IPI Research Topics No. 20

2nd revised edition

Potassium Status and Crop Response to Potassium on the Soils of Agroecological Regions of India

2011

INTERNATIONAL POTASH INSTITUTE

IPI Research Topics No. 20
2nd revised edition

Potassium Status and Crop Response to Potassium on the Soils of Agroecological Regions of India

A. Subba Rao
Indian Institute of Soil Science
Nabi Bagh, Berasia Road
Bhopal-462 038
Madhya Pradesh
India

Ch. Srinivasarao
Central Research Institute for Dryland Agriculture
Santoshnagar
Hyderabad-500 059
Andhra Pradesh
India

S. Srivastava
Indian Institute of Soil Science
Nabi Bagh, Berasia Road
Bhopal-462 038
Madhya Pradesh
India

INTERNATIONAL POTASH INSTITUTE

Citation: Subba Rao, A., Ch. Srinivasarao, and S. Srivastava. 2010. Potassium Status and Crop Response to Potassium on the Soils of Agroecological Regions of India. IPI Research Topics No. 20, International Potash Institute, Horgen, Switzerland, 185 p.

International Potash Institute
Baumgärtlistrasse 17
P.O. Box 569
CH-8810 Horgen, Switzerland
Tel: +41 43 810 49 22
Fax: +41 43 810 49 25
E-mail: ipi@ipipotash.org
www.ipipotash.org

2011

ISBN 978-3-905887-02-0

DOI 10.3235/978-3-905887-02-0

Printing: Imprimerie de Saint-Louis, France

Layout: Martha Vacano, IPI, Horgen/Switzerland

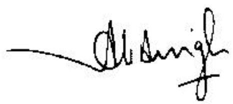
Foreword to the 2nd Revised Edition

Agriculture is the back bone of Indian economy with about two thirds of the population residing in rural areas directly or associated it for their livelihood and contributing to 19% of the Gross Domestic Product. With the initiation of green revolution in late seventies, India has made remarkable progress in food security, poverty reduction and per capita income. Even though India has made considerable progress over the years in increasing the food grain production to a recent 231 mt in 2007-2008, the performance over the last ten years has been unsatisfactory. The growth rate in agriculture has not kept pace with the phenomenal growth rate in industrial and services sectors. Obviously a concerted effort is required to improve the condition of Indian Agriculture, which involves policy intervention, frontier research, public-private partnership, and involvement of farmers at different stages starting from technology generation to its adoption. Soil fertility and its evaluation is one area which needs immediate attention since it is now established that an arrest in the productivity of several crops is due to ever decreasing soil fertility on one hand and an imbalanced application of plant nutrients on the other. The deficiency of several major and minor plant nutrients such as K, S, Ca, Zn. Fe and B are emerging in time and space. Among the essential plant nutrients, potassium assumes greater significance since it is required in relatively larger quantities by plants and besides increasing the yield, it immensely improves the quality of the crop produce.

The three estimates (Ramamurthy and Bajaj, 1967; Hasan and Ghosh, 1979; Motsara, 2002) of soil fertility for K based on information generated from soil testing laboratories in the country indicated discrepancies in the percentage of samples testing high, though the overall soil K fertility declined. It could quite possibly be due to poor representative character of sampling, noncognizance of pedological classification of soils, and lack of control over the choice of sampling sites. It is worthwhile to note that even in the most progressive states like Punjab and Haryana, the two big contributors to the national buffer stock, have the most skewed $N:P_2O_5:K_2O$ ratios. The focus has been on nitrogen followed by phosphorus and very little potassium application resulting in a huge imbalance. In the year 2020, the deficit of K in Indian agriculture has been projected to be around 8.1 million tonnes/annum while the estimates of N and P balances are positive. There is obviously an urgent need in delineating the K deficient areas and expected responses both in terms of quantity and quality in different agroclimatic regions of the country.

The first attempt in this direction was made way back in 1996 in the form of a publication “Potassium Status and Crop Response to Potassium on the Soils of Agroecological Regions of India” brought out by International Potash Institute, Switzerland. Since then, however, significant changes have taken place both in the available information on the subject and agricultural evolution as a whole. The revision of the bulletin is therefore, timely and much needed. This revised edition gives state-of-the-art information on K status and the responses to applied K in different agroclimatic zones of the country. The new edition has also incorporated the frontier concepts in K fertility assessment and the possibility of obtaining the K responses to applied fertilizer K. This involves incorporating the salient findings on K release rates, interrelationship between K replenishment rates and clay mineralogy, characterization of soil K based on K supplying minerals, which is primarily biotite mica, and characterization of soils based on non-exchangeable K release. I am confident that this information will go a long way in the better understanding and assessment of the K status of soils and correction of K deficiencies in the important agricultural production zones leading to a significant enhancement in crop productivity. I am sure this revised edition will be of immense help for all the stakeholders be it planners, researchers, fertilizer industries, other related business enterprises and finally the educated and innovative farmers.

I compliment the International Potash Institute, Switzerland for this timely initiative in bringing out the revised edition of the bulletin. The authors deserve special appreciation for working hard in compiling all the information and presenting it in a meaningful manner.



A.K. Singh

Deputy Director General (NRM)

Indian Council of Agricultural Research

Contents Page

List of Tables **Page**

List of Figures **Page**

1. Introduction

Many different types of soil occur in different regions of India. Their potassium content varies according to parent material, particle size distribution, degree of weathering and management practices. Potassium status of illitic soils depends largely on clay mineral content but in smectitic soils, it depends on the relative abundance of associated minerals and particle size (Srinivasarao *et al*, 2006).

Red, lateritic and acidic alluvial soils (Rhodustalfs, Paleustalfs, Haplustalfs, Haplaquepts, Ustifluvents, Ustochrepts, Dystropepts, Tropaquepts) occur in the Eastern Ghat, Tamil Nadu uplands, Deccan Plateau, Eastern (Chhota Nagpur) Plateau, Western Ghat and Coastal Plains. These tend to be low in exchangeable and non-exchangeable K.

Swell-shrink soils comprising Pellusterts, Chromusterts, and Vertic Ustochrepts are found in the Central Highlands (Malwa, Budelkhand and E. Satpura), Gujarat Plains, Kathiawar Peninsula, Daccan, Eastern Ghats: they are high in exchangeable and medium to high in non-exchangeable K. Within these regions, there are red soils low to medium in exchangeable and non-exchangeable K.

A range of alluvial soils (Ustochrepts, Haplustalfs, Ustrothents, Eutrochrepts, etc.) in the Northern Plains, Central Highlands, Assam and West Bengal Plains are medium to high in exchangeable and medium to very high in non-exchangeable K.

Brown forest and podzolic soils (Dystrochrepts and Inceptisols) in the Western Himalayas are variable (low to high) in both exchangeable and non-exchangeable K. Coastal alluvial soils (Vertic Halaquepts, Fluventic Ustochrepts, Udic Chromusterts) in Manipur are high in exchangeable but low in non-exchangeable K.

The National Bureau of Soil Survey and Land Use Planning established twenty agroecological regions (AER) based on physiography, soil, agroclimatic conditions, length of growing season and land use (Map 1.1) and issues discussed here relate to this classification.

Indian soils have been characterised on the basis of potassium fertility by Ramamoorthy and Bajaj (1969), Ghosh and Hasan (1976) and Sekhon *et al*. (1992). But no comprehensive study of potassium dynamics has been done in each region. Similarly, there has been no study of important crops or cropping systems in relation to plant-available K, response to K and K fertilizer management on a regional basis. Hence in recent years, much research work done on these aspects at several national institutes like Indian Institutute of Soil Science, Bhopal, Central Research Institute for Dryland Agriculture, Hyderabad and several other Research Instittues and agricultural universities in India (Subba Rao and Srinivasa Rao, 1996, Srinivasa Rao *et al*., 1997, 1998, 1999, 2000, 2001, 2002, 2004, 2006, 2007, 2010). Present publication includes the recent information on various aspects of potassium fertility management in different agroecological regions and production systems.

1.1. Agroecological regions of India (see also Map 1.1, page 14)

Arid Ecosystem

1. Western Himalayas, cold arid ecoregion, with shallow skeletal soils and length of growing period (GP) <90 days.
2. Western Plain, Kachh and part of Kathiawar Peninsula, hot arid ecoregion, with desert & saline soils & GP <90 days.
3. Deccan Plateau, hot arid ecoregion, with Red & Black soils & GP <90 days.

Semiarid Ecosystem

4. Northern Plain and Central Highlands including Aravallis, hot semi-arid ecoregion, with Alluvium derived soils & GP 90- 150 days.
5. Central (Malwa) Highlands, Gujarat Plains & Kathiawar Peninsula, hot semi-arid ecoregion, with medium & deep Black soils & GP 90-150 days.
6. Deccan Plateau, hot semi-arid ecoregion with shallow and medium (with inclusion of deep) Black soils & GP 90-150 days.
7. Deccan (Telangana) Plateau and Eastern Ghats, hot semi-arid ecoregion, with Red & Black soils & GP 90-150 days.
8. Eastern Ghats, TN uplands and Deccan (Karnataka) Plateau, hot semi-arid ecoregion with Red loamy soils & GP 90-150 days.

Subhumid Ecosystem

9. Northern Plain, hot subhumid (dry) ecoregion, with Alluvium-derived soils & GP 150-180 days.

10. Central Highlands (Malwa, Bundelkhand & Satputra), hot subhumid ecoregion, with Black and Red Soils & GP 150-180 (to 210) days.
11. Eastern Plateau (Chhattisgarh), hot subhmid ecoregion, with Red & Yellow soils, & GP 150-180 days.
12. Eastern (Chhotanagpur) Plateau and Eastern Ghats, hot subhumid ecoregion, with Red & Lateritic soils & GP 150-180 (to 210) days.
13. Eastern Plain, hot subhumid (moist) ecoregion, with Alluvium-derived soils & GP 180-210 days.
14. Western Himalayas, warm subhumid (to humid with inclusion of perhumid) ecoregion with Brown forest and Podzolic soils, & GP 180-210 + days.

Humid-Perhumid Ecosystem

15. Bengal and Assam Plain, hot subhumid (moist) to humid (inclusion of perhumid) ecoregion, with Alluvium-derived soils & GP 210 + days.
16. Eastern Himalayas, warm perhumid ecoregion, with Brown and Red hill soils & GP 210 + days.
17. North-eastern Hills (Purvachal), warm perhumid ecoregion, with Red and Lateritic soils & GP 210 + days.

Coastal Ecosystem

18. Eastern Coastal Plain, hot subhumid to semi-arid ecoregion, with Coastal Alluvium-derived soils & GP 90-210 + days.
19. Western Ghats & Coastal Plain, hot humid to perhumid ecoregion, with Red, Lateritic and Alluvium-derived soils and GP 219 + days.

Island Ecosystem

20. Islands of Andaman-Nicobar and Lakshadweep hot humid to perhumid island ecoregion, with Red loamy and sandy soils, and GP 210 + days.

Map 1.1. Agroecological regions of India. Each region is marked with a number (1-20) and with a code (e.g. A13E1) which indicates physiography, length of growing season, vegetation and more (not described in this publication). *Source*: NBSS & LUP, Nagpur.

2. Properties of Soils in the Agroecological Regions of India

A brief description of the soils occurring in each of the different regions is given in Table 2.1. Between 300 to 400 soil samples, broadly representing the major soil types and cropping systems in each region, were used for this description.

Agroecological region 1

Most of the soils in this region are classified as Inceptisols covering medium to deep alluvial soils with varying texture, non-saline, neutral to alkaline in regions with medium in organic carbon content. The dominant clay mineral is mica with vermiculite, smectice and cholorite as associate minerals.

Agroecological region 2

The soils in this region are Torripsamments, Torrifluvents, Ustochrepts, Calciorthids and Haplargids. These are coarse textured, saline/non-saline, moderately to highly alkaline in reaction and very low to low in organic matter. They have variable clay mineralogical composition depending upon the state in which they occur.

Agroecological region 3

The important soil type in this region is shallow to medium deep red soils belonging to Alfisols. Soils are acidic to neutral in reaction, non-saline and low in organic matter. Kaolinite is the dominant clay mineral with smectite and mica as associated minerals.

Agroecological region 4

The important great groups of soils in this area are Ustochrepts and Haplustalfs followed by Natraqualfs. These are coarse to fine loamy in texture, neutral to highly alkaline in reaction, calcareous/non-calcareous and low to high in organic matter. Clay mineralogy is smectitic in Rajasthan and Gujarat regions and illitic in the IGP of Punjab and Uttar Pradesh.

Agroecological region 5

Swell-shrink soils are the dominant group in this region with loam to clayey Vertic Ustochrepts and clayey Chromusterts. High clay content and smectitic mineralogy is the main characteristic of these soils. Soils are slightly to moderately alkaline, both calcareous and non-calcareous and low to high in organic matter.

Agroecological region 6

Soils in region 6 are also represented by swell-shrink soils with great groups Ustorthents, Chromusterts, and Ustropepts. Soils are loamy to clayey in texture (mostly clayey), calcareous, neutral to moderately alkaline and medium to high in organic matter. The clay mineralogy is dominated by smectite clay mineral.

Agroecological region 7

In this region, both red and black soils occur with dominant great groups of Vertic Ustochrepts, Chromusterts, Pellusterts and Paleustalfs. Swell-shrink soils are neutral to highly alkaline and calcareous whereas red soils are acidic to neutral, low to medium in organic matter and non-calcareous. The dominant clay mineralogy is kaolinitic in Alfisols and smectitic in Vertisols.

Agroecological region 8

The soils in this reqion are Ustorthents, Haplustalfs and paleustalfs. These soils are loamy sand to sand in texture, mostly non-calcareous, slightly acidic to neutral in reaction and low to medium in organic matter.

Agroecological region 9

The dominant soils representing the northern plains are Ustochrepts and Haplustalfs. There are some soil groups under orders Entisols and Mollisols also. These soils are neutral to alkaline and mostly low in organic matter.

Agroecological region 10

In this region, medium and deep black soils are interspersed in patches of red soil. The dominant great groups are Ustorthrepts, Ustochrepts, Chromusterts and Hapustalfs. Black soils are calcareous, slightly to moderately alkaline and low to high in organic matter. The soils are fine textured and smectite is the dominant clay mineral.

Agroecological region 11

The dominant soil groups are medium to deep black soils belonging to Vertic sub groups, alluvial and red soils in pockets. Soils are neutral and mostly non-saline and low in organic carbon.

Agroecological region 12

The dominant great groups in this area are Ustochrepts, Haplaquepts and other red soils. These soils are loamy sand to silt loam, acidic to near neutral, non-calcareous and low to medium in organic matter.

Agroecological region 13

These are alluvial soils with dominance of Ustifluvents and Eutrochrepts. These soils are loam to clay loam, neutral to alkaline, highly calcareous and low to high in organic matter.

Agroecological region 14

These represent brown forest and podzolic soils classified under the great groups: Eutrochrepts, Dystrochrepts and other acidic brown hill soils. These are fine textured, acidic to neutral and medium to generally high in organic matter content.

Agroecological region 15

The dominant soils are acidic alluvial soils and Alfisols represented by Halaqualfs and Eutrochrepts. These are slightly to strongly acidic, low to moderate in base status and high in organic matter, have kaolinite and illite as dominant clay minerals.

Agroecological region 16

The soils generally represent Inceptisols, Alfisols, Entisols and Mollisols. These are loamy to clayey, have acidic reaction and high organic matter.

Agroecological region 17

The major soils are red and lateritic and red and yellow soils. They occur both at high and low altitudes. They are acidic and high in organic matter.

Agroecological region 18

These are coastal alluvial derived soils classified under Chromusterts, Vertic Halaquepts, Fluventic Ustochrepts etc. These are medium to fine textured, acidic to alkaline and low to medium in organic matter.

Agroecological region 19

In this region, red lateritic and alluvial derived soils are dominant. They belong to great groups: Ustropepts, Fluventic Ustrochrepts and Tropaquepts. They are kaolinite dominant, acidic, porous, poor in the base status and fertility and high to very high in organic matter.

Agroecological region 20

These are red loamy soils, sandy soils derived from marine alluvium and acidic hill soils. They are acidic in nature and low to moderate in their base saturation.

Table 2.1. Properties of typical soils in the agroecological regions of India.

Notes:

(a) Number of agroecological regions or states, or locations sampled.

(b) Calc. = calcareous; Non-calc. = non-calcareous; when there is no value, it means that no analysis is available.

(c) The symbols used for the minerals are: Amorphous (A), Beidellite (Be), Calcite (Ca), Chlorite (Ch), Feldspars (F), Illite (I), Kaolinite (K), Mica (M), Mixed (Mix), Montmorillonite (Mo), Quartz (Q), Smectite (S) and Vermiculite (V). Numerical value against the mineral is the content of mineral in percentage; dominance by order.

Table 2.1. continued

Table 2.1. Properties of typical soils in the agroecological regions of India.

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		------------%------------			
	Agroecological region 1								
1	Jammu and Kashmir	Inceptisols	10	Fine	Neutral	<1.0	<1.2	M, K, S	Wani *et al*. (2009)
2	Jammu and Kashmir	Inceptisols	10	Fine	Neutral	0.80	Non-calc.	M, K, S	Wani and Datta (2007)
3	Jammu and Kashmir	Alluvial	64	Fine	6.5-8.4	0.42-0.96	Non-calc.	M, V	Sharma *et al*. (2009)
3	Jammu and Kashmir	Inceptiosl	30	Clay loam	6.0-80	1.35-2.67	8-10	M, Mixed layer, S, K, C	Wani and Kumar (2008)
	Agroecological region 2								
	Gujarat								
1	West Gujarat	Black	10	19.3-48.3	>7.0	0.24-0.96	5.5-50	S, M	Patel *et al*. (1989)
2	Gujarat	Ustalbic Haplargid	25	Sand-sandy loam	7.4-10.1	0.10-0.55	Traces	S, M	Sekhon *et al*. (1992)
3	Amreli	Vertic Ustochrept	1	Loam-clay	8.2-9.6	0.45-0.72	2.7-11.9	S, M	Srinivasarao *et al*. (2000)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		-------------%	-------------		
	Rajasthan								
4	Ganganagar	Typic Torrifluvent	25	Loamy sand-loam	8.5-9.2	0.11-0.48	2.2-7.5	M, V, S	Sekhon *et al*. (1992)
5	Dune soils	Torripsamment	18	Coarse loamy 2.6-6.9	8.3-8.9	0.03-0.2	-	-	Datta and Joshi (1989)
6	Jaisalmer, Barmer, Siker	Arid soils	8		Alkaline	<0.50	-	-	Joshi (1986)
7	Bharatpur	Soil associations	1	13.4-37.4	7.7-8.6	<0.5	-	-	Chand and Swami (2000)
	Haryana								
8	Hisar	Non calcareous (Typic Camborthid)	1	Coarse loamy	7	0.34	-	S, V, Q	Mittal *et al*. (1996)
9	Hisar	Typic Ustochrept	1	Sandy loam-23	8.4	0.37	0.95	K-14, M-53, Ch-12, V-5, S-6	Bhattacharyya and Poonia (1996)
10	Hisar	Alluvial/Aridisol	1	19.9-33.9	7.1-7.9	0.11-0.19	0.5-1.2	M	Srinivasarao *et al*. (2006)
11	Haryana	Typic Udorthent	1	26	5.93	0.75	0.5	M	Mehta *et al*. (2001)

Table 2.1. continued

S. No. [(a)]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [(b)]	Dominant clay minerals[(c)]	Source
				%		-------------%-------------			
12	Haryana	Typic Ustochrept	6	12-43	7.5-9.1	0.32-0.94	0.1-0.7	M	Mehta *et al*. (2001)
13	Haryana	Typic Torripsamment	2	5-18	7.7-8.7	0.07-1.2	Trace-4.66	M	Mehta *et al*. (2001)
14	Haryana	Typic Ustorthent	3	12-18	8.0-8.6	0.83-1	0.3-1.24	M	Mehta *et al*. (2001)
15	Haryana (Karnal)	Aquic Natrustalf	1	Aquic Nutrustalfs	8.7	0.32	2.1	M	Yaduvanshi & Swarup (2006)
	Punjab								
16	Dhar, Submontaneous	Typic Entrochre-pt	3	14.6-22.8	6.5-7.4	0.48-0.92	-	I, V, S	Pasricha *et al*. (2001)
17	Kandi, Submontaneous	Typic Ustorthent	1	4.2	8.2	0.13	6	I, V, S	Pasricha *et al*. (2001)
18	Laungowal, Central plain	Natric Camborthid	1	22.9	8.4	0.37	3.3	I, V, S	Pasricha *et al*. (2001)
19	Jalalabad, Central plain	Udic Ustochrept	1	32.4	8.3	0.45	-	I, V, S	Pasricha *et al*. (2001)
20	Sadhugarh, Central plain	Vertic Ustochrept	1	59.7	8.3	0.71	0.77	I, V, S	Pasricha *et al*. (2001)
21	Nihalkhera, Central plain	Typic Camborthid	1	16.6	8	0.57	1.38	I, V, S	Pasricha *et al*. (2001)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		-------------%-------------			
22	Naura, Central plain	Udic Haplustalf	1	23.6	8.3	0.58	0.07	I, V, S	Pasricha *et al.* (2001)
23	Zirakapur, Central plain	Acquic Ustorthent	3	14.5-16.3	8.0-8.8	0.45-0.69	1.4-5.9	I, V, S	Pasricha *et al.* (2001)
24	Sand dunes, South-western	Ustic Torripsamment	1	5	8.2	0.09	2.2	I	Pasricha *et al.* (2001)
25	Interdunal, South-western	Ustochreptic Camborthid	1	9	8.1	0.09	3	I	Pasricha *et al.* (2001)
26	Alluvial terraces, South-western	Ustochreptic Camborthid	1	17.8	8.4	0.36	3.9	I	Pasricha *et al.* (2001)
27	Sand dunes, South-western	Sandy	2	4.9-17.7	7.9-8.2	0.06-0.13	0.2-3.5	-	Pasricha *et al.* (2001)
28	Nabha	Alluvial soils	1	Loam-16.8	7.3	0.47	0.6	I	Dhillon & Dhillon (1996)
29	Kanjli	Alluvial soils	1	Loam-16.9	8.2	0.44	0.2	I	Dhillon & Dhillon (1996)
30	Tulewal	Alluvial soils	10	Loamy sand -6.0	8.2	0.41	0.2	II	Dhillon & Dhillon (1996)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals[c]	Source
				%		------------%------------			
	Agroecological region 3								
	Andrha Pradesh								
1	Anantapur	Red Alfisols	10	Sandy loam	Acid	<0.25	Non-calc.	K, I, S	Srinivasarao *et al*. (2007)
2	Anantapur	Red soils	60	Sandy loam	Acidic	0.15-0.35	Non-calc.	K, I, S	Srinivasarao (2006)
3	Anantapur	Red soils	110	Sandy loam	Acidic-neutral	0.32-0.45	Non-calc.	K	Srinivasarao (2010)
	Agroecological region 4								
	Rajasthan								
1	Chambal	-	3	33-34	8.6-9.0	0.22-0.36	4.1-13.1	S: 26.4-28.7, M: 20.4-23.9	Mishra *et al*. (1993)
	Madhya Pradesh								
2	Gwalior	Medium black	10	22-50	7-7.8	0.51-1.29	1.5-3.5	S, M, V	Tiwari & Bansal (1992)
3	Morena & Bhind	Sodic, saline, alkali	120	15.0 -43.6	6.3-10.0	0.16-0.52	0.5-8.0	S, I	Tomar *et al*. (1997)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$[b]	Dominant clay minerals[c]	Source
				%		-------------%-------------			
	Uttar Pradesh								
4	Varanasi	Typic Natraqualf	30	Sandy loam	10.3	<0.4	1.5	I	Srivastava & Srivastava (1992)
5	Kanpur	Typic Ustochrept	28	Sandy loam-silty loam	7.8-8.5	0.23-0.69	1 to 3	I, S, V, Ch	Tiwari *et al*. (1988)
6	Agra	Alluvial	20	Sandy loam	Alkaline	0.12-0.3	1-4	I, S, Ch	Chandra Prakash & Vinay Singh (1986)
7	Meerut	Typic Haplustalf	25	Sandy loam-clay loam	7.2-8.7	0.28-0.59	Non-calc.	I	Sekhon *et al*. (1992)
8	Etah	Udic Haplustalf	25	Sandy loam-loam	7.7-9.8	0.20-0.68	Non-calc.	I	Sekhon *et al*. (1992)
9	Kanpur	Udic Ustochrept	25	Loamy sand-silt loam	8.1-8.8	0.30-0.80	Non-calc.	I	Sekhon *et al*. (1992)
10	Kanpur, Faizabad, Varanasi	Inceptisols	30	Silty loam-loam-20.6-24.6	7.6-9.28	0.3-0.35	Non-calc.	I	Srinivasrao *et al*. (2002)
11	Meerut	Typic Haplustalf	25	Silty loam-clay loam	7.2-8.7	0.28-0.75	Nil	Il, Ch, V	Bansal & Umar (1998), Srinivasarao *et al*. (2001)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals[c]	Source
				%		-------------%	-------------		
12	Agra	Sandy loam (Typic Ustipsamm-ent)	1	Sandy loam	8.1	0.37	Non-calc.	I	Singh *et al*. (1999)
13	Etah	Udic Ustochrept	25	Silty loam-loam	7.7-9.8	0.27-0.59	Nil	S, Ch, V	Bansal & Umar (1998), Srinivasarao *et al*. (2001)
14	Kanpur	Udic Ustochrept	25	Loamy sand-silt loam	8.1-8.8	0.2-0.68	Nil	I, Ch, V	Srinivasarao *et al*. (2001)
15	Kanpur	Inceptisols	10	Silty loam-20.6	7.60	0.30	-	I	Srinivasarao *et al*. (2002)
16	Firozabad	Alluvial soil	8	10-16	7.5-8.8	0.17-0.46	0.5-1	I	Singh *et al*. (2001)
17	Banda	Alluvial/Inc-eptisol	11	33.9-39.9	8.1-9.2	0.12-0.36	0.5-2.1	I	Srinivasarao *et al*. (2006)
18	Banda	Steep hill slope	1	40.4-53.0	6.3-6	0.42-1.45	Non-calc.	I	Ahmed & Walia (1999)
19	Banda	Subued plateau	1	16.0-22.6	5.0-6.3	0.34-0.83	Non-calc.	K	Ahmed & Walia (1999)
20	Banda	Flat topped hill	1	26.4-43.8	6.3-6.5	0.33-0.85	Non-calc.	II	Ahmed &Walia (1999)
21	Banda	Undulating plateau	1	24.0-31.9	6.4-6.6	0.38-0.5.2	Non-calc.	K	Ahmed &Walia (1999)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals[c]	Source
				%		-------------%-------------			
22	Banda	Monadnock	1	12.2-28.0	5.8-6.3	0.32-0.5	Non-calc.	K	Ahmed &Walia (1999)
23	Banda	Foot hill slope	1	15.4-43.2	6.2-86	0.47-0.66	Non-calc.	Il	Ahmed & Walia (1999)
24	Banda	Plain	4	15.4-55.5	6.0-7.5	0.1-1.04	Non-calc.	II, S	Ahmed & Walia (1999)
	Delhi								
25	Delhi	Typic Ustochrept	80	5.7-20.2	8.1-9.0	0.13-0.42	0.06-56	Il-34-62, Mo-3-18, Ch-5-19	Srinivasa Rao & Khera (1994)
26	Delhi	Alluvial	10	11 to35	7.4-7.9	<0.30	Non-calc.	Il	Singh & Ghosh (1984)
27	Delhi	Inceptisols	20	10-13	8.6-9	0.19-0.42	Non-calc.	II, Ch, S	Srinivasarao *et al*. (1997)
28	Delhi	Inceptisols	10	Loam-18.0	7.58	0.42	Non-calc.	I, Ch, S	Srinivasarao *et al*. (2004)
	Haryana								
29	Haryana	Alluvial	24	Coarse loamy	7.1-8.2	0.09-0.45	Non-calc.	I	Mehta *et al*. (1991)
30	Haryana	Alluvial	4	15-22.4	7.5-7.7	0.21-0.32	Traces 3.5	I	Singh *et al*. (1984)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		-------------%-------------			
31	Gurgaon	Udic Ustochrept	25	Sandy loam	7.7-9.8	0.15-0.75	Non-calc.	I	Sekhon *et al*. (1992)
32	Gurgaon	Loamy sand (Udic Ustochrept)	4	Sandy loam to loamy sand-11-14.0	7.1-9.2	0.09-0.65	Non-calc.	I	Singh *et al*. (2002), Bansal & Umar (1998), Chauhan & Abha Tikkoo (2002)
	Punjab								
33	Ludhiana	Udic Ustochrept	25	Sand-sandy loam	7.1-9.2	0.09-0.45	Non-calc.	I	Sekhon *et al*. (1992)
34	Ludhiana	Udic Ustochrept	20	Sandy loam	7.6-9.8	0.15-0.9	Non-calc.	I-60	Bansal & Umar (1998), Debnath & Majumdar (1998)
35	Ludhiana	Typic Ustochrept	10	20.9	8.6	0.54	2.1	I	Pasricha *et al*. (2001)
36	Ludhiana	Sandy loam	1	Sandy loam	8.5	0.62	-	I	Dhillon *et al*. (1999)
37	Submontane zone	Alluvial soils	7	6-30	7-7.8	0.11-0.38	1.9-5	S-4-20, V-2-14, Ch-3-12, Il-58-70, K-1-7, Mix-5-13	Benipal *et al*. (2001)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals[c]	Source
				%		------------%------------			
38	Central-plain zone	Alluvial soils	5	14-46	7.3-7.8	0.12-0.41	0.9-1.9	S-2-21, V-7-14, Ch-2-8, Il-46-69, K-2-8, Mix-4-6	Benipal *et al*. (2001)
39	South-western zone	Alluvial soils	4	14-32	7.8-8.7	0.16-0.41	3-5.8	S-2-3, V-9-14, Ch-6-9, Il-55-65, K-4-11, Mix-7-8	Benipal *et al*. (2001)
40	Zirakpur	Aquic Ustorthent	1	Coarse loamy-9.9-20.4	8.3 -8.8	0.09 -0.34	1.5 -9.3	I, S	Brar *et al*. (1999)
41	Abohar	Aquic Ustorthent	1	Coarse loamy-0.4-30.5	7.7 -9.6	0.03 -0.77	0.00 -61.1	I, S	Brar *et al*. (1999)
42	Amritsar	Typic Ustochrept	1	20.66	8	0.42	2	I	Pasricha *et al*. (2001)
43	Kapurthala	Alluvial soil	10	Sandy loam to loamy sand-9.9-33.4	8.1-8.8	0.21-0.48	Nil-0.25	I	Sharma & Sharma (2001)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		------------%------------			
	Gujarat								
44	Saurashtra	Black soils (Ustrochrept)	1	16.0 -51.0		0.24 -0.96	3.0 -50.0	S, K	Patel & Golakiya (1996)
	Agroecological region 5								
	Rajasthan								
1	Kota & Jhalawar	Pellusterts, Chromustert	6	55-69	7 to 8	0.36-0.8	2.7-10.2	S, M, Ch	Sehgal *et al*. (1992)
2	Jhalawar	Vertisols	4	51-61	7-8.1	0.12-0.54	2.7-6.2	S	Das *et al*. (1993)
3	Rajasthan	Haplustalfs	30	1.2-2.9	39-269	<0.5	<4.0	K, M	Yadav & Swami (1987)
4	Arjia	Vertisols	1	33.1	8.1	0.47	2.15	S, I	Srinivasarao *et al*. (2007)
	Gujarat								
5	Saurastra	Black soils	7	22-71	7.5-8.1	<0.5	7 to 42	S, I	Koria *et al*. (1989)
6	Gujarat	Black soils	10	Clay	Alkaline	<0.50	Calc.	S, I	Ann. Res. Rpt.(1988) GAU, Junagarh
7	Amreli	Vertic Ustochrept	25	Loam-clay	8.2-9.6	0.45-1.2	2.7-11.9	S, Ch, Il, K	Sekhon *et al*. (1992); Srinivasarao *et al*. (2001)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$[b]	Dominant clay minerals[c]	Source
				%		-------------%	-------------		
8	Junagarh	Black calcareous soils (Vertic Ustochrept)	1	Fine	8.2	1.05	4.5	S, I	Tomar *et al*. (2001)
9	Junagarh	Calcareous-soil	1	Silty clay	8.0	0.4	30.6	S, I	Patil *et al*. (2003)
10	Rajkot	Black/Verti-sols	1	66.7	8.0	0.5	5.82	S, I	Srinivasarao *et al*. (2007)
11	Nagar	Desert/Arid-isols	1	10.6	8.2	0.23	1.34	I	Srinivasarao *et al*. (2007)
	Madhya Pradesh								
12	Antralia	Black soils	6	31-53	>7.0	<0.50	<5	S, I	Solankey *et al*. (1991)
13	Madhya Pradesh	Vertic Ustochrept	25	Clay-silty clay	7-8.3	0.3-1.03	1.5-8.6	S, I	Sekhon *et al*. (1992)
14	Indore	Typic Chromustert	10	Clay-silty clay	7.5-8.4	0.18-1.29	2.4-11.6	S, I	Bansal & Umar (1998)
15	Indore	Vertisols	10	51	7.3	1.8 (Organic matter)	<5	S-87, Ch-3, Il-5, K-3	Datta (1996)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		-------------%-------------			
16	Indore & Rewa	Vertisols	20	47.4-65.1	7.6-7.9	0.23-0.68	0.68-4.65	S	Srinivasarao *et al*. (2007)
	Agroecological region 6								
	Karnataka								
1	North Karnataka	Vertisols	100	23-71	7.7-9.2	2.4-12.3	Calc.	S	Venkatesh & Satyanarayana (1994)
	Maharashtra								
2	Dhule	Typic Chromustert	25	Clay-silty clay	7.6-9.1	0.31-0.68	2.6-6.7	S, I	Sekhon *et al*. (1992)
3	Repoli	Inceptisols	10	Loam to clayey 21.0-51.4	6.3 -7.1	0.53 -0.89	2.95 -5.90	I, S	Kaskar *et al*. (2001)
4	Nimone	Udic Chromustert	1	Clay-53	8.6	0.36	19.7	S, I	Bele *et al*. (1997)
5	Otur	Typic Chromustert	1	Clay-56	8.7	0.48	15.0	S, I	Bele *et al*. (1997)
6	Sawargaon	Vertic Ustropept	2	Clay-45-53	8.5-8.7	0.3-0.53	14.2-18.4	-	Bele *et al*. (1997)
7	Pargaon	Lithic Ustrothents	2	Clay loam-32-39	8.3-8.6	0.42-0.46	6.1-14.2	-	Bele *et al*. (1997)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$[b]	Dominant clay minerals[c]	Source
				%		-------------%-------------			
8	Zone IA	Oxisol	3	Clay loam-clayey	5.2 -5.9	1.10 -2.15	0.02 -0.03	K	Sonar & Patil (1996)
9	Zone IB	Entisol	3	Clayey	6.3 -7.2	0.35 -0.56	0.03 -0.25	-	Sonar & Patil (1996)
10	Zone II	Inceptisol/ Vertisol	4	Clayey	7.0 -7.9	0.69 -0.83	0.02 -0.36	S	Sonar & Patil (1996)
11	Zone III	Vertisol	16	Clay loam-clay	7.8 -9.1	0.46 -0.72	1.8 -14.4	S	Sonar & Patil (1996)
12	Zone IVA	Vertisol	9	Clayey	7.6 -8.3	0.37 -0.86	3.25 -8.78	S, I	Sonar & Patil (1996)
13	Zone IVB	Vertisol	5	Clayey	7.9 -8.7	0.38 -0.77	1.19 -8.03	S, I	Sonar & Patil (1996)
14	Zone VA	Alfisol	2	Clayey	6.2 -6.3	0.79 -0.81	0.14 -0.27	K, I	Sonar & Patil (1996)
15	Zone VB	Vertisol	8	Clayey	6.8 -8.4	0.33 -0.67	0.20 -5.76	S, I	Sonar & Patil (1996)
16	Zone VI	Alfisol	3	Sandy clay loam-clay	5.9 -6.2	0.80 -0.93	0.01 -0.01	K, I	Sonar & Patil (1996)
17	Parbhani (Tadpangari)	Chromustert	50	50-78	8.3-8.7	0.58-0.99	4.0-13.5	I, S	Pharande & Sonar (1996)
18	Maharashtra	Vertisols	50	44-72	8.2-9.1	0.62-1.23	6.8-21.9	S	Raskar & Pharande (1997)
19	Maharashtra	Alfisols	40	52-72	5.7-6.1	1.29-2.09	3.8-4.7	K, S, I	Raskar & Pharande (1997)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		-------------%	-------------		
20	Akola	Black/Verti-sols	10	60.2-65.9 (62.2)	8.2-8.5 (8.3)	0.12-0.25 (0.18)	18.1-20.3 (19.0)	S, I	Srinivasarao *et al*. (2006)
21	Solapur	Black/Verti-sols	10	74.5-75.6 (74.86)	8.0-8.2 (8.1)	0.30-0.31 (0.30)	3.7-6.2 (5.37)	S, I	Srinivasarao *et al*. (2006)
	Agroecological region 7								
	Andhra Pradesh								
1	Nellore	Vertisol	60	40-50	8.2-9.4	<0.40	Non-calc.	S	Srinivasarao *et al*. (1991)
2	Nellore	Laterite soil	60	Fine	Acidic	<0.32	Non-calc.	K	Subbaiah *et al*. (1994)
3	Nellore	Laterite soil	60	16-39	6.0-7.1	0.06-0.48	0.08-1.25	K	Srinivasarao & Subbaiah (1997)
4	Warangal	Vertic Ustochrept	25	Loamy-clay	7.6-9.1	0.36-1.0	3-6.9	S, I, K	Sekhon *et al*. (1992)
5	Nalgonda	Typic Paleustalf	25	Sandy loam-sandy clay loam	5.4-7.2	0.2-9.6	Non-calc.	K, S, I	Sekhon *et al*. (1992)
6	Nalgonda	Typic Paleustalf	10	Sandy loam-sandy clay loam	5.4-7.2	0.2-0.96	Non-calc.	K	Srinivasarao *et al*. (2000)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		-------------%	-------------		
7	Nalgonda	Typic Palesustalf	10	Sandy loam	6.3	0.4	Non-calc.	II-60	Debnath & Majumdar (1998)
8	Hyderabad	Alfisol	10	Sandy clay loam	5.29	0.36	Non-calc.	K, S, M	Srinivasarao *et al*. (2002)
9	Mahaboobnagar	Black	8	12.4-20.4	7.3-8.1	0.2-0.61	Non-calc.	S, I, K	Padmaja & Sreenivasa Raju (1999)
10	Medak	Red soils	40	15.0-27.5	7.3-8	0.12-0.83	Non-calc.	S, I, K	Padmaja & Sreenivasa Raju (1999)
11	Guntur	Vertic Halargid	10	Sand clay-clay	7.0-8.8	0.52-1.20	0.04-6.8	S, I	Bansal & Umar (1998)
12	Andhra Pradesh	Black soils (Vertisols)	16	Clay loams-33.5-62.3	7.9-8.9	0.21-0.49	3.0-13.9	S, I, K	Surekha & Subba Rao (1997)
13	V.V. Palem	Aridic Ustochrept	20	Sandy clay-sandy clay loam	6.2-7.4	0.13-0.29	Non-calc.	Mo, K	Srinivasarao *et al*. (1997)
14	Tummagunta	Typic Haplustalf	10	Sandy clay-clay loam	6.8-7.2	0.17-0.21	Non-calc.	S, K	Srinivasarao *et al*. (1997)
15	Darsiguntapeta	Typic Rhodustalf	10	Sandy clay-clay loam	6.8-7.2	0.17-0.22	Non-calc.	S, K	Srinivasarao *et al*. (1997)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals[c]	Source
				%		-------------%-------------			
16	Potluru	Aridic Ustochrept	10	Sandy clay-sandy clay loam	6.6-7.2	0.21-0.33	Non-calc.	S, K	Srinivasarao *et al*. (1997)
17	Ambajipet, Kollur, Jonnapadu	Alluvium	30	Clay-52.8-64.4	7.5-8.7	0.36-1.25	Non-calc.	S	Srinivasarao *et al*. (1996)
18	Hyderabad	Alfisols	10	Sandy clay loam-32.6	5.29	0.36	Non-calc.	K	Srinivasarao *et al*. (2002)
19	Patancheru	Red soils	3	Sandy loam-13.2	6.3	0.36	Non-calc.	K	Dhillon & Dhillon (1996)
20	Teligi	Black soils	3	Clay-46.7	8.4	0.36	4.4	S	Dhillon & Dhillon (1996)
21	Kasireddipalli	Black soils	3	Silty clay loam-39.7	8	0.48	1.1	S	Dhillon & Dhillon (1996)
	Agroecological region 8								
	Tamil Nadu								
1	Pudukottai	-	4	Loamy sandy-silty clay	-	<0.5	0.8-1.12	-	Masilamani *et al*. (1993)
2	Coimbatore	Udorthentic Chromustert	25	Sand-sand loam	5.8-8.5	0.1-0.58	Non-calc.	S, I, K	Sekhon *et al*. (1992)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		-------------%	-------------		
3	Noyyal (Coimbatore)	Ustorthentic Chromustert	10	Loam-clay	7.7-9.0	0.39-1.10	1.4-8.2	S, Il, K	Srinivasarao *et al*. (2001)
4	Doddabhavi (Coimbatore)	Rhodustalfs	20	Loamy sand-sandy loam	5.8-8.5	0.1-0.58	Non-calc.	II-60, K	Debnath & Majumdar (1998), Srinivasarao *et al*. (2000)
5	Coimbatore	Black calcareous soil (Vertic Ustropept)	5	Fine	8	0.31	-	S, I, K	Santhy *et al*. (2003)
6	Kalathur, Thanjavur	Udic Chromustert	25	Clay loam-clay	7.2-8.5	0.36-0.75	2.0-4.0	S	Srinivasarao *et al*. (2000)
7	Kovilpatti	Black/Verti-sols	10	61.9-66.0	7.9-8.1 (8.01)	0.26-0.45 (0.36)	9.70-12.5 (11.25)	S, I	Srinivasarao *et al*. (2006)
	Karnataka								
8	Bangalore	Oxic Paleustalfs	25	Loamy sand -sandy	4.9-6.7	0.14-0.58	Non-calc.	K, Am, I, V	Sekhon *et al*. (1992), Srinivasarao *et al*. (2001)
9	Vijayapura, Bangalore	Oxic Haplustalfs	10	Sandy loam-sandy clay loam	4.8-7.6	0.14-0.6	Non-calc.	K	Srinivasarao *et al*. (2000)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$[b]	Dominant clay minerals[c]	Source
				%		-------------%-------------			
10	Karnataka (Bangalore)	Red/Alfisols	10	24.9-44.9	5.5-6.2 (5.81)	0.12-0.22 (0.16)	0.20-1.48 (0.93)	K	Srinivasarao *et al*. (2006)
11	Jadigenahalli Watershed	Kandic Alfisols	40	12.8-37.7	6.2-7.2	0.3-0.78	Non-calc.	K	Naidu *et al*. (1996)
12	Siruguppa	Typic Pellustert (Vertisols)	3	Clay	8.0-8.2	0.45-0.58	-	S	Veeranna *et al*. (1996)
13	Karnataka	Alfisols	10	Sandy clay loam-36.6	5.30	0.32	Non-calc.	K	Srinivasarao *et al*. (2002)
14	Karnataka	Black/Verti-sols	20	56.7-62.7	8.2-8.5	0.3-0.37	14.5-20.8	S, I, K	Srinivasarao *et al*. (2007)
	Andhra Pradesh								
15	Rangareddy	Red soil	12	9.4-29.8	7-8.3	0.21-0.64	Non-calc.	K	Padmaja & Sreenivasa Raju (1999)
	Agroecological region 9								
	Haryana								
1	Ambala Kurukshetra	Alluvial	6	4.8-20.2	Alkaline	<0.5	-	I	Singh *et al*. (1983)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		-------------%-------------			
	Punjab								
2	Jalandhar (Naura series)	Udic Haplustalf	4	Fine clayey- 14.3-31.1	8.4-9.0	0.23-0.80	0.00-1.05	I	Shamra *et al*. (1997)
3	Jalandhar	Typic Ustochrept	3	19.2	8.3	0.14	-	I	Pasricha *et al*. (2001)
4	Gurdaspur	Typic Haplustalf	3	17.5	7.4	0.44	-	I	Pasricha *et al*. (2001)
5	Patiala Ki Rao	Typic Ustorthent	3	18.9	9.9	0.23	0.9	I	Pasricha *et al*. (2001)
6	Fatehpur	Typic Ustipsamm-ent	3	10.58	8.2	0.15	-	I	Pasricha *et al*. (2001)
7	Jalandhar	Alluvial soil	8	Sandy loam- 14.0-31.4	8.0-8.4 (8.24)	0.29-0.63 (0.45)	Nil-1.50 (0.55)	I	Sharma & Sharma (2001)
8	Hoshiarpur	Alluvial/In-ceptisols	10	17.9	7.8	0.52	3.16	I	Srinivasarao *et al*. (2007)
	Uttar Pradesh								
9	Lucknow	Sandy loam(Ustifluvent)	4	Loamy	7.4	0.5	Non-calc.	I	Yaduvanshi & Singh (1999)
10	Faizabad	Alluvial soil	4	Clay loam	8.9	0.4	Non-calc.	I	Prasad & Chauhan (2000)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals[c]	Source
				%		-------------%	-------------		
11	Faizabad	Inceptisols	10	Silty loam-24.6	9.28	0.35	Non-calc.	I	Srinivasarao *et al*. (2002)
12	Varanasi	Inceptisols	10	Loam-23.5	7.56	0.31	Non-calc.	I	Srinivasarao *et al*. (2002)
13	Eastern (U.P.)	Alluvial/Inceptisols	30	27.7-43.9	6.7-8.3	0.08-0.52 (0.18)	0.46-1.88 (1.10)	I	Srinivasarao *et al*. (2006)
	Bihar								
14	Pusa	Sandy loam calcareous	3	Sandy loam	8.2	0.62	28.0	I	Prasad *et al*. (1996)
16	Muzaffarpur	Typic Ustifluvent	25	Loam-silty loam	7.8-9.4	0.3-0.8	28.1-38-7	I	Srinivasarao *et al*. (2000)
17	Raghopur, Muzaffarpur	Aquic Eutrochrept	25	Silty loam-silty clay	7.8-9.0	0.41-1.2	13.9-40.4	I	Srinivasarao *et al*. (2000)
	Agroecological region 10								
	Madhya Pradesh								
1	Bhopal	Vertic Ustocrept	15	39-54	7.8-8.5	0.3-1.0	4 to 15	S	Srinivasarao (1994)
2	Bhopal	Vertic Ustocrept	47	43-59	8-8.4	0.3-1.0	1-4.8	S	Srinivasarao *et al*. (1995)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		------------%------------			
3	Bhopal (Nabibagh)	Vertisols	50	39-55	7.5-8.5	0.3-1.0	2.2 -15.0	S, Il, Ch, V, K	Srinivasarao *et al*. (1997, 1999); Srinivasarao & Takkar (1997); Srinivasarao & Subba Rao (1999)
4	Bhopal (M.P.)	Non-ingested soil	10	56-59	7.6-7.8	0.62-0.66	2.2-2.8	S, K, M, V, Q	Srinivasarao *et al*. (1997)
5	Nabibagh[†] (series 3)	Typic Haplustert	70	56-63	7.6-7.7	0.46-0.74	-	S	Srinivasarao *et al*. (1997)
6	Nabibagh (series 4)	Typic Haplustert	70	55-60	7.4-8.0	0.27-0.66	-	S	Srinivasarao *et al*. (1997)
7	Nabibagh (series 5)	Typic Haplustert	70	59-65	7.6-7.7	0.4-0.85	-	S	Srinivasarao *et al*. (1997)
8	Sanchi	Black soils	10	42-48	7.4-8.5	0.51-0.75	5-8.4	S, Ch, Il	Srinivasarao & Takkar (1995); Srinivasarao *et al*. (1997)
9	Sehore	Vertisols	10	Clay-61.5	7.85	0.46	-	S	Srinivasarao *et al*. (2002)

[†] Nabibagh series 3 to 5 indicates that soil series identified under Nabibagh region by NBSS & LUP, Nagpur, India as per USDA soil taxonomy.

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		------------%------------			
10	Vidisha	Vertisols	10	41	8.2	0.51	6.1	S	Srinivasarao *et al*. (1996)
11	Salamatpur	Vertisols	10	47.5	7.8	0.57	5	S	Srinivasarao *et al*. (1996)
12	Berkhedi	Vertisols	20	46.5-48.5	8.2-8.4	0.59-0.79	5.8-8.6	S	Srinivasarao *et al*. (1996)
13	Chapna	Vertisols	10	46	8.6	0.59	7	S	Srinivasarao *et al*. (1996)
14	Islamnagar series 3 & 4	Vertisols	80	39-54	8.05-8.46	0.44-1.0	2.2-15.0	S	Srinivasarao *et al*. (1998)
	Agroecological region 11								
	Madhya Pradesh								
1	Raipur	Vertisol	10	Clay-65.5	7.3	0.41	-	S	Srinivasarao *et al*. (2002)
	Agroecological region 12								
	Bihar								
1	Chotanagpur	-	9	10 -28	5.4-5.6	0.22-0.48	-	-	Singh *et al*. (1989)
2	Bihar	Red soils	24	4.4-32	5 to 6	0.1-0.5	Non-calc.	K	Roy & Kumar (1993)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		-------------%	-------------		
	West Bengal								
3	Mondouri, Memari, Chinsurah	Entisols	9	31.6-64.8	5.85-7.99	0.66	-	S, II	Saha & Sanyal (1997)
4	Jhargram	Alfisols	3	14.3	5.67	0.49	Non-calc.	K, II	Saha & Sanyal (1997)
5	Bardhaman	Vertic Eutrochrept	26	Silty clay loam-silty clay	5.0-5.9	0.51-1.03	Nil	S, Il V, K, Q, F, Ch	Sekhon *et al*. (1992), Srinivasarao *et al*. (2001)
6	Kalimpong	Typic Haplumbrept	3	37.3	5.8	1.89	-	-	Singh & Sanyal (2000)
7	Matimahal	Typic Paleustalf	3	23.1	5.7	0.23	-	-	Singh & Sanyal (2000)
	Jharkhand								
8	Ranchi	Alluvail soils	3	Loam to sandy clay loam	5.6	0.59	Non-calc.	K, I, S	Roy & Srivastava (1996)
9	Ranchi	Red sandy loam	3	Sandy loam	6.1	0.6	Non-calc.	K	Kumar *et al*. (1996)
10	Ranchi	Alfisols	2	Sandy clay loam-20.6-25.0	6.1-6.20	0.28-0.62	1.19	K	Srinivasarao *et al*. (2002)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		------------%------------			
11	Birbhum	Typic Haplaquept	25	Loamy sand -silt loam	4.5-6.8	0.22-0.56	Non-calc.	-	Sekhon *et al*. (1992)
12	Jharkhand	Hyperthermic haplustalfs	8	4.0-46.8	4.1-9.9	0.11-0.99	-	-	Roy & Sarkar (1997)
	Orissa								
13	Phulbani	Red/Alfisol	1	19.4-43.4	5.2-6.5 (6.0)	0.06-0.24 (0.12)	0.11-0.62 (0.38)	K	Srinivasarao *et al*. (2006)
14	Phulbani	Aridic Kanhaplic Haplustalfs	5	7.4-21.4	5.5-6.1	0.17-0.4	Non-calc.	-	Das *et al*. (1997)
15	Balisahi (Puri)	Fluventic Ustochrept	10	Loamy sand-loam	4.6-6.5	0.3-0.72	Traces	K, Il S, Q F, V	Srinivasarao *et al*. (2001)
	Agroecological region 13								
	Uttaranchal								
1	Garhwal	Alluvial	5	18 - 38	Acidic	0.69-1.62	Non-calc.	-	Mishra & Srivastava (1991)
	Bihar								
2	North Bihar	Inceptisol/ Entisol	25	-	6.8-9.0	0.51	20.8	-	Kumar & Jha (1987)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		-------------%	-------------		
3	Muzaffarpur	Typic Ustifluvent	25	Loam-silt loam	7.8-9.4	0.3-0.8	28-39	I	Sekhon *et al*. (1992)
4	Bihar	Aquic Eutrochrept	25	Silt loam - silty clay loam	7.8-9.0	0.41-1.17	13.9-40.0	I	Sekhon *et al*. (1992)
5	North Bihar	Calcareous soils (Calciorthent)	5		8.1-8.3	0.41-0.56	15.6-24.5	I	Prasad & Prasad (1997)
6	Bihar	Typic Ustochrept	2	17.7-20.0	7.1-7.5	0.44-0.68	Calc.	I	Chaudhary & Prasad (1997)
7	Pusa	Calcareous Typic Haplaquept	3	14.3-21.6	8-8.5	0.41-0.55	32.5-33.5	-	Chaudhary & Prasad (1997)
8	Madhopur	Calcareous Typic Udorthent	2	12.3-23.6	7.6-8	0.39-0.58	10-35	-	Chaudhary & Prasad (1997)
9	Mokama	Calcareous Typic Ustifluvent	3	24.4-48.5	7.1-7.7	0.51-0.65	6.5	-	Chaudhary & Prasad (1997)
10	Madhepura	Typic Ustifluvent	1	Coarse loamy-26.3	7.1	0.65	-	-	Chaudhary & Prasad (1997)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		------------%	------------		
	Agroecological region 14								
	Himachal Pradesh								
1	Himachal Pradesh	-	10	9.8-26	6.2-7.3	0.27-1.68	0.0-10	-	Singh & Tripathi (1993)
2	Shimla	Acidic brown hill soils	24	Silty loam-silty clay	5.4-6.5	0.42-2.32	Non-calc.	K	Grewal & Sharma (1980)
3	Kangra	Typic Dystrochrept	25	Silty loam	4.8-5.6	0.5-1.2	Non-calc.	I, K, S, V, Ch	Sekhon *et al*. (1992)
4	Himachal Pradesh	Slightly acidic	20	Loam-Sandy loam	6.1-8.7	0.03-0.83	1.5-4.5	I, K, S	Shankhayan *et al*. (1996)
	Jammu & Kashmir								
5	Udampur	Inceptisols	21	14-44	5.7-8.1	0.5-1.0	-	I, V, S	Gupta *et al*. (1980)
6	Anantnag	Dystrochrept	25	Silty loam-clay loam	4 to 6	0.63-2.43	Nil	I, V, S	Sekhon *et al*. (1992)
7	High Altitude	Alluvial soils	4	Clay loam-30.72-33.14	6.9-7.1	1.84-2.2	0.4-0.8	I	Nakashgir *et al*. (1997)
10	Middle Altitude	Alluvial soils	4	Clay loam-27.92-29.00	7-7.3	1.2-1.61	0.7-0.9	I	Nakashgir *et al*. (1997)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		-------------%-------------			
11	Low Altitude	Alluvial soils	4	Loam- 23.02-24.60	8-8.4	0.96-1.05	2.1-2.7	I	Nakashgir *et al*. (1997)
12	Jammu & Kashmir (Rakh Dhiansar)	Alluvial/ Inceptisol	50	11.9-18.1	6.9-7.6 (7.2)	0.32-0.56 (0.38)	2.20-2.85 (2.43)	I, S, V, K	Srinivasarao *et al*. (2006)
	Agroecological region 15								
	West Bengal								
1	West Bengal	Alfisol	4	20-24	4.5-5.1	<0.5	Non-calc.	K	Adhikari & Ghosh (1991)
2	West Bengal	Alluvium	6	19-58	6.7-8.5	<0.5	Non-calc.	S, Il	Adhikari & Ghosh (1991)
3	Barrackpore	Alluvium	3	26.3	6.2	0.56	Non-calc.	K, II, Q	Chaudhary (1998)
4	Kharbona (Birbhum)	Typic Haplaquept	25	Loamy sand-silty loam	4.5-6.8	0.22-0.56	Nil	K, Il, S	Bansal & Umar (1998), Srinivasarao *et al*. (2001)
5	Kalyani	Entisols	3	Clay loam- 20.6-25.0	7.2	0.66	Non-calc.	K, I	Raychaudhuri & Sanyal (1999)
6	Susunia	Alfisols	3	Sandy clay- 41.8	5.7	0.31	Non-calc.	K, I	Raychaudhuri & Sanyal (1999)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$[b]	Dominant clay minerals[c]	Source
				%		-------------%-------------			
7	Bakkali	Inceptisols	3	Clayey-61.8	8	0.25	Non-calc.	I, K	Raychaudhuri & Sanyal (1999)
8	West Bengal	Red & laterite soils	3	Sandy loam to clay loam-27.4-55.7		0.36-0.88	Non-calc.	K, I	Das *et al*. (2000)
9	Fulbari, Gangarmpur, Coochbehar	Acid soils	4	14.5-27.5	4.5-5.3	<0.5	Non-calc.	K, I	Patra & Debnath (1998)
10	Anandapur	Alfisols	3	Clay-24.3	5.25	<0.5	Non-calc.	K	Dhar *et al*. (2009)
	Assam								
11	Jorhat	Acidic soils	3	-	4.2	0.75	-	I, K	Chakravarty *et al*. (1996)
12	Jorhat	Coarse loamy (Typic Fluvaquent)	9	7-24.5	6.4-8	0.62-1.81	2.61-3.15	-	Bhaskar *et al*. (2001)
13	Brahmaputra	Alluvial soil	7	7.86-13.79	4.55-7	0.19-1.29	-	-	Tamuli & Baruah (2000)
14	Sibsagar	Dystrochrept	6	15-43.2	4.3-5.2	0.84-1.84	-	-	Medhi *et al*. (2000)
15	Golaghat	Haplaquept	5	9.5-22.5	4.7-5.9	0.361.11	-	-	Medhi *et al*. (2000)
16	Jorhat	Fluvaquent	2	11.5-13.2	5.9	0.3-0.36	-	-	Medhi *et al*. (2000)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		------------%------------			
	Agroecological region 16								
	Sikkim								
1	Sikkim	Haplumbrept	23	-	4.6-5.5	1.4-7.6	-	-	Patiram & Prasad (1991)
2	Sikkim	Mollisols	3	Clayey-53.1	4.7	38.2	-	-	Raychaudhuri & Sanyal (1999)
	West Bengal								
3	Jalpaiguri	Tarai acid soils	9	10-18	5-5.4	-	-	-	Patra & Debnath (1998)
	Assam								
4	Bokajan	Typic Paleudult	3	Clay-42	4.3	0.48	-	K-38, M-40, Ch-3	Bhattacharyya & Poonia (1996)
5	Phansidewa, Boglahagi	Tarai acid soils	3	13.5-18.4	5-5.3	-	-	-	Patra & Debnath (1998)
	Arunachal Pradesh								
6	Takso	Typic Udorthent	3	Fine loamy-16.8	4.6	1.05	-	-	Singh *et al*. (1999)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		-------------%-------------			
7	Subansiri	Typic Udifluvent	3	Coarse loamy over sandy-10.4	5.08	3.51	-	-	Singh *et al*. (1999)
8	Kalleng	Typic Haplumbrept	3	Fine loamy-27.0	4.3	3.03	-	-	Singh *et al*. (1999)
9	Garu	Typic Dystrochrept	3	Fine loamy-19.2	4.6	1.17	-	-	Singh *et al*. (1999)
10	Renging	Typic Hapludalf	3	Fine loamy-12.5	5.5	3	-	-	Singh *et al*. (1999)
11	Bomte	Ultic hapludalf	3	Fine loamy-19.9	5	1	-	-	Singh *et al*. (1999)
12	Dalbeng	Entic Hapludoll	3	Fine loamy-20.1	4.97	4.47	-	-	Singh *et al*. (1999)
13	Buda	Typic Hapludoll	3	Fine loamy-19.4	5.19	3.85	-	-	Singh *et al*. (1999)
	Agroecological region 17								
	Meghalaya								
1	East Khasi	High altitude soils	10	Silty loam	4.3-5.6	1.14-5.6	-	-	Patiram & Prasad (1984)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		-------------%-------------			
2	East Khasi	Low altitude soils	20	Silty loam-loam	4.3-5.6	1.14-5.6	-	-	Patiram & Prasad (1984)
	Mizoram								
3	Mizoram	Hill soils	15	19-30.7	4.1-5.1	>0.5	-	-	Singh & Datta (1986)
	Nagaland								
4	Nagaland	Acid soils	24	-	4.3-5.9	-	-	-	Gupta *et al*. (1983)
5	Chalkot	Dystric Eutrochrept	3	Fine loamy-27.8	5.7	0.72	-	-	Singh *et al*. (1999)
6	Zukheshsema	Typic Dystrochrept	3	Fine loamy-38.3	4.88	0.92	-	-	Singh *et al*. (1999)
7	Kangan	Typic Udorthent	3	Fine loamy-34.1	4.87	1.08	-	-	Singh *et al*. (1999)
8	Bhaghty	Ultic Hapludalf	3	Fine loamy-27.0	4.87	1.24	-	-	Singh *et al*. (1999)
9	Zusuma	Entic Hapludoll	3	Coarse loamy-16.9	4.35	3.39	-	-	Singh *et al*. (1999)
	Manipur						-	-	
10	Kharam	Typic Udorthent	3	Clayey-skeletal-29.4	5.5	2.3	-	-	Singh *et al*. (2006)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		-------------%-------------			
11	Landon, Biyang, Maha Koirang	Typic Kandiudult	9	14.9-18.8	4.7-5.2	0.8-1.7	-	-	Singh *et al*. (2006)
12	Khambang, Kadamtala	Typic Haplaquept	6	19.9-39.5	4.6-5.1	0.9-1.2	-	-	Singh *et al*. (2006)
13	Lamphelpat	Typic Haplaqent	3	25.6	4.6	3.5	-	-	Singh *et al*. (2006)
14	Kaimai	Mollic Paleudalf	3	Loam-9.8	4.2	2.8	-	-	Singh *et al*. (2006)
15	Bhutnkhal	Umbric Dystropept	3	Fine loamy-7.2	4.6	1.3	-	-	Singh *et al*. (2006)
	Agroecological region 18								
	Andhra Pradesh	Alluvial	30	23-49	7.6-8.6	0.15-0.72	1 to 4	I, K, S	Sailakshmiswari *et al*. (1985)
1	Coastal A.P.								
2	Guntur	Vertic Haplaquept	25	Sandy clay-clay	7-8.8	0.10-0.55	0.4-6.8	S, V, I, K	Sekhon *et al*. (1992)
3	Bapatla (Guntur)	Sandy soil (Ustipsamment)	10	Sandy	7.2	<0.5	Non-calc.	I, K, S	Pillai & Nookaraju (1997)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		-------------%	-------------		
4	Rajahmundry	Black soil (Vertisols)	10	Clay-50	8.2	<0.5	-	Mo, II	Krishnamurthy & Ramakishnayya (1997)
5	Devarapalli	Light soil (Alfisols)	10	Sandy-8	7.2	<0.5	-	Mo, II	Krishnamurthy & Ramakishnayya (1997)
6	Guntur	Black soil (Vertisols)	10	Clay-49	8.3	<0.5	-	Mo, II	Krishnamurthy & Ramakishnayya (1997)
7	Nellore	Black soil (Entisols)	10	Silty loam-28	7.8	<0.5	-	II, Mo	Krishnamurthy & Ramakishnayya (1997)
8	Kandukur	Light soil (Alfisols)	10	Sandy loam-17	7.4	<0.5	-	K, Be	Krishnamurthy & Ramakishnayya (1997)
9	Hunsur	Light soil (Alfisols)	10	Loamy sand-13	5.4	<0.5	Non-calc.	II, K	Krishnamurthy & Ramakishnayya (1997)
10	Anantpur	Red/Alfisol	50	24.6-37.3	6.5-6.9 (6.8)	0.16-0.19 (0.17)	0.98-4.90 (3.19)	K, I, S	Srinivasarao *et al*. (2006)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals [c]	Source
				%		-------------%-------------			
	Tamil Nadu								
11	Thanjavur	Udic Chromustert	25	Clay loam-clay	7.2-8.5	0.36-0.75	2.0-4.0	S, K, Il, V, Ch	Sekhon *et al*. (1992), Srinivasarao *et al*. (2001)
	Orissa								
12	Puri	Fluventic Ustochrept	25	Loamy sand -loam	4.6-6.5	0.3-0.72	Traces	K	Sekhon *et al*. (1992); Srinivasarao *et al*. (2000)
13	Phulbani	Red/Alfisol	10	19.4	5.2	0.24	0.38	K, I, S	Srinivasarao *et al*. (2007)
	Agroecological region 19								
	Kerala								
1	Kerala	Laterite/ Red soil	15	Loam	Acidic	>0.5	Non-calc.	K, I	Prabha Kumari & Aiyer (1993)
2	Trivandrum	Oxic Dystropept	25	Gravelly clay-clay loam	4.8-7.2	0.44-2.40	Non-calc.	K, Am, I, V	Sekhon *et al*. (1992)
3	Allepy	Tropaquept	25	Sandy clay loam-clay	2.7-5.0	2.83-8.24	Nil	K, S, I, V, Al	Sekhon *et al*. (1992)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals[c]	Source
				%		-------------%------------			
4	Purakkad (Allappey)	Tropaquent	10	Sandy clay loam-clay	2.7-5.0	Nil	Sandy clay loam-clay	K, S, I, V, Al	Bansal & Umar (1998)
5	Kerala	Entisols	12	Sandy to clayey- 4.1-21.1	2.60 -6.1	0.28 - 11.01	Non-calc.	K	Thampatti & Jose (1999)
6	Kerala	Fluventic Dystropept	3	Sandy to silty loam- 24.0-36.5	3.30-5.50	0.07-2.75	Non-calc.	K	Thampatti & Jose (1999)
	Maharastra								
7	Maharashtra	Lateritic/ soils	30	13.1-25.1	5.4-6.0	0.69-1.5	1.47-4.92	K, I	Sutar *et al*. (1992)
8	Ratnagiri	Fluventic Ustropept	35	Gravelly loam-silty clay loam	5.7-6.9	1.38-2.52	Non-calc.	K, I, V, M	Sekhon *et al*. (1992), Srinivasarao *et al*. (2001)
9	Ratnagiri	Alfisols	10	30	6.3	1.9	Non-calc.	K, Il, V	Srinivasarao *et al*. (1997)
10	Ratnagiri (Dapoli)	Lateritic soil	3	Clay loam	5.4	1.51	Non-calc.	K	Patil *et al*. (2006)

Table 2.1. continued

S. No. [a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Texture/ % clay	pH	Organic carbon	$CaCO_3$ [b]	Dominant clay minerals[c]	Source
				%		-------------%-------------			
	Agroecological region 20								
1	Andamans & Nicobar	Acidic hill soils	30	29	5.6	0.99	-	K, I	Mongia & Bandyopadhyay (1991)

3. Potassium Status of Soils

To categorize the soils in the different agroecological regions on the basis of available K (1N NH_4OAc extractable as described by Jackson, 1968) and non-exchangeable K (1N boiling HNO_3 extractable minus 1N NH_4OAc extractable as described by Jackson, 1968). Water-soluble K was determined after extracting K from soil in water and determined with flame photometer. Exchangeable K was derived by substracting water-soluble K from available K. The following norms were employed for categorizing soils:

- Exchangeable K (mg kg^{-1}): Low (0-50), medium (50-110) and high (>110). *Source*: Muhr *et al*., 1965.
- Non-exchangeable K (mg kg^{-1}): Low (0-300), medium (300-600) and high (>600). *Source*: Subba Rao *et al*., 1993; Srinivasarao *et al.*, 2007; Srinivasarao *et al.*, 2010.

Potassium status of soils in the different agroecological regions is described in Table 3.1.

Agroecological region 1

The alluvial soils in Himalayan region are medium in exchangeable K and to high non-exchangeable K. Being mica dominant soils, K supplying potential is very high.

Agroecological region 2

The arid and alluvial soils in region 2 are low to high in available K and low to high in non-exchangeable K. These soils showed a wide variability in their non-exchangeable K reserves, having very high values at some locations (Hisar and Sri Ganganagar) and extremely low values at others (Jaisalmer).

Agroecological region 3

This region covers mostly Alfisols which are medium in available K and low to medium in non-exchangeable K. Illite is the associated clay mineral. Long-term K supplying power of soils is low and is under continuous groundnut based production systems.

Agroecological region 4

These are predominantly alluvial soils under intensive system of agriculture. These soils are low to high in available K and medium to high in non-exchangeable K, however, at few places the soils have low non-exchangeable K. Light textured alluvial soils with moderate amounts of both available and non-exchangeable K, particularly in parts of Punjab, may respond to K in this region.

Agroecological region 5

Vertisols and associated soils are the dominant group of soils in this region. These are predominantly high in available K, but medium/medium to high in non-exchangeable K. These soils have high CEC and relatively high available K, but the percent K saturation is quit low. There are instances where swell-shrink soils having high exchangeable K respond to K application. The lack of information on critical limits of K for important crops on these soils also limits interpretation of soil test data and formulation of K fertilizer recommendations.

Agroecological region 6

The soils in this belt are dominantly Vertisols and associated Alfisols. These are medium to high in available K and low to high in non-exchangeable K.

Agroecological region 7

In this region, both swell-shrink and red and lateritic soils occur in association. While swell-shrink soils are high in available K, red and lateritic soils are low to medium. Non-exchangeable K reserves are medium in swell-shrink soils but low in red soils. Thus, the red and lateritic soils in this belt need greater attention as they are poor in both available and reserve K and may respond to K fertilizer.

Agroecological region 8

Red soils are the dominant group in this belt and these are medium in available K but low in reserve K. Crop responses to K have frequently been reported in this region. From the point of view of potash fertilization, this is an important area which needs the immediate attention of administraters and extension workers.

Agroecological region 9

Inceptisols, Entisols and Mollisols are dominant in this region. These are medium in available K and generally high in non-exchangeable K. This region covers many agriculturally important areas.

Agroecological region 10

Vertisols and Vertic Ustochrepts are dominant in this area. The soils are high in available K and medium to high in non-exchangeable K.

Agroecological region 11

Vertisols and Verrtic Ustochrept are dominant soils with wide variability in texture and soil properties. These soils have medium to high available K and non-exchangeable K.

Agroecological region 12

Soils in this region are red and acidic alluvial soils. These are low to medium in available K and low in non-exchangeable K. Soils in this belt showed larger responses to applied K and there is a great potential for K fertilization.

Agroecological region 13

These are alluvial soils with medium to high available K and low to high non-exchangeable K. They are calcareous and are among the most intensively cultivated alluvial soils.

Agroecological region 14

Brown forest and acidic hill soils occur in this region. They vary widely in their K status with low to high range in respect of both available and non-exchangeable K. The less K fertile Dydtrochrepts may respond to added K. Here again, there is a potential for fertilizer use. However, the soils have low non-exchabgeable-K, except those which occur in the state of Punjab.

Agroecological region 15

Acidic alluvial soils are dominant in this area. They are marginally high in available K but are mostly low to medium in non-exchangeable K.

Agroecological region 16

The available K is medium to high. However, they contain medium to high non-exchangeable K with a few areas having very high values.

Agroecological region 17

Soils are acidic and occur at different altitudes in this region. These soils are low to medium in respect of available and medium to high in non-exchangeable reserves. Crop responses to K have been reported on soils of this belt. Soils of Nagaland are especially low in available K.

Agroecological region 18

This region represents coastal and deltaic alluvial soils. These are predominantly high in available K and medium to high in non-exchangeable K. Rice followed by legume or rice-rice is the important cropping sequence in this region and responses of rice to K have been reported.

Agroecological region 19

Red and lateritic soils occur in this region. These soils are largely medium to high in available K and low to high in reserve K. Agricultural, horticultural and plantation crops in this region respond to K application. Regular K fertilizer application is already in practice in several parts of this region.

Agroecological region 20

These soils are light textured acidic soils with low to medium in available K and low in non-exchangeable K. Crops need external application of K to most of the crops grown in this region.

Table 3.1. Potassium status of soils in the different agroecological regions of India.

(a) Number of states or agroecological regions, or locations sampled

(b) Mean of water-soluble K

(c) Value in bracket is the mean of exchangeable K (available K-water-soluble K)

(d) Non-exchangeable K is HNO_3 K minus exchangeable

(e) In some cases, range is given with or without mean. Data in brackets beside range represent the mean value.

Exchangeable K: 0-50 mg kg^{-1} low (L), 50-110 mg kg^{-1} medium (M) and above 110 mg kg^{-1} high (H).

Non-exchangeable K: 0-300 mg kg^{-1} low (L), 300-600 mg kg^{-1} medium (M) and above 600 mg kg^{-1} high (H).

Table 3.1. continued

Table 3.1. Potassium status of soils in the different agroecological regions of India.

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				--------------------------------mg kg^{-1}	--------------------------------			
	Agroecological region 1							
1	Jammu and Kashmir	Inceptisols	10	-	50-169 M	600-1,017	600-900 H	Wani *et al*. (2009)
2	Jammu and Kashmir	Inceptisols	10	-	60-90 M	-	>600 H	Wani and Datta (2007)
3	Jammu and Kashmir	Alluvial	64	9-30	55-118 M	840-1,351	741-1,215 H	Sharma *et al*. (2009)
4	Jammu and Kashmir	Inceptisols	30	5-15 (7.2)	55-155 (72) M	-	552-918 (681) H	Wani and Kumar (2008)
	Agroecological region 2							
	Gujarat							
1	West Gujarat	Black	10	5.98	148 H	499	383 M	Patel *et al*. (1989)
2	Gujarat	Ustalbic Haplargid	25	12.4	87 M	-	700 H	Sekhon *et al*. (1992)
3	Gujarat (Pithvajal; Amreli)	Vertic Ustochrept	10	13	H	580	600-800	Srinivasarao *et al*. (2000)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				---------------------------------*mg kg^{-1}*---------------------------------				
	Rajasthan							
4	Dune & interdune soils	Torripsamments	18	-	100-129 M-H	224-344	124-214 L	Datta & Joshi (1989)
5	Jaisalmer, Barmer, Siker	Arid soils	8	-	66 M	78	12.6 L	Joshi (1986)
6	Mazodar (Banaskantha)	Ustalbic Haplargid	10	9	M	-	845 H	Srinivasarao *et al*. (2001)
7	Ganganagar	Typic Torrifluvent	26	21-41	237 H	1,278-1,460	1,041 H	Sekhon *et al*. (1992); Srinivasarao *et al*. (2000)
8	Bharatpur	Dominant soil	3	26	29.2 L	170-180	M	Chand & Swami (2000)
	Haryana							
9	Hisar	Alluvial/ Aridisols	25	8-18 (11)	53-72 M (60)	-	1,030-1,999 H (1,464)	Srinivasarao *et al*. (2007)
10	Hisar	Non-calcareous (Typic Camborthids)	3	-	M	-	H	Mittal *et al*. (1996)
11	Haryana	Typic Udorthents	2	-	M	326-1,160	H	Mehta *et al*. (2001)
12	Haryana	Typic Ustochrepts	6	-	M	216-1,326	H	Mehta *et al*. (2001)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				--------------------------------*mg kg^{-1}*--------------------------------				
13	Haryana	Typic Torripsamme-nts	1	-	M	113	-	Mehta *et al*. (2001)
14	Haryana	Typic Ustipsamments	1	-	M	968	H	Mehta *et al*. (2001)
15	Haryana	Typic Ustifluvents	1	-	M	176	-	Mehta *et al*. (2001)
	Punjab							
16	Dhar	Typic Entrochrept	3	-	42.3-57.8 L-M	-	H	Pasricha *et al*. (2001)
17	Laungowal	Natric Camborthid	1	-	38.8 L	-	H	Pasricha *et al*. (2001)
18	Nihalkhera	Typic CAmborthid	1	-	73.5 M	-	H	Pasricha *et al*. (2001)
19	Interdunal. Alluvial terraces	Ustochreptic Camborthid	2	-	76.1-127.6 M-H	-	H	Pasricha *et al*. (2001)
20	Jalalabad	Udic Ustochrept	1	-	169.2 H	-	H	Pasricha *et al*. (2001)
21	Sadhugarh	Vertic Ustochrepts	1	-	221.2 H	-	H	Pasricha *et al*. (2001)
22	Naura	Udic Haplustalf	1	-	88.5 M	-	M	Pasricha *et al*. (2001)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				---------------mg kg^{-1}---------------				
23	Zirakapur	Acquic Ustorthents	3	-	45.7-66.4 L-M	-	H	Pasricha *et al*. (2001)
24	Sand dunes	Ustic Torripsamment	1		22.5 L	-	M	Pasricha *et al*. (2001)
25	Abohar	-	2		66-77.1 M		M	Pasricha *et al*. (2001)
26	Kandi	Typic Ustorthent	1		17.8 L	-	M	Pasricha *et al*. (2001)
	Agroecological region 3							
	Andhra Pradesh							
1	Anantpur	Red/Alfisols	10	1-2 (1)	41-62 (47) L	-	L	Srinivasarao *et al*. (2007)
2	Anantapur	Red soils	60	4-8	45-74 (62) M	-	250-619 (365) L-M	Srinivasarao (2006)
3	Anantapur	Red soils	110	-	39-84 (71) L-M	-	290-700 (410) L-M	Srinivasarao (2010)
4	Anantapur	Red soils	25	4-7	L-M	-	M	Srinivasarao *et al*. (2010)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				----------*mg kg^{-1}*----------				
	Agroecological region 4							
	Rajasthan							
1	Chambal		3	11.7	172 H	-	788 H	Mishra *et al*. (1993)
2	Chandwal	Sandy loam soils	8	-	70-191 M-H		468-748.8 M-H	Sharma & Swami (2000)
	Madhya Pradesh							
3	Gwalior	Medium black	18	24.7-27.7	185-203 H	890-970	>600 H	Tiwari & Bansal (1992)
4	Gwalior	Alluvial	4	23.7	172 H	1,840	>1,500 H	Tiwari & Bansal (1992)
5	Morena & Bhind	Sodic, saline-alkali	120	2.38-4.75	11.9-18.8 L	108-159	<300L	Tomar *et al*. (1997)
	Uttar Pradesh							
6	Eastern U.P.	Alluvial/Incep-tisols	10	4-20 (8)	33-87 (66) L-M	-	1,186-2,413 (1,947) H	Srinivasarao *et al*. (2007)
7	Eastern U.P.	Alluvial/Incep-tisols	10	4-12 (7)	57-69 (63) M	-	1,287-1,473 (1,401) H	Srinivasarao *et al*. (2007)
8	Western U.P.	Alluvial/Incep-tisols	10	2-12 (5)	35-47 (40) L	-	1,279-1,703 (1,546) H	Srinivasarao *et al*. (2007)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				--------------------------------*mg kg*$^{-1}$--------------------------------				
9	Western U.P.	Alluvial/Incep-tisols	10	12-16 (13)	128-145 (137) H	-	1,055-1,207 (1,135) H	Srinivasarao *et al*. (2007)
10	Kanpur	Typic Ustochrept	28	47	88 M	1,251	>1,100 H	Tiwari *et al*. (1988)
11	Kanpur	Udic Ustochrept	25	15.3	88 M	1,570	1,482 H	Sekhon *et al*. (1992)
12	Kanpur	Inceptisols	1	5.3	-	1,187	-	Srinivasarao *et al*. (2002)
13	Agra	Alluvial	20	24.7	126 H	1,452	1,326 H	Chandraprakash & Vinay Singh (1986)
14	Meerut	Typic Haplustalf	25	15.4	91 M	1,440	1,349 H	Sekhon *et al*. (1992)
15	Etah	Udic Haplustalf	25	26.3	134 H	1,480	1,346 H	Sekhon *et al*. (1992)
16	Markundi soil	Steep hill slope	1	54	191 H	-	635 H	Ahmed & Walia (1999)
17	Tikria soil	Subdued plateau	1	17	83 M	-	200 L	Ahmed & Walia (1999)
18	Devagan soil	Flat topped hill	1	22	68 M	-	730 H	Ahmed & Walia (1999)
19	Bahilpurwa soil	Undulating plateau	1	1	54 M	-	205 L	Ahmed & Walia (1999)
20	Gonda soil	Monadnock	1	11	59 M	-	430 M	Ahmed & Walia (1999)
21	Mariahu soil	Foot hill slope	1	13	67 M	-	300 L	Ahmed & Walia (1999)
22	Khraund soil	Pedimont plain	1	16	44 L	-	340 M	Ahmed & Walia (1999)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				--------------------------------*mg kg*$^{-1}$--------------------------------				
23	Badusa soil	Slightly Undulation flood plain	1	5	150 H	-	565 M	Ahmed & Walia (1999)
24	Anuwan soil	Level flood plain	1	11	164 H	-	825 H	Ahmed & Walia (1999)
25	Makhanpur, Shikohabad. Sirsaganj	Alluvial soil	3	9.5-25	60-100 M	-	>600 H	Singh *et al*. (2001)
	Delhi							
26	Delhi	Inceptisols	1	7	70-95 M	832	>700 H	Srinivasarao *et al*. (2002)
27	Delhi	Typic Ustochrept	8	26	119 H	1,556	H	Srivastava *et al*. (1994)
	Haryana							
28	Haryana	Alluvial	24	16	115 H	421	307 M	Mehta *et al*. (1991)
29	Haryana	Alluvial	4	23.5	262 H	801		Singh *et al*. (1984)
30	Gurgaon	Udic Ustochrept	25	20.5	86 M	520	434 M	Sekhon *et al*. (1992)
	Punjab							
31	Ludhiana	Udic Ustochrept	25	35.7	119 H	990	871 H	Sekhon *et al*. (1992)
32	Ludhiana	Udic Ustochrept	1	15	90-112 M	860	750 H	Srinivasarao *et al*. (2001)
33	Ludhiana	Loamy sand	9	8.8-14.2	-	-	-	Pannu *et al*. (2002)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				---------------------------------*mg kg*$^{-1}$	---------------------------------			
34	Submontane zone	Alluvial soils	7	2-4	8 -47 L	77-410	49-379 L-M	Benipal *et al*. (2001)
35	Central Plain zone	Alluvial soils	5	2-3	6-26 L	154-349	143-340 L-M	Benipal *et al*. (2001)
36	South-Western zone	Alluvial soils	4	3-5	26-71 L-M	246-508	212-437 L-M	Benipal *et al*. (2001)
37	Zirakpur	Alluvial	3	-	19.9-69.9	-	64-270 M-H	Brar *et al*. (1999)
38	Amritsar	Typic Ustorthent	2	43.8-53.3	M	-	>600	Pasricha *et al*. (2001)
39	Kapurthala	Alluvial soil	10	12-45	37-265 L-H	-	705-1,523 H	Sharma & Sharma (2001)
	Agroecological region 5							
	Rajasthan							
1	Kota & Jhalawar	Pellusterts Chromusterts	6	12.5	165 H	840	675 H	Sehgal *et al*. (1992)
2	Jhalawar	Vertisols	4	98	121 H	743	637 H	Das *et al*. (1993)
3	Arjia	Black/Vertisols	10	6-12 (8)	19-76 (40) L-M	-	350-490 M	Srinivasarao and Vittal (2007)
4	Southem Rajasthan	Haplustalfs	30	1.2-29	39-269 L-H	-	-	Yadav & Swami (1887)
5	Rajkot	Black/Vertisols	10	1-4 (2)	21-157 (81) L-H	-	90-319 (182)	Srinivasarao *et al*. (2007)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				---------------------------------*mg kg^{-1}*---------------------------------				
6	Nagar	Desert/Aridisols	10	4-18 (11)	20-39 (28) M	-	355-417 (389)	Srinivasarao *et al*. (2007)
7	Amreli	Vertic Ustochrept	25	16.7	396 H	744	378 M	Sekhon *et al*. (1992)
8	Rajkot	Black/Vertisols	10	1-4 (2)	21-157 (81) L-H	-	90-319 (182)	Srinivasarao *et al*. (2007)
	Gujarat							
9	Saurastra	Black soils (Ustrochrepts)	10	-	3.4-10.1 L	-	-	Patel & Golakiya (1996)
10	Saurastra	Black soils	7	11	171 H	610	438 M	Koria *et al*. (1989)
11	Saurastra	Black soils	10	5.86	154 H	484	330 M	Ann. Res.Rpt. (1988), GAU Junagarh
	Madhya Pradesh							
12	Antralia	Black soils	6	2	123 H	575	452 M	Solankey *et al*. (1991)
13	Indore	Black/Vertisols	1	4-16 (10)	101-147 (132) M-H	-	-	Srinivasarao *et al*. (2007)
14	Rewa	Black/Vertisols	1	6-14 (9)	141-208 (171) H	-	832-1,167 (1,051)	Srinivasarao *et al*. (2007)
15	Madhya Pradesh	Vertisols	4	7.3	215 H	2,010	1,795 H	
16	Indore	Vertic Ustochrept	25	80	269 H	586	317 M	Sekhon *et al*. (1992)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				--------------------------------*mg kg*$^{-1}$--------------------------------				
17	Sarol (Indore)	Typic Chromustert	1	100	350 H	780	>1,300 H	Srinivasarao *et al*. (2001)
18	Kamliakheri (Indore)	Vertic Ustochrept	1	9	265 H	800	>1,000 H	Srinivasarao *et al*. (2001)
	Agroecological region 6							
	Maharashtra							
1	Vidarbha	Vertisols	28	8	135 H	-	>600 H	Gajbhiye *et al*. (1993)
2	Akola & Amravati	Vertic/Entisols	12	-	212 H	521	309 M	Deshmukh & Rangacharya (1992)
3	Panvel, Radhanagari, Latur	Vertic/Entisols	6	12.5	311 H	-	791 H	Talele *et al*. (1993)
4	Akola	Black/Vertisols	10	1-2 (1)	15-69 (32) L-M	-	M	Srinivasarao *et al*. (2007)
5	Solapur	Black/Vertisols	10	2-5 (3)	198-256 (217) H	520	640-720 (661) H	Srinivasarao *et al*. (2007)
6	Karnataka (North)	Vertisols	10	20	212 H	-	625 H	Venkatesh & Satyanarayana (1994)
7	Dhule	Typic Chromustert	25	12.4	455 H	1,072	617 H	Sekhon *et al*. (1992)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e] Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	Source
				--------------------------------*mg kg^{-1}*--------------------------------				
8	Repoli	Inceptisols	1	0.91	31 L	-	88 L	Kaskar *et al.* (2001)
9	Nimone	Udic Chromusterts	1	-	310 H	-	540 M	Bele *et al*. (1997)
10	Otur	Typic Chromusterts	1	-	340 H	-	580 M	Bele *et al*. (1997)
11	Sawargaon	Vertic Ustropepts	1	-	270 H	-	540 M	Bele *et al*. (1997)
12	Dholwad	Vertic Ustropepts	1	-	320 H	-	840 H	Bele *et al*. (1997)
13	Pargaon	Tropic Lithic Ustrothents	1	-	132 H	-	260 L	Bele *et al*. (1997)
14	Khanapur	Tropic Lithic Ustrothents	1	-	96 M	-	240 L	Bele *et al*. (1997)
15	Zone IA	Oxisols	3	3.7-5.6	52-260 M-H	-	199-175 L	Sonar & Patil (1996)
16	Zone IB	Entisols	3	3.8-5.6	42-217 L-H	-	167-229 L	Sonar & Patil (1996)
17	Zone II	Inceptisols/ Vertisols	4	5.6-10.6	117-546 H	-	141-911 H	Sonar & Patil (1996)
18	Zone III	Vertisols	16	16.2-16.6	140-744 H	-	268-1,597 H	Sonar & Patil (1996)
19	Zone IVA	Vertisols	9	10.0-16.9	110-487 H	-	221-1,241 H	Sonar & Patil (1996)
20	Zone IVB	Vertisols	5	14.5-16.9	267-565 H	-	510-1,625 H	Sonar & Patil (1996)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				---------------*mg kg*$^{-1}$	---------------	---------------	---------------	
21	Zone VA	Alfisols	2	13.1-16.9	305-306 H	-	858-1,901 H	Sonar & Patil (1996)
22	Zone VB	Vertisols	8	10.3-16.9	208-325 H	-	516-840 H	Sonar & Patil (1996)
23	Zone VI	Alfisols	9	7.5-9.4	143-227 H	-	688-1,599 H	Sonar & Patil (1996)
24	Parbhani, Jalgaon, Solapur	Typic Chromusterts	9	9.8-19.1	202-311 H	-	553-632 M-H	Pharande & Sonar (1996)
25	Nagpur (Kirnapur)	Entic Chromusterts	3	10	201 H	-	762 H	Pharande & Sonar (1996)
26	Ahmednagar (Nimone)	Udic Chromusterts	3	11	191 H	-	642 H	Pharande & Sonar (1996)
27	Barshi, Kolhapur, Padegaon, Rastapur, Shendvada	Vertisols	5	4.2-20.5	71-278 H	-	130-727 L-H	Raskar & Pharande (1997)
28	Taldeo, Chikhali, Pali, Kumbharoshi	Alfisols	12	8.7-35	87-318 H	-	267-610 L-H	Raskar & Pharande (1997)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				--------------------------------*mg kg^{-1}*--------------------------------				
	Agroecological region 7							
	Andhra Pradesh							
1	Nellore	Vertisols	36	-	190 H	800	H	Srinivasarao *et al*. (1991)
2	Warangal	Vertic Ustochrepts	25	19.8	212 H	700	488 M	Sekhon *et al*. (1992)
3	Nalgonda	Typic Paleustalf	25	10.7	65 M	269	204 L	Sekhon *et al*. (1992)
4	Nellore	Laterite soils	36		101 M	-	<300 L	Subbaiah *et al*. (1994)
5	Nellore	Laterite soils	36	6	-	-	-	Srinivasarao & Subbaiah (1997)
6	Hyderabad	Alfisols	10	5.2	M	364	M	Srinivasarao *et al*. (2002)
7	Mahaboobna-Gar	Red soils	8	3-15	10-77 L-M	441-1,100	M	Padmaja & Sreenivasa Raju (1999)
8	Medak	Red soils	4	4-13	20-84 L-M	720-1,180	M	Padmaja & Sreenivasa Raju (1999)
9	Nalgonda (Kodad)	Typic Paleustalf	35	9.3-19	L	231-304	M	Bansal *et al*. (1996), Srinivasarao *et al*. (2001)
10	Andhra Pradesh	Black soils (Vertisols)	16	2-4	H	H	>600 H	Surekha & Subba Rao (1997)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				--------------------------------*mg kg*$^{-1}$--------------------------------				
11	V.V.Palem	Aridic Ustochrepts	10	40	125 H	-	1,150 H	Srinivasarao *et al*. (1997)
12	Madhavaram	Aridic Ustochrepts	10	37	90 M	-	1,235 H	Srinivasarao *et al*. (1997)
13	Tummagunta	Typic Haplustalfs	10	30	63 M	-	1,763 H	Srinivasarao *et al*. (1997)
14	Darsiguntapeta	Typic Rhodustalfs	10	38	115 H	-	1,010 H	Srinivasarao *et al*. (1997)
15	Buradapalem	Typic Rhodustalfs	10	31	105 M	-	1,370 H	Srinivasarao *et al*. (1997)
16	Potluru	Aridic Ustochrepts	10	43	145 H	-	2,280 H	Srinivasarao *et al*. (1997)
17	Ambajipet, Kollur, Jonnapadu	Alluvium	30	-	155-197 H	-	942-1,860 H	Srinivasarao *et al*. (1996)
	Agroecological region 8							
	Tamil Nadu							
1	Pudukottai	-	4	-	88 M	-	M	Masilamani *et al*. (1993)
2	Coimbatore	Udorthentic Chromustert	25	15	77 M	1,074	982 H	Sekhon *et al*. (1992)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				--------------------------------*mg kg^{-1}*--------------------------------				
3	Doddabhavi (Coimbatore)	Rhodustalf	1	18.7-27.2	M	983-1,002	H	Bansal *et al*. (1996)
4	Doddabhavi (Coimbatore)	Rhodustalf	1	9	M	1,040	H	Srinivasarao *et al*. (2001)
5	Coimbatore (Noyyal)	Chromustert	1	77.5-85.3	H	2,285-2,233	H	Bansal *et al*. (1996)
6	Coimbatore (Noyyal)	Ustorthentic Chromustert	1	33	>150	1,900	1,500 H	Srinivasarao *et al*. (2001)
7	Kovilpatti	Black/Vertisols	1	3-10 (6)	88-198 (114) M	-	411-596 (473) M	Srinivasarao *et al*. (2007)
8	Thanjavur	Udic Chromustert	1	13.2-26.5	H	810-833	H	Bansal *et al*. (1996)
9	Tamil Nadu	Udic Chromustert	1	12	H	1,040	H	Srinivasarao *et al*. (2000)
	Karnataka							
10	Bangalore	Oxic Haplustalf	25	16.2	55 M	140	95 L	Sekhon *et al*. (1992)
11	Bangalore	Alfisols	1	5.6	M	337	L	Srinivas Rao *et al*. (2002)
12	Bangalore urban	Fine, Kandic paleustalf	40	1.1-2.8	M	-	L	Naidu *et al*. (1996)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				-------------------------------*mg kg*$^{-1}$-------------------------------				
13	Vijayapura (Bangalore)	Oxic Haplustalf	10	12	L	120	L	Srinivasarao *et al*. (2001)
14	Tyamagondalu (Bangalore)	Oxic Paleustalf	10	13	L	320	L	Srinivasarao *et al*. (2001)
15	Karnataka	Black/Vertisols	20	3-9 (5)	135-211 (162) H	-	267-429 (342) M	Srinivasarao *et al*. (2007)
16	Bangalore	Red/Alfisols	10	1-5 (2)	19-38 (22) L	-	93-158 (123) L	Srinivasarao *et al*. (2007)
	Andhra Pradesh							
17	Rangareddy	Red soils	12	5-10.6	8-59 L-M	470-1,010	M	Padmaja & Sreenivasa Raju (1999)
18	Telangana & Rayalaseema regions	Vertisols	10	15	H	-	H	Surekha *et al*. (1996)
	Agroecological region 9							
	Haryana							
1	Ambala, Kurukshetra	Alluvial	6	22	118 H	-	687 H	Singh *et al*. (1983)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				--------------------------------*mg kg⁻¹*	--------------------------------			
	Punjab							
2	Hoshiarpur	Inceptisols	6	12	75 M	618	543 M	Gajbhiye (1985)
3	Hoshiarpur	Entisols	4	15.5	80 M	864	784 H	Gajbhiye (1985)
4	Hushiarpur	Inceptisols	1	4-12 (7)	23-47 (33) L	-	893-959 (923) H	Srinivasarao *et al*. (2007)
5	Gurdaspur	Typic Haplustalf	2	39.9-61.8	M	-	H	Pasricha *et al*. (2001)
6	Ludhiana	Typic Ustochrepts	1	73.9	M	-	H	Pasricha *et al*. (2001)
7	Ludhiana	Udic Ustrochrept	1	15	M	860	H	Srinivasarao *et al*. (2000)
8	Jalandhar	Typic Ustochrept	1	64.2	M	-	H	Pasricha *et al*. (2001)
9	Jalandhar	Alluvial soil	8	20.3-58.8	42-219 H		727-1,762 H	Sharma & Sharma (2001)
10	Patiala Ki Rao	Typic Ustorthent	1	189	H	-	H	Pasricha *et al*. (2001)
11	Fatehpur	Typic Ustipsamment	1	29.5	H	-	H	Pasricha *et al*. (2001)
12	Nawanshahar	Alluvial soil	5	14.0-65.0	46-185 H	-	850-1,290 H	Sharma & Sharma (2001)
	Uttarakhand							
13	Nainital	Mollisols	20	17	107 M	861	753 H	Singh *et al*. (1983)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				--------------------------------*mg kg*$^{-1}$--------------------------------				
	Uttar Pradesh							
14	Eastern U.P.	Alluvial/Incep-tisols	1	4-20 (8)	M	1,600	1,186-2,413 H	Srinivasarao *et al*. (2007)
15	Faizabad	Inceptisols	10	9.1	H	1,596	H	Srinivasarao *et al*. (2002)
16	Firozabad	Alluvial soil	5	8.5-22	50-90 M	-	H	Kaptan Singh *et al*. (2001)
17	Varanasi	Inceptisols	10	8.3	M	1,307	H	Srinivas Rao *et al*. (2002)
18	Varanasi	Typic Natraqualf	30	21.9	102 M	-	1,869 H	Srivastava & Srivastava (1992)
	Bihar							
19	Jagadishpur Bagha, Muzaffarpur	Typic Uastifluvent	10	13	H	1,636	H	Srinivasarao *et al*. (2000)
20	Raghopur, Muzaffarpur	Aquic Eutrochrept	10	9	M-H	1,936	H	Srinivasarao *et al*. (2000)
	Agroecological region 10							
	Madhya Pradesh							
1	Bhopal	Vertic Ustocrept	15	-	247 H	823	>600 H	Srinivasarao (1994)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				---------------------------------*mg kg*$^{-1}$---------------------------------				
2	Bhopal	Vertic Ustocrept	50	-	247 H	855	608 H	Srinivasarao *et al*. (1995)
3	Bhopal	Haplustalf	18	-	263 H	737	474 M	Srinivasarao *et al*. (1995)
4	Bhopal	Non-ingested soil	10	47.9	H	-	H	Srinivasarao *et al*. (1997)
5	Nabibagh, Bhopal	Typic Haplustert	21	5 to 13	171-252 H	-	H	Srinivasarao *et al*. (1997)
6	Sanchi	Black soils	60	22	H	821	H	Srinivasarao & Takkar (pers.comm., 1995)
7	Sehore	Vertisols	10	7.7	H	855	H	Srinivas Rao *et al*. (2002)
8	Vidisha	Vertisols	10	8.5	H	-	H	Srinivasarao *et al*. (1996)
9	Salamatpur	Vertisols	10	8.5	H	-	H	Srinivasarao *et al*. (1996)
10	Berkhedi	Vertisols	20	10-11	H	-	H	Srinivasarao *et al*. (1996)
11	Chapna	Vertisols	10	16.5	H	-	H	Srinivasarao *et al*. (1996)
12	Sarol, Indore	Typic Chromustert	10	100	H	730	1,780 H	Srinivasarao *et al*. (2000)
13	Kamliakheri, Indore	Vertic Ustochrept	10	9	H	800	>700 H	Srinivasarao *et al*. (2000)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				----------mg kg^{-1}----------				
	Agroecological region 11							
	Chhattisgarh							
1	Raipur	Vertisols	10	16.3	102 M	-	788 H	Srinivasarao *et al*. (2002)
	Agroecological region 12							
	Bihar							
1	Chotanagpur		9	-	27.4 L	224	197 L	Singh *et al*. (1989)
2	Bihar	Red soils	24	7.8	98 M	-	176 L	Roy & Kumar (1993)
	West Bengal							
3	Birbhum	Typic Haplaquept	25	156	45 L	125	80 L	Sekhon *et al*. (1992)
4	Birbhum	Typic Haplaquept	10	6	67 M	156	>300 M	Srinivasarao *et al*. (2000)
5	Kalimpong	Typic Haplumbrept	1	8.8	39.2 L	-	213 L	Singh & Sanyal (2000)
6	Matimahal	Typic Paleustalf	1	0.7	M	-	554 M	Singh & Sanyal (2000)
7	Bardhaman	Vertic Eutrochrept	10	20	L	360	>300 M	Srinivasarao *et al*. (2000)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				--------------------------------*mg kg*$^{-1}$	--------------------------------			
	Jharkhand							
8	Mondouri, Memari, Chinsurah	Entisols	3	8-25	48-58 L-M	-	323-633 M-H	Saha & Sanyal (1997)
9	Jhargram	Alfisols	1	5	35 L	-	43 L	Saha & Sanyal (1997)
10	Ranchi	Hyperthermic haplustalfs	1	-	10-45 (20) L	-	M	Roy & Sarkar (1997)
11	Ranchi	Alfisols	1	6.5	45 L	393	395 M	Srinivasarao *et al*. (2002)
12	Ranchi	Red/Alfisols	1	2-10 (4)	49-65 M (57)	-	645-725 (681) H	Srinivasarao *et al*. (2007)
13	Puto, Singhbhum & Bandhdi	Hyperthermic haplustalfs	3	-	7-85	-	M	Roy & Sarkar (1997)
	Orissa							
14	Phulbani	Arenic Kanhaplic Haplustalfs	5	13.5-20	39-96 L-M	-	460-675 M-H	Das *et al*. (1997)
15	Puri	Fluventic Ustochrept	1	18	L	142	L	Srinivasarao *et al*. (2001)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				---------------*mg kg^{-1}*---------------				
	Agroecological region 13							
	Uttar Pradesh							
1	Garhwal	Hill soils	5	20	193 H	-	887 H	Mishra & Srivastava (1991)
	Bihar							
2	North Bihar	Inceptisols/Entisols	25	20	49 L	-	774 H	Kumar & Jha (1987)
3	Muzaffarpur	Typic Ustifluvent	25	22	78 M	-	1,500 H	Sekhon *et al.* (1992)
4	Muzaffarpur	Aquic Eutrochrept	25	9.1	131 H	446	315 M	Sekhon *et al.* (1992)
5	Sakari, Darhar	Typic Ustochrepts	2	3-4	M	-	210-330 L-M	Choudhary & Prasad (1997)
6	Pusa, Dholi, Kanti	Calcareous Typic Haplaquepts	3	2-3	M	-	100-180 L	Choudhary & Prasad (1997)
7	Madhopur	Calcareous Typic Udorthents	3	3-8	M	-	150-450 L-M	Choudhary & Prasad (1997)
8	Jagatpur, Mokama, Agwanpur, Mithapur	Calcareous Typic Ustifluvents	4	3-8	M	-	-	Choudhary & Prasad (1997)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				-------------------------------*mg kg*$^{-1}$	-------------------------------			
9	Madhepura	Typic Ustifluvents	1	3	M	-	750 H	Choudhary & Prasad (1997)
	Agroecological region 14							
	Himachal Pradesh							
1	Himachal Pradesh		10	129	142 H	2,893	2,737 H	Singh & Tripathi (1993)
2	Shimla	Acidic brown hill soils	24	-	122 H	-	M	Grewal & Sharma (1980)
3	Kangra	Typic Dystrochrept	25	21	94 M	361	267 L	Sekhon *et al*. (1992)
4	Khanpur	Slightly acidic	1	14	110 M	-	625 H	Shankhayan *et al*. (1996)
5	Kutharkalan	Slightly acidic	1	15	70 M	-	335 M	Shankhayan *et al*. (1996)
6	Oel	Slightly acidic	1	13	40 L	-	448 M	Shankhayan *et al*. (1996)
7	Kori	Slightly acidic	1	10	85 M	-	531 M	Shankhayan *et al*. (1996)
8	Una	Slightly acidic	1	15	115 H	-	446 M	Shankhayan *et al*. (1996)
9	Basal	Slightly acidic	1	18	35 L	-	348 M	Shankhayan *et al*. (1996)
10	Tohsara	Slightly acidic	1	10	80 M	-	300 M	Shankhayan *et al*. (1996)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				---------------------------------*mg kg^{-1}*---------------------------------				
11	Haroli	Slightly acidic	1	10	145 H	-	995 H	Shankhayan *et al*. (1996)
12	Thathal	Slightly acidic	1	9	60 M	-	347 M	Shankhayan *et al*. (1996)
13	Kante	Slightly acidic	1	5	105 M	-	940 H	Shankhayan *et al*. (1996)
14	Sattibala	Slightly acidic	1	29	50 M	-	181 L	Shankhayan *et al*. (1996)
15	Bherabala	Slightly acidic	1	14	115 H	-	142 L	Shankhayan *et al*. (1996)
16	Nihalgarh	Slightly acidic	1	15	130 H	-	187 L	Shankhayan *et al*. (1996)
17	Barabna	Slightly acidic	1	13	130 H	-	235 L	Shankhayan *et al*. (1996)
	Jammu & Kashmir							
18	Udampur	Alluvial soils	21	-	M	-	M	Gupta *et al*. (1980)
19	Anantnag	Dystrochrept	25	9.9	M	441	394 M	Sekhon *et al*. (1992)
20	High Altitude	Alluvial soils	4	2.7-3.2	M	845-915	H	Nakashgir *et al*. (1997)
21	Middle Altitude	Alluvial soils	4	2-2.5	M	655-836	H	Nakashgir *et al*. (1997)
22	Low Altitude	Alluvial soils	4	1.6-1.8	-	735-758	-	Nakashgir *et al*. (1997)
23	Rakh Dhiansar	Alluvial/ Inceptisols	10	6-10 (7)	M	-	398-472 (436) M	Srinivasarao *et al*. (2007)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				--------------------------------*mg kg*$^{-1}$--------------------------------				
	North West India							
24	Nagar	Fluventic Ustochrept	1	-	231 H	-	H	Sidhu & Manjaiah (1999)
25	Naura	Typic Haplustalf	1	-	282 H	-	H	Sidhu & Manjaiah (1999)
26	Kangawal	Udic Ustochrept	1	-	333 H	-	H	Sidhu & Manjaiah (1999)
27	Badowal	Typic Ustipsamment	1	-	38 L	-	M	Sidhu & Manjaiah (1999)
	Punjab							
28	Hoshiarpur	Alluvial soil	7	11.50-35.50	42-139 L-H	-	1,100-1,420 H	Sharma & Sharma (2001)
	Agroecological region 15							
	West Bengal		6	27	134 H	-	1,169 H	Adhikari & Ghosh (1991)
1	Bardhaman	Vertic Eutrochrept	25	9.1	131 H	446	315 M	Sekhon *et al.* (1992)
2	Coochbehar	Tarai acid soils	1	9.8	95.2 M	276	L	Patra & Debnath (1998)
3	Mekhliganj	Tarai acid soils	1	18.2	37.4 L	3,540	H	Patra & Debnath (1998)
4	Guriapara	Tarai acid soils	1	20.4	168 H	1,990	H	Patra & Debnath (1998)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				--------------------------------*mg kg*$^{-1}$--------------------------------				
5	Chatchilakhana	Tarai acid soils	1	44.3	90.7 M	1,499	H	Patra & Debnath (1998)
6	Birbhum	Typic Haplaquept	10	6	M	156	L	Srinivasarao *et al*. (2001)
7	Birbhum	Vertic Ochraqualfs	1	18	103 M	351	229 L	Das *et al*. (2000)
8	Kalyani	Entisols	1	3	23 L	-	321 M	Raychaudhuri & Sanyal (1999)
9	Susunia	Alfisols	1	26	28 L	-	92 L	Raychaudhuri & Sanyal (1999)
10	Bakkali	Inceptisols	1	58	234 H	-	667 H	Raychaudhuri & Sanyal (1999)
11	Medinipur	Rhodic Paleustalfs	1	18	90 M	191	84 L	Das *et al*. (2000)
12	Purulia	Hyperthermic, Plinthustalfs	1	9	64 M	108	74 L	Das *et al*. (2000)
13	Purulia	Typic Paleustalfs	1	12	42 L	72	18 L	Das *et al*. (2000)
14	Medinipur	Aquic Haplustalfs	1	4	48 L	60	9 L	Das *et al*. (2000)
15	Anandapur	Alfisols	1	1.6	L	-	L	Dhar *et al*. (2009)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				---------------------------------*mg kg^{-1}*---------------------------------				
	Assam							
16	Jorhat	Coarse loamy (Typic Fluvaquents)	3	6.6-14.4	39-122 L-H	-	78-122 L	Bhaskar *et al*. (2001)
	Agroecological region 16							
	Sikkim							
1	Darjeeling	Acidic hill soils	23	-	186H	-	894 H	Patiram & Prasad (1991)
2	Naxalbari	Tarai acid soils	2	22-66	98-220 M-H	4,865-6,796	H	Patra & Debnath (1998)
3	Baragachia	Tarai acid soils	1	61.3	94.2 M	6,926	H	Patra & Debnath (1998)
4	Phansidewa	Tarai acid soils	1	40.9	104.4 M	6,174	H	Patra & Debnath (1998)
5	Boglahagi	Tarai acid soils	1	13.6	77.2 M	4,306	H	Patra & Debnath (1998)
6	Kalyanpur	Tarai acid soils	1	12.5	60.1 M	4,401	H	Patra & Debnath (1998)
	West Bengal							
7	Jalpaiguri	Tarai acid soils	6	18.2-88.5	46-163 L-H	1,052-1,951	H	Patra & Debnath (1998)
	Arunachal Pradesh							
8	Takso	Typic Udorthents	1	11.7	142.9 H	-	726 H	Singh *et al*. (1999)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				----------*mg kg^{-1}*----------				
9	Subansiri	Typic Udifluvents	1	20	304.2 H	-	1,146 H	Singh *et al*. (1999)
10	Kalleng	Typic Haplumbrepts	1	30	356 H	-	452 M	Singh *et al*. (1999)
11	Garu	Typic Dystrochrepts	1	34.9	329.6 H	-	1,266 H	Singh *et al*. (1999)
12	Renging	Typic Hapludalfs	1	30.6	320.7 H	-	637 H	Singh *et al*. (1999)
13	Bomte	Ultic Hapludalfs	1	13	256 H	-	1,169 H	Singh *et al*. (1999)
14	Dalbeng	Entic Hapludolls	1	41	371 H	-	433 M	Singh *et al*. (1999)
15	Buda	Typic Hapludolls	1	48.2	357.6 H	-	1,155 H	Singh *et al*. (1999)
	Agroecological region 17							
	Meghalaya							
1	East Khasi	High altitude soils	10	5.7	93.6 M	588	494 M	Patiram & Prasad (1984)
2	East Khasi	Low altitude soils	20	6.8	91.8 M	753	661 H	Patiram & Prasad (1984)
	Nagaland	Acid soils	24	8.2	99.4 M	542	423 M	Gupta *et al*. (1983)
3	Chalkot	Dystric Eutrochrepts	1	3	L	-	M	Singh *et al*. (1999)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				----------------------------------*mg kg^{-1}*----------------------------------				
4	Zukheshsema	Typic Dystrochrepts	1	11	L	-	M	Singh *et al*. (1999)
5	Kangan	Typic Udorthents	1	12.9	L	-	M	Singh *et al*. (1999)
6	Bhaghty	Ultic Hapludalfs	1	11.3	L	-	M	Singh *et al*. (1999)
7	Zusuma	Entic Hapludolls	1	37.5	L	-	M	Singh *et al*. (1999)
	Manipur							
8	Kharam	Typic Udorthents	1	12.2	250	1,062	800 H	Singh *et al*. (2006)
9	Landon, Biyang, Maha Koirang	Typic Kandiudults	3	9.6-15.7	176-409	640-1,477	H	Singh *et al*. (2006)
10	Khambang, Kadamtala	Typic Haplaquepts	2	12.4-16.4	338-423	730-1,427	H	Singh *et al*. (2006)
11	Lamphelpat	Typic Haplaqents	1	10.6	218	810	H	Singh *et al*. (2006)
12	Kaimai	Mollic Paleudalfs	1	16.2	308	-	H	Singh *et al*. (2006)
13	Bhutnkhal	Umbric Dystrudepts	1	14.1	379	-	H	Singh *et al*. (2006)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				---------------------------------*mg kg^{-1}*---------------------------------				
	Mizoram							
14	Mizoram		5	29	359 H	-	>600 H	Singh & Datta (1986)
	Agroecological region 18							
	Andhra Pradesh							
1	Coastal A.P.	Alluvial	10	6-8	102 H	427	325 M	Sailakshmiswari *et al*. (1985)
2	Guntur	Vertic Haplaquept	25	17.2	352 H	889	537 M	Sekhon *et al*. (1992)
	Orissa							
3	Puri	Fluventic Ustochrept	25	8.2	39 L	106	67 L	Sekhon *et al*. (1992)
4	Phulbani	Red/Alfisols	10	1-18 (14)	63-95 (81) M	-	456-866 M	Srinivasarao *et al*. (2007)
	Tamil Nadu							
5	Tanjavur	Udic Chromustert	25	11	193 H	896	703 H	Sekhon *et al*. (1992)
6	Kalathur (Thanjavur)	Udic Chromustert	10	12	-	1,040	-	Srinivasarao *et al*. (2001)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				-------------------------------*mg kg^{-1}*-------------------------------				
	Andhra Pradesh							
7	Guntur (Chandole)	Vertic Halaquept	10	-	H	-	H	Bansal *et al*. (1996)
8	Guntur	Black soil (Vertisols)	10	6	94 M	-	H	Krishnamurthy & Ramakishnayya (1997)
9	Rajahmundry	Black soil (Vertisols)	10	-	72 M	-	H	Krishnamurthy & Ramakishnayya (1997)
10	Devarapalli	Light soil (Alfisols)	10	-	12 L	-	M	Krishnamurthy & Ramakishnayya (1997)
11	Nellore	Black soil (Entisols)	10	-	62 M	-	H	Krishnamurthy & Ramakishnayya (1997)
12	Kandukur	Light soil (Alfisols)	10	-	93 M	-	M	Krishnamurthy & Ramakishnayya (1997)
13	Hunsur	Light soil (Alfisols)	10	-	39 L	-	M	Krishnamurthy & Ramakishnayya (1997)

Table 3.1. continued

S. No.[a]	Agroecological region/State	Soil/Soil group	No. of soil samples	Range and mean (mean in brackets)[e]				Source
				Water-sol. K[b]	Exch. K[c]	HNO_3 K	Non-exch. K[d]	
				--------------------------------*mg kg^{-1}*--------------------------------				
	Agroecological region 19							
	Kerala							
1	Kerala	Laterite/ Red soils	15	117	288 H	321	33L	Prabha Kumari & Aiyer (1993)
2	Trivandrum	Oxic Dystropept	25	12.5	84 M	140	56 L	Sekhon *et al*. (1992)
3	Allepy	Tropaquept	25	75.5	242 H	391	149 L	Sekhon *et al*. (1992)
4	Kerala	Entisols	5	10.2-22.5	188-405 H	-	M	Thampatti *et al*. (1999)
5	Maharashtra	Laterite soils	30	5	70 M	-	162 L	Sutar *et al*. (1992)
6	Ratnagiri	Fluventic Ustropept	25	2.5	73 M	202	129 L	Sekhon *et al*. (1992)
7	Repoli	Black soil (Inceptisols)	3	0.91	M	-	M	Kaskar *et al*. (2001)
	Agroecological region 20							
	Andamans & Nicobar							
1	Andamans & Nicobar	Acidic hill soils	30	-	65.8 M	87	L	Mongia & Bandyopadhyay (1991)

4. New Concepts in Soil K Fertility

4.1. Release rates

Soil potassium supply to crop plants is a complex phenomenon involving relationships among its various chemical forms. The dynamic equilibrium among the forms directs the release of K from non-exchangeable to slowly available forms to available forms under K stress environment. Srinivasarao *et al*. (1999) reported that continuous cropping for 20 years reduced the release rates significantly and stated that many plants feed on non-exchangeable source of K, particularly the monocots. Therefore, current interest in K fertility of soils has switched from simple measurement of the amounts of exchangeable or non-exchangeable K to determination of the rate at which K^+ is supplied from these forms during the crop growth (Srinivasarao *et al*., 1996, 2003, 2004, 2008).

Non-exchangeable K release kinetics of six major benchmark soil series of India as affected by mineralogy of clay and silt fractions, soil depth and extraction media was investigated (Srinivasarao *et al*., 1997, 2006, 2010; Srinivasarao, 2010). Organic acids were used to extract non-exchageable K from soil to represent plant root extraction of soil K under intensive cropping. The cumulative release of non-exchangeable K was greater in smectitic soils (353 mg K kg^{-1} at 0-15 cm depth and 296 mg K kg^{-1} at 15-30 cm depth, averaged for two soils and 3 extractants) as compared to illitic (151 mg K kg^{-1} at 0-15 cm depth and 112 mg K kg^{-1} at 15-30 cm depth) and kaolinitic (194 mg K kg^{-1} at 0-15 cm depth and 167 mg K kg^{-1} at 15-30 cm depth) soils. This work shows that surface soils exhibited larger cumulative K release in smectitic and illitic soils whereas sub-surface soils had larger K release in kaolinitic soils. Among the extractants, 0.01 M citric acid extracted larger amount of non-exchangeable K followed by 0.01 M $CaCl_2$ and 0.01 M HCl. The efficiency of citric acid extractant was greater in illitic soils as compared to smectitic and kaolinitic soils (Table 4.1.1). Release kinetics of non-exchangeable K conformed well to parabolic and first-order kinetic models. Fit of the data to the parabolic diffusion model suggested diffusion controlled kinetics in all the soils with a characteristic initial fast rate up to 7 hours, followed by a slower rate. Greater non-exchangeable K release rates in smectitic soils, calculated from the first-order equation ($b = 91.13 \times 10^{-4}\ h^{-1}$), suggested that the layer edge and wedge zones and swelling nature of clay facilitated the easier exchange (Table 4.1.2). In contrast to smectitic soils, higher release rate constants ($b = 39.23 \times 10^{-3}\ h^{-1}$) obtained from parabolic diffusion equation in illitic soils revealed that the low amount of exchangeable K on clay surface and larger amount of interlayer K allowed greater diffusion gradients, thus justifying the better fit of first order kinetic equation in smectitic soils and parabolic diffusion equation in illitic soils.

Table 4.1.1. Cumulative non-exchangeable K released in different media of extraction (mg kg^{-1}).

Soil series	0.01 M $CaCl_2$		0.01 M Citric acid		0.01 M HCl	
	A	B	A	B	A	B
Smectitic soils						
Kamliakheri	165	131	152	135	142	120
Noyyal	518	392	668	616	473	380
Mean	342	262	410	376	308	250
Illitic soils						
Lukhi	105	84	163	135	94	77
Rarha	138	97	289	195	118	82
Mean	122	91	226	165	106	80
Kaolinitic soils						
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

A = 0-15 cm; B = 15-30 cm

Source: Adapted from Srinivasarao *et al*., 2006.

Table 4.1.2. Non-exchangeable K release rate constant (b) (h^{-1}) and intercept (a) for mineralogically different soils (average of 4 soils).

Mathematical model/ Soil group	Extraction medium					
	0.01 M $CaCl_2$		0.01 M Citric acid		0.01 M HCl acid	
First-order equation	b x 10^{-4}	a	b x 10^{-4}	a	b x 10^{-4}	a
Smectitic	91.13	5.09	101.55	5.47	99.59	4.81
Illitic	87.49	4.52	91.38	5.20	81.02	3.91
Kaolinitic	74.75	4.13	81.26	4.61	63.81	3.53
Mean	84.45	4.58	91.40	5.09	81.47	4.08
Parabolic diffusion	b x 10^{-3}	a	b x 10^{-3}	a	b x 10^{-3}	a
Smectitic	30.85	0.41	36.08	0.32	28.03	0.48
Illitic	39.23	0.23	41.25	0.19	28.84	0.46
Kaolinitc	34.40	0.25	40.78	0.17	27.30	0.42
Mean	34.83	0.30	39.37	0.23	28.05	0.45

Source: Adapted from Srinivasarao *et al*., 2006.

4.2. Step and constant K rates

Twenty one profiles representing wide variety of soils from rainfed production systems were characterized for potassium supplying characteristics such as step K, constant rate K and cumulative K using boiling 1N HNO_3 extraction media. Constant K was taken at a stage when similar amounts of K were extracted in consecurive extractions whereas step K was computed by substracting the constant rate K values from the K extracted in each extraction and by summation of all those values. Cumulative K was computed by summation of step K in all the extractions. Among production systems, groundnut system and fingermillet showed extremely low level of profile mean step K below 500 mg kg^{-1}. It indicates these soils do not have soil K reserves and K additions to crops are needed regularly.Among other production systems some locations under pearlmillet and maize also showed relatively lower step and cumulative K release. Among soil types, Alfisols at Bangalore and Anantapur, Vertisols at Akola and Aridisol at S.K. Nagar showed lower K release parameters. Soils under lower rainfall (<500 mm) showed higher release of K. Clay and CEC showed positive correlation with K supplying parameters of soils in most of the soils while pH showed mainly positive relation K release in Alfisols and Inceptisols (Srinivasarao *et al*., 1996, 2006; Srinivasarao and Bansal, 2000).

4.3. K replenishment rate and clay mineralogy

The important factor in soil fertility is that the K release rates from soils are matching with plant K requirements or not. The release rate or K replenishment rates are governed by the amount and nature of clay mineral present in the soils. Relative contribution of clay and illite to K replenishment capacity of ustochrepts under intensive cropping was reported by Srinivasarao and Khera (1994). Though soils of Hamidpur, Hisar and Kakra soil series had same percentage of illite, variation in K replenishment rate could be attributed to varied clay contents. Similarly, among Manesar, Khoh and Palam soils, the lowest K replenishment rate in Palam series could be due to lower relative illite percentage (Table 4.3.1). Thus, percentage and relative illite content play an equally important role in K supplying power of the soil. Thus, knowing soil K reserve and distribution of K forms coupled with mineralogical data can help in comprehending K replenishment capacity of soils under intensive cropping. Similarly, significant association of amount of illite in silt and clay fraction of smectitic soils with release rates of K determined by chemical extractants was reported for smectitic soils of central India (Srinivasarao *et al*., 1998, 2000, 2001, 2007, 2010).

Table 4.3.1. Effect of amount of clay and its relative illite content on total release of non-exchangeable K and K replenishment rate in eight soils.

Soil	Clay	Illite	Total release of non-exchangeable K	K replenishment rate
	---------%---------		*mg kg^{-1}*	*kg ha^{-1} day^{-1}*
Hamidpur	8.3	61.73	314	2.98
Hisar	20.2	60.90	352	3.36
Kakra	5.7	59.23	307	2.93
Thaska	6.2	50.90	293	2.89
Manesar	10.0	53.70	301	2.89
Khoh	10.3	53.68	280	2.53
Palam	9.7	34.00	182	1.81
Mehrauli	13.2	53.35	337	3.11

Source: Adapted from Srinivasarao and Khera, 1994.

4.4. Sub soil potassium

Although a major portion of plant nutrients is absorbed by crop plants from the surface soil, contribution of sub soil layers is often substantial. Sub soil nutrient contribution may be more important to crops in dryland regions where root growth and function depend on sub soil water. The drying of surface soil under dry land cultivation reduces diffusion of nutrients and plant uptake from that layer. In that condition, nutrient availability in sub soil is crucial during critical times of plant development such as flowering and grain filling.

Among 10 locations of pulse growing region of India, surface soils of Gulbarga and Sehore were in high range of available K and of Kanpur, Faizabad, Ranchi and Varanasi were low in available K (Srinivasarao *et al*., 2001, 2004, 2006, 2008, 2010). Rest of the soils were medium in K status. Contribution of sub soil layers to available K was relatively higher in Kanpur, Faizabad, Ranchi and Bangalore profiles than other soils. Overall the two lower layers contributed from 47 percent in Sehore profile to 75 percent in Kanpur profile. Based on results of 34 field experiments in north Germany, Kuhlman (10) reported that the sub soil supplied, on an average, 34 percent of the total K uptake (offtake) by spring wheat. Different forms of available K in sub soil (15-30 cm) were evaluated in relation to those in surface soil (0-15 cm) in 22 benchmark soil series of India, which indicated that K in the sub soil constituted up to 96 percent of the surface soil K (Fig. 4.1).

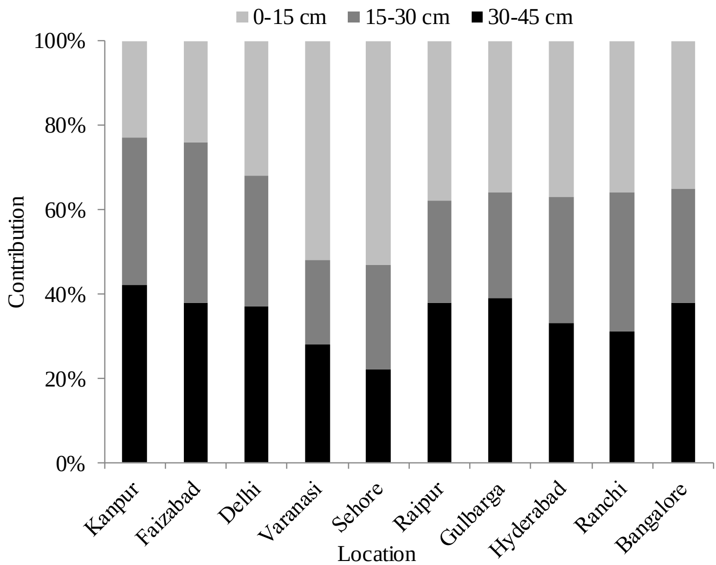


Fig. 4.1. Contribution of different soil layers to available K in different soil types.

Source: Adapted from Srinivasarao *et al*., 2004, 2008.

4.5. Minimal exchangeable K

Under intensive cropping, in the absence of K fertilization, initially exchangeable K in the soil contributes to plant K nutrition, but with further cropping, exchangeable K attains a certain minimal level, afterwards plant K removal from soil and contribution of non-exchangeable K to K uptake are almost synonymous and accounts for up to 90-95 percent of the total plant uptake. Therefore, minimal exchangeable K in particular soil is fixed and it is controlled by the amount and nature of mineralogy, seems a good indication of soil K fertility (Srinivasarao and Khera, 1994; Srinivasarao *et al*., 1998, 2000).

4.6. Categorization of soils based on biotite

Research endeavours on K have failed to achieve momentum over the past few decades due to the general impression that, except for highly weathered ferruginous soils, most Indian soils are well supplied with K and for most crops, there is a little need for K fertilizers (Sekhon and Ghosh, 1982). Although widespread responses to K fertilizer have been noticed (Sekhon and Ghosh, 1982) due to intensive agricultural activities during 1970-1980, comprehensive information on crop response to K fertilizers has not been available. In subsequent years, it was observed that crops do not respond to K fertilizers in many of these soils even over a long period of time (Pal and Mondal, 1980; Pal and Durge, 1987; Ghosh and Biswas, 1978; Rego *et al*., 1986). The prime K-bearing minerals in alluvial, black and ferruginous soils of India are micas that are concentrated mainly in their silt and clay fractions (Ghosh and Bhattacharyya, 1984; Pal and Durge, 1987; Pal *et al*., 1993). Despite this favourable natural mineral endowment, crop response to K fertilizers in many of these soils has been anomalous (Pal and Durge, 1987; Pal *et al*., 1993). Both di- and trioctahedral micas, which are mainly muscovite and biotite, are very common in these soils (Kapoor *et al*., 1981; Pal *et al*., 1987; Pal and Durge, 1987; Pal *et al*., 1993). Lack of crop response to K fertilizers has been ascribed to the rapid release of K from biotite, whereas response to K has been attributed to the much reduced rate of K release of mica with muscovitic character (Pal and Durge, 1993; Pal and Srinivasarao, 2001). The X-ray intensity ratio of 001 and 002 basal reflections of mica has been found to be an effective diagnostic parameter to find out the quality of mica and therefore to judge the K releasing potential of soils (Srinivasarao *et al*., 1994, 1998, 2000). However, actual quantification of fine-grained mica of soils is possible by following chemical procedures.

A project was undertaken at Indian institute of Soil Science, Bhopal to assess the relative content of biotite and muscovite mica and relate them with K release and crop responses. Twenty-two benchmark soil series were selected for the study. The soils selected covered the semi-arid tropical region of India and included alluvial, red and black soils (Table 4.6.1). As per the soil orders they representated Inceptisols (11), Alfisols (8), Vertisols (2) and Entisols (1). The Inceptisols mostly represented the Indo-Gangetic Plain (IGP) with an exception of Chandole, Kamliakheri, PN Palayam and Irugur. Chandole soils represent the coastal region in central-western Andhra Pradesh and Kamliakheri, though classified as Inceptisol, has properties very similar to Vertisols. PN Palayam and Irugur soil series are extensive in Tamil Nadu and both are developed on grainite gneiss parent material. Alfisols are mostly red in colour with an exception of Kaseridipalli (black) and are developed on gneissic parent material. Kaseriddipalli has been developed on basalt.

Table 4.6.1. Description of soil series.

Name of series	Classification	Parent	Location
Alluvial (Inceptisols/Alfisols)			
Nabha	Udic Ustochrepts	Alluvium	Ludhiana (Punjab)
Ladwa (Hisar 1)	Typic Haplustepts	Alluvium	Hisar (Haryana)
Nindana (Hisar 2)	Typic Haplustepts	Alluvium	Hisar (Haryana)
Khatki	Typic Haplustalfs	Alluvium	Meerut (U.P.)
Kakra	Udic Ustochrepts	Alluvium	Delhi
Lukhi	Udic Ustochrepts	Alluvium	Gurgaon (Haryana)
Rarha	Udic Ustochrepts	Alluvium	Kanpur (U.P.)
Pura	Udic Haplustalfs	Alluvium	Kanpur (U.P.)
Chomu	Typic Ustipsamments	Aeolian alluvium	Jobner (Rajasthan)
Chandole	Vertic Halaquepts	Coastal alluvium	Guntur (A.P.)
Black soils (Vertisols/Inceptisols)			
Sarol	Typic Chromusterts	Basalt alluvium	Indore (M.P.)
Kamliakheri	Vertic Ustochrepts	Basalt	Indore (M.P.)
Shendvada	Typic Chromusterts	Alluvium	Dhule (M.S.)
Alluvial (Inceptisols/Alfisols)			
Kasireddipalli	Sodic Haplustalfs	Basaltic alluvium	Medak (A.P.)
Pemberty	Vertic Ustochrepts	Granitic alluvium	Warangal (A.P.)
Periyanaickenpalayam	Vertic Ustropepts	Calcic gneiss	Coimbatore (T.N.)
Red Soils (Alfisol/Inceptisols)			
Patancheru	Udic Rhodustalfs	Granitic gneiss	Medak (A.P.)
Kodad	Typic Paleustalfs	Granite	Nalagonda (A.P.)
Vijaypura	Oxic Haplustalfs	Granitic gneiss	Bangalore (Karnataka)
Tyamagondalu	Oxic Paleustalfs	Gneiss	Bangalore (Karnataka)
Palathurai	Typic Haplustalfs	Calcic gneiss	Coimbatore (T.N.)
Irugur	Typic Ustropepts	Gneiss	Coimbatore (T.N.)

The 001/002 peak ratio of mica in different size fractions is shown in Table 4.6.2. It can be seen that the soil series like Chandole, PN Palayam, Sarol, Shendwada and Kamaliakeri (001/002 ranging from 1.3 to 2.35) had relatively less proportion of biotite mica, while the soil series like Hisar, Rarha, Khatki, Palathurai and Tymagondalu (001/002 >3.0) were relatively richer in biotite mica. Other soil series were intermediate. The sand fraction of almost all the soils is dominated by quartz mineral followed by feldspars (data not shown). The Sarol series contained large quantities of calcite minerals. M minerals were present in the series like Hisar, Kakra, Lukhi, Nabha, Khatki, Pura and Rarha in the sand fraction. This shows that in the soils of Indo-gangetic alluvium, the mica minerals are present even in sand fraction. M minerals are absent in the sand fraction in the red and black soils of Indian semi-arid tropics (SAT). The silt fraction of the alluvial soils of Indo-Gangetic alluvium contained high mica content ranging from 53% to 70%. The black soils were poor in mica, the content ranging from 3% to 36% with most of the soils falling below 10%. In the red soils it ranged from 8 to 30%. The minerals present in clay fraction are shown in Table 4.6.3 and 4.6.4. In the clay fraction the mica content ranged from 58 to 88% in the Indo-Gangetic alluvial soils followed by 4 to 45% in red soils. The black soils contained 2 to 34% mica. The actual clay sized biotite and muscovite mica content in the different soil series is shown in Fig. 4.2. The soils of Hisar contained the highest amount of biotite mica i.e. anound 8% followed by the soils of middle Indo-Gangetic plains (Pura and Rarha). These soils are very rich in K stock and so they have a very long-term K supplying power among all the soil series studied. The soils series like Kakra, Nabha, Lukhi and Khatki (upper Indo-gangetic alluvium) also contained high amount of biotite mica that was generally more than 4%. Palathurai soil series which is in Coimbatore, TN, and is a red soil, contained exceptionally high amount of biotite mica that was around 5%. The other two soil series (PN Palayam and Irugur) in Coimbatore region contained little amount of biotite mica. The two red soils in the Bangalore region differ considerably in their biotite content. It was higher in Tymagondalu soil series than in Vijaypura soils series. This explains the striking K response obtained in Vijaypura soil series in many experiments including the Long-Term Fertilizer Experiment of ICAR. The biotite mica content was also measured in silt fraction (Fig. 4.3). Fig. 4.3 reveals that in the soil series like Irugur, Kamliakheri, Kasireddipalli and Khatki, the biotite mica is mainly concentrated in the silt fraction indicating the presence of silt size biotite and in these soils, crop requirement of K may be met from the K supply from the silt fraction. In addition to measurement of K in clay fraction, efforts should be made to measure K in silt fraction to get comprehensive knowledge of K supply from a particular soil (Srinivasarao *et al*., 2000).

The K response data were compiled from secondary sources and presented in Tables 4.6.4 and 4.6.5. Nabha series contains >4% biotite mica (clay sized) and hence does supply sufficient K to rice crop. Both Pemberty and Kodad contain less than 2.5% biotite but K supply to rice in Kodad soils may be more restricted due to the presence of iron oxides that serve as coatings on clay particles. Chandole soil series might be supplying K due to the presence of zeolites and soluble salts. Wheat crop generally appears to be deficient and more responsive to K than rice. Sorgum crop growing in Vijayapura and Tymagondalu soils was deficient in K, however, the deficiency was less in Tymagondalu soils. Vijaypura soils are extremely deficient in biotite mica (less than 1%) compared to Tymagondalu series hence most of the sorghum samples fell in the deficient category in Vijaypurs soil series. In another study, the response to K application in fodder maize was higher in Vijayapura than in Tymagondalu. Soybean plants growing on Vertisols were found deficient in K but more percentage of samples were falling in deficient category in Kamliakheri series than in Sarol series since Sarol contained more than 2% biotite mica as against Kamliakheri that contained less than 1% biotite mica. Thus knowing soil K reserves and distribution of K forms coupled with mineralogical data can help in comprehending more about K replenishment capacity of soils under intensive cropping. There is no response to applied K in the soils of Hisar which matches with the mineralogical investigation i.e. high biotite content.

In Irugur series rice crop responded upto K_3 level and in pearl millet, a significant increase in yield was obtained due to K application. This is expected since Irugur series contains very little biotite. However, sorghum crop did not respond to K application. Tomato has responded to K application in PN Palayam. PN Palayam contains less than 1% clay sized biotite. In Patancheru, maize crop responded to K application upto 60 kg K_2O ha^{-1} and in Kasireddipalli, it responded upto 30 kg K_2O ha^{-1}. Both the soils contain less than 1% biotite mica. The data base of crop responses to applied K in all the soil series investigated is limited and calls for more studies on these soils. The limited K response data available, however, shows a clear trend of crop response to K wherever the soil biotite reserves are low. The response is not spectacular in soils rich in biotite. There is an urgent need for broad based field studies in the areas where the biotite reserves are low or the K release reached the limiting values.

Table 4.6.2. (Biotite+Muscovite)/Muscovite peak ratios (001/002) in the soil fractions of some benchmark soil series of Indian Semi-Arid Tropics (SAT). Figures in parenthesis indicate the percentage of sand, silt and clay, respectively.

S. No.	Soil series	Sand	Silt	Clay
1	Chandole	M peaks not present (58)	1.6 (4)	2.0 (38)
2	Chomu	M peaks not present (85)	3.0 (3)	3.5 (12)
3	Hisar 1	3.4 (62)	3.5 (22)	4.1 (15)
4	Hisar 2	3.2 (56)	4.0 (24)	3.5 (19)
5	Irugur	M peaks not present (76)	3.1 (9)	4.9 (15)
6	Kakra	002 peak not present (85)	4.8 (7)	3.3 (8)
7	Kamaliakheri	M peaks not present (57)	4.75 (10)	1.67 (33)
8	Kasireddipalli	M peaks not present (57)	3.5 (10)	2.35 (33)
9	Khatki	3.5 (63)	4.6 (32)	4.6 (5)
10	Kodad	M peaks not present (82)	4.16 (4)	2.82 (14)
11	Lukhi	002 peak not present (85)	3.5 (8)	3.3 (7)
12	Nabha	3.0 (88)	4.8 (4)	3.5 (8)
13	Palathurai	M peaks not present (74)	5.0 (6)	4.1 (20)
14	Patancheru	M peaks not present (86)	2.7 (4)	3.4 (10)
15	Pemberty	M peaks not present (83)	6.7 (6)	2.6 (11)
16	PN Palayam	M peaks not present (71)	1.5 (6)	1.3 (23)
17	Pura	1.9 (82)	4.5 (8)	3.1 (10)
18	Rarha	2.1 (57)	4.3 (34)	4.9 (9)
19	Sarol	M peaks not present (55)	2.6 (16)	2.4 (29)
20	Shendwada	M peaks not present (55)	4.14 (6)	1.82 (39)
21	Tyamogondalu	M peaks not present (81)	5.0 (7)	4.1 (12)
22	Vijayapura	001 peak not present (90)	2.8 (2)	2.8 (8)

Source: Subba Rao and Srivastava, unpublished data.

Table 4.6.3. Minerals present in the clay fraction of Indian SAT.

S. No.	Soil series	Minerals identified*
1	Chandole	S (91%), M (5%), K (2%), Q (2%)
2	Chomu	M, Ch, K, S, Ca
3	Hisar 1	S (3%), V (8%), M (78%), K (11%)
4	Hisar 2	S (3%), M (58%), Ch (3%), K (15%), V (19%), Q (2%)
5	Irugur	M (6%), K (4%), S (12%), Intergrades (78%)
6	Kakra	M (82%), S (21%), V (6%), K (6%), Q (3%)
7	Kamliakheri	S (90%), M (3%), K (6%), Q (4%)
8	Kasireddipalli	S (91%), M (2%), K (3%), Q (4%)
9	Khatki	M (88%), V (5%) and Ch (1%), K (6%)
10	Kodad	S (14%), M (30%), K (49%), Q (2%), F (5%)
11	Lukhi	M (74%), V (8%), K (16%), Q (2%)
12	Nabha	M (78%), K (8%), V (2%), Ch (2%), S (6%), Q (1%), F (1%)
13	Palathurai	M (34%), V (47%), S (16%), K (3%)
14	Patancheru	M (45%), S (7%), K (45%), Q (3%)
15	Pemberty	S (57%), M (34%), Ca (4%), K (3%), Q (2%)
16	PN Palayam	S (90%), V (3%), M (4%), K (2%), Q (1%)
17	Pura	S (5%), V (3%), Ch (3%), M (74%), K (15%)
18	Rarha	M (84%), Ch (2%), K (9%), V (4%), Q (1%)
19	Sarol	S (47%), Ch (9%), M (13%), K (14%), V (5%), Q (11%)
20	Shendwada	S (67%), M (13%), K (15%), Q (5%)
21	Tyamogondalu	K (78%), S (2%), M (17%), V (5%), F (2%), Q (1%)
22	Vijaypura	K (94%), M (4%), Q (1%), F (1%)

*The symbols used for the minerals are: Calcite (Ca), Chlorite (Ch), Feldspars (F), Kaolinite (K), Mica (M), Smectite (S), Quartz (Q), and Vermiculite (V).

Source: Subba Rao and Srivastava, unpublished data.

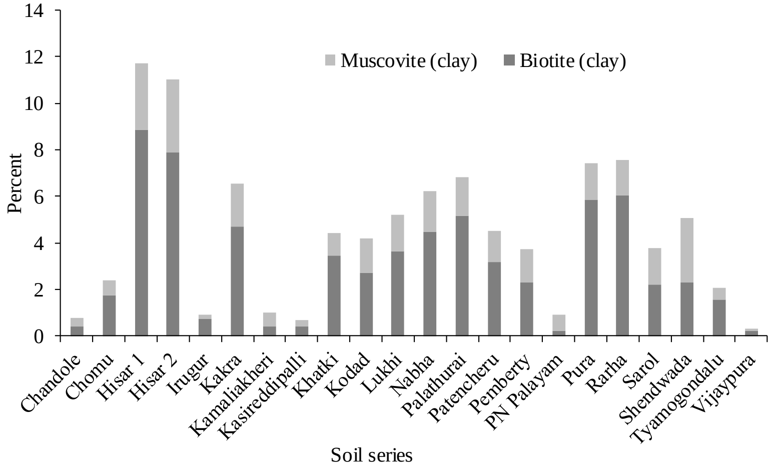


Fig. 4.2. Clay sized muscovite and biotite mica in soil. *Source*: Subba Rao and Srivastava, unpublished data.

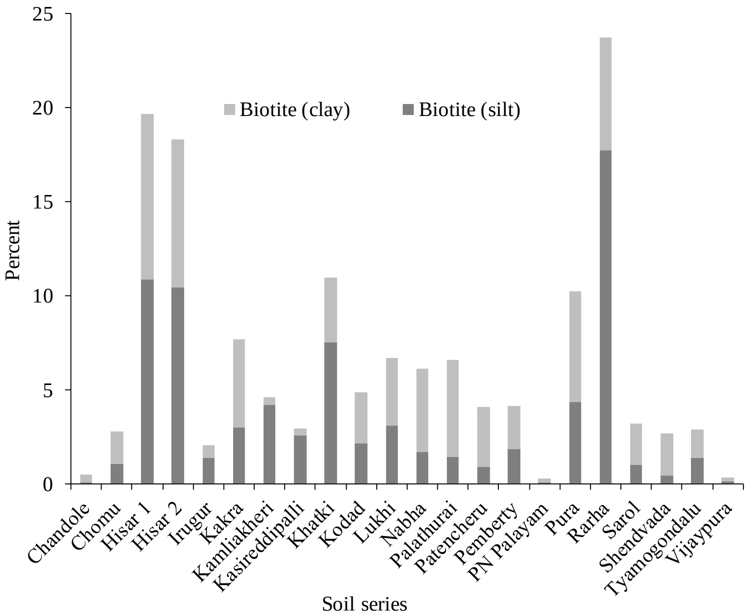


Fig. 4.3. Clay and silt sized biotite mica in 100 g of soil. *Source*: Subba Rao and Srivastava, unpublished data.

Table 4.6.4. Potassium content in leaves and distribution of percent plant samples in indicated categories of K sufficiency/deficiency of various crops grown on benchmark soils.

Crop/Soil series	K concentration; mean +/- SD	Percent samples in indicated categories[1]				
		H	*S*	*SD*	*MD*	*ED*
	------------------------------------%------------------------------------					
Rice						
Nabha	2.15 +/- 0.23	2	96	2	0	0
Pemberty	2.10 +/- 0.33	7	83	10	0	0
Kodad	1.36 +/- 0.12	0	3	65	32	0
Chandole	2.20 +/- 0.26	3	97	0	0	0
Wheat						
Nabha	2.18 +/- 0.39	0	2	18	80	0
Lukhi	2.00 +/- 0.41	0	0	20	65	15
Khatki	2.65 +/- 0.42	0	5	61	34	0
Akbarpur (Pura)	2.47 +/- 0.51	0	11	33	56	0
Rarha	1.90 +/- 0.40	0	2	9	89	0
Sorghum						
Tymagondalu	2.55 +/- 0.46	2	60	19	17	2
Vijayapura	2.19 +/- 0.49	0	30	21	35	14
Soybean						
Sarol	1.65 +/- 0.30	0	60	0	40	0
Kamliakheri	1.57 +/- 0.26	0	56	0	44	0

[1]H = high; S = sufficient; SD = severerly deficient; MD = moderately deficient; ED = extremely deficient.

Source: Adapted from Bansal and Umar, 1998.

Table 4.6.5. Potassium responses in some benchmark soils of India (see location of the soil series in Table 4.6.1).

S. No.	Soil series	Crop	Response		Source
			Dose (K_2O)	*Yield (g pot^{-1})*	
1	Irugur	Rice	K0	22.59	Lathabanumathi (1997)
			K50	30.73	
			K100	31.05	
2	Irugur	Pearl millet	Significant increase in yield due to K application		Selvakumari (1981)
3	Irugur	Sorghum	Sorghum did not respond to K application		Selvakumari (1981)
4	Tyamagondalu	Finger millet	K0	9.54	Selvakumari (1981)
			K25	12.26	
			K50	14.67	
			K75	16.27	
			K uptake	*kg ha^{-1}*	
5	Tyamagondalu	Finger millet	K0	9.22	
			K25	13.28	
			K50	17.75	
			K_2O ha^{-1}	*Uptake of K (kg ha^{-1})*	
6	Tyamagondalu	Fodder maize	0	40.7	Varavipour (1993)
			30	51.3	
			60	56.3	
			90	50.0	

Table 4.6.5. continued

S. No.	Soil series	Crop	Response			Source
			Dose (K_2O)	*Yield (g pot^{-1})*		
7	Vijayapura	Fodder maize	0	36.6		
			30	49.6		
			60	58.2		
			90	54.3		
			K_2O kg ha^{-1}	*Uptake of K (mg pot^{-1})*	*Dry matter g pot^{-1}*	
8	Patancheru	Maize	0	415.2	23.6	Vijaya (1997)
			30	494.0	27.6	
			60	585.0	32.0	
			90	578.4	31.6	
9	Kasireddipalli	Maize	0	730.0	35.0	
			30	881.2	45.2	
			60	864.6	40.4	
			90	881.3	40.8	

4.7. Categorization of soils based on potassium reserves: Implication in K management

Non-exchangeable K buffering characteristics along with critical levels of exchangeable K have important implications in soil K fertility management. However, non-exchangeable/reserve K is not considered in K fertilizer management. Crop fertilization with potassium in rainfed agriculture in India is altogether missing merely on the assumption that Indian soils are rich in potassium and crops do not need external K supply. However, under continuous cropping in rainfed regions, huge crop K removals are reported up to 150-200 kg ha^{-1} annually depending upon amount and distribution of rainfall and biomass production. Thus most of the crops essentially deplete soil K reserves. Present study evaluates the soil K reserves under diverse rainfed production systems and to categorize rainfed soils based on different soil K fractions. Depth-wise sampling was done from 21 locations across different soil types under eight production systems and various fractions of soil K were determined. Total K was the highest in Inceptisols (1.60-2.28%) followed by Aridisols (1.45-1.84%), Vertisols and Vertic sub-groups (0.24-1.72%) and Alfisols and Oxisols (0.30-1.86%) showing a wide variation within each group. Non-exchangeable K reserves were found in a proportionate manner with that of total K in most of the soil profiles. Contrary to non-exchangeable K reserves, Vertisols had higher exchangeable K than Inceptisols and Alfisols/Oxisols. Non-exchageable K showed significant positive correlation with total K in Inceptisols and Vertisols while it was non-significant in Alfisols/Oxisosls (Table 4.7.1). However, significant positive correlations were recorded with exchangeable K and non-exchangeable K in all the soil types indicating the dynamic equilibrium between two soil K fractions. Non-exchangeable K reserves were also included along with exchangeable K in categorizing soils into 9 categories for evolving better strategies to manage soil K fertility in rainfed agriculture in India. Finger millet and groundnut crops at Bangalore and Anantapur regions (Category I) need immediate attention on K nutrition as these soils are low both in exchangeable and non-exchangeable K. Similarl crops grown on soils of S.K. Nagar, Ballowal-Saunkri and Rakh-Dhiansar, where exchangeable K was low and non-exchangeable K was medium, would need K fertilization as these crops are K exhaustive (maize and pearlmillet) (Category II). Pearl millet and upland rice in category III and cotton in category IV need K additions at critical stages. Upland rice in category V needs maintenance dose of K. In category VI, cereal crops may not need K additions immediately as they have medium exchangeable K and high non-exchangeable K. Long-term sorghum cropping may need K supply after few years (category VII). Soils under category VIII are adequate in non-exchangeable K and medium exchangeable K and crops viz., groundnut, cotton, sorghum and soybean may not need external K immediately. While soils under category IX, K fertilization is not required to the crops (sorghum and soybean) as these soils had high exchangeable and non-exchangeable K. As an aid to guide for ferttilizer recommendation the critical level of non-exchangeable K for different crops have been compiled and given in Table 4.7.2.

Table 4.7.1. Categorization of soils based on soil K reserves and K recommendations for different rainfed regions in India.

Category	Exchangeable K	Non-exchangeable K	Locations	Recommendation
I	Low	Low	Bangalore (Alfisol, Karnataka), Anantapur (Alfisol, Andhra Pradesh)	Inclusion of K in fertilization is must as fingermillet based production system at Bangalore is K exhaustive and soil K status is low
II	Low	Medium	S.K.Nagar (Aridisol, Gujrat), Ballowal-Saunkri (Inceptisol, Punjab), Rakh-Dhiansar (Inceptisol, Jammu & Kashmir)	K fertilization is essential as maize and pearlmillet systems are K exhaustive and soil K levels are low.
III	Low	High	Agra (Inceptisol, Uttar Pradesh), Ranchi (Alfisol, Jharkhand) , Varanasi (Inceptisol, Uttar Pradesh)	K additions at critical stages of crops improve yield levels.
IV	Medium	Low	Akola (Vertisol, Maharashtra)	Continuous cotton system needs K addition at critical stages as non-exchangeable K fraction does not contribute to plant K nutrition substantially.
V	Medium	Medium	Phulbani (Alfisol, Orissa)	As soils are light textured, maintenance doses of K may be required for upland rice systems

Table 4.7.1. continued

Category	Exchangeable K	Non-exchangeable K	Locations	Recommendation
VI	Medium	High	Hisar (Aridisol, Haryana), Arjia (Vertisol, Rajasthan), Faizabad (Inceptisol, Uttar Pradesh)	Crops may not need immediate K additions.
VII	High	Low	Bijapur (Vertisol, Karnataka)	Long-term sorghum system would need K additions after few years
VIII	High	Medium	Rajkot (Vertisol, Gujrat), Kovilpatti (Vertisol, Tamil Nadu), Bellary (Vertisol, Karnataka), Solapur (Vertisol, Maharashtra), Indore (Vertisol, Madhya Pradesh)	K application is not required immediately
IX	High	High	Jhansi (Inceptisol, Uttar Pradesh), Rewa (Vertisol, Madhya Pradesh)	K application is not required

Exchangeable K: Low = <50 mg kg^{-1}, medium = 50-120 mg kg^{-1}, high = >120 mg kg^{-1}.

Non-exchangeable K: Low = <300 mg kg^{-1}, medium = 300-600 mg kg^{-1}, high = >600 mg kg^{-1}.

Source: Adapted from Srinivasarao *et al*., 2007; Srinivasarao and Venkateswarlu, 2009; Srinivasarao *et al*., 2010.

Table 4.7.2. Critical levels for non-exchangeable (1M HNO_3) K in different soils and crops.

Crop	Soil and state	Critical level (mg kg^{-1})	Reference
Rice	Uttari series, Udic Ustochrepts (UP)	1,275	Tiwari *et al.* (1995)
	Khatki series, Typic Haplustalf (UP)	1,960	Sharma *et al.* (1995)
Wheat	Jagdishpur Bagha, Calcareous soils (Bihar)	1,600	Prasad and Prasad (1990)
Maize	Uttari series, Udic Ustochrepts (UP)	1,200	Tiwari *et al.* (1999)
	Jagdishpur Bagha, Calcareous soils (Bihar)	1,580	Prasad (1990)
Chickpea	Valuthalakudi series (Tamil Nadu)	1,940	Jeyabaskaran and Raghupart (1993)
	Haplustalfs, Rajasthan		Yadav and Swami (1984)
	Jagdishpur Bagha, Calcareous soils (Bihar)		Prasad and Prasad (1995)
	Uttari series, Udic Ustochrepts (UP)		Tiwari *et al.* (1996)

Source: Subba Rao *et al*., 2001.

4.7.1. Categorization of districts based on non-exchangeable and exchangeable K

Recommendations of potassic fertilizer 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 non-exchangeable K indicated a very substantial contribution of non-exchangeable fraction of soil K to crop K uptake. An attempt was made to examine the information generated in the last 30 years on the status of non-exchangeable K in Indian soils, its contribution to crop K needs, categorization of Indian soils based on exchangeable and non-exchangeable K fractions and K recommendations considering both the fractions of soil K. Inclusion of non-exchangeable 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 non-exchangeable K and K deficient districts of the country were identified where K application is a must (Srinivasarao *et al*., 2010)

4.7.2. Geographical Information System (GIS) based maps for Exchangeable K and Non-exchangeable K

Geographic information systems (GIS) was used for categorizing Indian districts into low, medium and high in terms of exchangeable and non-exchageable 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 non-exchangeable K and boundaries of agroecological regions on these maps were imposed.

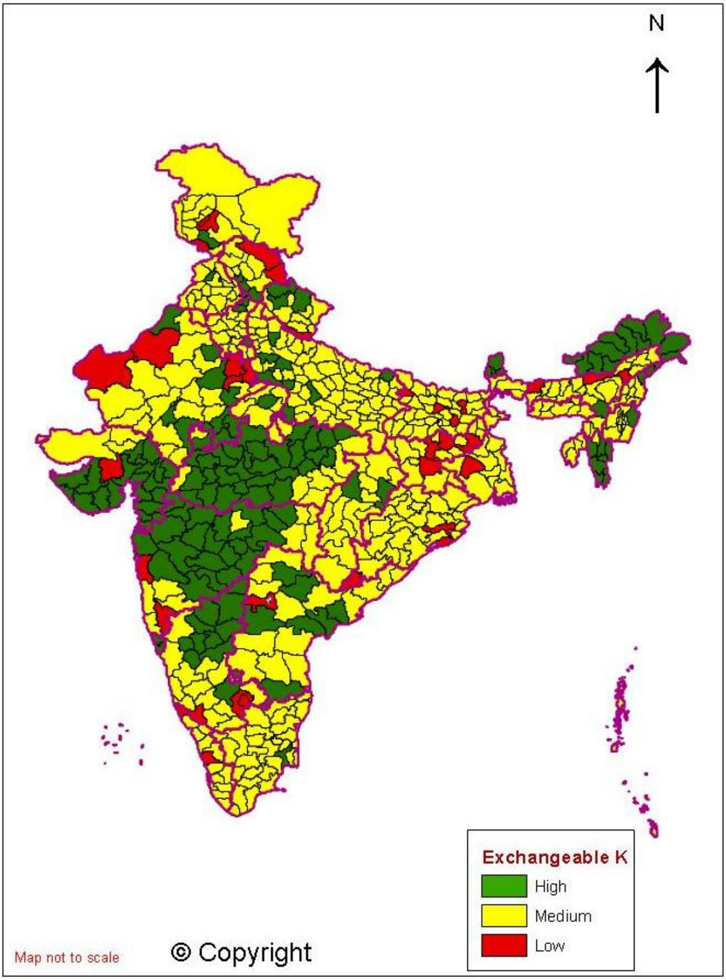
4.7.3. Categorization of districts as per their K reserves and availability

Data for exchangeable and non-exchangeable potassium (K) (mg kg^{-1}) 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 non-exchangeable K as fields of classification. For deriving the maps for AESR and AERs for exchangeable K and non-exchangeable K, weighted average approach was followed for deriving a single unit valuefor for the whole sub region, region as the case may be by unioning the maps of districts with sub region/region. For categorizing soils for exchangeable K three levels were used viz., low (<50 mg kg^{-1}), medium (50-120 mg kg^{-1}) and high (>120 mg kg^{-1}). For non-exchangeable K, the categories used were low (<300 mg kg^{-1}), medium (300-600 mg kg^{-1}) and high (>600 mg kg^{-1}) (Srinivasarao *et al*., 2007, 2010).

4.7.4. Identification of K efficient districts for K fertilizer

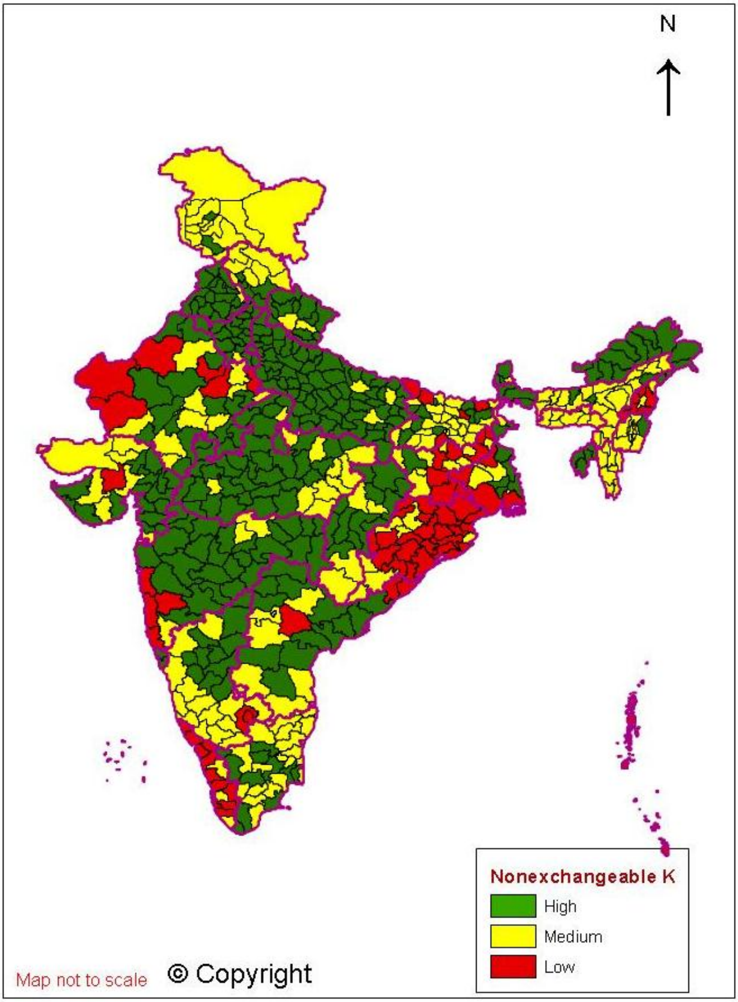
Based on above maps, districts were identified with low, medium and high in exchangeable as well as non-exchangeable K fractions (Map 4.7.4.1 and 4.7.4.2) (Srinivasarao *et al*., 2010). Nine categories of districts were identified in combination of exchangeable and non-exchangeable K fractions (Mengel, 1985; Srinivasarao *et al*. 1994, 1997, 2000, 2006, 2010). Fifteen districts were identified where both exchangeable and non-exchangeable K status was low (Category I). 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 fertilization 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 non-exchangeable 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 non-exchangeable 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 non-exchangeable 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 are 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 non-exchangeable K fractions were medium. These regions represents 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 non-exhangeable 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) fall under Category VII, where exchangeable K was high and non-exchangeable 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 cover 24 districts where exchangeable K was high and medium non-exchangeable 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 non-exchangeable 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 (Srinivasarao *et al*., 2010).



Map 4.7.4.1. District wise exchangeable K status of Indian soils (Map is copyright protected).

Source: Srinivasarao *et al*., 2010.



Map 4.7.4.2. District wise non-exchangeable K status of Indian soils (Map is copyright protected).

Source: Srinivasarao *et al*., 2010.

5. Predominant Crops and Cropping Systems

The predominant crops grown in the different agroecological regions both under irrigation and dry farming conditions are given in Table 5.1.

Table 5.1. Crops grown in different agroecological regions under rainfed and irrigated conditions.

Agroecological region	Kharif		Rabi	
	Irrigated	Rainfed	Irrigated	Rainfed
Region 2	Cotton	Pearl millet	Mustard	
	Sugarcane	Sorghum (fodder)	Gram	
		Pulses	Wheat	
Region 3	Cotton	Pearl millet	Sunflower	Sorghum
	Sugarcane			Safflower
	Groundnut			
Region 4	Rice, Millets	Sorghum	Mustard	Gram
	Maize, Pulses	Pigeon pea	Berseem	Lentil
	Sugarcane	Soybean	Wheat	Wheat
	Cotton			
Region 5	Sorghum		Sorghum	Wheat
	Pearl millet		Safflower	
	Pigeon pea		Sunflower	
	Groundnut		Gram	
	Soybean, Maize			
	Pulses			
Region 6	Cotton	Sorghum		Sorghum
	Groundnut	Pigeon pea		Safflower
		Pearl millet		Sunflower

Table 5.1. continued

Agroecological region	Kharif		Rabi	
	Irrigated	Rainfed	Irrigated	Rainfed
Region 7		Sorghum	Rice	Sorghum
		Cotton		Safflower
		Pigeon pea		Sunflower
		Rice, Groundnut		Oilseeds
		Castor		
Region 8	Cotton	Millets	Rice	Sorghum
	Sugarcane	Pulses		Safflower
		Groundnut		
Region 9	Cotton	Rice, Maize		Wheat
	Sugarcane	Barley		Mustard
		Pigeon pea		Lentil
		Jute		
Region 10	Cotton	Rice, Sorghum	Rice	Gram
		Pigeon pea	Wheat	Wheat
		Soybean	Gram	Vegetables
Region 11		Rice, Millet	Rice	
		Pigeon pea	Wheat	
		Green gram		
		Black gram		
Region 12		Groundnut	Rice	Rice, Moong
			Wheat	Black gram
				Pigeon Pea
Region 13	Sugarcane	Rice, Maize		Wheat
	Tobacco	Pigeon pea		Lentil, Pea
	Chillies	Moong		Sesasum

Table 5.1. continued

Agroecological region	Kharif		Rabi	
	Irrigated	Rainfed	Irrigated	Rainfed
	Turmeric			Groundnut
	Potato			
	Coriander			
Region 14		Millet, Maize	Paddy, Apple	Rice, Wheat
Region 15		Rice, Jute	Rice, Wheat	Rice, Jute
			Sugarcane	Pulses
				Oilseed
				Mustard
Region 16	Cotton	Cotton	Rice, Maize	Rice, Maize
	Mesta	Mesta	Millet, Potato	Millet
	Sugarcane	Sugarcane	Sweet potato	Potato
			Mustard	Sweet potato
			Sesame	Mustard
				Sesamum
				Oilseed
Region 17	Millet	Rice, Jute		Mustard
	Maize			Pulses
	Potato			(Blackgram)
				Millet
				Lentil
Region 18	Rice		Rice	Blackgram
				Lentil
				Sunflower
				Groundnut

Table 5.1. continued

Agroecological region	Kharif		Rabi	
	Irrigated	Rainfed	Irrigated	Rainfed
Region 20	Rice	Rice		

Source: Summarised from Sehgal *et al*., 1992.

6. Crop Response to Potassium and Economies of K Application

Bhargava *et al*. (1985) employed time series analysis to trace the trends in the response of rice and wheat crops in different agroclimatic regions (Table 6.1). With a few exceptions, in all the regions there was progressive build up in crop response to 60 kg ha^{-1} K_2O. The increasing trend in response over the years could be due to progressive intensification of agriculture with the introduction of high yielding varieties, high inputs of other nutrients especially N and P, irrigation and use of improved crop production technologies. Table 6.2 summarises the response of rice (irrigated and rainfed) and wheat (irrigated) in different agroclimatic regions during the period 1977 to 1982. The response of rice both under irrigated and rainfed condition increased at 20, 40 and 60 kg ha^{-1} K_2O rates of application over $N_{40}P_{20}$, N_{80} P_{40} and N_{120} P_{60}. Pillai *et al*. (1987) summarised the response of crops to K in selected cropping systems in long-term experiments in progress at various centers in different regions of India (Table 6.3). Rice responded to K both in rice-rice and rice-wheat systems at several centres.Wheat responded to K in 3 systems at all locations except Rudrur and Siruguppa. Sorghum responded to K at Akola and Siruguppa and failed to respond at Gwalior and Sehore. The data of mean response to added K at different levels for rice, wheat and soybean crops is shown in Fig. 6.1 and calculated from Table 6.4. The data is from experiments conducted in different agroecological regions by PDCSR, Modipuram. Very high response to added K is found in regions 8, 9, 13, and 16 whereas regions 2, 5, and 14 showed a response which was relatively lower in magnitude. Nambiar and Abrol (1989) summarised the average yields of crops over the years 1971-1987 under intensive cropping systems at different locations (Table 6.5). Average yield over the years showed positive responses to K in maize and wheat at Ludhiana and Palampur, rice and wheat at Pantnagar and kharif (rainy season) rice at Bhubaneswar. The yields computed over the last 3 years showed increased responses in maize at Coimbatore, soybean at Jabalpur, soybean and wheat at Ranchi and rice at Bhubaneswar. Similarly, crop response to K application after 5 to 10 years intensive cropping was obtained in several long-term fertilizer experiments under All India Coordinated Research Project on Long-Term Fertilizer Experiments (Swarup and Srinivasarao, 1999).

Crop response to K application in some selected regions is presented in Table 6.1. In this chapter not all the tables cover the same extend of data.

Table 6.1. Response to applied potassium at application of 60 kg ha^{-1} K_2O (kg grain per kg K_2O; agronomic efficiency) in different agroecological regions during different seasons. N and P were supplied to sufficiency.

Agroecological region	Kharif (rainy season) rice			Rabi (irrigated) wheat		
	1969-70	1974-75	1977-78	1969-70	1974-75	1977-78
	---------------------------------*kg kg^{-1} ha^{-1}*---------------------------------					
Humid Western Himalayan	6.7	-	8.9	4.2	6.5	10.6
Humid West Bengal-Assam	2.0	4.2	4.4	4.1	-	8.0
Humid Eastern Himalayan	5.3	5.8	7.7	-	-	-
Sub-humid Sutlej-Ganga Alluvial plains	4.0	3.3	5.8	2.8	2.6	6.5
Sub-humid to humid Eastern and South Eastern Uplands	3.7	3.5	8.2	1.7	4.7	5.9
Arid Western plains	1.5	-	5.4	2.2	3.3	5.6
Semi-arid Lava Plateau and central Highlands	3.5	8.0	8.9	3.2	2.1	6.0
Humid to semi-arid Western Ghats and Karnataka Plateau	5.1	5.3	8.1	3.1	2.3	5.6

Source: Bhargava *et al*., 1985.

Table 6.2. Response of rice and wheat (kg ha^{-1}) to potassium in different agroclimatic regions during 1977-1982.

Agroecological region	No. of trials	Ave. yield untreated*	Average yield			Response (additional yield) to potassium		
			N_{40} P_{20}	$N_{80}P_{40}$	$N_{120}P_{60}K_{20}$	$N_{40}P_{20}K_{20}$	$N_{80}P_{40}K_{40}$	$N_{120}P_{60}K_{60}$
		------------------------------------	------------------------------------	------------------------------------	*kg ha^{-1}*	------------------------------------	------------------------------------	------------------------------------
Humid Western Himalayan	49	2,318	3,318	3,756	3,927	546	416	534
Sub-humid sutlej-Ganga alluvial plains	852	2,398	3,390	3,954	4,592	196	268	350
Sub-humid to humid eastern and south eastern uplands	747	2,569	3,422	3,878	4,302	254	335	491
Arid western plains	284	2,727	3,389	3,849	4,261	257	236	323
Semi-arid Lava Plateau and central highlands	286	2,647	3,671	3,924	4,465	384	465	535
Humid to semi-arid western Ghats and Karnataka Plateau	854	3,414	4,350	4,729	5,092	303	367	488
Humid western Himalayan	21	2,016	2,939	3,244	3,493	500	436	575
Humid west Bengal-Assam	117	2,253	2,690	2,970	3,117	169	241	267
Humid eastern Himalayan	162	2,104	2,779	3,337	3,673	223	282	460
Sub-humid to humid eastern and south eastern uplands	244	2,429	3,226	3,877	4,619	197	248	374
Semi-arid Lava Plateau and centeral highlands	70	2,317	3,058	3,558	3,954	481	300	406

Table 6.2. continued

Agroecological region	No. of trials	Ave. yield untreated*	Average yield			Response (additional yield) to potassium		
			N_{40} P_{20}	$N_{80}P_{40}$	$N_{120}P_{60}K_{20}$	$N_{40}P_{20}K_{20}$	$N_{80}P_{40}K_{40}$	$N_{120}P_{60}K_{60}$
		----------*kg ha*$^{-1}$----------						
Humid to semi-arid western Ghats and Karnataka Plateau	424	3,427	3,624	4,726	4,647	542	529	633
Humid western Himalayan	85	1,411	2,352	2,723	3,142	358	401	634
Humid West Bengal-Assam	19	1,401	2,404	2,475	2,778	205	238	479
Sub-humid Sutlej-Ganga alluvial plains	1,600	1,854	2,860	3,416	3,775	201	236	392
Sub-humid to humid eastern and South eastern uplands	687	1,070	1,547	1,884	2,229	213	254	354
Arid western plains	1,256	2,073	2,768	3,211	3,592	253	231	338
Semi-arid Lava Plateau and central highlands	1,145	1,295	1,924	2,270	2,614	252	248	362

*Indicates the zero fertilizer application treatment.

Source: Adapted from Annual Report PDCSR, 1977-1982.

Table 6.3. Response to K in selected cropping systems from experiments on long-term effect of continuos cropping and manuring (AICARP) data for 1982-1983: the experiment started in 1977-1978.

Cropping system and agroecological region	Centre	Mean yield at K_0		Mean response at K = 40 kg K_2O ha^{-1}	
		Kharif (rainy season)	Rabi (winter)	Kharif (rainy season)	Rabi (winter)
		mt ha^{-1}		*kg grain per kg K_2O*	
Rice-rice					
I	Titabar	1.88	2.49	12.8	3.50
V	Chiplima	1.64	2.99	6.80	7.50
VIII	Mangalore	4.10	3.04	6.50	6.30
	Karamana	4.41	2.48	NR	6.00
Rice-wheat					
I	Palampur	4.16	2.47	10.0	18.0
V	Rudrur	3.43	1.27	9.00	2.80
Maize-wheat					
IV	Ludhiana	2.73	3.45	7.00	8.50
Sorghum-wheat					
VII	Gwalior		3.43		15.8
	Sehore	1.86	1.64	NR	5.80
	Akola	1.40	1.41	4.80	5.80
VIII	Siruguppa	3.39	1.75	10.5	N.S.

NR = No clear response.

Source: Adapted from Pillai *et al*., 1987.

Table 6.4. Yield increase of rice, wheat and soybean (kg ha^{-1}) through potassium application in different agroclimatic regions during 2003-2004. (Data on crop response is not available in regions 1, 18 and 19).

S. No.	Agroecological region/Place	Crop	Application rate							Grain yield	Response to K
			N	P_2O_5	K_2O	S	$ZnSO_4$	$MnSO_4$	Borax		
			kg ha^{-1}								*kg grain kg^{-1} K_2O*
	Agroecological region 2										
1	Kota	Soybean	60	120	0	40	40	30	15	1,355	-
			60	120	30	40	40	30	15	1,476	4.0
			60	120	60	40	40	30	15	1,509	2.6
		Wheat	120	120	0	-	-	-	-	4,666	-
			120	120	30	-	-	-	-	4,778	3.7
			120	120	60	-	-	-	-	4,889	3.7
	Agroecological region 4										
2	Modipuram	Rice	170	30	0	20	30	17	5	7,840	-
			170	30	40	20	30	17	5	9,290	36.3
			170	30	120	20	30	17	5	9,240	11.7
		Wheat	150	30	0	-	-	-	-	5,010	-
			150	30	40	-	-	-	-	5,430	10.5

Table 6.4. continued

S. No.	Agroecological region/Place	Crop	Application rate							Grain yield	Response to K
			N	P_2O_5	K_2O	S	$ZnSO_4$	$MnSO_4$	Borax		
			---kg ha^{-1}---								kg grain kg^{-1} K_2O
			150	30	120	-	-	-	-	5,520	4.3
3	Kanpur	Rice	150	30	0	25	40	-	-	8,329	-
			150	30	40	25	40	-	-	8,413	2.1
		Wheat	150	30	0	-	-	-	-	5,481	-
			150	30	40	-	-	-	-	5,553	1.8
			150	30	120	-	-	-	-	6,406	7.7
4	Faizabad	Rice	150	60	0	40	25	20	5	6,784	-
			150	60	40	40	25	20	5	7,096	7.8
		Wheat	150	60	0	-	-	-	-	3,436	-
			150	60	40	-	-	-	-	3,948	12.8
			150	60	120	-	-	-	-	3,856	3.5
5	Varanasi	Rice	150	30	0	40	40	20	5	6,132	-
			150	30	40	40	40	20	5	6,757	15.6
			150	30	120	40	40	20	5	6,458	2.7
		Wheat	150	30	0	-	-	-	-	3,294	-
			150	30	40	-	-	-	-	3,632	8.5

Table 6.4. continued

S. No.	Agroecological region/Place	Crop	Application rate							Grain yield	Response to K
			N	P_2O_5	K_2O	S	$ZnSO_4$	$MnSO_4$	Borax		
			---------------------------------------*kg ha*$^{-1}$---------------------------------------								*kg grain kg*$^{-1}$ *K*$_2$*O*
6	Ludhiana	Rice	150	60	0	40	25	20	5	8,939	-
			150	60	50	40	25	20	5	9,367	8.6
			150	60	150	40	25	0	5	10,125	7.9
		Wheat	150	60	0	-	-	-	-	5,710	-
			150	60	50	-	-	-	-	6,050	6.8
			150	60	150	-	-	-	-	5,990	1.9
7	Palampur	Rice	100	25	0	40	20	-	5	5,833	-
			100	25	40	40	20	-	5	5,754	-
			100	25	125	40	0	-	5	6,092	2.1
		Wheat	100	25	0	-	-	-	-	2,538	-
			100	25	40	-	-	-	-	2,948	10.3
	Agroecological region 5										
8	Navsari	Kharif rice	150	120	0	25	40	30	-	4,233	-
			150	120	40	-	-	-	-	4,167	-
			150	120	120	-	-	-	-	4,317	0.7

Table 6.4. continued

S. No.	Agroecological region/Place	Crop	Application rate							Grain yield	Response to K
			N	P_2O_5	K_2O	S	$ZnSO_4$	$MnSO_4$	Borax		
			--*kg ha*$^{-1}$							--	*kg grain kg*$^{-1}$ K_2O
		Rabi rice	150	120	0	-	-	-	-	5,778	-
			150	120	40	-	-	-	-	6,222	11.1
			150	120	120	-	-	-	-	6,556	6.5
9	Sirguppa	Kharif rice	150	100	0	25	0	20	5	4,073	-
			150	100	40	-	25	20	5	4,288	5.4
			150	100	120	-	25	20	5	3,956	-
		Rabi rice	150	100	0	-	-	-	-	-	-
			150	100	40	-	-	-	-	-	-
	Agroecological region 8										
10	Coimbatore	Kharif rice	150	120	0	-	-	-	-	6,018	-
			150	120	30	-	-	-	-	6,320	10.1
			150	120	60	-	-	-	-	7,169	19.2
		Rabi rice	150	120	0	-	-	-	-	7,239	-
			150	120	30	-	-	-	-	7,729	16.3
			150	120	60	-	-	-	-	7,560	5.4

Table 6.4. continued

S. No.	Agroecological region/Place	Crop	Application rate							Grain yield	Response to K
			N	P_2O_5	K_2O	S	$ZnSO_4$	$MnSO_4$	Borax		
			kg ha⁻¹								*kg grain kg⁻¹ K₂O*
11	Thanjavur	Kharif rice	150	30	0	60	-	30	-	8,396	-
			150	30	100	60	-	30	-	9,438	10.4
		Rabi rice	150	30	0	-	-	-	-	6,303	-
			150	30	100	-	-	-	-	6,618	3.2
			150	30	150	-	-	-	-	6,660	2.4
12	Maruteru	Kharif rice	150	120	0	-	-	-	5	3,793	-
			150	120	40	-	-	-	5	4,553	19.0
			150	120	120	-	-	-	0	4,048	2.1
		Rabi rice	150	120	0	-	-	-	-	6,811	-
			150	120	40	-	-	-	-	7,283	11.8
			150	120	120	-	-	-	-	7,045	-
			150	30	120	-	-	-	-	3,802	-
	Agroecological region 9										
13	Pantnagar	Rice	170	30	0	30	30	-	5	7,100	-
			170	30	40	30	30	-	5	7,400	7.5

Table 6.4. continued

S. No.	Agroecological region/Place	Crop	Application rate							Grain yield	Response to K
			N	P_2O_5	K_2O	S	$ZnSO_4$	$MnSO_4$	Borax		
			-----kg ha^{-1}-----								*kg grain kg^{-1} K_2O*
		Wheat	170	30	0	-	-	-	-	5,281	-
			170	30	40	-	-	-	-	6,218	23.4
	Agroecological region 12										
14	Ranchi	Rice	150	60	0	25	30	-	5	4,890	-
			150	60	50	25	30	-	5	5,750	17.2
			150	60	150	25	30	-	5	6,694	12.0
		Wheat	150	60	0	-	-	-	-	3,350	-
			150	60	50	-	-	-	-	3,430	1.6
			150	60	150	-	-	-	-	4,135	5.23
	Agroecological region 13										
15	Bhubaneswar	Kharif rice	150	100	0	40	25	-	5	5,306	-
			150	100	40	40	25	-	5	6,250	23.6
			150	100	120	40	0	-	5	5,202	-

Table 6.4. continued

S. No.	Agroecological region/Place	Crop	Application rate							Grain yield	Response to K
			N	P_2O_5	K_2O	S	$ZnSO_4$	$MnSO_4$	Borax		
			kg ha^{-1}								*kg grain kg^{-1} K_2O*
	Agroecological region 14										
16	Jammu	Rice	150	100	0	50	150	40	15	9,502	-
			150	100	40	50	150	40	15	9,559	1.4
		Wheat	150	100	0	-	-	-	-	6,172	-
			150	100	40	-	-	-	-	6,776	15.1
			150	100	120	-	-	-	-	7,227	8.8
			170	30	120	-	-	-	-	5,156	-
	Agroecological region 16										
17	Sabour	Rice	150	30	0	40	-	-	-	6,826	-
			150	30	50	40	-	-	-	7,672	16.9
		Wheat	150	30	0	-	-	-	-	4,470	-
			150	30	50	-	-	-	-	5,132	13.2
			150	30	100	-	-	-	-	5,343	8.73

Source: Adapted from Annual Report PDCSR, 2005-2006.

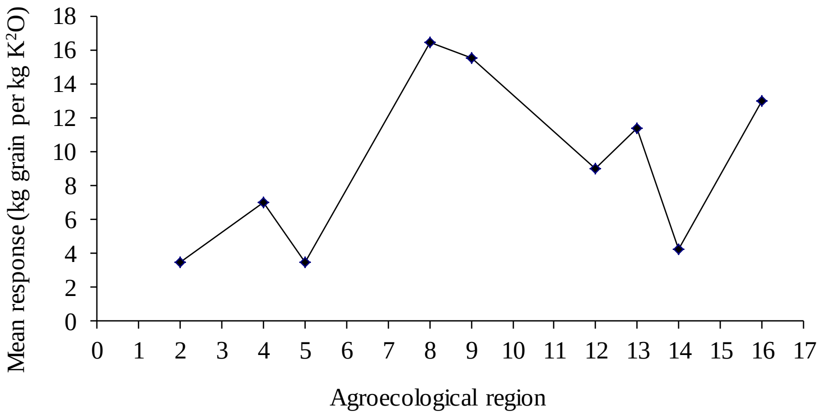


Fig. 6.1. Mean response of rice and wheat to added K in different agroecological regions in 2003-2004.

Source: Adapted from PDCSR Annual Report, 2005.

Table 6.5. Average grain yield of crops (mt ha^{-1}) over the years (1971-1987) under moderately intensive farming.

Soil type/Location	Crop	Mean grain yield (1971-1987)				Last 3 years period (1984-1987)			
		Control	N	NP	NPK	Control	N	NP	NPK
Alluvial									
Ludhiana	Maize	0.4	1.4	1.9	2.5	0.3	1.5	1.8	2.2
	Wheat	0.9	2.7	4.0	4.7	1.0	2.3	4.2	5.2
Medium deep black									
Coimbatore	Finger millet	0.7	0.9	2.6	2.6	0.8	1.1	3.1	3.3
	Maize	0.6	0.7	2.7	2.9	0.8	0.9	3.0	3.5
	Cowpea	0.2	0.3	0.5	0.5	0.2	0.2	0.5	0.5
Jabalpur	Soybean	1.0	1.3	2.1	2.2	1.1	1.0	2.2	2.6**
	Wheat	1.1	1.6	3.7	3.9	1.2	1.7	3.8	4.0*
Red loam									
Ranchi	Soybean	1.0	0.5	1.1	1.4	0.9	0.3	1.1	1.7
	Wheat	1.2	0.6	2.3	2.5	1.0	0.5	2.7	3.2
Submontane									
Palampur	Maize	0.3	0.1	2.6	3.2	0.1	0.1	1.3	2.4*
	Wheat	0.4	0.7	2.1	2.6	0.2	0.1	1.6	2.8*
Laterite									
Bhubaneshwar	Rice Kharif	1.7	2.3	2.4	2.9	1.7	1.9	1.8	2.8*
	Rice Rabi	1.5	2.5	2.8	3.1	1.5	2.2	2.7	3.3
Foothill									
Pantnagar	Rice	4.3	5.7	5.7	6.2	3.8	5.1	5.2	5.8**
	Wheat	1.8	3.9	3.9	4.0	2.0	4.1	4.1	4.0

*Sulphur limiting the crop yields; **Zinc limiting the crop yields.

Source: Adapted from Nambiar and Abrol, 1989.

Agroecological region 1

A significant response to potassium was observed at all the three altitudes in Kashmir valley even though the available potassium was high (Table 6.6; Nakashgir *et al*, 1997).

Table 6.6. Effect of K levels on dry matter yield and Bray's percentage yield of rice in alluvial soils at different altitude in Kashmir valley.

Location	Site	Available K	kg applied (K_2O ha^{-1})					Mean	Bray's yield
			0	20	40	60	80		
		kg ha^{-1}	*Dry matter yield (g pot^{-1})*						*%*
High Altitude Tangmarg soil (1,975 m)	S1	224	9.9	13.8	13.9	14.5	16.0	14.5	62.1
	S2	213	9.5	13.2	14.1	14.1	16.1	14.4	59.0
	S3	213	9.5	13.5	13.9	14.3	16.2	14.4	56.8
	S4	235	9.9	14.0	14.5	14.6	16.6	14.7	59.7
Mean		221	9.6	13.6	13.9	14.4	16.2	14.5	
Middle Altitude Kunzer soils (1,760 m)	S1	157	10.3	13.4	13.5	13.1	13.9	13.5	74.1
	S2	179	9.6	12.4	12.6	13.1	13.7	13.0	70.0
	S3	190	10.4	12.9	13.1	13.7	14.3	13.5	72.7
	S4	168	10.5	13.3	13.6	13.3	14.1	13.5	74.5
Mean		174	10.2	13.0	13.2	13.3	14.0	13.4	
Low Altitude Narbal soils (1,600 m)	S1	146	12.5	12.9	13.3	13.5	14.5	13.5	86.2
	S2	139	12.0	13.0	13.2	13.5	14.0	13.4	85.0
	S3	134	12.4	12.8	12.8	12.9	14.2	13.2	87.3
	S4	132	12.6	13.0	13.2	13.6	14.1	13.4	89.0
Mean		138	12.5	12.9	13.1	13.4	14.2	13.4	

Source: Adapted from Nakashgir *et al*., 1997.

Agroecological region 2

In field experiments on two major soil series of Haryana on cultivators' fields, wheat grain yield increased significantly at medium ($N_{80}P_{40}Zn_{25}$) and high fertility ($N_{120}P_{60}Zn_{25}$) levels with the application of 25 kg ha^{-1} K_2O (Table 6.7; Naidu *et al*., 1988). At Gurgaon, there was significant increase in yield of mustard due to K application. The oil content of mustard also increased at higher K rates in one year out of the two years experiment (Table 6.8; Singh *et al*., 2002). The effect of higher level of K application on yield increase of wheat was also prominently observed in wheat at Gurgaon (Fig. 6.2, Chauhan and Tikkoo, 2002).

Table 6.7. Response of wheat to potassium on two soil series from Haryana.

Treatment	Hisar		Taska series	
	Grain yield	K response	Grain yield	K response
	mt ha^{-1}	*%*	*mt ha^{-1}*	*%*
$N_{80}P_{40}Zn_{25}$	4.20		1.90	
$N_{80}P_{40}K_{25}Zn_{25}$	4.40	4.8	2.25	18.4
$N_{120}P_{60}Zn_{25}$	3.66		2.20	
$N_{120}P_{60}K_{25}Zn_{25}$	4.00	11.9	2.75	25.0

Source: Adapted from Naidu *et al*., 1988.

Table 6.8. Effect of potassium on yield and oil content of mustard in a sandy loam soil at Gurgaon.

Treatments K_2O (kg ha^{-1})	Yield (mt ha^{-1})		Oil content (%)	
	1996-1997	1997-1998	1996-1997	1997-1998
0	1.30	1.12	39.6	40.2
50	1.57	1.32	40.1	40.7
75	1.69	1.55	40.8	41.3
C.D. (0.05)	1.1	0.9	0.67	NS

Source: Adapted from Singh *et al*., 2002.

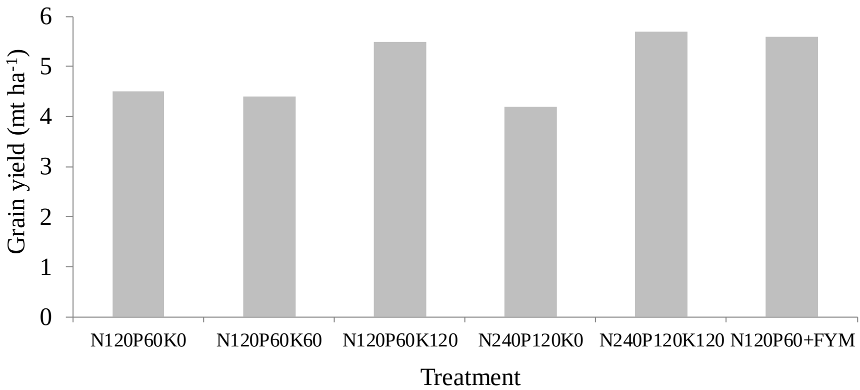


Fig. 6.2. Effect of potassium on grain yield of wheat in a loamy sand soil at Gurgaon, Haryana.

Source: Adapted from Chauhan and Tikkoo, 2002.

Agroecological region 4

In a field experiment on an alluvial soil at Aligarh , the response of pigeon pea (cv Type 21) to potassium was studied at different irrigation levels (Table 6.9). With two or three irrigations, optimum yield was obtained at 50 kg ha^{-1} K under rainfed conditions, 75 kg ha^{-1} K proved the best (Afridi *et al*., 1990).

In a field experiment on an alluvial soil at Ludhiana, a significant response to added potassium was observed in grapes. Here, however, major increase in yield was observed in first K dose and thereafter the yield nearly stabilized. The quality of the grapes also improved with potassium application. It may be noted that though yield increase was more at initial K rate but the acidity percentage increased more at higher K rates, showing the importance of higher K fertilization in obtaining higher produce with better quality (Fig. 6.3a and 6.3b; Dhillon *et al*, 1999).

A linear response to added potassium was observed in potato at Allahabad. The potato tuber yield increased from 32 mt ha^{-1} in control plot to as high as 37 mt ha^{-1} with an application of 100 kg K_2O ha^{-1} (Fig. 6.4; Rai *et al*., 2002). At Agra, a quadratic and plateau response was observed in case of rice (Fig. 6.5; Singh *et al*., 1999).

Table 6.9. Effect of irrigation levels (I1-3), potassium fertilization and their interaction on yield of pigeon (cv. Type 21) at harvest.

K_2O application	Seed yield			
	I1	I2	I3	Mean
kg ha^{-1}	-----------------------------	*mt ha^{-1}*	-----------------------------	
K_0	0.65	0.87	1.05	0.85
K_{25}	0.82	1.23	1.32	1.12
K_{50}	1.02	1.51	1.73	1.42
K_{75}	1.23	1.51	1.71	1.48
K_{100}	1.18	1.49	1.73	1.47

Source: PRII Sponsored project, Aligarh Muslim University, Aligarh, Report, 1989.

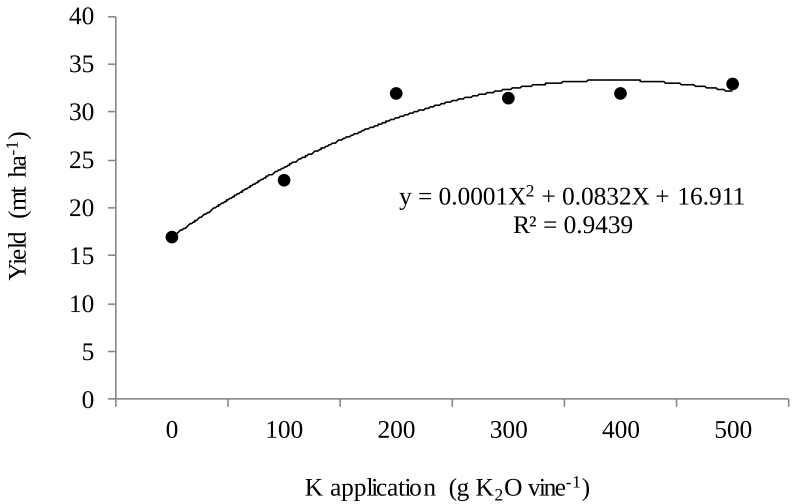


Fig. 6.3a. Effect of graded doses of potassium on yield of grapes at Ludhiana. Nitrogen, P and FYM were given at 500 g, 720 g and 80 kg per vine.

Source: Adapted from Dhillon *et al*., 1999.

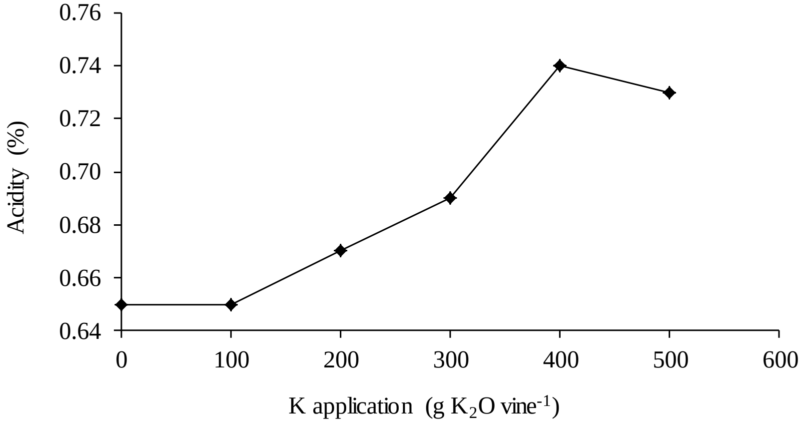


Fig. 6.3b. Effect of graded doses of potassium on acidity percentage of grapes at Ludhiana. Nitrogen, P and FYM were given at 500 g, 720 g and 80 kg per vine.

Source: Adapted from Dhillon *et al*., 1999.

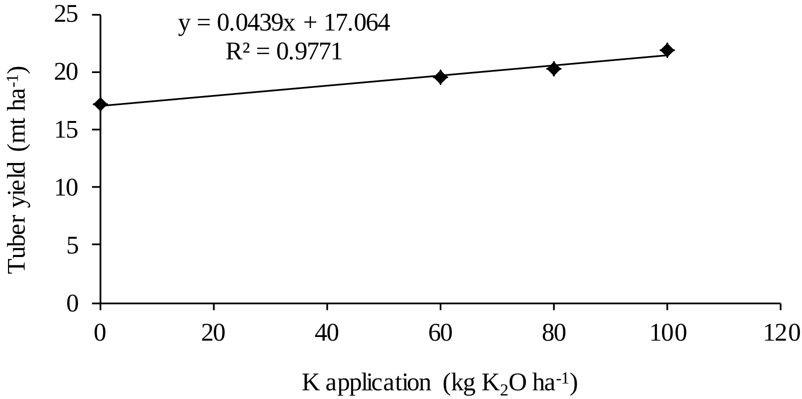


Fig. 6.4. Effect of potassium on potato tuber yield in a sandy loam soil of Allahabad.

Source: Adapted from Rai *et al*., 2002.

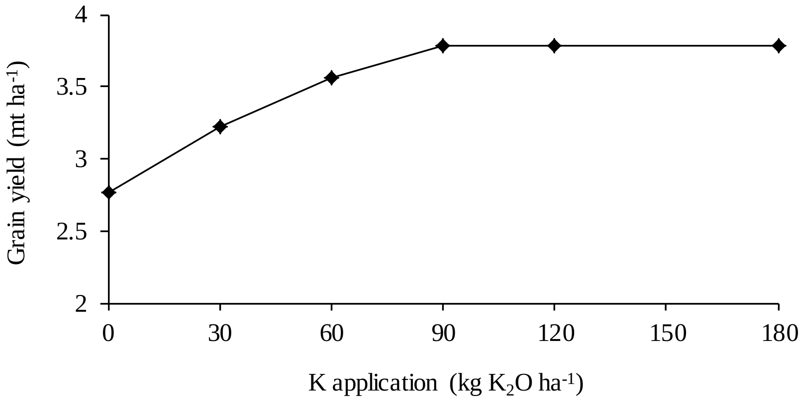


Fig. 6.5. Effect of graded doses of potassium on grain yield of rice at Agra (pooled data of 1992-1993); CD (P = 0.05) = 0.22.

Source: Adapted from Singh *et al.*, 1999.

Agroecological region 5

In a long-term field experiment on a calcareous medium black soil with a fixed rotation of groundnut, wheat and fodder sorgum response to K was tested over half the recommended rate of NP, full dose of NP and NP based on soil test. All The three test crops responded to K over the respective NP applications (Table 6.10). Further, the extent of response was more when K was applied with recommended dose or soil test based NP (Malavia *et al.*, 1993).

In a field experiment, both grain yield and protein content of chickpea improved with potassium application in black calcareous soils at Junagarh (Table 6.11; Tomar *et al.*, 2001). Fifty kg K_2O ha^{-1} is the optimum dose for maximum yield and best quality of chickpea in this region. Also at Junagarh, in similar soils, the total K uptake increased significantly in five different varieties of groundnut (Fig. 6.6; Patil *et al.*, 2003). This shows that the fresh K fertilization has a significant impact on K supply or availability in these soils.

Table 6.10. Effect of various fertilizer treatments on yield levels of groundnut, wheat and fodder crops (pooled data for 10 years).

Year	Treatment	Groundnut (pod yield)	Wheat	Green fodder
		-----------*kg ha^{-1}*-----------		*mt ha^{-1}*
1	Control	669	840	8.3
2	Full does of N recommended	683	862	8.2
3	Half does of N recommended	700	989	9.0
4	Direct effect of 25 mt FYM ha^{-1}	1,281	2,725	17.7
5	First residual effect of 25 mt FYM ha^{-1}	921	1,907	15.5
6	Second residual effect of 25 mt FYM ha^{-1}	734	1,362	11.2
7	Half does of N and P recommended for irrigated conditions but no K	706	1,199	17.1
8	As per treatment F 7 but with K	1,206	2,695	14.9
9	Full does of N and P recommended for irrigated conditions but no K	668	2,133	18.1
10	As per treatment F 9 but with K	1,226	3,178	24.1
11	Application of N and P according to soil test but no K	693	2,248	18.9
12	N and P according to soil test but with K.	1,240	3,132	24.4
SEM		21.1	47.3	0.44

Source: Adapted from Malavia *et al*., 1993.

Table 6.11. Effect of levels and varieties on yield and quality of chickpea in black calcareous soils at Junagarh, Gujarat.

Treatments/K_2O levels	Yield		100 grain wt.	Protein content
	Grain	Straw		
kg ha^{-1}	---------*kg ha^{-1}*---------		*g*	*%*
K_0	1,138	1,795	13.93	16.73
K_{25}	1,230	1,991	14.25	19.21
K_{50}	1,335	2,230	14.71	19.92
K_{75}	1,491	2,157	14.62	19.84
K_{100}	1,437	2,168	14.68	18.14
SEM	27	49	0.11	0.62
C.D. (0.05)	80	144	0.34	1.81

Source: Adapted from Tomar *et. al*, 2001.

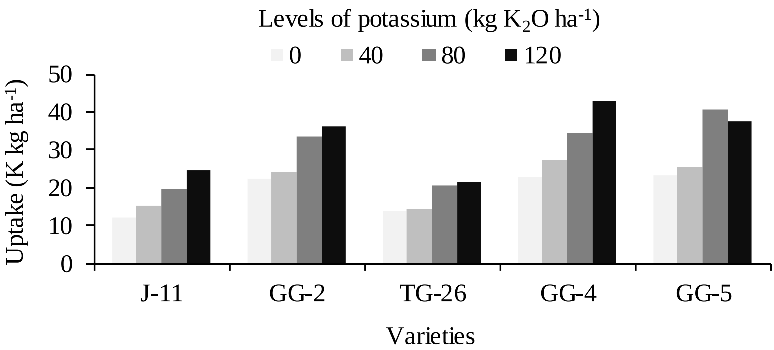


Fig. 6.6. Effect of potassium on total K uptake (by above-ground parts) by five varieties of groundnut in a calcareous soil at Junagarh, Gujarat.

Source: Adapted from Patil *et al*., 2003.

Agroecological region 7

In a field experiment on medium deep Alfisol, Hyderabad sorghum cultivar SPV 462 responded significantly to 40 kg ha^{-1} K_2O in terms of both total dry matter and grain yields (Table 6.12; Sharma and Ramana, 1993).

In black cotton soils at LAM, Gunter, Andhra Pradesh, foliar application of K at 5 kg K_2O ha^{-1} over and above a dose of NPK (90:45:45) kg ha^{-1} at early and peak boll formation stage improved fibre properties of cotton. This could be due to increased translocation of photosynthates to the reproductive sinks, which improved the quality of cotton fibre (Ratna Kumari *et al*. 2008).

Table 6.12. Response of sorghum to K on an Alfisol.

Treatment	Yield	Total above-ground DM
kg ha^{-1} K_2O	----------------------*mt ha^{-1}*----------------------	
0	3.95	13.0
40	5.48	16.4
80	5.58	16.4
CD (0.05)	0.41	0.23

Source: Adapted from Sharma and Ramana, 1993.

Agroecological region 8

In a long-term field experiment in medium black calcareous soils, the yields of finger millet and maize crops increased with 100 kg K_2O ha^{-1}. The response, however, was more prominent for maize (Fig. 6.7; Santhi *et al.*, 2003).

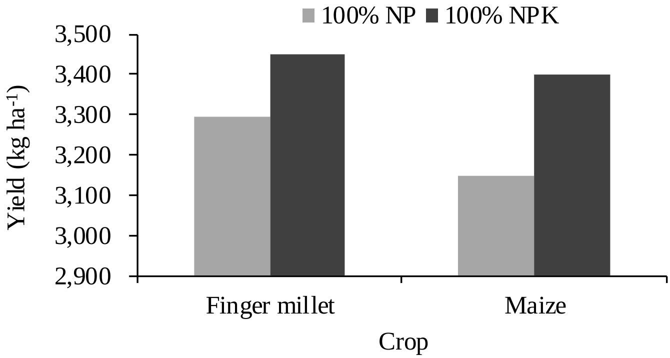


Fig. 6.7. Effect of potassium fertilization on the grain yield of finger millet and maize in medium black calcareous soil of Coimbatore (mean of five crops 1993-1998).

Source: Adapted from Santhi *et al.*, 2003.

Agroecological region 9

In a two-year field experiment, response of two varieties of wheat HD 1941 and UP301 was tested with four rates of K application on sandy loam (pH 7.6) alluvial soils of Varanasi. 50 kg K_2O significatly increased the grain and straw yields, the response being 4 kg grain kg^{-1} K_2O applied (Table 6.13; Singh *et al.*, 1993).

In a lager number of field experiments conducted on cultivators' fields in alluvial tracts of UP, positive responses to potassium up to 60 kg ha^{-1} for rice, wheat and maize under irrigated conditions, up to 20 to 30 kg ha^{-1} K_2O in pulses like gram, lentil, blackgram and pigeonpea under rainfed conditions, 40 to 60 kg in oilseed crops like mustard and linseed under rainfed conditions were observed (Tables 6.14 a, b, and c). The yield response was 3 to 8 kg grain kg^{-1} K_2O in rice, wheat and maize, 4 to 8 kg grain kg^{-1} K_2O in pulses, 1.5 to 3.5 kg grain kg^{-1} K_2O in oilseed crops and 19 kg tuber kg^{-1} K_2O in potato (Table 6.15; Yadav *et al.*, 1993).

In a field experimenent conducted in a clay loam soil at Faizabad, yield of rice increased from 2 mt ha^{-1} to approx. 2.9 mt ha^{-1} with an application of 50 kg K_2O ha^{-1} (Table 6.16; Prasad and Chauhan, 2000).

Both sugarcane and sugar yields increased with the application of potassium in a sandy loam soil at Lucknow. Here again, the influence of added potassium was more in increasing the sugar percentage of cane, thereby showing the role of potassium in improving the crop quality (Fig. 6.8; Yaduvanshi and Singh, 1999).

Table 6.13. Response of dwarf wheat to K at Varanasi.

kg K_2O ha^{-1}	Grain yield			Straw yield		1,000 grain wt	
Year	1st	2nd	Pooled	1st	2nd	1st	2nd
	mt ha^{-1}					*g*	
0	4.41	4.04	4.23	6.73	6.71	38.0	37.6
50	4.57	4.26	4.43	7.12	7.02	38.5	38.0
100	4.73	4.51	4.62	7.19	7.25	38.9	38.6
150	4.92	4.71	4.82	7.36	7.49	39.4	39.2
SEM	0.07	0.05	0.06	0.02	0.01	0.16	0.1
CD (0.05)	0.2	0.12	0.13	0.06	0.03	0.45	0.2

Source: Adapted from Singh *et al*., 1993.

Table 6.14a. Response of cereal crops to potassium on cultivator's fields under irrigated conditions.

Crop	No. of trials	Year	Additional K over treatment (kg K_2O ha^{-1})			
			20	30	40	60
			$N_{40}P_{20}$	$N_{60}P_{30}$	$N_{80}P_{40}$	$N_{120}P_{80}$
			-------------------------------*Response to K kg* ha^{-1}-------------------------------			
Kharif rice	313	1976-1982	180	182	262	278
Rabi wheat	863	1975-1982	202	174	254	263
Kharif maize	95	1977-1982	144	-	147	280

Source: Adapted from Yadav *et al.*, 1993.

Table 6.14b. Response of pulses to potassium on cultivator's fields under rainfed condition.

Crop	No. of trials	Year	Additional K over treatment (kg K_2O ha^{-1})		
			20	30	40
			$N_{20}P_{40}$	$N_{30}P_{60}$	$N_{40}P_{80}$
			---------------------------*Response to K kg* ha^{-1}---------------------------		
Rabi gram	205	1982-1990	95	72	24
Urd (blackgram)	105	1982-1988	77	20	42
Lentil	90	1983-1988	112	85	73
Pigeon pea (Kharif)	69	1986-1990	163	29	59
Pea	15	1986-1988	148	87	81
Moong	14	1986-1988	30	29	-
Soybean	32	1986-1988	56	17	27

Source: Adapted from Yadav *et al.*, 1993.

Table 6.14c. Response of oilseeds to potassium on cultivator's fields under rainfed conditions (1980-1982).

Crop	No. of trials	Response to K over $N_{60}P_{40}K_0$ at		
		K_{20}	K_{40}	K_{60}
		------------------*kg ha*$^{-1}$-------------------		
Rabi mustard	81	89	108	142
Rabi linseed	72	48	94	142
Kharif sesamum	48	49	92	119

Source: Adapted from Yadav *et al*., 1993.

Table 6.15. Additional profit (Rs ha^{-1}) and the value: cost ratio (VCR; in parenthesis) in crops at various levels of potash fertilizer application.

Crops	Levels of K (kg ha^{-1} K_2O)						
	20	30	40	50	60	70	100
	Rs ha^{-1} (VCR)						
Rice	342 (7.52)	322 (4.72)	472 (5.20)	-	426 (3.10)	-	-
Wheat	388 (5.20)	306 (4.49)	455 (5.04)	-	429 (3.15)	-	-
Maize	185 (4.07)	-	144 (1.60)	-	311 (2.28)	-	-
Gram	431 (9.47)	294 (4.30)	29 (0.30)	-	-	-	-
Urd	341 (7.50)	32 (0.46)	29 (1.31)	-	-	-	-
Lentil	401 (8.82)	273 (4.00)	200 (2.20)	-	-	-	-
Pigeon pea	770 (16.95)	77 (1.13)	205 (2.25)	-	-	-	-
Soybean	179 (3.93)	-	15 (0.17)	-	-	-	-
Pea	695 (15.29)	367 (5.28)	314 (3.46)	-	-	-	-
Mustard	487 (10.22)	-	557 (6.13)	-	716 (5.25)	-	-
Linseed	195 (4.29)	-	379 (4.17)	-	574 (4.21)	-	-
Sesamum	247 (5.45)	-	459 (5.05)	-	578 (4.25)	-	-
Potato	-	-	-	1,731 (15.3)	-	1,626 (9.54)	1,685 (7.9)

Note: Figures in parenthesis indicate the gain (Rs. per Rs. invested) in K.

Source: Adapted from Yadav *et al.*, 1993.

Table 6.16. Effect of potassium on yield of rice in clay loam soils at Faizabad.

Treatments (K_2O ha^{-1})	Grain Yield (mt ha^{-1})	
	1996	1997
0	2.07	2.04
25	2.80	2.69
50	2.81	3.00

Source: Adapted from Prasad and Chauhan, 2000.

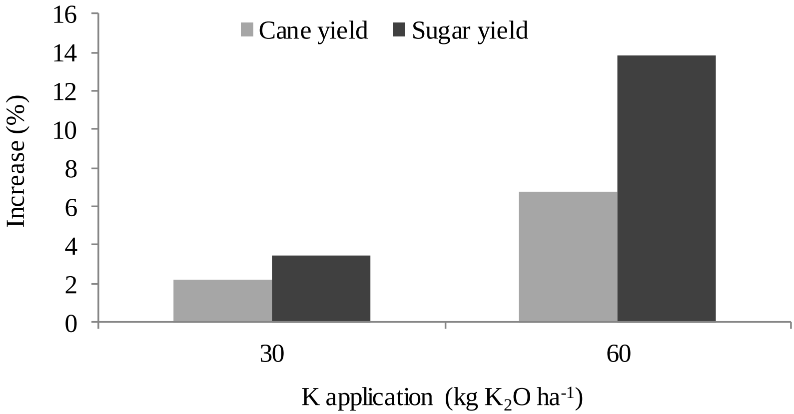


Fig. 6.8. Effect of K application on increase in sugarcane yield and sugar yield over control (0 kg K ha^{-1}) in a sandy loam soil at Lucknow.

Source: Adapted from Yaduvanshi and Singh, 1999.

Agroecological region 10

Puri and Jaipurkar (1989) studied the response of linseed (*Linum usitatissimum* L.) and safflower (*Carthamus tinctorious* L.) to applied potassium on typic Chromusterts (available kg 412 K ha^{-1}) (Table 6.17). Derived yield maxima in linseed (seed) at optimum level of K_2O, i.e. 22 kg ha^{-1} in the presence of 50 kg N and 40 kg P_2O_5 ha^{-1} was 1,690 kg ha^{-1} and 1,660 kg ha^{-1} at 16 kg K_2O along with 75 kg N + 60 kg P_2O_5 ha^{-1}. The maximum production of safflower was 1,720 kg ha^{-1} with application of 38 kg K_2O + 60 Kg N + 60 kg P_2O_5 ha^{-1}.

Table 6.17. Maximum yield and economic indices due to potash fertilization of safflower and linseed (data pooled for 3 years).

Soil K test (available K)	Fertilizer nutrient added			Maximum yield	Yield response	Agronomic efficiency	Benefit cost ratio
	N	P_2O_5	K_2O				
	kg ha^{-1}				*%*	*kg kg^{-1}*	
				Safflower (12)*			
347-605 (461)**	60	60	38	1,720	22	8.0	12.0
				Linseed (11)*			
386-491(423)**	50	40	22	1,690	7	5.5	16.2
386-453 (398)**	75	60	16	1,660	3	3.7	10.6

*Number of replicates; **average value.

Note: Rates taken into account of cost/benefit calculations: Safflower at Rs. 2,060 mt^{-1} of grain; linseed (grain) at Rs. 4,250 mt^{-1}; cost of N:Rs. 3.05 kg^{-1}; P_2O_5:Rs. 3.30 kg^{-1}; K_2O:Rs. 1.40 kg^{-1}.

Source: Adapted from Puri and Jaipurkar, 1989.

Pandey *et al*. (1993) studied the response of rice to applied potassium on a vertisol (available K 287 kg ha^{-1}) at Raipur. Application of 40 kg ha^{-1} K_2O in two equal splits as basal and at panicle initiation stage of rice significantly increased the grain yield (Table 6.18).

Table 6.18. Effect of potassium (kg ha^{-1}) on grain yield of rice.

Potassium treatments	Application time	Grain yield	
		1990	1991
K_2O kg ha^{-1}		---------------*mt ha^{-1}*---------------	
0		4.37	4.21
20	Basal	-	4.60
20+20	Basal + PI	5.14	5.13
40	Basal	4.83	4.90
30+30	Basal + PI	5.16	5.26
60	Basal	5.11	5.26
CD (0.05)		0.17	0.31

Note: PI = Panicle initiation.

Source: Adapted from Pandey *et al*., 1993.

Agroecological region 12

In eleven field experiments on farmers' fields conducted in soils of Umendanda series (Typic Paleustalf) during 1988-1989, maize (Ganga Safed-2) responded significantly to potassium up to 60 kg ha^{-1} K_2O (Table 6.19; Roy *et al*., 1991). The economic optimum rate was 60 kg ha^{-1} K_2O.

Table 6.19. Response of maize to potassium in soils of Umendanda series of Ranchi.

Potassium treatments	Grain	Response
K_2O kg ha^{-1}	*mt ha^{-1}*	*kg grain per kg K_2O*
0	2.74	-
20	2.94 (7.3)*	10.0
40	3.10 (13.4)	9.0
60	3.27 (19.7)	8.8
80	3.25 (18.7)	6.3
CD (0.05)	0.079	

*Percentage increase over control.

Source: Adapted from Roy *et al*., 1991.

Agroecological region 13

Prasad and Prasad (1993) studied the response of winter maize and rapeseed to potassium on farmers' fields in Calciorthents of north Bihar. The largest responses of rapeseed and winter maize to 60 kg ha^{-1} K_2O application were 11.6 and 20.8 kg grain kg^{-1} K_2O, respectively. The benefit:cost ratio at this level of K_2O was 10.7 for rapeseed and 23.3 for winter maize. The computed economic dose of potash was 61 kg ha^{-1} K_2O for winter maize (Table 6.20).

Table 6.20. Response of winter maize (var. Laxmi) and rapeseed (var. Varuna) to K application on farmers' fields (Village-Lautan) in Jagdishpur-Bagha soil series.

K application	Grain yield	Attional yield	Response to K	Cost of potash	Return due to additional yield	Net profit	Benefit:cost ratio
kg K_2O ha^{-1}	---------------*mt ha^{-1}*---------------		*kg kg^{-1}*	--------------------------*Rs. ha^{-1}*--------------------------			
			Winter maize				
0	5.63	-	-	-	-	-	-
30	6.25	0.62	20.7	90	2,170	2,080	23.1
60	6.88	1.25	20.8	180	4,375	4,195	23.3
90	6.25	0.62	6.9	270	2,170	1,900	7.0
120	5.75	0.12	1.0	360	420	60	1.2
CD (0.05)	0.26						
			Rapeseed				
0	1.38	-	-	-	-	-	-
30	1.75	0.37	12.3	90	1,110	1,020	11.3
60	2.08	0.70	11.6	180	2,100	1,920	10.7
90	2.38	1.00	11.1	270	3,000	2,730	10.1
CD (0.05)	0.18						

Source: Adapted from Prasad and Prasad, 1993.

Agroecological region 14

In a field experiment in acid sandy loam, the yield of potato tubers increased with an application of potassium at locations Fagu and Kufri. Both K uptake and K recovery percentages also increased significantly. The optimum rate of K application in this region is found to be 60 kg K_2O ha^{-1} (Table 6.21; Sud and Sharma, 2002).

Table 6.21. Effect of potassium on tuber yield, uptake and K recovery by potato in acid sandy loam soils of Shimla.

Location	K levels	Tuber yield	K-uptake	K-recovery
	K_2O kg ha^{-1}	*mt ha^{-1}*	*kg ha^{-1}*	*%*
Fagu	0	12.1	39	
	30	19.5	76	61.7
	60	21.1	82	44.4
	90	20.4	84	34.2
C.D. (0.05)		1.1	4.9	
Kufri	0	8	24	
	30	11.1	41	33.9
	60	12.9	55	41.6
	90	13.4	50	26.7
C.D. (0.05)		1.9	7.4	

Source: Adapted from Sud and Sharma, 2002.

Agroecological region 15

In a field experiment on sandy loam (pH 7.1), rainfed groundnut responded to 40 kg ha^{-1} K_2O applied as basal and 80 kg K_2O applied in two splits (1/2 as basal 1/2 top dressed at 35 DAS). The economic optimum does of K was 43.2 kg ha-[1] K_2O to attain 1.27 mt ha^{-1} and 82.5 kg ha^{-1} K_2O to attain 1.42 mt ha^{-1} (Mandal and Goswami, 1991) with basal and split application respectively (Table 6.22). Application of fertilizer K at 49.8 kg ha^{-1} helped in preventing the depletion of non-exchangeable K reserves in an Alfisol (Anandapur, West Bengal) after a crop of rice, however, when a high K exhaustive crop of potato followed as the second crop, the non-exchangeable reserves of K declined to an extent of 9% in less than one year, despite application of recommended dose of fertilizer K (i.e. 125 kg K ha^{-1}) to the second crop. A higher dose of applied K (i.e. 166 kg K ha^{-1}) helped in minimizing the mining of the soil K from its original status (Dhar *et al*., 2009).

Table 6.22. Effect of split application of potassium on rainfed groundnut.

Treatment	Application[(1)]	Total dry matter	Pod yield
kg K_2O ha^{-1}		----------------------*mt ha^{-1}*	----------------------
0		3.55	1.10
40	Basal	5.55	1.26
80	Basal	5.77	1.23
120	Basal	4.33	1.19
40	Split	5.10	1.12
80	Split	5.82	1.42
120	Split	5.16	1.20
CD (0.05)		0.62	0.13

[(1)]Split is $^1/_2$ as basal and $^1/_2$ as top dressing at 35 DAS.

Source: Adapted from Mandal and Goswami, 1991.

Agroecological region 18

Papaya yield increased and acidity percentage decreased in a sandy loam soil of Tamil Nadu. There was a steady decrease in the acidity of papaya with an application of potassium (Fig. 6.9 and 6.10; Kumar *et al*., 2006). At Bapatla in a sandy soil, both shoot and root dry matter of sorghum increased upto 80 kg K_2O ha^{-1} showing the potentiality of K response in these soils for sorghum (Table 6.23; Pillai and Nookaraju, 1997).

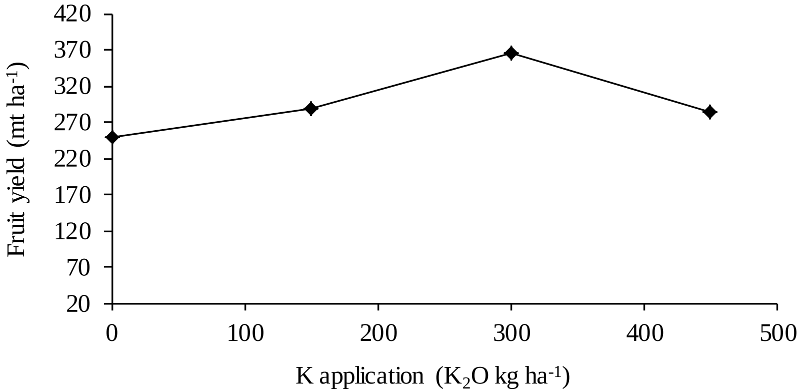


Fig. 6.9. Effect of graded doses of potassium on yield of papaya in a sandy loam soil at Tamil Nadu (mean of four trials).

Source: Adapted from Kumar *et al*., 2006.

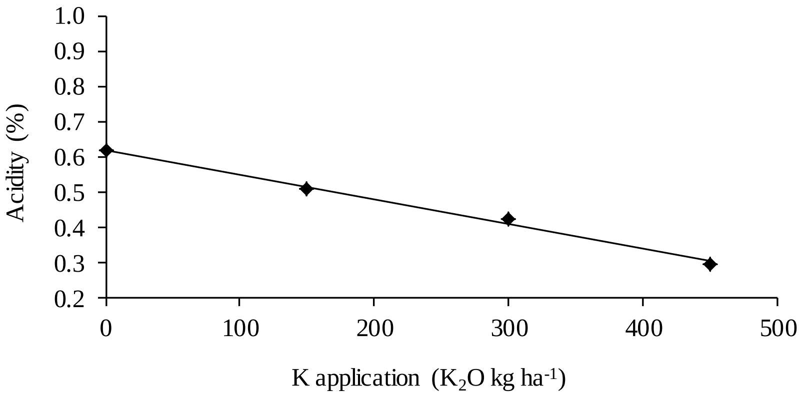


Fig. 6.10. Effect of graded doses of potassium on acidity percentage of papaya in a sandy loam soil of Tamil Nadu (mean of four trials).

Source: Adapted from Kumar *et al*., 2006.

Table 6.23. Effect of graded levels of added potassium on total dry matter production (g plant^{-1}) in Sorghum varieties in a sandy soil of Bapatla (mean of three replications).

Potassium levels	NTJ-1				PSV-5				CSV-15			
	Root	Shoot	Grain	Total	Root	Shoot	Grain	Total	Root	Shoot	Grain	Total
kg K_2O ha^{-1}	*Dry matter (g plant^{-1})*											
0	6.7	22.5	13.9	43.1	7.3	21.0	12.0	40.3	6.2	22.4	13.8	42.4
20	7.4	26.0	15.5	48.9	8.4	23.4	13.6	45.4	7.4	27.4	17.6	52.4
40	8.1	27.9	17.3	53.3	7.7	24.8	15.6	48.1	9.1	28.1	19.6	56.8
60	8.9	28.8	19.2	56.9	8.6	27.0	18.3	53.9	9.6	29.3	21.2	60.1
80	9.4	30.8	20.8	61.0	10.3	27.6	20.5	58.6	10.7	31.3	23.9	65.9

Source: Adapted from Pillai and Nookaraju, 1997.

7. Critical Limits Calculation and K Recommendation

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 (Muhr *et al*., 1965). Unfortunately, these ratings limits are irrespective of crops or soils.

Solankey *et al*. (1992) studied the response of two wheat varieties to potassium on farmers' fields in swell-shrink soils. Though these soils were adequate in ammonium acetate extractable 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 (Fig. 7.1).

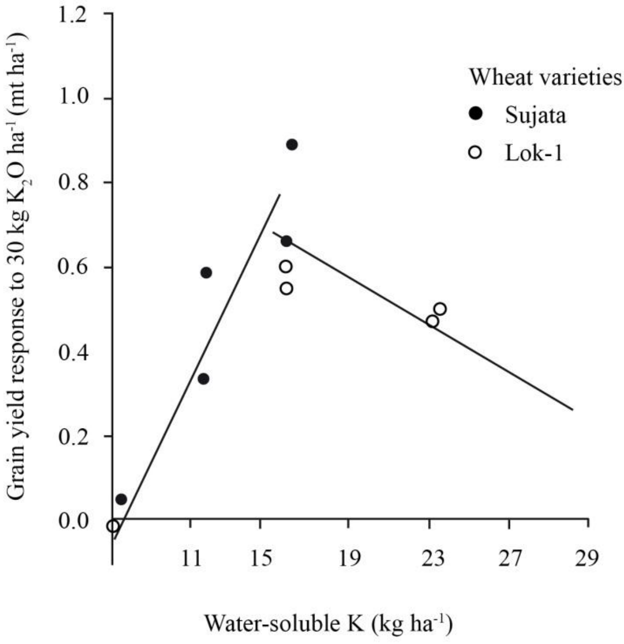


Fig. 7.1. The correlation between water-soluble K in the soil to the wheat grain yield response to K_2O ha^{-1}.

Source: Adapted from Solankey *et al*., 1992.

Gajbhiye *et al*. (1993), using cotton, sorghum and wheat as a test crops, established a critical limit of 165 mg kg^{-1} soil of ammonium acetate K in vertisols. They also showed that yield of the test crops increased beyond the level of 200 mg K kg^{-1} soil. They attributed the lack of response below 200 mg kg^{-1} NH_4OAc K to the state of "soil hunger" for K (Fig. 7.2).

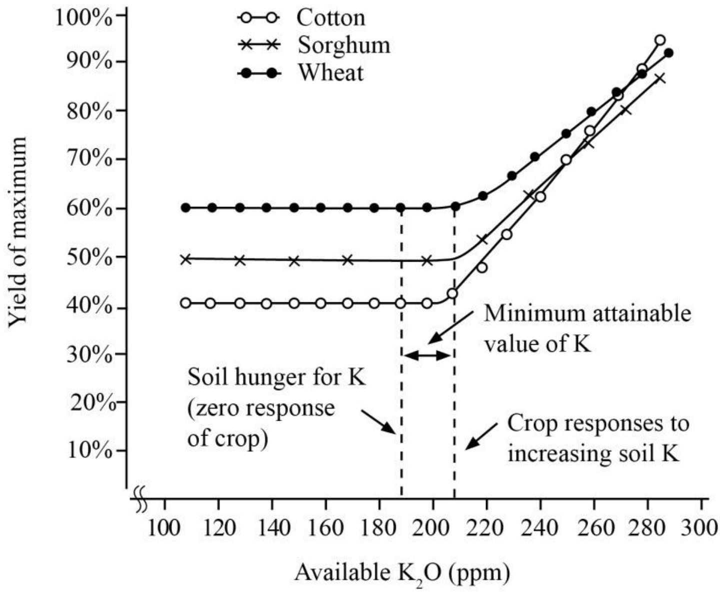


Fig. 7.2. Crop response curve to soil K.

Source: Adapted from Gajbhiye *et al*., 1993.

Akolkar and Sonar (1994), in a field experiment conducted on Otur series (Typic Chromusterts) having ammonium acetate K from 437 to 1,992 kg ha^{-1}, established a critical limit of 750 kg K ha^{-1} for sorghum. The fore-mentioned three studies indicate the need to initiate more elaborate studies on vertisols, grouped on the basis of water-soluble K or the upper limit based on NH_4OAc for the "state of soil hunger" (200 mg kg^{-1}) to test the reponse of crops on Vertisols and establish calibration system for K fertilize recommendations.

For delineation of fertility status, to isolate responsive soils from non-responsive ones and to recommend fertilizer K, critical limits for different crops in soils of various agroecological regions are needed. Table 7.1 (Subba Rao and Srinivasarao, 1996) provides critical limits of available K in different crops on some well-defined soils. The data show a great diversity in the critical limits ranging from 48 to 137 mg kg^{-1} soil. It is also seen that there is lack of information on critical limits for K on vertisols for important crops. Table 7.2 shows the potash fertilizer recommendations for some tobacco growing soils of India. Table 4.7.1 (presented earlier) shows the K fertilizer recommendations based on critical limits of exchangeable and non-exchangeable K for different soils of India. Non-exchangeable K reserves were included along with exchangeable K in categorising soils into 9 groups for evolving better strategies to manage soil K fertility in rainfed agriculture in India. Finger millet and groundnut crops at Bangalore and Anantapur regions (category I) need immediate attention on K nutrition, as these soils are low in both exchangeable and non-exchangeable K. Similarly, crops grown on soils of S.K. Nagar, Ballowal-Saunkri, and Rakh-Dhiansar, with low exchangeable K and medium non-exchangeable K, would need K fertilisation as these crops (maize and pearlmillet) are K-exhaustive (category II). Pearl millet and upland rice in category III and cotton in category IV need K additions at critical stages. Upland rice in category V needs a maintenance dose of K. In category VI, cereal crops may not need K additions immediately as they have medium exchangeable K and high non-exchangeable K. Long-term sorghum cropping may need K supply after few years (category VII). Soils in category VIII are adequate in non-exchangeable K and medium exchangeable K and with the crops, groundnut, cotton, sorghum, and soybean, application of K can be planned according to market conditions with no immediate risk of yield loss. For soils in category IX, K fertilisation is not required to the crops (sorghum and soybean) as these soils have high exchangeable and non-exchangeable K (Srinivasarao *et al*., 2007).

Table 7.1. Critical levels of available (NH_4 OAc) K in different soils for different crops.

Crop	State	Soil type	Critical level	Reference
			mg kg^{-1}	
Rice	Andrah Pradesh	Medium black soil	100	Venkatasubbaiah *et al*. (1976)
	Andrah Pradesh	Red soils, Dubba & Chalka (surface hard soils)	75	Subba Rao *et al*. (1976)
	Andrah Pradesh	Light soils of Kodad	67.5	Venkatasubbaiah *et al*. (1991)
	Andrah Pradesh	Alluvial soils	190	Subramanyeswara Rao and Rajagopal (1981)
	Uttah Pradesh	Rarha series, alluvial soil	117	Tiwari (1985)
	Uttah Pradesh	Uttari series, alluvial soils	120	Tiwari *et al*. (1995)
	Bihar	Calcareous soils	58	Sinha (1985)
	Maharashtra	Phondaghat series, lateritic soils	76	Sutar *et al*. (1992)
	Uttah Pradesh	Udic Ustochrepts, Uttari series	110	Tiwari *et al*. (1999)
	Maharashtra	Lateritic soils, Kumbhave series	86.6	Kale and Chavan (1996)
	Orissa	Fluventic Ustochrept	64	Panda and Panda (1993)
	Uttah Pradesh	Khatki series Typic Haplustalf	71	Sharma *et al*. (1995)
	West Bengal	Belar series, Vertic Haplaquept	112	Ghosh and Mukhopadhyay (1996
	West Bengal	Bankati series, Aeric Ochraqualf	110	Ghosh and Mukhopadhyay (1996)
Wheat	Uttah Pradesh	Uttari series, Typic Ustochrepts	100	Tiwari *et al*. (1995)
	Uttah Pradesh	Rarha series, alluvial soil	95	Tiwari and Dev (1987)
	Bihar	Jagdishpur Bagha, calcareous soil	60	Prasad (1990)

Table 7.1. continued

Crop	State	Soil type	Critical level	Reference
			mg kg^{-1}	
	Bihar	Umendanda soil series	50	Roy (1987)
	Bihar	Puto series, Alfisol	48	Roy *et al*. (1989)
	Uttah Pradesh	Khatki series, Typic Haplustalf	71	Sharma *et al*. (1995)
Maize	Rajasthan	Haplustalfs	47	Yadav and Swami (1984)
	Tamil Nadu	Valuthalakudi series	71	Jeyabaskaran and Raghupathy (1993)
	Bihar	Jagdishpur Bagha, calcareous soil	81	Prasad and Prasad (1995)
Sorghum	Madhya Pradesh	Islamnagar series 3 & 4	240	Srinivasarao and Takkar (1997)
	Maharashtra	Typic Chromusterts	335	Akolkar and Sonar (1994)
Pearl millet	Andrah Pradesh	Medium black soil	95	Venkatasubbaiah *et al*. (1976)
	Gujarat	Black calcareous soils	60	Meisheri *et al*. (1995)
	Andrah Pradesh	Alluvial soils	160	Sailakshmiswari (1984)
Groundnut	Andrah Pradesh	Light soils of Kodad	60	Subramanyeswara Rao and Rajagopa1 (1981)
	Gujarat	Black calcareous soils	65	Golakiya (1999)
Potato	Himachal Pradesh	Sub montane soils	120	Grewa1 and Sharma (1980)
Cotton	Punjab	Tulewal and Samana series, alluvial soils	50	Sidhu and Brar (1989)
Chickpea	Uttah Pradesh	Rarha series, alluvial soil	137	Tiwari (1985)
	Uttah Pradesh	Uttari series, Typic Ustochrepts	105	Tiwari *et al*. (1996)

Source: Subba Rao and Reddy, 2005.

Table 7.2. Potash fertilizer recommendation for tobacco growing soils of India.

Agroclimatic zone	Soil texture	Availability of K to the plant	Recommended dose of K (kg K_2O ha^{-1})	Remaks for effcient K use
Northern Black Soil (NBS)	Heavy clays	High K reserves. Poor air-water balance affects K-availability	Omit K for 5 years & review	No response to K, hence omit K
Northern Light Soil (NLS)	Sands and Sandy loams	Inadequate K status, leaching losses of K occur	80-120	1. Split applications of K 2. N-K balance is needed 3. Dollop method of placement
Central Black Soil (CBS)	Heavy clays	High K reserves. Poor air-water balance affects K-availability	Omit K for 5 years & review	No response to K, hence omit K
Southern Black Soil (SBS)	Silt loams	Medium K status. Severe moisture stress affects crop growth	60	Basal application by plant row-plough furrow method (PRPF)
Southern Light Soil (SLS)	Red Sandy loams & loams	Medium K status. Severe moisture stress affects crop growth	60	Basal application by plant row-plough furrow method (PRPF)
Karnataka Light Soil (KLS)	Loamy sands & Sandy, loam	High K reserves. Poor air-water balance affects K-availability	80	Add potash by Dollop method in splits as maintenance dose.

Source: Adapted from Krishnamurthy and Ramakrishnayya, 1997.

8. Conclusion

The available information on potassium status in soils and crop responses to applied K in soils of the different agroecological zones indicate that crops may respond to K fertilizer in the following conditions:

- Alluvial soils in Himalayan regions (Jammu and Kashmir and Himachal Pradesh) have medium in exchangeable and medium to high non-exchangeable K. High K demanding cropping systems based on potato need regular K application.
- Some soils in the agroecological region 2 have high amount of biotite mica (e.g. in Hisar) but others (e.g. Gurgaon), showed more prominent responses to K and need K fertilization.
- Red shallow soils in the agroecological region 3 are low to medium in exchangeable K and low to medium in non-exchangeable K, and hence regular application of K is needed for groundnut and finger millet based cropping systems.
- Light textured alluvial soils with moderate amounts of both available and non-exchangeable K in the agroecological region 4 sub-soils (Rajasthan, Uttar Pradesh) are relatively low in available K and this could be a reason for prominent responses observed at some places under intensive cropping. Hence K application to K loving cropping systems in this agroecological region (rice-wheat, potato or sugarcan based systems) is required.
- Red and lateritic soils with medium amount of available K but low reserve K are found in the agroecological region 7 (Andra Pradesh and Karnataka). The predominant cropping systems like groundnut, fingermillet and horticulture based - all need K application. Moreover, commertial crops like tobacco needs special attention as per as K nutrition is concerned.
- Red soils with medium available K but low reserve K are found in the agroecological region 8 (Tamil Nadu and Karnataka). Since soil reserves are low in some of these red soils, cotton, finger millet and other crops grown in this agroecological region require K fertilization.
- In the agroecological region 9 (U.P, Bihar), where K deficient Alfisols and Inceptisols prevail, crops like sugarcane and potato need frequent K application. Special care should be taken on K nutrition of crops on highly calcareous soils of Bihar.

- The K deficient red and acidic alluvial soils with low to medium available K and low non-exchangeable K in the agroecological region 12 and in the agroecological region 13 (Orissa, Chattisgadh, West Bengal), require frequent K application for improving crop yields. Potassium application is also essential in soils where iron toxicity is found, particularly in Orissa.
- The agroecological region 14 is characterized with brown forest and acidic hill soils with low to high available and non-exchangeable K. Potash loving crops like potato may be recommended K application.
- Acidic alluvial soils with marginally high available K but low to medium non-exchangeable K are found in the agroecological region 15. K application is needed to only K loving crops like potato and plantation crops based soil K deficiency.
- Soils of the agroecological region 16 (West Bengal and North-East Hills states like Assam Mizoram and Manipur) have low to high available and reserve K. Crops grown on the low K soils of West Bengal require regular K additions.
- In the acidic soils of the agroecological region 17 (Arunachal Pradesh), soils with medium level of available and reserve K require crop specific K recommendation K deficient soils.
- In eed and lateritic soils with medium level of available K but low reserve K in the agroecological region 19 (Coastal regions of Eastern India), K application is needed on site specific K deficient locations.

Further studies are needed on these soils to work out the magnitude of responses, economics and the fertilizer recommendations for crops grown in these agroecological regions.

It is observed that there are variations in crop responses even within an agroclimatic region. This may be due to differential prior exhaustion of K under varrying management conditions. The information generated has shown a better way of assessing fertilizer responses when chemical extraction is supplemented with mineralogical investigations. Smectitic soils have higher K release rates than illitic soils but the reserves are not sufficient if the cropping continues without adequate K supplementation for long period. Some soils have high amount of K supplying minerals in the silt fraction and this also need to be accounted while assessing the K fertilizer requirements.

The K recommendations by taking both exchangeable and non-exchangeable K reserves simultaneously as shown in Table 4.7.1 are also promising. There is a need to generate several such informations. Such type of soil test calibration system has to be established for important soils and crops in each agroecological region to prescribe location specific K fertilizer recommendations.

At present, under rice-wheat cropping system in the Indo-Gangetic plains, with intensive cropping, soil K depletion is continuing. These intesive rice-wheat systems require K application at critical crop stages. Most of the crops grown on red and lateritic soils and acidic alluvial soils need regular K application. Oil seed crops mostly grown under rainfed conditions need K fertilization based on the extent of K deficiency. For K loving crops like potato, cassava, sugarcane and banana, potassium application should be a regular practice. Commercial crops like tobacco and many horticultural crops, grown on K deficient red and lateritic soils of southern India, need regular K application.

9. References

Adhikari, M., and T.K. Ghosh. 1991. Potash resources and quantity/intensity relationships of different soils of West Bengal. Journal of Potassium Research 7:161-170.

Afridi, M.M.R.K., A. lnam, Samiullah, and Md. Yahiya. 1990. Morphological studies on mustard and pigeon pea with special reference to K nutrition under irrigated and un-irrigated conditions. Third progress report, Potash Research Institute of India Dept.of Botany, Aligarh Muslim University, Aligarh.

Ahmed, N., and C.S. Walia. 1999. Profile distribution of various forms of potassium in some landforms of Bundelkhand region. Journal of Potassium Research 15:1-4.

Akolkar, R.D., and K.R. Sonar. 1994. Calibration of soil test methods for available potassium in Vertisols for sorghum. Journal of Potassium Research 10:63-68.

Annual Report. 2005-2006. AICRP on Cropping Systems. Project Directorate for Cropping Systems Research, Modipuram.

Annual Research Report. 1988. Dept. of Agricultural Chemistry and Soil Science. Gujarat Agricultural University, Junagarh.

Bansal, S.K., and S. Umar. 1998. Nutrient indexing of crop plants grown on twenty six benchmark soil series of India. Journal of Potassium Research 15:7-18.

Bansal, S.K., G. Debnath, and S. Umar. 1996. Monitoring changes in Potassium Fertility of Five Bench Mark Soil Series from Southern India. Journal of Potassium Research 12:337-344.

Bele, Nilima R., K.R. Sonar, and Y.M. Patil. 1997. Quantity-intensity parameters of potassium in six dominant soil series of western Maharashtra. Journal of Potassium Research 131:31-36.

Benipal. D.S., R. Kumar, and N.S. Pasricha. 2001. Fractional distribution of potassium and its relationship with clay mineralogy in alluvial soils of Punjab. Journal of Potassium Research 17:28-33.

Bhargava, P.N., H.C. Jain, and A.K. Bhatia. 1985. Response of rice and wheat to potassium. Journal of Potassium Research 1:45-61.

Bhaskar, B.P., S. Vadivelu, U. Baruah, P.S. Butte, D.P. Dutta, and J.P. Mishra. 2001. Distribution of potassium forms in chars and marshy soils of Brahmaputra valley, Jorhat District, Assam. Journal of Potassium Research 17:39-47.

Bhattacharyya, D., and S.R. Poonia. 1996. Kinetics of potassium release in ammonium acetate in some soils of semi-arid and humid regions. Journal of Potassium Research 44:44-48.

Brar, M.S., B.D. Sharma, R. Singh, and P.S. Sidhu. 1999. Potassium status of Abohar and Zirakpur soil series in Punjab. Journal of Research Punjab Agricultural Univiversity 36:163-68.

Chakarvarty, B.K., D. Borgohain, and M.C. Talukdar. 1996. Effect of levels of potassium and growth and yield of banana cv. Barjahaji (AAA). Journal of Potassium Research 12:174-179.

Chand, S., and B.N. Swami. 2000. Different forms of potassium in some important soil associations of Bharatpur district of Rajasthan. Journal of Potassium Research 16:59-61.

Chandra, P., and V. Singh. 1986. Evaluation of soil test methods for available potassium in alluvial soils. Journal of the Indian Society of Soil Science 34:425-27.

Chaudhary, J. 1997. Quantity-intensity relationship of potassium in Barrackpore soils. Journal of Potassium Research 15:93-99.

Chaudhary, K., and B. Prasad. 1997. Distribution of different forms of potassium in alluvial soils of Bihar. Journal of Potassium Research 13:233-238.

Chauhan, D.R., and A. Tikkoo. 2002. Response of varying levels of potassium and sulphur on yield and oil content in Indian mustard, Brasica juncea L. Journal of Potassium Research 18:64-67.

Das, K., D. Sarkar, and D.C. Nayak. 2000. Forms of potassium and their distribution in some soils representing red and lateritic ecosystem of West Bengal. Journal of Potassium Research 16:1-6.

Das, P.K., G.C. Saha, and N. Das. 1997. Vertical distribution and release characteristics of potassium in some lateritic soils of Orissa. I. Vertical distribution of potassium. Journal of Potassium Research 13:105-110.

Das. K., S.K. Singh, and R.L. Shyampura. 1993. Forms of potassium in relation to land form and soil properties of Basaltic Terrain. Journal of the Indian Society of Soil Science 41:557-559.

Datta, B.K., and D.C. Joshi. 1989. Influence of soil properties on forms of potassium in Dune and Interdune soils of arid Rajasthan. Journal of Potassium Research 6:61-69.

Datta, M. 1996. Potassium changes in soil upon incorporation of leaf prunings of multipurpose tree species in an acid soils of Tripura. Journal Indian Society of Soil Science 44:398-401.

Datta, S.C. 1996. Determination of threshold level of K fixation:plateau of labile K and its practical imlication. Journal of Potassium Research 12:14-22.

Debnath, G., and K. Majumdar. 1998. Potassium adsorption kinetics in some benchmark soils differing in mineralogy. Journal of Potassium Research 151:19-24.

Deshmukh, V.N., and R.P. Rangacharya. 1992. Potassium supplying power of soils of Western Vidharbha. Journal of potassium Research 8:26-30.

Dhar, A., A. Debnath, and S.K. Sanyal. 2009. Planning judicious potassium fertilization for maintaining native soil potassium reserves in an Ultic Paleustalf in relation to its uptake by rice and potato. Journal Indian Society of Soil Science 57:58-61.

Dhillon, S.K., and K.S. Dhillon. 1996. Effect of total electrolute concentration on K^+-$Ca2^+$ exchange in some benchmark soils of India. Journal of Potassium Research 133-145.

Dhillon, W.S., A.S. Bindra, and B.S. Brar. 1999. Response of grapes to potassium fertilization in relation to fruit yield, quality and petiole nutrient status. Journal of the Indian Society of Soil Science 47:89-94.

Gajbhiye, K.S. 1985. Forms of potassium in some Inceptisols and Entisols. Journal of the Indian Society of Soil Science 33:412-415.

Gajbhiye, K.S., S.T. Gaikawad, J.L. Seghal, K.S. Bhaskar, and R. Gupta. 1993. Studies of available potassium and crop response in soils of Sawangi watershed in Vertisol region of Vidarbha. Journal of Potassium Research 9:233-240.

Ghosh, A.B., and R. Hasan. 1976. Available potassium status of Indian soils. Indian Society of Soil Science. Bulletin No. 10:1-5.

Ghosh, A.B., and C.R. Biswas. 1978. Potassium responses and changes in soil potassium status with time. Potassium in Soils and Crops. Potash Research Institute of India, New Delhi. p. 379-390.

Ghosh, B.N., and A.K. Mukhopadhyaya. 1996. Critical limit of potassium in rice plant in Belar and Bankati series of West Bengal. Journal of the Indian Society of Soil Science 44:286-289.

Ghosh, S.K., and T. Bhattacharyya. 1984. Mineralogy of soils of Bihar, Uttar Pradesh, Gujarat and Rajasthan. Mineralogy of Soil Potassium. PRII Research Review Series, vol. 1, Potash Research Institute of India, Gurgaon, India. p. 15-29.

Golakia, B.A. 1999. Potassium fertilization of groundnut in Saurashtra region, India. Proceedings of workshop organized by the International Potash Institute at the 16th World Congress of Soil Science, Montpellier, France, 20-26 August 1998.

Grewal, J.S., and R.C. Sharma. 1980. Evaluation of soil test methods for potassium in acidic brown hill soils for recommending fertilizer doses for potatoes. Journal of the Indian Society of Soil Science 28:355-360.

Gupta, R.D., K.K. Jha, P.K. Sharma, and R.D. Sud. 1980. Distribution of microorganisms in relation to physico-chemical properties of soils of Jammu and Kashmir. Journal of the Indian Society of Soil Science 28:259-262.

Gupta, R.K., M. Datta, and S. Sharma. 1983. Different forms and Q/1 parameters of potassium in acid soils of Nagaland. Journal of the Indian Society of Soil Science 31:305-307.

Jackson, M.L. 1968. Soil Chemical Analysis, Prentice Hall of India Private Limited, New Delhi.

Jeyabaskaran, K.J., and B.J. Raghupathy. 1993. Critical limits of potassium for maize in Valuthalakudi series. Journal of Potassium Research 9:353-359.

Joshi, D.C. 1986. Potassium release behaviour of some arid soils. Journal of the Indian Society of Soil Science 34:56-63.

Kale, V.B., and A.S. Chavan. 1996. Critical limit of potassium in relation to paddy yield in Kumbhave soil series of Konkan, India, Punjabrao Krishividyapeeth research Journal 20:90-93.

Kapoor, B.S., H.B. Singh, S.C. Goswami, I.P. Abrol, G.P. Bhargava, and D.K. Pal. 1981. Weathering of micaceous minerals in some salt-affected soils. Journal of the Indian Society of Soil Science 29:486–492.

Kaskar, D.R., V.G. Salvi, B.S. Mayekar, and D.J. Dabke. 2001. Forms of potassium, their inter relationship and relationships with other soil properties of inceptisols of west coast of Maharashtra. Journal of Potassium Research 17:23-27.

Koria, R.G., M.S. Patel, and B.S. Yadav. 1989. Vertical distribution of forms of potassium in some soil profiles of dry farming areas of Saurastra region of Gujarat. Journal of potassium Research 5:47-52.

Krishnamurthy, V., and B.V. Ramakrishnayya. 1997. Potassium fertility of flue-cured tobacco growing soils of India. Journal of Potassium Research 13:159-169.

Kumar, Binod, and S.N. Jha. 1987. Index of availability and critical limits of potassium in soils of North Bihar. Journal of Potassium Research 3:17-25.

Kumar, N., N. Meenakshi, J. Suresh, and V. Nosov. 2006. Effect of potassium nutrition on growth, yield and quality of papaya, Carica papaya L. Indian Journal of Fertilizers 2:43-47.

Kumar, Ram, S.C. Kotur, and H.P. Singh. 1996. Response of Guava (Psidium guajava L.) cv. Allahabad safeda to potassium on a Sandy Loam soil. Journal of Potassium Research 12:59-64.

Lathabanumathi, G. 1997. Studies on dynamics of potssium in Irugur and Noyyal soil series of Coimbatore and Periyar districts. MSc. thesis, Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore.

Malavia, D.D., J.C. Patel, K.P. Patel, and V.B. Ramani. 1993. Response to potassium application under intensive cropping systems in Saurastra region. Proceedings of Workship on Potassium in Gujarat Agriculture. Junagarh. p. 94-106.

Mandal, S.S., and S.B. Goswami. 1991. Effect of split application of potassium on rainfed groundnut. Journal of Potassium Research 7:304-308.

Masilamani, S. Durairaj, N. Muthiah, and K. Vijaya Lakshmi. 1993. potassium fixation studies in major soil series of Pudukottai district in Tamil Nadu. Journal of Potassium Research 9:228-232.

Medhi, M., D.K. Borah, and T.C. Baruah. 2000. Effect of sources and levels of lime on available potassium in soils from different agroecological situations of Assam. Journal of Potassium Research 16:27-31.

Mehta, S.C., N. Singh, and M. Singh. 1991. Critical limit of potassium in soil and response of pearl millet in Lukhi soil series. Journal of potassium Research 7:102-108.

Mehta, S.C., Robert S. Shiel, K.S. Grewal, and S.B. Mittal. 2001. Relative efficiency of different extractants for non-exchangeable K release in soils. Journal of Potassium Research 17:48-51.

Meisheri, M.B., G.J. Hadvani., B.P. Talavia, and M.K. Shiroya. 1995. Potassium response and its critical limit for pearl millet in calcareous soils. Gujarat Agricultural University Research journal 21:41-46.

Mishra, M.K., and P.C. Srivastava. 1991. Depthwise distribution of forms of potassium in some profiles of Garhwal Himalaya. Journal of Potassium Research 7:75-84.

Mishra, M.K., P.C. Srivastava, and D. Ghosh. 1993. Forms of potassium in relation to soil properties and clay minerology in some profiles of Chambal command area, Rajasthan. Journal of Potassium Research 9:187-194.

Mittal, S.B., Raghbir Singh, M.L. Dixit, S.C. Mehta, and O.P. Yadav. 1996. Potassium fertilization of pearl-millet and wheat: Results of a long-term field experiment at Hisar. Journal of Potassium Research 12:160-168.

Mongia, A.D., and A.K. Bandyopadhyay. 1991. Forms of potassium in the acidic hill soils of Andamans. Journal of the Indian Society of Soil Science 39:573-76.

Muhr, G.R., N.P. Datta, H. Shankara Subramoney, V.K. Leley, and R.L. Donahu. 1965. Soil Testing in India. USAID, New Delhi. p. 120.

Naidu, L.G.K., R. S. Reddy, E.V.S. Prakasa Rao, P. Krishan, and R.A. Nasre. 1996. Potassium deficiency in crops- an emerging problem in red and lateritic soils. Journal of Potassium Research 12:23-29.

Naidu, L.G.K., C.B. Sachedev, and K.P.C. Rana. 1988. Response of wheat to potassium and zinc on two major soil series of Haryana. Journal of Potassium Research 4:129-133.

Nakashgir, G.H., M.A. Peer, M.M. Rafique, and C.L. Arora. 1997. Critical limits of potassium for rice in soils of Kashmir Valley as influenced by altitude of the region. Journal of Potassium Research 13:249-256.

Nambiar, K.K.M., and I.P. Abrol. 1989. Long-term fertilizer experiments in India. Fertilizer News 34:11-20.

Padmaja. G., and A. Sreenivasa Raju. 1999. Status of potassium found in Alfisols of southern Telangana zone of Andhra Pradesh. Journal of Potassium Research 151:15-24.

Pal, D.K., and S.L. Durge. 1987. Potassium release and fixation reactions in some benchmark Vertisols of India in relation to their mineralogy. Pedologie 37:103-116.

Pal, D.K., and S.L. Durge. 1993. Potassium release from clay micas. Journal of the Indian Society of Soil Science 41:67-69.

Pal, D.K., and R.C. Mondal. 1980. Crops response to potassium in sodic soils in relation to potassium release behaviour in salt solutions. Journal of the Indian Society of Soil Science 28:247-254.

Pal, D.K., S.B. Deshpande, and S.L. Durge. 1987. Weathering of biotite in some alluvial soils of different agroclimatic zones. Clay Research 6:69-75.

Pal, D.K., S.B. Deshpande, and S.L. Durge. 1993. Potassium release and adsorption reactions in two ferruginous & polygenetic.soils of southern India in relation to their mineralogy. Pedologie 43:403-415.

Pal, D.K., and Ch. Srinivasa Rao 2001. Role of minerals in potassium management of Indian soils. Invited Lead paper in International Seminar on “Importance of potassium in nutrient management for sustainable production in India during 3-5th Dec. 2001. International Potash Institute, New Delhi. p. 151-166.

Panda, M., and A.K. Panda. 1993. Evaluation of some potassium soil tests for rice in Fluventic Ustochrept. Journal of the Indian Society of Soil Science 41:188-189.

Pandey, N., S.S. Tuteja, R. Lakpale, and R.S. Tripathi. 1993. Effect of potassium and nitrogen on grain yield, K content and uptake of rice in vertisol. Journal of Potassium Research 9:262-265.

Pannu, R.P.S, Y. Singh, B. Singh, and C.S. Khind. 2002. Long-term effects of organic materials oon depthwise distributionof different K fractions in soil profile under rice-wheat cropping system. Journal of Potassium Research 18:1-5.

Pasricha, N.S., B.D. Sharma, C.L. Arora, and P.S. Singh. 2001. Potassium distribution in soils and ground waters of Punjab. Journal of Potassium Research 17:1-13.

Patel, M.S., and B.A. Golakia. 1996. Potassium in soils and crops of Gujarat. Journal of Potassium Research 12:48-58.

Patel, M.S., G.J. Hadvani, and B.S. Yadav. 1989. Fixation of potassium in important soil groups of Western Gujarat. Journal of Potassium Research 5:134-142.

Patil, P.S., J.V. Polara, and N.B. Babaria. 2003. Potassium uptake of different varieties of groundnut under varying K levels. Journal of Potassium Research 19:78-81.

Patil, R.R., M.H. Khanvilkar, D.R. Kaskar, and S.S. Prabudesai. 2006. Effect of potassium nutrition on dry matter accumulation, sugars, starch and nutrient concentration in sweet potato. Indian Journal of Fertilizers 22:29-31.

Patiram, and R.N. Prasad. 1984. Forms of potassium in the soils of East Khasi Hills, Meghalaya. Journal of the Indian Society of Soil Science 32:168-171.

Patiram, and R.N. Prasad. 1991. Release of non-exchangeable potassium and its relation to potassium supplying power of soils. Journal of the Indian Society of Soil Science 39:488-493.

Patra, S.K., and A. Debnath. 1998. Potassium fixation and releasing power of tarai acid soils of West Bengal. Journal of Potassium Research 15:109-114.

Pharande, A.L., and K.R. Sonar. 1996. Depthwise distribution of different forms of potassium in important Vertisol soil series of Maharashtra. Journal of Potassium Research 12:127-134.

Pillai, K.G., L. Sushila Devi, M.V. Sholapurkar, and M.K. Jagannath. 1987. Effect of continuous cropping and manuring in selected cropping systems. Fertilizer News 32:31-37.

Pillai, P.N., and Y. Nookaraju. 1997. Effect of graded levels of applied potassium on dry matter production and Nutrient uptake in Sorghum. Journal of Potassium Research 13:239-244.

Prabha Kumari, P., and R.S. Aiyer. 1993. Soil test and crop response studies for potassium in laterite/red loam soils of Kerala. Journal of Potassium Research 9:62-66.

Prasad, B. 1990. Availability and critical limits of potassium in wheat in Jagdishpur Bagha soil series (calciorthents) of Bihar. Journal of Potssium Research 6:62-65.

Prasad, B., and J. Prasad. 1990. Critical limits of soil K for rice in Jagdishpur Bagha soil series. Annual report, Potash Research Institute of India, Gurgaon, Haryana. p. 30.

Prasad, B., and J. Prasad. 1993. Potassium for winter maize and rapeseed in calciorthent of north Bihar. Journal of Potassium Research 9:365-369.

Prasad, B., and J. Prasad. 1995. Critical limits of potassium for winter maize in calcareous soil. Journal of Potassium Research 11:319-326.

Prasad, B., and J. Prasad. 1997. Response of rice to potassium application in calcareous soils . Journal of Potassium Research 13:50-57.

Prasad, Kanti, and R.P.S. Chauhan. 2000. Rice response to rate and time of application of potassium in an upland ecosystem. Journal of Potassium Research 16:32-34.

Prasad, R., U.S. Prasad, and R. Sakal. 1996. Effect of potassium and sulphur on yield and quality of sugarcane grown in calcareous soils . Journal of Potassium Research 12:29-38.

Puri, G., and S.A. Jaipurkar. 1989. Potassic fertilization of linseed (Linum usitatissimum L.) and safflower (Carthamus tinctorious L.) yield response and utilization of soil potassium in a Vertisol. Journal of Potassium Research 5:26-34.

Rai, G.K., M.M. Verma, J. Singh, and K.P. Singh. 2002. Effect of nitrogen and potassium on crop growth, tuber yield and nutrient uptake in potato Solanum tuberosum L. Journal of Potassium Research 18:75-78.

Rajeswar, M., Ch. Sujini Rao, D. Balaguravaiah, and M.A. Aariff Khan. 2009. Distribution of available macro and micronutrients in soils of Garikapadu of Krishna district of Andhra Pradesh. Journal of Indian Society of Soil Science 57:210-213.

Ramamoorthy, B., and J.C. Bajaj. 1969. Available nitrogen, phosphorus and potassium status of Indian soils. Fertilizer News 14:24-36.

Raskar, B.N, and A.L. Pharande. 1997. Different forms of potassium and their distribution in some important soil series of vertisol and alfisol of Western Maharashtra. Journal of Potassium Research 131:21-30.

Ratna Kumari, S., P. Subbaravamma, K. Hema, and D.H.D Prasad. 2008. Effect of potassium on production, quality and nutrient uptake in cotton (Gossypium hirsutum). Indian Journal of Agricultural Sciences 78:1053-1057.

Raychaudhuri, M., and S.K. Sanyal. 1999. Potassium Release Characteristics of some soils of West Bengal and Sikkim. Journal of the Indian Society of Soil Science 47:45-49.

Rego, T.J., K.L. Sahrawat, and J.R. Burford. 1986. Depletion of soil potassium in an Alfisol under improved rainfed cereal-legume cropping system in the Indian SAT. Transactions of 13th International Congress of Soil Science 3:928-929.

Roy K., and V.C. Srivastava. 1996. Effect of Potassium on Potato + wheat Intercropping system. Journal of Potassium Research 12:169-173.

Roy, H.K. 1987. Soil and fertilizer potassium in relation to crop growth. Potash Research Institute of India Annual Report 1986-87, Gurgaon, India.

Roy, H.K., and A.K. Sarkar. 1997. Status, forms and Q/I parameters of potassium in some major soil series of Chhotanagpur region. Journal of Potassium Research 131:37-44.

Roy, H.K., and A. Kumar. 1993. Quantity/Intensity relations of potassium in texturally different acid red loam soils. Journal of the Indian Society of Soil Science 41:356-358.

Roy, H.K., A. Kumar, and A.K. Sarkar. 1989. Critical limits of potassium in soil and plant and response of wheat in soils of Puto series (Alfisol) of Ranchi. Journal of Potassium Research 5:157-163.

Roy, H.K., A. Kumar, and A.K. Sarkar. 1991. Response of maize (Zea mays) to potassium in soils of Umendanda series of Ranchi .Journal of Potassium Research 7:285-292.

Saha, S.N., and S.K. Sanyal. 1997. Quantity/intensity relations of soil potassium in four West Bengal soils. Journal of Potassium Research 2:117-122.

Sailakshmiswari, Y., A. Subha Roa, and R.N. Pillai. 1985. An assessment of potassium release characteristics of some deltaic alluvial soils. Journal of Potassium Research 1:109-116.

Santhy, P., D. Selvi, M. Dhakshinamoorthy, and P.K. Karthikeyan. 2003. Effect of continuous application of potassium on crop yields, K uptake and soil K status in a long-term fertilizer experiment. Journal of Potassium Research 19:49-54.

Sarmah, A.C., and H.C. Baruah. 1997. Response of summer rice (Oryza sativa) to potassium application in Barak Valley zone of Assam. Journal of Potassium Research 13:143-147.

Sehgal, J.L., D.K. Mandal, C. Mandal, and S. Vadivedu. 1992. Agroecological regions of India. National Bureau of Soil Survey and Land Use Planning, ICAR, Nagpur, India.

Sehgal, J.L., R.L. Shyampura, S.K. Singh, and K. Das. 1992. Forms of potassium in relation to geology and physiography of black soils in South eastern Rajasthan. Journal of Potassium Research 8:200-210.

Sekhon, G.S., and A.B. Ghosh. 1982. Potassium. Review of Soil Research in India. International Congress on Soil Science, 12th, Part 1. p. 331-341.

Sekhon, G.S., M.S. Brar, and A. Subba Rao. 1992. Potassium in some benchmark soils of India. Potash Research Institute of India, Gurgaon, Haryana, India. p. 1-82.

Selvakumari, G. 1981. Studies on the effect of P, K and FYM on soil properties, nutrition and yield of crops viz. sorghum, pearl millet grown in a fixed crop rotation. PhD. Thesis, Division of Soil Science and Agricultural Chemistry, TNAU, Coimbatore.

Shankhayan, S.D., H.R. Sharma, and S.K. Bhrdwaj. 1996. Response of wheat potassium application in soils of Una and Paonta Valleys of Himachal Pradesh. Journal of Potassium Research 12:290-297.

Sharma, A., V.K. Jalali, V.M. Arya, and P. Rai. 2009. Distribution of various forms of potassium in soils representing intermediatezone of Jammu region. Journal of Indian Society of Soil Science 57:205-208

Sharma, B.D., R. Singh, M.S. Brar, and P.S. Sidhu. 1997. Forms of potassium in typic haplustalfs of Punjab II. Naura soil series. Journal of Potassium Research 13:195-202.

Sharma, P.S., and S. Ramana. 1993. Response of sorghum to nitrogen and potassium in an Alfisol. Journal of Potassium Research 9:171-175.

Sharma, R.D., A. Sikander, and S. Ali. 1995. Potssium critical limit and response to rice and wheat in Khataki soil series of Uttar Pradesh. Journal of Potassium Research 11:143-153.

Sharma, R.K., and B.N. Swami. 2000. Kinetics of potassium release from important soil series of western Rajasthan of India. Journal of Potassium Research 16:20-26.

Sharma, V.K., M. Singh, G.S. Sidhu, S.T. Gaikwad, C.B. Sachdev, and K.P.C. Rana. 1995. A comparison of conventional estimates with electro-ultrafiltration measurements of soil potassium in some illitic and smectitic soils. Journal of Potassium Research 11:15-22.

Sharma, V., and K.N. Sharma. 2001. Distribution of different forms of potassium in potato growing soils of Punjab. Journal of Potassium Research 17:112-115.

Sharma, A., V.K. Jalali, V.M. Arya, and P. Rai. 2009. Distribution of various forms of potassium in soils representing intermediate zone of Jammu region. Journal of Indian Society of Soil Science 57:205-2007.

Sidhu, G.S., and K.M. Manjaiah. 1999. Quantity-intensity and kinetic parameters of potassium in relation to K nutrition of crops in four benchmark soils from sub-tropical north west India. Journal Potassium Research 15:55-65.

Sidhu, P.S., and M.S. Brar. 1989. Native soil potassium and crop response to potassium. Potash Research Institute of India Annual Report 1988-89, Gurgaon, India. p. 30-33.

Singh, B.P., M. Singh, and V.C. Shukla. 1983. Forms of potassium in some soils of different agroclimatic regions of eastern Haryana. Journal of the Indian Society of Soil Science 31:31-37.

Singh, B.P., V. Kumar, and M. Singh. 1984. Potassium fixation and release behaviour in some soil series of Inceptisols of Haryana. Journal of the Indian Society of Soil Science 32:740-43.

Singh, D., and A.B. Ghosh. 1984. Removal of non-exchangeable potassium through intensive cropping in greenhouse study with alluvial soils. Journal of Indian Society of Soil Society 32:303-308.

Singh, D., V. Singh, and R. Singh. 1999. Potassium status of soils and response of rice to applied potassium. Journal of Potassium Research 151:83-87.
Singh, D., V. Singh, and R. Singh. 1999. Response of rice to nitrogen and potassium levels in alluvial soil. Journal of Potassium Research 151:88-92.
Singh, G.B., and N.P.S. Yaduvanshi. 1999. Effect of nitrogen and potassium on germination, yield and nutrients uptake in sugarcane. Journal of Potassium Research 15:93-102.
Singh, H.R., T.A. Singh, and S. Singh. 1993. Potassium forms in Mollisols of Nainital Tarai. Joural of Potassium Research 9:8-15.
Singh, J., H.L. Sharma, A. Singh, R. Singh and A. Singh. 1997. Effect of potassium application on growth and production efficiency of lentil in different agroclimatic zones of H.P. Journal of Potassium Research 13:68-73.
Singh, K., R.V.S. Malik, and V. Singh. 2001. Distribution of forms of potassium in alluvial soils. Journal of Potassium Research 17:116-118.
Singh, K., and D. Tripathi. 1993. Different forms of potassium and their distribution in some representative soil groups of Himachal Pradesh. Journal of Potassium Research 9:196-205.
Singh, K., S.K. Bansal, and Moinuddin. 2002. Effect of potassium fertilization on build-up/depletion of NPK in a long-term fodder sorghum-wheat cropping system on an Inceptisol. Journal of Potassium Research 18:16-22.
Singh, O.P., and B. Datta. 1986. Forms of potassium in some soils of Mizoram. Journal of the Indian Society of Soil Science 34:87-190.
Singh, R.N., V.N. Singh, and J.P. Singh. 1993. Response of dwarf wheat to phosphorus and potassium. Journal of Potassium Research 9:384-387.
Singh, R.S., P.N. Dubey, T.K. Sen, and A.K. Maji. 2006. Distribution of potassium in soils of Manipur encompassing physiographic and hydrothermal variations. Journal of Potassium Research 54:197-202.
Singh, S.P., N. Singh, A.L. Das, and J. Ram. 1989. Potassium distribution in some dominant soils of Chotanagpur region of Bihar. Journal of Potassium Research 5:53-60.
Singh, S.P., R. Jagar, N. Singh, and D. Sarkar. 1999. Distribution of potassium in soils of Arunachal Pradesh. Journal of Potassium Research 151:15-24.
Singh, U. Kumar, and S.K. Sanyal. 2000. Potassium and aluminum dynamics in acidic soils under different rates of lime application. Journal of the Indian Society of Soil Science 48:64-70.

Singh, Y.P., M. Singh, and R. Singh. 1985. Forms of soil potassium in western part of Haryana. Journal of the Indian Society of Soil Science 33:284-291.

Sinha, M.K. 1985. Response of crops in the recommended and locally practiced cropping systems in selected soil associations differing in mineralogy, physical and chemical properties. *In*: Annual Report PRII, Gurgaon (Haryana) for the year 1984-85. p. 35-36.

Solankey, B.S., D.A. Shinde, K.S. Yadav, and J. Singh. 1992. Response of wheat to K application in swell-shrink soils in relation to water-soluble K contents. Journal of Potassium Research 7:9-19.

Solankey, B.S., D.A. Shinde and A.K. Mahajan. 1991. Potassium status of Antralia and Panchderia swell-shrink soil series of Madhya Pradesh. Journal of Potassium Research 7:9-19.

Sonar, K.R., and Y.M. Patil. 1996. Forms of potassium as influenced by geology and physiography of soils in Maharashtra. Journal of Potassium Research 12:230-236.

Srinivasarao, Ch., A. Subba Rao, K.V. Rao, B. Venkateswarlu, and A.K. Singh. 2010. Categorization of Districts Based on Non-exchangeable Potassium: Implications in Efficient K Fertility Management in Indian Agriculture. Indian Journal of Fertilizers 6(7):1-15.

Srinavasarao, Ch., and A. Subba Rao. 1999. Impact of farmyard manure and phosphorus application on soil potassium status and K uptake in a vertisol under soybean-wheat system. Journal of the Indian Society of Soil Science 47:176-178.

Srinivasa Rao, Ch., and S.K. Bansal. 2000. Potassium dynamics in calcareous soils of India. Proceedings of National Seminar on Balanced Nutrition of groundnut and other field crops grown on calcareous soils of India held at GAU, Junagadh during 19 to 22nd September 2000. p. 85-98.

Srinivasarai, Ch., M. Ali., A.N. Ganeshamurthy, and R.N. Singh. 2003. Potassium availability, releasing power and uptake by chickpea and rajmash in different soil types of pulse growing regions of India. Indian Journal of Pulses Research 16:128-132.

Srinivasarao, Ch., K.P.R. Vittal, G.R. Chary, P.N. Gajbhiye, and B. Venkateswarlu. 2006. Characterization of available major nutrients in dominant soils of rainfed crop production systems of India. Indian Journal of Dryland Agricultural Research and Development 21:5105-113.

Srinivasarao, Ch., and K.P.R. Vittal. 2007. Emerging nutrient deficiencies in different soil types in rainfed regions of India. Indian Journal of Fertilizers 3:37-46.

Srinivasarao, Ch., S.C. Datta, and M.S. Khera. 2004. Degradation of illite as a consequence of potassium depletion under intensive cropping. Indian Journal of Fertilizers 49(5):11-17.

Srinivasarao, Ch., and G.V. Subbaiah. 1997. Association of some forms of potassium with soil acidity and mica content in six profiles of laterite soils. Journal of Potassium Research 13:12-20.

Srinivasarao, Ch. 1994. Crop response to applied potassium in Islamnagar series in relation to soil K status. National Seminar on "Developments in Soil Science". Indian Society of Soil Science. New Delhi. p. 501-502.

Srinivasarao, Ch. 1997. Kinetics of potassium release by exhaustive cropping from some illitic soils. Journal of Potassium Research 13:227-232.

Srinivasarao, Ch. 2006. Assessing Soil Phosphorus and Potassium Supplying Power Under Major Rainfed Production Systems of India and Yield Maximization of Some Dryland Crops by Optimum Nutrient Supply. Final report of Central Research Institute for Dryland Agriculture collaborative project. Potash and Phosphate Institute of Canada (India programme). p. 210.

Srinivasarao, Ch. 2010. Rationalizing potassium fertilizer recommendations in Indian agriculture. XIV Sukumar Basu Memorial Lecture, Indian Agricultural Research Institute, New Delhi, Feb 13th, 2010.

Srinivasarao, Ch., and M.S. Khera. 1994. Potassium replenishment capacity of illitic soils at their minimal exchangeable K in relation to clay mineralogy. Z. pflanzenernahr Bodenk 157:467-470.

Srinivasarao, Ch., and M.S. Khera. 1994. Effect of exhaustive cropping on various potassium forms. Journal of Potassium Research 10:109-116.

Srinivasarao, Ch., and M.S. Khera. 1994. Potassium replenishment capacity of illitic soils at their minimal exchangeable K in relation to clay mineralogy. Journal of Plant Nutrition and Soil Science 157:467-470.

Srinivasarao, Ch., and M.S. Khera. 1995. Potassium fixation characteristics and fertilizer K requirements of illitic alluvial soils by two-step alternate method. Journal of the Indian Society of Soil Science 43:186-191.

Srinivasarao, Ch., and M.S. Khera. 1997. Response to potassium in K-depleted Ustochrepts in relation to K fixation. Journal of Potassium Research 12:351-357.

Srinivasarao, Ch., and P.N. Takkar. 1997. Evaluation of different extractants for measuring the soil potassium and determination of critical levels for plant available K in smectitic soils for sorghum. Journal of the Indian Society of Soil Science 45:113-119.

Srinivasarao, Ch., and P.N. Takkar. 1995. Personal communication.

Srinivasarao, Ch., and B. Venkateswarlu. 2009. Nutrient ratio and crop response to potassium in relation to exchangeable and non-exchangeable potassium in different agroecological regions of India. Proceedings of Workshop on nutrient ratio and crop response. National Academy of Agricultural Sciences, May, 2010, New Delhi. p. 45-56.

Srinivasarao, Ch., A. Subba Rao, and P.N. Takkar. 1997. Potassium availability and release behaviour in earthwork casts and non-ingested soils. Journal of the Indian Society of Soil Science 45:310-314.

Srinivasarao, Ch., A. Subba Rao, and A.N. Ganeshamurthy. 1995. Status and desorption kinetics of potassium in some swell-shrink soils. Journal of the Indian Society of Soil Science 43:356-360.

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

Srinivasarao, Ch., A. Subba Rao, and S.P. Singh. 2000. Extraction of non-exchangeable potassium from soils with boiling one molar nitric acid:Evaluation of different modes of boiling the soil-acid suspension. Communication in Soil Science and Plant Analysis 31:905-911.

Srinivasarao, Ch., A. Swarup, A. Subba Rao, and V. Rajagopal. 1999. Kinetics of non-exchangeable potassium release from a Tropaquept as influenced by long-term cropping, fertilization and manuring. Australian Journal of Soil Research 37:317-328.

Srinivasarao, Ch., A.N. Ganeshamurthy, Masood Ali, R.N. Singh, and K.K. Singh. 2002. Distribution of forms of potassium in different soil types of pulse growing regions of India. Journal of Potassium Research 18:23-30.

Srinivasarao, Ch., A. Subba Rao, and T.R. Rupa. 2001. Need for inclusion of non-exchangeable potassium as a measure in soil test calibration and K recommendations. Fertilizer News 46(5):31-38.

Srinivasarao, Ch., D.K. Pal, and P.N. Takkar. 1998. Mathematical models to study the kinetics of potassium release from swell-shrink soils of central India in relation to their mineralogy. Journal of Plant Nutrition and Soil Science 161:67-71.

Srinivasarao, Ch., D.K. Pal, A. Subba Rao, and P.N. Takkar. 1996. Potassium supplying characteristics of some swell-shrink soils from different elevations of Sanchi area in relation to their mineralogy. Clay Research 15:4-14.

Srinivasarao, Ch., G.V. Subbaiah, and R.N. Pillai. 1991. Nutrient status of black soils of Telugu Ganga Protect area in Nellore district of A.P. The Andhra Agricultural Journal 38:201-205.

Srinivasarao, Ch., J. Prasad, S.P. Singh, and P.N. Takkar. 1997. Distribution of forms of potassium and K release kinetics in some Vertisol profiles. Journal of the Indian Society of Soil Science 45:465-468.

Srinivasarao, Ch., K.P.R. Vittal, B. Venkateswarlu, K.N. Tiwari, G.R. Chary, and J.V.N.S. Prasad. 2008. Emerging nutrient deficiencies in different soil types under rainfed production systems of India. Lead paper presented at National Seminar on Integrated Nutrient management in rainfed agro-ecosystems held at CRIDA, during March 3-4, 2008, Hyderabad.

Srinivasarao, Ch., K.P.R. Vittal, B. Venkateswarlu, K.N. Tiwari, G.R. Chary, and J.V.N.S. Prasad. 2008. Emerging nutrient deficiencies in different soil types under rainfed production systems of India. Lead paper presented at National Seminar on Integrated Nutrient management in rainfed agro-ecosystems held at CRIDA, during March 3-4, 2008, Hyderabad .

Srinivasarao, Ch., K.P.R. Vittal, K.N. Tiwari, P.N. Gajbhiye, S. Kundu, A.L. Pharande, Y. Yellamanda Reddy, and M.A. Shankar. 2007. Potassium supplying characteristics of twenty one soil profiles under diverse rainfed production systems. Journal of the Indian Society of Soil Science 55:14-22.

Srinivasarao, Ch., M. Ali, A.N. Ganeshamurthy, R.N Singh, and K.K. Singh. 2004. Sub soil nutrient availability in different soil types of pulse growing regions of India. Indian Journal of Fertilizers 49:55-59.

Srinivasarao, Ch., M.S. Khera, and A. Subba Rao. 1994. Soil potassium depletion and K replenishment capacity of soils under intensive cropping. Journal of Potassium Research 10:229-235.

Srinivasarao, Ch., P.R.K. Prasad, P.N. Takkar, and S.K. Bansal. 1996. Minerology, Potassium status and K releasing power of some black soils in Krishna, Godavari delta in A.P Journal of Potassium Research 12(3):245-252

Srinivasarao, Ch., S.P. Datta, A. Subba Rao, S.P. Singh, and P.N. Takkar. 1997. Kinetics of non-exchangeable potassium release by organic acids from mineralogically different soils. Journal of the Indian Society of Soil Science 45:728-734.

Srinivasarao, Ch., T.R. Rupa, A. Subba Rao, and S.K. Bansal. 2000. Potassium fixation characteristics of major benchmark soils of India. Journal of the Indian Society of Soil Science 48:220-228.

Srinivasarao, Ch., T.R. Rupa, A. Subba Rao, and S.K. Bansal. 2001. Sub soil potassium availability in twenty-two benchmark soil series of India. Communication in Soil Science and Plant Analysis 32:863-876.

Srinivasarao, Ch., T.R. Rupa, A. Subba Rao, S.P. Singh, and S.K. Bansal. 2006. Kinetics of non-exchangeable potassium release from important benchmark soils of India: Effects of mineralogy, soil depth and extraction media. Communications in Soil Science and Plant Analysis 36:1-19.

Srinivasarao, Ch., V.B. Prasad, P.R.K. Prasad, S.K. Bansal, A. Subba Rao, and P.N. Takkar. 1997. An assessment of potassium reserves and K desorption in macaceous Alfisols and Inceptisols using conventional estimates and electroultrafiltration. Journal of Indian Society of Soil Science 45:44-47.

Srinivasarao, Ch., K.P.R. Vittal, S. Kundu, P.N. Gajbhiye, and M. Vijayasankarbabu. 2010. Twenty Years of Continuous Cropping, Fertilization and Organic Manure Application Effects on Forms of Potassium and Kinetics of Non-exchangeable K Release in the Profile of an Alfisol Under Arid Conditions. Communications in Soil Science and Plant Analysis 41(6):783-796.

Srinivasarao, Ch., K.P.R. Vittal, K.N. Tiwar, P.N. Gajbhiye, and S. Kundu. 2007. Categorization of soils based on potassium reserves and production systems: Implications in K management. Australian Journal of Soil Research 45:438-447.

Srinivasarao, Ch., A. Subba Rao, A. Swarup, S.K. Bansal, and V. Rajagopal. 2000. Monitoring the changes in soil potassium by extraction procedures and electroultrafiltraiton (EUF) in a Tropaquept under twenty years of rice-rice cropping. Nutrient Cycling in Agro-ecosystems 56:277-282.

Srinivasarao, Ch., and A. Subba Rao. 2000. Minimal exchangeable potassium status of fifteen smectitic soils in relation to soil mineralogy and K uptake. Communications in Soil Science and Plant Analysis 31(7&8):913-921.

Srinivasarao, Ch. 2010. Analysing nitrogen use efficiency in relation to potassium in long-term manurial trials in dryland agriculture. IPI-FAI Round Table Discussion on “Analyzing Nutrient Use Efficiency in Relation to Potassium” Fertilizer Association of India, New Delhi 9-6-2010, New Delhi.

Srivastava, A.K., and O.P. Srivastava. 1992. Distribution of various forms of potassium in salt affected soils and changes after reclamation. Journal of Potassium Research 8:31-37.

Subba Rao, A., and Ch. Srinivasarao. 1996. Potassium status and crop response to potassium on the soils of Agroecological regions of India. IPI Research Topics No.20. International Potash Institute, Basel, Switzerland. p. 57.

Subba Rao, A. 1993. Analysis of soils for major nutrients. *In*: Methods of Analysis of Soils, Plants, Waters and Fertilizers Ed. HLS Tandon, FDCO, New Delhi. p. 143.

Subba Rao, A., and K.S. Reddy. 2005. Analysis of soils for pH, EC and available major nutrient. *In*: H.L.S. Tandon (ed.). Methods of analysis of soils, plant, waters, fertilizers and organic manures. Fertilizer Development and Consultant Organization, New Delhi, India: 21-59.

Subba Rao, A., M.V.R. Sesha Sai, and S.K. Pal. 1993. Non-exchangeable potassium reserves and thier categorization in some soils of India. Journal of the Indian Society of Soil Science 41:667-673.

Subba Rao, A., T.R. Rupa, and S. Srivastava. 2001. Assessing potassium availability in Indian Soils. *In*: N.S. Pasricha and S.K. Banasal (ed.) Potassium in Indian Agriculture, special publication: Potash Research Institute of India, Gurgaon, Haryana: 125-157.

Subba Rao, I.V., J. Venkateswarlu, V. Seetharamana Rao, A. Srinivasa Raju, and N. Mukhlis. 1976. Potassium fertilization in Pochampad project area. Potassium in Soils, Crop and Fertilizers. Indian Society of Soil Science, Bulletin No. 10, New Delhi. p. 195-199.

Subbaiah, G.V., G. Venkateswar Rao, and Ch. Srinivasarao. 1994. Profile distribution of macro- and micro-nutrients in some lateritic soils. The Andhra Agricultural Journal Communicated.

Subramaneyeswara Rao, A., and V. Rajagopal. 1981. The Andhra Agriculture Journal 28:200.

Sud, K.C., and R.C. Sharma. 2002. Role of potassium in potato nutrition under rainfed agriculture in state of Himachal Pradesh, Journal Potassium Research 18:79-83.

Surekha, K., and I.V. Subba Rao. 1997. Differential Response of Maize to Potassium in Vertisols. Journal of Potassium Research 13:261-265.

Surekha, K., I.V. Subba Rao, A. Prasad Rao, and V. Adinarayana. 1996. Long-term potassium releasing power of Vertisols of Andhra Pradesh. Journal Potassium Research 12:345-350.

Sutar, V.S., J.H. Dongale, and A.S. Chavan. 1992. Forms of potassium and evaluation of soil K test methods along with critical limits of K in lateritic soils. Journal Potassium Research 8:187-199.

Swarup, A., and Ch. Srinivasa Rao. 1999. Current status of crop responses to nutrients. Experiences from All India Coordinated Research Project on Long-Term Fertilizer Experiments. Fertilizer News 44(4):27-43.

Talele, P.E., G.K. Zende, Y.M. Patil, K.R. Sonar, and B.D. Tamboli. 1993. Effect of added K and incubation time on transformation of available K and non-exchangeable K in different soils of Maharastra. Journal of the Indian Society of Soil Science 41:238-242.

Tamuli, A., and T.C. Baruah. 2000. Effect of lime sludge on Q/I parameters of potassium in some soils of upper Brahmaputra Valley Zone of Assam. Journal of Potassium Research 16:62-64.

Thampatti, M.K.C., and A.I. Jose. 1999. Vertical distribution and dynamics of potassium in acid sulphate rice soils of south India. Journal of Potassium Research 15:39-47.

Tiwari, A., K.N. Tiwari, and A.N. Pathak. 1988. Evaluation of some soil test methods for potassium and assessment of critical limits for wheat under greenhouse conditions. Journal of Potassium Research 4:110-121.

Tiwari, A., K.N. Tiwari, and S.G. Mishra. 1999. Comparison of soil test methods and potassium critical limits for rice in Udic ustochrepts of Kanpur: Uttari series. Journal of Potassium Research 15:75-82.

Tiwari, A., S.G. Mishra, and R. Tiwari. 1996. Calibration of soil test methods and assessment of critical limits of potassium and soils and plants of chickpea. Journal of the Indian Society of Soil Science 43:408-413.

Tiwari, A.K., and K.N. Bansal. 1992. Vertical distribution of forms of potassium in some soil series of northern Madhya Pradesh. Journal of Potassium Research 8:223-230.

Tiwari, K.N. 1985. Changes in potassium status of alluvial soils under intensive cropping. Fertilizer News 30:17-23.

Tiwari, K.N., and G. Dev. 1987. Potassium availability in soils growing wheat. Potash Research Institute of India, Gurgaon, India, Research Review Series 4:29-44.

Tiwari, R.C., U.N. Verma, and A.K. Mishra. 1995. Effect of long-term cropping systems on chemical characteristics of soil profiles. Journal of the Indian Society of Soil Science 43:278-279.

Tomar, R.A.S., R.S. Verma, P.S. Tomar, and K.N. Bansal. 1997. Vertical distribution of forms of potassium in some normal and salt affected soil series of grid region of Madhya Pradesh. Journal of Potassium Research 13:203-208.

Tomar, R.S., M.V. Kanzaria, and V.K. Jain. 2001. Response of chickpea to potassium in a calcareous soil. Journal of Potassium Research 17:98-100.

Varavipour, M. 1993. The response of fodder maize (Zea mays L.) to potassium and sulphur in two selected soil series of south India. MSc. Thesis submitted to the University of Agricultural Sciences, Bangalore.

Veeranna, V.S., S. Panchaksharaiah, T.S. Vageesh, R.A. Shetty, and K.M.S. Sharma. 1996. Potassium application for sustained productivity of sorghum -wheat sequence under long-term fertilizer management Journal of Potassium Research 12:39-47.

Venkatasubbaiah, V., A. Sreenivasaraju., M.B. Rao, T.P. Geoffrey, L. Nageswara Rao, and B.R. Bhaskara Rao. 1991. Paper presented in seminar on potassium held in Nov. 91 at Hyderabad.

Venkatasubbaiah, V., J. Venkateswarlu, and V.V.K. Sastry. 1976. Potssium supplying power of black soils of West Godavari, Andhra Pradesh. Potassium in Soils, Crops and Fertilizers, Indian Society of Soil Science, Bulletin No. 10, New Delhi, 219-226.

Venkatesh, M.S., and T. Satyanarayana. 1994. Status and distribution of potassium in vertisols of north Karnataka. Journal of the Indian Society of Soil Science 42:239-233.

Vijayabhaskar, M. 1997. Nature, distribution and availability of potassiumin in benchmark soils of Andhra Pradesh. MSc. Thesis, Department of Soil Science and Agricultural Chemistry, Andhra Pradesh Agricultural University, Rajendranagar, Hyderabad.

Wani, M., and R. Kumar. 2008. Distribution of potassium and clay minerals assemblage in some paddy soils of Lesser Himalyas. Agropedology 18:98-105.

Wani, M.A. 2009. Kinetics of non-exchangeable potassium release from soil soils and their separates of lessor Himalayas of India. Journal of Indian Society of Soil Science 57:137-144.

Wani, M.A., and S.C. Datta. 2007. Non-exchangeable potassium release of H+ saturated resin and its diffusion characteristics in some soils of lessor Himalayas. Soil Science 172:546-552.

Yadav, B.S., and B.N. Swami. 1987. Studies on potassium in some red soils Haplustalfs of southern Rajasthan. Journal of Potassium Research 3:1-9.

Yadav, B.S., and B.N. Swami. 1984. Critical limits of soil potssium for maize crop in red soils (Haplustalfs) of Dungarpur district of Rajasthan. Proceedings of International Symposium on Soil Test Crop Response Correlation Studies, Dhaka, Bangladesh. p. 84-96.

Yadav, D.S., A. Kumar, and V.K. Singh. 1993. Response of different of crops to potassium on cultivators' fields in UP under irrigated and rainfed conditions. Journal of Potassium Research 9:253-261.

Yaduvanshi, N.P.S., and A. Swarup. 2006. Effect of long-term fertilization and manuring on potassium balance and non-exchangeable K release in a reclaimed sodic soil. Journal of Potassium Research 54:203-207.

Yaduvanshi, N.P.S., and G.B. Singh. 1999. Effects of nitrogen and potassium on germination, yield and nutrients uptake in sugarcane. Journal of Potassium Research 15:93-102.