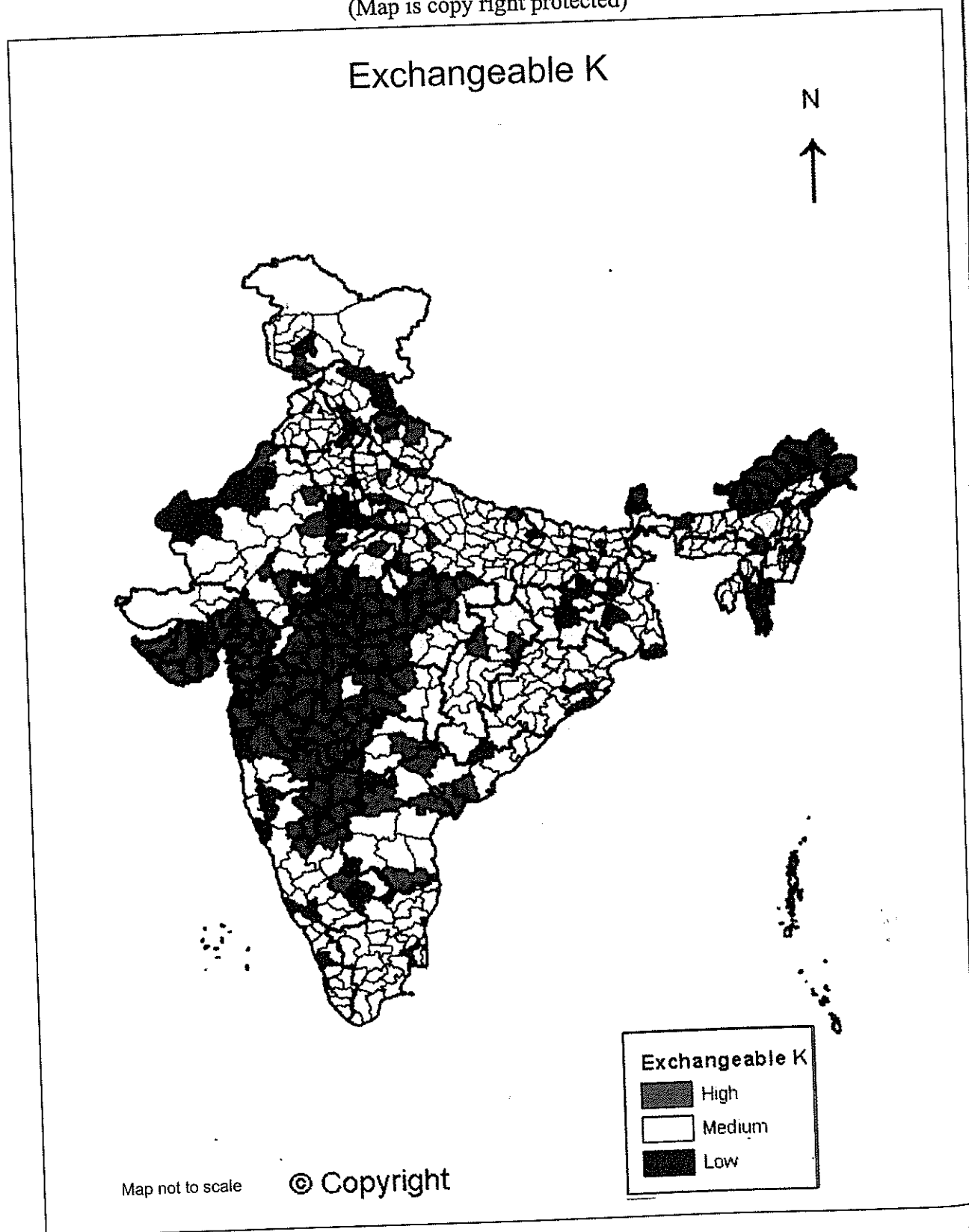
Cate gory	Ex K	Non Ex K	No of districts	Status (districts)	Recommen- dations
I	L	L	15	GUJARAT (Surendranagar), JHARKHAND (Giridhi, Dumka, Hazaribagh, Ranchi), KARNATAKA (Bangalore(u), Bangalore), KERALA (Kasaragod, Thrissur), MAHARASTRA (Raigad), ORISSA (Cuttack, Puri), RAJASTHAN (Bikaner, Jaisalmer, Bharatpur)	K fertilization is must
II	L	M	18	ANDHRA PRADESH (Ranga Reddy), ASSAM (Jorhat, Sonipur, Kokrajhar), BIHAR (Gopalganj, Samastipur, Munger), HIMACHAL PRADESH (Lahul & Spiti), JAMMU AND KASHMIR (Anantnag, Pulwama, Jammu), KARNATAKA (KODAGU), ORISSA (Malkangiri), RAJASTHAN (Alwar, Dausa), WEST BENGAL (Bankura)	K fertilization is essential
III	L	H	2	BIHAR (Madhupura), Uttarakhand (Udhamsingh Nagar),	K additions at critical stages of crops improve yield levels.
IV	M	L	58	ANDHRA PRADESH (Nalgonda, Srikakulam, Vizianagaram), BIHAR (Araria, Champaran(East), Champaran(West), Nawadah, Saharsa), JHARKHAND (Sahebganj, Godda, Pashchimi Singhbhum, Purbi Singhbhum), KERALA (Kannur, Wayanad, Kozhikode, Mallapuram, Ernakulam, Idukki, Alappuzha, Pathanamthitta, Kollam), MAHARASTRA (Satara, Ratnagiri, Sindhudurg), NAGALAND (Tuensang, Mokokchung, Wokha, Kohima, Phek, Dimapur), ORISSA (Sundargarh, Mayurbhanj, Kendujhar, Jharsuguda, Baleswar, Deogarh, Anugui, Bhadrak, Dhenkanal, Jajapur, Bolangir, Naupada, Boudh, Kandhamal, Nayagarh, Khordha, Jaghatsinghapur, Kalahandi, Ganjam, Rayagada, Gajapati), RAJASTHAN (Siker, Barmer), WEST BENGAL (Birbhum, Purulia, Midnapur(West), South 24 Paraganas),	Continuous cropping needs K addition at critical stages as nonexchangeable K fraction does not contribute to plant K nutrition substantially.
V	M	M	115	ANDHRA PRADESH (Ananthapur, Nellore), ASSAM (Tinsukla, Dhemaji, Dibrugarh, N.Lakhimpur, Barpeta, Bongaigaon, Cachar, Darrang, Dhubri, Goalpara, Golaghat, Hailakandi, K. Anglong, Kamrup, Karimganj, Nagaon), BIHAR (Aurangabad, Banke, Begusarai, Bhagalpur, Bunar, Darbhanga, Gaya, Jahanabad, Jamui, Kaimier, Katihar, Khagaria, Kishan Ganj, Lakhi sarai, Madhubani, Muzaffarpur, Patna, Sheikh pura, Sitamarhi, Vaishali), CHATTISGARH (Bastar, Dantiwada, Janjigirchampa), DADRA&NAGAR HAVELI (Silvassa), DAMAN & DIU (Diu, Daman), GUJARAT (Kutch, Basantkanta, Patan), HARYANA (Rewari), HIMACHAL PRADESH (Chamba, Kangra, Kullu, Mandi, Una), JAMMU AND KASHMIR (Badgam, Baramala, Doda, Kargil, Kathua, Kupwara, Leh, Poonch, Rajauri), JHARKHAND (Bokarao, Chatra, Deoghar, Dhanbad, Garhwa, Gumla, Kodarma, Lohardaga, Pakaur), KARNATAKA (Belgaum, Chamerajanagar, Chikmagalur, Dhakshin Kannad, Hassan, Kolar, Mandya, MysoreShimoga, Udupi, Utarkannada), KERALA (Palakkad, Kottayam, Triyandrum), LAKSHADWEEP (Lakshadweep), MADHYA PRADESH (Balaghat, Datia, Dindori, Mandla, Seoni, Shahdol, Sidhi, Tikamgarh), MAHARASTRA (Akola), MANIPUR (Bishnupur, Chandel, Churachandapur, Imphal(East), Imphal(West), Senapathi, Tamenglong, Thoubal), MEGHALAYA (Ribhoi, West Garo Hills, East Garo Hills, West Khasi Hill, Jaintia Hills, East Khasi Hill, South Garo Hills), MIZORAM (Kolasib), NAGALAND (Zunheboto), ORISSA (Sambalpur, Bargarh, Sonapur, Kendrapara, Nabarangapur, Koraput), PONDICHERRY (Yanam, Pondicherry, Karaikal), PUNJAB (Roopnagar, Chandigarh), RAJASTHAN (Ajmer, Bhilwara, Bundi, Churu, Dholpur, Dungarpur, Jalore, Udaipur), TAMILNADU (Thiruvallur, Madras, Vellore, Kancheepuram, Dharmapuri, Tiruvannamalai, Viluppuram, Erode, Cuddalore, Perambalur, Ariyalur, Nagapattinam, Namakkal, Pudukkottai, Sivaganga, Madurai, Theni, Virudhunagar, Toothukudi), UTTAR PRADESH (Gonda, Gorakhpur, Jaunpur), UTTARAKHAND (Garhwal, Almorah), WEST BENGAL (Calcutta, Burdwan)	Maintenance doses of K may be required for intensive cropping systems

VI	M	H	172	<p>ANDHRA PRADESH (Adilabad, Cuddapah, East Godavari, Khammam, Kurnool, Medak, Nizamabad, Prakasam, Visakhapatnam), ASSAM (Sibsagar, Nalbari, Morigaon), BIHAR (Supaul, Sheohar, Saran, Siwan, Purnea, Bhojpur, Nalanda, Rohtas), CHATTISGARH (Dhamrati, Durg, Jashpur, Kanker, Kawardha, Korba, Koriya, Mahasamund, Raipur, Rajnandgaon, Sarguja), HARYANA (Bhiwani, Faridabad, Fatehabad, Gurgaon, Hissar, Jhajjar, Kaithal, Karnal, Mohindergarh, Panipat, Rohtak, Sirsa, Sonapat, Yamunanagar), HIMACHAL PRADESH (Hamirpur, Shimla), JAMMU AND KASHMIR (Srinagar), JHARKHAND (Palamau), KARNATAKA (Chitradurga, Devanagari), MADHYA PRADESH (Bhind, Jhabua, Morena, Neemurch, Sheopur, Shivpuri), MAHARASTRA (Bhandara, Chandrapur, Gadchiroli, Gandiya, Sangli), PUNJAB (Amritsar, Bhatinda, Faridkot, Fatehgarhsahib, Ferozepur, Gurdaspur, Hoshiarpur, Jullundur, Ludhiana, Mansa, Moga, Musktisar, Nawanshahr, Patiala, Sangrur), RAJASTHAN (Banswara, Hanumangarh, Jodhpur, Karauli, Nagaur, Pali, Sirohi, Tonk), TAMILNADU (Anna Dindigul, Coimbatore, Ramanathapuram, Salem, The Nilgiris, Thiruvannamalai, Tiruchirappalli, Tirunelveli), TRIPURA (North Tripura, Dhalai, West Tripura, South Tripura), UTTAR PRADESH (Allahabad, Ambedkar Nagar, Aunriya, Azamgarh, Badaun, Bahraich, Bal, Ballia, Banda, Barabanki, Bareilly, Basti, Bhagpat, Bijnor, Bulandshahr, Chandauli, Chitrakut, Deoria, Faizabad, Farrukhabad, Fatehpur, Ghaziabad, Ghazipur, Goutambudda Nagar, Hamirpur, Hardoi, Hathraspur, Jalaun, Kanno, Kanpur Dehat, Kaushambi, Kheri, Kushi Nagar, Lalitpur, Lucknow, Mahoba, Mainpuri, Mathura, Mau, Meerut, Mirzapur, Moradabad, Muzaffarnagar, Pilibhit, Pratapgarh, Rae Bareilly, Rampur, Saharanpur, Sant Kabir Nagar, Sant Ravidas Nagar, Shahjahanpur, Shrawasti, Sidharth Nagar, Sitapur, Sonbhadra, Sultanpur, Unnao), UTTARAKHAND (Bageswar, Champawat, Dehradun, Haridwar, Nainital, Pithoragarh, Rudrapur), WEST BENGAL (24 Paraganas (North), Cooch Behar, Darjeeling, Haora, Hooghly, Jalpaiguri, Malda, Murshidabad, Nadia, Uttar Dinagpur)</p>	Crops may not need immediate K additions.
VII	H	L	1	RAJASTHAN (Jaipur)	Long term cropping would need K additions after few years
VIII	H	M	24	<p>ANDHRA PRADESH (Chittoor, Mehbubnagar, Warangal), ASSAM (N.C.Hills), CHATTISGARH (Bilaspur), GUJARAT (Ahmedabad, Amreli, Rajkot, Valasad), KARNATAKA (Bijapur, Tumkur), MADHYA PRADESH (Indore, Panna, Umaria), MAHARASTRA (Amaravati), MIZORAM (Aizawl, Chhittap, Lawangtlai, Lunglei, Mamit, Saina, Serchhip), NAGALAND (Mon), SIKKIM (Sikkim East),</p>	K application is not required immediately.
IX	H	H	129	<p>ANDHRA PRADESH (Guntur, Karimnagar, Krishna, West Godavari), ARUNACHAL PRADESH (Changuang, Dibang Valley, East Kameng, East Siang, Lohit, Lower Subansiri, Papum Pori, Taksang, Tirap, Upper Siang, Upper Subansiri, West Kameng, West Siang), CHATTISGARH (Raigarh), GOA (North Goa, South Goa), GUJARAT (Amreli, Anand, Bhavanagar, Broach/Bharuch, Dhod, Gandhi Nagar, Jamnagar, Junagad, Kheda, Mehsana, Narmada, Panchmahal, Porbandar, Sabarkanta, Surat, The Dangs, Vadodara), HARYANA (Panchakula, Ambala, Kurukshetra), HIMACHAL PRADESH (Bilaspur, Solan, Sirmour), JAMMU AND KASHMIR (Udhampur), KARNATAKA (Bagalkot, Bellary, Bidar, Dharwad, Gadage, Gulbarga, Haveri, Koppal, Raichur), MADHYA PRADESH (Barwani, Betul, Bhopal, Chhatarpur, Chhindwara, Damoh, Dewas, Dhar, East Nimar, Guna, Gwalior, Harda, Hoshangabad, Jabalpur, Katni, Mandasaur, Narsimhpur, Raisen, Rajgarh, Ratlam, Rewa, Sagar, Satna, Sehore, Shajapur, Ujjain, Vidisha, West Nimar), MAHARASTRA (Ahmednagar, Amaravati, Aurangabad, Beed, Buldhana, Dhule, Hingoli, Jalgaon, Jalna, Latur, Mumbai, Nagpur, Nanded, Nandurbar, Nasik, Osmanabad, Parbhani, Pune, Solapur, Thane, Wardha, Washim, Yavatmal), MANIPUR (UKHRUL), PUNJAB (Kapurthala), RAJASTHAN (Baran, Chittorgarh, Ganganagar, Jhalawar, Jhunjhunu, Kota, Rajsmand, Sawai Madhopur), SIKKIM (Sikkim North, Sikkim West, Sikkim South), TAMILNADU (Thanjavur), UTTAR PRADESH (Agra, Aligarh, Etah, Etawah, Jhansi, Jyotibaphulenagar, Kanpur Nagar, Maharajgunj), UTTARAKHAND (Uttar Kashi, Chamoli, Tehri Garhwal),</p>	K application is not required.

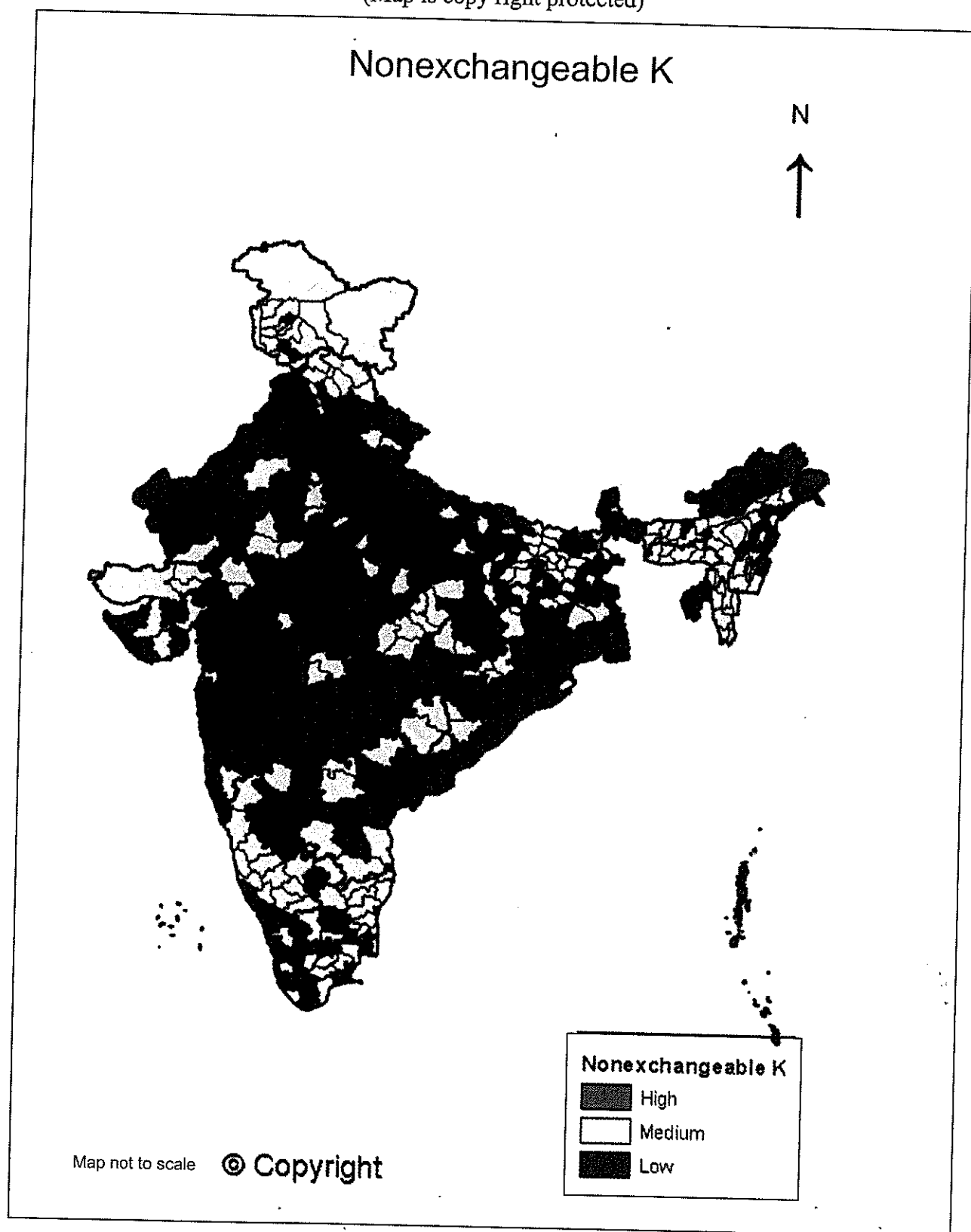
Exchangeable K: Low=<50 mg kg<sup>-1</sup>, Medium= 50-120 mg kg<sup>-1</sup>, High=>120 mg kg<sup>-1</sup>  
Nonexchangeable K: Low=<300 mg kg<sup>-1</sup>, Medium= 300-600 mg kg<sup>-1</sup>, High=>600 mg kg<sup>-1</sup>



Map 1. District wise exchangeable K status of Indian soils  
(Map is copy right protected)



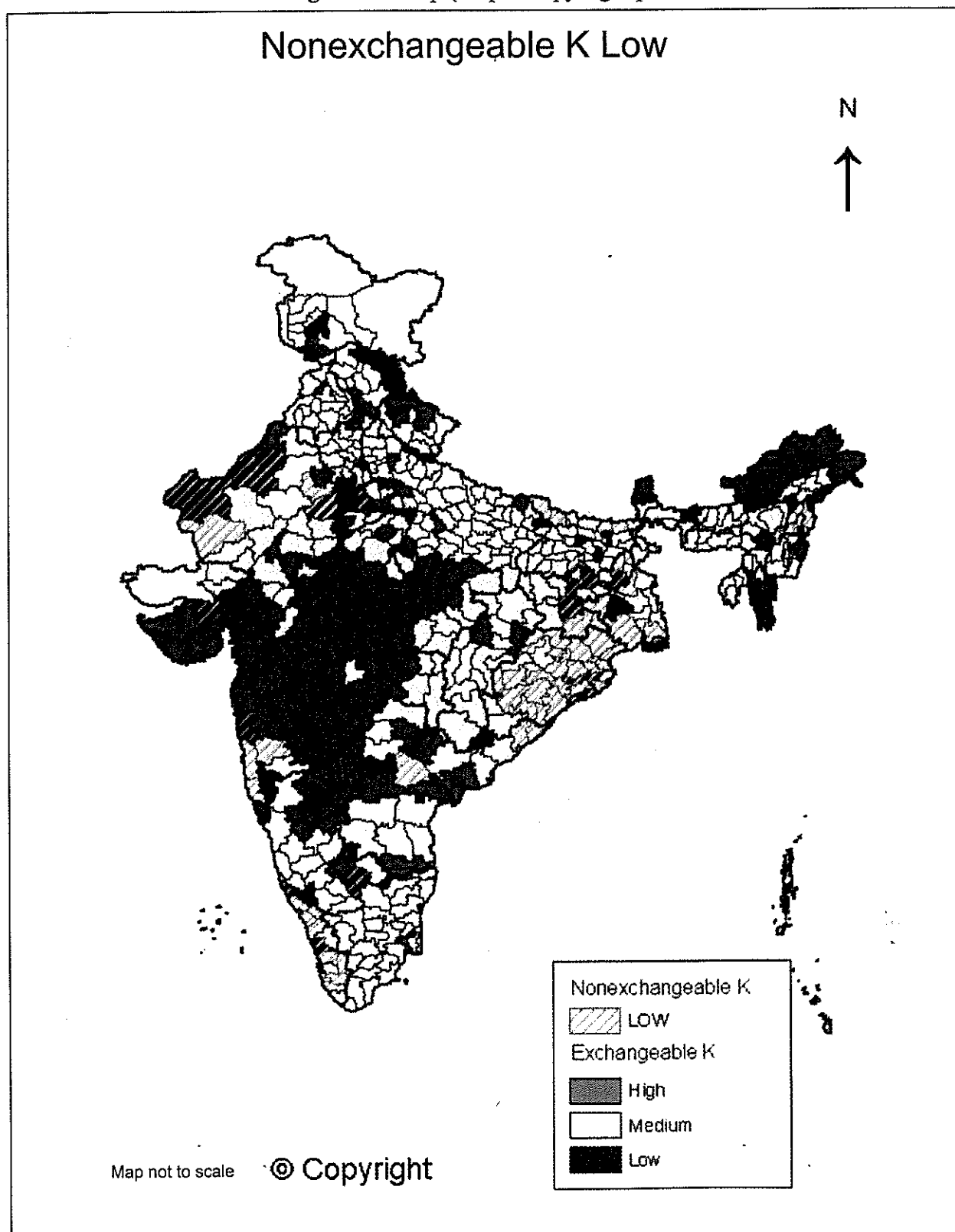
Map 2. District wise nonexchangeable K status of Indian soils  
(Map is copy right protected)







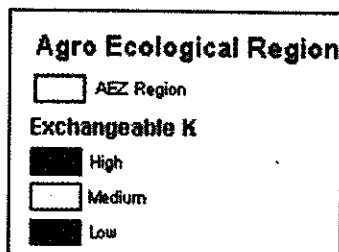
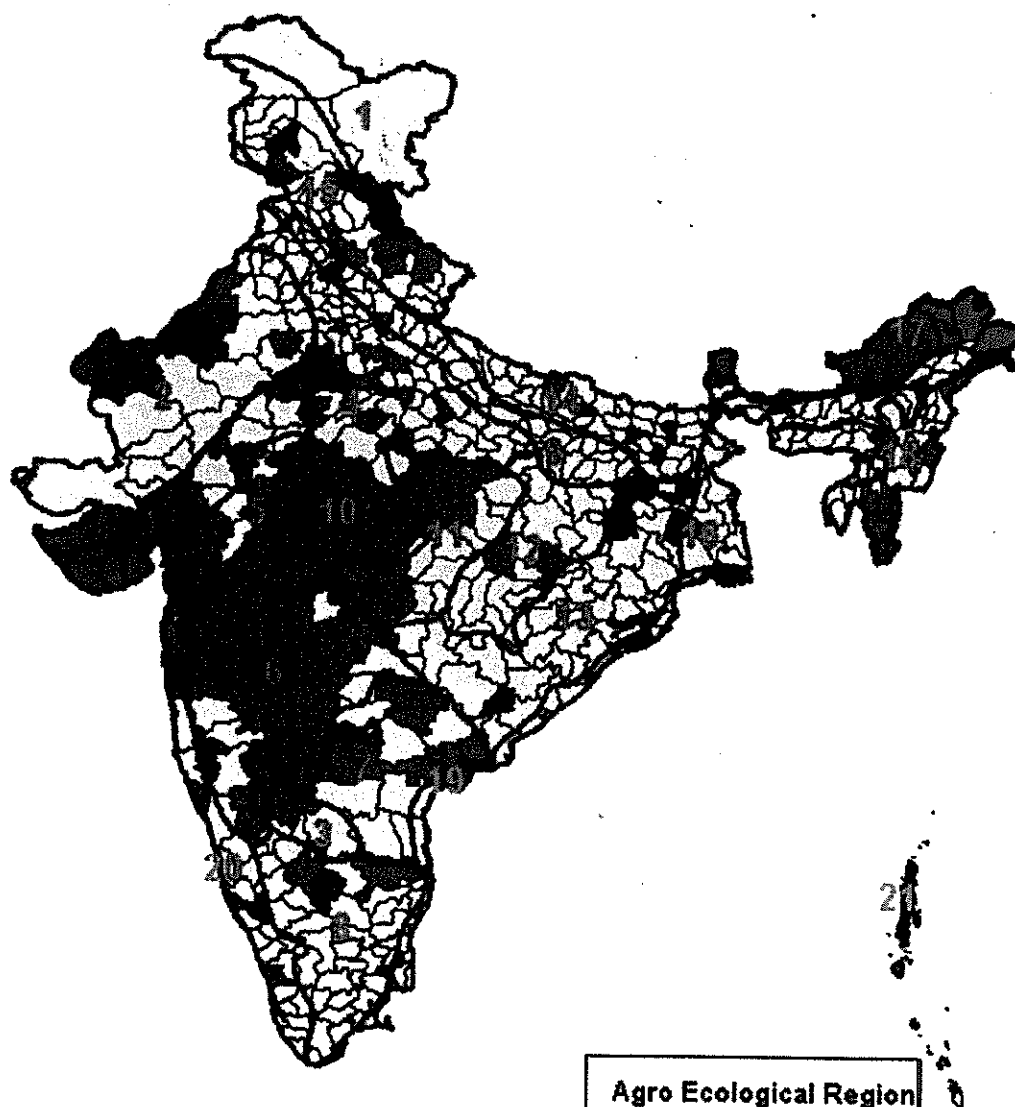
Map 3. Districts with low nonexchangeable K super imposed on exchangeable K map (Map is copy right protected)



Map 4. Exchangeable K status in different agroecological regions of India  
(Map is copy right protected)

## Exchangeable K and Agro Ecological Region

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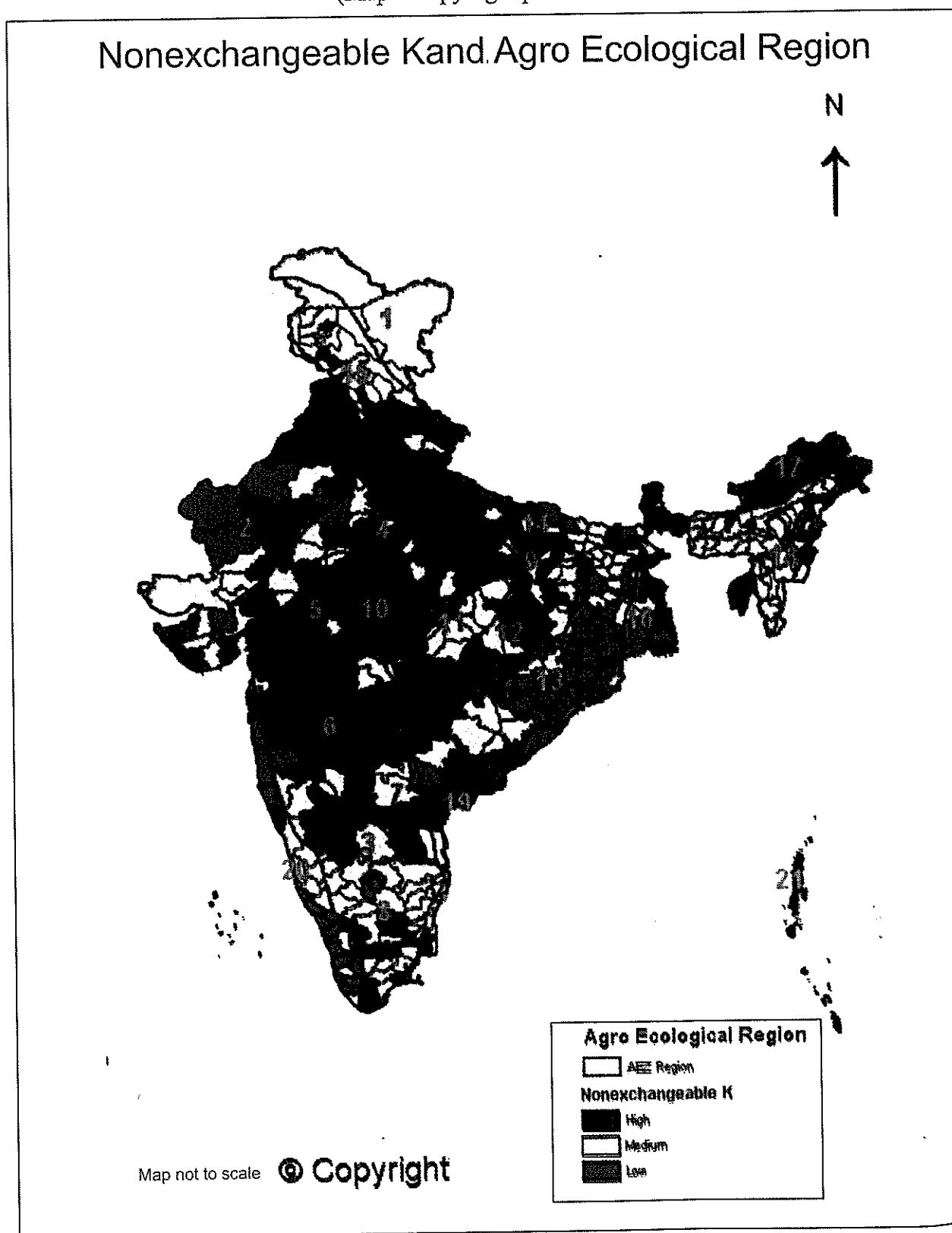


Map not to scale

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Map 5. Nonexchangeable K status in different agroecological regions of India  
(Map is copy right protected)



(>600 mg kg<sup>-1</sup>).

### Identification of K Efficient Districts for K Fertiliser Use

Based on above maps, districts were identified with low, medium and high in exchangeable as well as nonexchangeable K fractions (**Maps 1, 2, 3, 4 and 5**). Nine categories of districts were identified in combination of exchangeable and nonexchangeable K fractions (32, 34, 38, 45, 46, 55). Fifteen districts were identified where both exchangeable and nonexchangeable K status was low (Category I) (**Table 5**). These districts represent mostly red, lateritic soils, light textured and shallow soils. Since both the K fractions were low, K supply to crops grown on these soils is a must and therefore regular K fertilisation should be done considering crop K removal and the recommendations generated in the local university or ICAR institutes. Another 18 districts are categorized under Category II where exchangeable K was low while nonexchangeable K was medium. These soils also represent light textured and acidic alluvial soils. As exchangeable K was low and medium K reserves, regular K application is essential. Two districts under Category III, where exchangeable was low and nonexchangeable K was high, K addition at critical stages is required to improve the crop yields. Category IV covers 58 districts where exchangeable K medium and nonexchangeable low. These districts represent light textured alluvial, red and lateritic, acid sulfate and sandy soils. These soils need considerable attention from K management point of view. Continuous cropping on these soils result in depletion of soil reserve K, therefore, K addition at critical stages is required. If K demanding cropping systems like rice-wheat, rice-wheat-fodder, sunflower based, potato and other tuber crops, banana, intensive fodder and vegetables based systems are grown, regular additions of K is essential. Category V covers 115

districts of India, where both exchangeable and nonexchangeable K fractions were medium. These regions represent various types of soils from acid to alkaline, red, medium to deep black and alluvial. As both the fractions were medium, K additions are required for high value, quality (tobacco) and K exhaustive crops (sugarcane, potato etc.). Another 172 districts fall under Category VI, where exchangeable K was medium and nonexchangeable K was high. These districts represent variety of soils starting from heavy textured red soils, medium to deep black soils, heavy textured alluvial soils, high organic carbon Mollisols. Crops may not need immediate application of K unless specific K loving crops like banana and potato are grown. One district (Jaipur) falls under Category VII, where exchangeable K was high and nonexchangeable K was low. This district represents medium deep alluvial soils with less K bearing minerals. Long term intensive cropping would need some maintenance level of K. Category VIII covers 24 districts where exchangeable K was high and medium nonexchangeable K. These districts represent medium to deep black soils, fine textured alluvial and red soils with sufficient K rich mica. Potassium application is not required immediately. Category IX represents 129 districts where both exchangeable and nonexchangeable K was high. These soils represent deep black and fine textured alluvial soils and show higher long term K supplying power and do not require K application.

### Verification of the Categorisation of K Availability with Crop Responses

Above recommendations have been verified with existing crop response data published in these regions. Bangalore rural where both exchangeable and nonexchangeable K reserves were low (category I)

showed significant response to K in groundnut and ragi crops (7, 17, 51). Under long-term cropping at Bangalore rural, the decrease in exchangeable K was from 123 kg ha<sup>-1</sup> to 66 kg<sup>-1</sup> under NP treatment, observed severe yield decline in ragi and maize in subsequent years under 100 % N and 100 % NP with drastic depletion of soil reserve K (61). Similarly, in light textured alluvial soils where exchangeable K was low and nonexchangeable K was medium (category II), significant yield responses of various field crops were obtained due to K application (57, 64). In light textured Alfisols of Rangareddy district of Andhra Pradesh, sorghum responded significantly to added K (64). In soils of category III, while exchangeable K was low and nonexchangeable K was high, response of field crops to moderate amounts of K was obtained (64). In category IV soils where medium exchangeable K and low nonexchangeable K, crop response to K application was significant in later years of long term cropping (17). Similarly in several districts of Orissa, where nonexchangeable K is low, continuous rice-rice cultivation resulted in the significant response to K (17). Deep black and alluvial soils under category VIII and IX where high exchangeable K and medium to high nonexchangeable K, applied K to field crops was rare (35, 58).

### CONCLUSIONS

Above results suggest that soils of India vary widely in their K status as reflected by variations in readily available K and nonexchangeable K reserves. This exercise is first of its kind where two distinct fractions of K were involved in categorizing Indian soils for K fertility management and identified some districts as priority regions where regular K application is a must. However, the maps generated with available information using GIS technique, should be interpreted with some caution. At many locations, high levels of K reserves



in deeper layers indicate their substantial potential to supply K from sub-soil K to crop K nutrition under intensive systems of production. Alfisols and Oxisols and light textured Inceptisols were definitely low in soil K reserves. Inceptisols with higher ratio of nonexchangeable to exchangeable K, have larger reserves but lower readily available K and so need maintenance doses of K. Vertisols and associated soils with relatively low levels of this ratio have higher available K but low to medium nonexchangeable K which under long-term cropping, may get depleted faster. Soils were categorised by including nonexchangeable K along with exchangeable K, as contribution of nonexchangeable is substantial in K removals by different production systems. In soils with low levels of both exchangeable and nonexchangeable K, K application must be done to realise full yield potential of different cropping systems. Similarly, for different categories, K recommendations have been suggested based on soil K reserve status. This categorization of soils into different groups provides a comprehensive assessment of K supply for plant uptake and better recommendation of potash application. Fertiliser recommendations evolved on the basis of soil test calibration including both exchangeable and nonexchangeable K reserves and crop response studies carried out on soils classified should be extended immediately for crop K advisory purposes. This work resulted in the identification of the Indian districts where both the readily available and soil reserve K sources are low and where K application is essential. Where nonexchangeable K is low and medium in several districts, continuous cultivation of crops gradually results in soil K depletion and reduction in crop yields. Potassium fertiliser is not produced in India and its use is therefore completely import dependent. Government of India is spending a huge amount of foreign

exchange on importing K fertilisers. These costly imported K fertilisers should therefore be used more rationally, judiciously and efficiently. The K fertiliser material should be made available in the regions or districts where soil K reserves are low and high K requirement crops are grown during crop season at the village level.

#### FUTURE NEEDS OF WORK

- Use the maps generated and districts identified in the present study in prioritizing regions for K fertiliser use.
- Need to link up these maps with predominant crops/cropping systems being followed in the different districts or regions, so that further fine tuning to K recommendations can be evolved.
- Introduce the new methodology for estimating nonexchangeable K in all soil testing laboratories in India (40).
- Continuous monitoring of both K fractions (exchangeable and nonexchangeable) in different soil types under predominant cropping systems.
- Prepare balance sheets of soil potassium in different production systems and zones at least after every decade.
- For monitoring of K status/dynamics, and crop yield sustainability, new long term fertiliser experiments may be initiated in each of nine categories of soils suggested in the present paper considering predominant soil types and cropping systems.

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