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A GEO-Saptial approach for the efficient potassium fertility management of north Bihar soils

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Abstract

The present investigation was carried out at Tirhut College of Agriculture, Dholi an unique campus of Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar in year 2016-2017. Soils of North Bihar extending between 88°17'17.04" E to 83°54'18.02" E longitude and 27°17'4.44" N to 25°29'58.17" N latitude having a vast area of 52,925 sq km.

Potassium (K) is the third major nutrient after N and P, required by plants for buildup of biomass. It exists in soil in different forms and these forms are in quasi equilibrium with each other. Now a day, K is recognized as an important limiting factor in crop production.

In the absence of adequate K fertilization, significant depletion of soil K reserve takes place, effect of which is substantial yield loss and higher economic risk of farmers. In the year 2020, the deficit of K in Indian agriculture is projected to be around 10 million tonnes/annum while the estimates for N and P balances are positive (Srinivasarao *et al.*, 2001). Such a deficit will create serious nutrient imbalances with major implications on factor productivity and environment. It is worthwhile to note that even the most progressive and productive states like Punjab and Haryana, have most skewed N:P_2O_5:K_2O ratio. The focus has been on N followed by P and very little use of K resulting in a huge imbalance.

One hundred twenty one samples were collected on grid basis with coordinates through GPS and thematic soil maps were prepared using TNTmips (2010) GIS software.

Wide variation in water soluble K (3.5 ppm to 67 ppm), exchangeable K (12 ppm to 274 ppm), available K (17 ppm to 330 ppm), non-exchangeable K (65 ppm to 2101 ppm), nitric acid soluble K (126 ppm to 2431 ppm) and total K (469 ppm to 22471.20 ppm) were recorded in soils of North Bihar and are present in following order *viz*. total K > nitric acid soluble K > non-exchangeable K > available K > exchangeable K > water soluble K.

Spatial distribution of pools of potassium generated on the basis of interpolation of point data provides spatial information for potassium management in North Bihar. Soil map generated by combination of exchangeable and non-exchangeable K of soil into nine classes among which, Class I, Class II, Class IV and Class VII cumulatively cover 45.23% area comprising in Motihari, Bettiah, Jaynagar, Sitamarhi, Darbhanga, Kisanganj, Purnia and Araria districts of North Bihar, where K application must be done to realize full yield potential of different cropaping systems.

Keywords: Pools of K, spatial distribution, GIS

Introduction

Different forms of K play important role in their availability. In soil, K is found in four different forms, namely, constituent of primary minerals (structural/ lattice), non-exchangeable or fixed K, exchangeable K and solution K; these forms are inter-related and tend to maintain equilibrium. The last two i.e. exchangeable and solution K are very important for the growth of plants and microbes. Any depletion in a given form is likely to shift the equilibrium in the direction to replenish it.

The pool of K present in the soil solution is called solution K. A part of the released potassium cation is held around the negatively charged fine particles (colloids) by electrostatic attraction which is called exchangeable K. The third pool of soil K is termed as non-exchangeable K which occupies internal position of clay sheets as well as hexagonal cavities within the interlayer spaces of certain minerals. Although non-exchangeable K reserves are not immediately available, they can contribute significantly to exchangeable or liable pool of soil K. The rate of non-exchangeable K release and its mechanism are controlled by the nature and amount of clay minerals (Feigenbaum, 1986) [6] and organic acids present in soil environment. Total or mineral K is used to describe a much larger fraction of K that remains entrapped within the clay structure. Among different fractions a large portion of the total potassium (98%) in soil occurs as structural components of soil minerals and is unavailable to plants. Plants can use only the exchangeable potassium (1-2%) that exists on the surface of clay particles and the potassium dissolved in soil water.

This often constitutes a very small fraction of the total soil potassium. The importance of non-exchangeable potassium in both the K cycle and plant nutrition is widely recognized. The concentration of K in the soil solution needs to be quite low before non-exchangeable or fixed K can be released to soil solution. So the categorization of the soils usually analyzing less than 50 mg kg^{-1} are rated low in available K, between 50 and 125 mg kg^{-1} K medium and above 125 mg kg^{-1} K as high in available K (Muhr *et al.*, 1965) are irrespective of crops or soils. Under intensive cropping, in the absence of K fertilization, initially exchangeable K in soil contributes to plant K nutrition, but with further cropping exchangeable K attains a certain minimal level, thereafter, plant K removal from soil and contribution of non-exchangeable K to K uptake are almost synonymous and accounts for up to 90-95% of the total plant K uptake (Srinivasarao *et al.*, 2010) [21]. Due to larger contribution of non-exchangeable K to plant K requirement, lack of crop responses to applied K have been reported even in soils with low exchangeable K.

The major sources of non-exchangeable K in soils are K rich 2:1 clay minerals such as micas and vermiculite (Sparks and Huang, 1985). However, the release of K from the interlayer of these minerals may be very slow process depending upon the weathering stage of these minerals, and therefore, whether the K release rates of soils under cropping are in tune with plant K needs becomes the most important aspect as far as K nutrition of crop plants is concerned.

India has 182 million ha cultivable land with 142.1 million ha net area sown and 121 million farmers. Among the states, Rajasthan has the largest portion of cultivable land followed by Maharashtra, Uttar Pradesh, Madhya Pradesh, Andhra Pradesh, Karnataka and Gujarat. The earlier estimates of soil fertility for K based on data generated from soil testing laboratories in the country indicated discrepancies in the percentage of samples testing high, though the overall soil K fertility of soils declined (Ghosh, 1976; Sekhon *et al*., 1992; Subbarao *et al*., 1996) [4]. Besides, existing categorization of soils based on available K status is not able to explain the crop response pattern in many regions of India. Therefore, it has become essential to look into soil dynamics under intensive production systems and confirm which K fraction in soil is predominantly contributing to crop K nutrition (Subbarao, 1993; Srinivasarao *et al*., 2000) [24]. It was also essential to examine whether imported K fertilizer is efficiently used in Indian agriculture and whether it is applied to right crop or right soil, where K application is a must.

There is obviously an urgent need for delineating the K status of soil and assess the expected responses to applied K so that the K fertilizer management can be taken up with emphasis on efficient use of K and the consequent economy in K use.

GIS Use in Agriculture

Geographical Information Systems offer the flexibility to visualize the spatial information in an easier way. With the availability of open source geographic information system software and high end computing facilities at low cost, use of GIS for scientific and utilities management has increased substantially. The GIS consists of organizing the information of an attribute in systematic continuous grids popularly known as raster maps or in continuous polygon (vector maps). Some of the important parameters for which public domain datasets are available which include weather parameters and soil parameters on a grid basis (Siebert, 2007). The maps generated through GIS serve three primary purposes. They provide specific information about particular location, they provide general information about spatial patterns and they can be used to compare patterns on two or more maps.

GPS enables the user to know about the precise location on earth surface. It is a spaced based satellite navigation system that provides location in terms of longitude, latitude, altitude and time information in all-weather condition, anywhere on or near the earth where there is an unobstructed line of sight to four or more GPS satellites.

Geographical Information Systems (GIS) offer the flexibility to visualize the spatial information of different pools of potassium in an easier way. It will maximize the efficiency of planning & decision making. Spatial analysis is the beauty of GIS technology. Spatial variability of different fraction of soil K and their combined impact on soil potassium stock under different administrative boundaries will help in understanding the K- fertilization programme for the future.

Keeping in mind, the above mentioned facts, it is necessary to assess different forms of K with their spatial distribution in intensively cropped soils of North Bihar to avoid unwanted decline in soil potassium.

Materials and Methods

Toposheet: Soil Map of Bihar (1:5,00,000) published by NBSS&LUP in co-operation with SS, LUP, RAU, Sabour, Bihar in 1988 was used as the base map.

GPS: Battery operated Global Positioning System, Magellan made mobile mapper (CX) has been used for the location of soil sample

GIS software: The preparation of thematic map was performed in the GIS platform. TNTmips is a full-featured Geographic Information System that integrates, display and process map data, imagery, and terrain data along with the creation and management of associated relational databases. This advanced GIS software provides the tools needed to prepare, analyze, interpret, and publish any type of geospatial data.

Digital map creation: The digitisation of visible features of North Bihar performed by using point, line and polygon tools of the GIS software. Rivers and district head-quarters were marked by vector tools. All digitized features overlayed in single windows during layout. The GIS map prepared in this way was further used as base for identification and marking of area for sampling.

Grid formation: 40 x 40 km grid map of Bihar prepared by the GIS software. All together 54 grid formed (Fig. 1) in which 34 grid for soil sampling fall under north Bihar.

Sampling points: Sampling point was navigated by Hand Held Global Positioning System (Magellan makes Mobile Mapper - CX). At the sampling point a point log maintained in the GPS with every sampling. After the completion of sampling the GPS data uploaded in computer and then in the GIS environment. The details of sampling points displayed on the geo-referenced Soil Map of Bihar as shown in the Fig. 2.

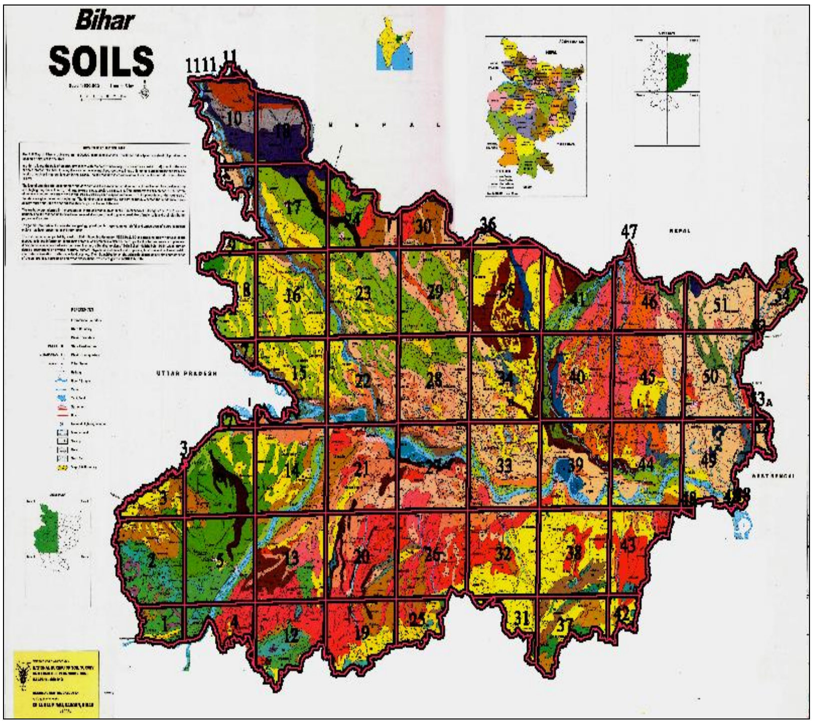


Fig 1: Grid map (40 km x 40 km) of Bihar for soil sampling in North Bihar

Soil sampling: From the grid cell at random, soil samples for surface (0-15 cm depth) were collected with Khurpi during June, 2016 before onset of monsoon. From one complete grid, six soil samples comprised of two from each, lowland, midland and upland were taken, whereas from incomplete grid less no. (6/3/0) of soil samples collected. All together 121 soil samples were collected and were air dried in shade; the stubbles, pebbles and weeds etc. were discarded; grounded to pass through 2 mm sieve and kept in polythene bags separately along with the proper labels. These samples were analyzed for their physical, chemical properties and forms of K content by standard methodology.

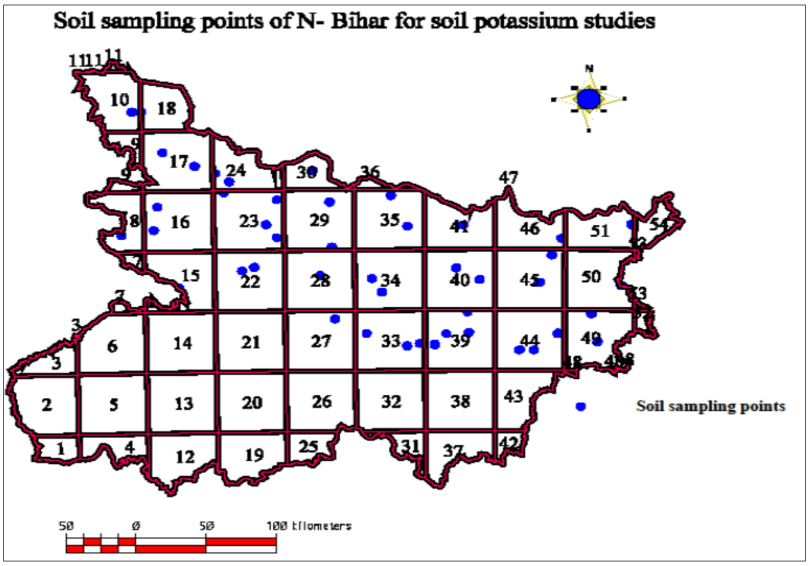


Fig 2: Soil sampling point of North Bihar for pools of K study

3.2. Methods

Chemical Analysis for pools of Potassium (K)

Water soluble – K

The content of water soluble K in soils was determined by extracting the soils with distilled water in the 1:5:: soil : water ratio and shaken for half an hour. Then the K in the filtrate was estimated with the help of flame photometer as described by USSLS (1954).

Available-K

The available-k of soils was estimated in the leachate which was obtained by equilibrating the soils with the extractant in 1N neutral Ammonium Acetate for five minutes and K determined with the help of flame photometer as per method by Hanway and Heidel (1952).

HNO_3-K:

The HNO_3-K known as fixed K was estimated in the soils by boiling 1:10:: soil: nitric acid for ten minutes and estimated with the help of flame photometer as per standard method by Wood and De Turk (1940)

Total-K

The total-K was determined in soil by extraction with H_2SO_4,

$HClO_4$ and HF mixture in platinum crucible at 220-225 °C using flame photometer by following the standard method of Jackson (1973).

3.3. Spatial analysis
GIS map for the spatial distribution of different pools of potassium and their possible combination were accomplished using TNTmips GIS software (Version 2010).

Result and Discussion
Available potassium
Tabulated data for available K (ppm) of North Bihar soil have been presented in table 1 - 4. Based on laboratory analysis, the values of available K of soils varied from 26 ppm to 330 ppm with mean value of 82.37 ppm and standard deviation ±64.04, 20.50 ppm to 256.50 ppm with mean value of 81.40 ppm and standard deviation ±57.90 and 17 ppm to 311.50 ppm with mean value of 77.99 ppm and standard deviation ± 55.09 in upland, midland and lowland, respectively. Among 121 samples 54% of the samples recorded low level of available K (<61 ppm), 31% medium level of available K (61-121 ppm) and 15% of samples recorded high level of available K (>121 ppm). Lowland soils showed generally higher values of available K than upland soils.

Water soluble K
Data for water soluble K are tabulated in table 1 – 4. Water soluble K of soils varied from 3.50 ppm to 67.00 ppm with mean value of 19.40 ppm and standard deviation ±15.82, 4.06 ppm to 66.50 ppm with mean value of 18.14 ppm and standard deviation ±12.64 and 4 ppm to 60 ppm with mean value of 17.29 ppm and standard deviation ±11.62 in upland, midland and lowland, respectively. On an average Water soluble K of North Bihar soil varied from 3.50 ppm to 67 ppm with mean value 18.26 ppm and standard deviation ±13.35.

Exchangeable K
Exchangeable K, an important component of available K in soils have been presented in table 1 – 4. According to the table exchangeable K of soils varied from 2 ppm to 264.50 ppm with mean value of 62.97 ppm and standard deviation ±56.58, 8 ppm to 207 ppm with mean value of 63.26 ppm and standard deviation ±50.27 and 7 ppm to 274 ppm with mean value of 60.70 ppm and standard deviation ±52.56 in upland, midland and lowland respectively. On an average exchangeable K of North Bihar soils varied from 2 ppm to 274 ppm with mean value 62.30 ppm and standard deviation ±52.71.

Nitric acid soluble K
Values pertaining to nitric acid soluble K in table 1 – 4, the maximum, minimum, mean and standard deviation of HNO_3 soluble K of soils of North Bihar. According to the table HNO_3 soluble K of soils varied from 126 ppm to 2431 ppm with mean value of 939.36 ppm and standard deviation ±482.36, 164 ppm to 2322 ppm with mean value of 976.56 ppm and standard deviation ±464.38 and 166.50 ppm to 2039 ppm with mean value of 869.45 ppm and standard deviation ±501.28 in upland, midland and lowland respectively. Overall HNO_3 soluble K of North Bihar soils varied from 126 ppm to 2431 ppm with mean value 928.28 ppm and standard deviation ± 480.98.

Non-exchangeable K
The maximum, minimum, mean and standard deviation of non-exchangeable K for upland, midland, lowland and overall soils of North Bihar are tabulated in table 1-4. Non-exchangeable K of soils varied from 67 ppm to 2101 ppm with mean value of 856.98 ppm and standard deviation ±468.42, 121 ppm to 2066.50 ppm with mean value of 895.16 ppm and standard deviation ±451.23 and 65 ppm to 1985.50 ppm with mean value of 791.46 ppm and standard deviation ±499.08 in upland, midland and lowland, respectively. Overall non-exchangeable K of North Bihar soils varied from 65 ppm to 2101 ppm with mean value of 847.72 ppm and standard deviation ±471.44

Total K
In table 1 – 4, the maximum, minimum, mean and standard deviation of total K of soils of North Bihar. Total K of soils varied from 469 ppm to 14707 ppm with mean value of 7022.63 ppm and standard deviation ±3540.25, 1347 ppm to 22471.20 ppm with mean value of 7438.68 ppm and standard deviation ±4331.18 and 805 ppm to 18562.50 ppm with mean value of 6167.37 ppm and standard deviation ±3822.77 in upland, midland and lowland, respectively. Total K of North Bihar soils varies from 469 ppm to 22471.20 ppm with mean value of 6873.80 ppm and standard deviation ±3921.72.From the data it was also observed that the amount of total K in the lowland soils was higher than that of upland soils.

Table 1: Range, mean and standard deviation of pools of K under upland soils of North Bihar

	Available K (ppm)	**Water soluble K (ppm)**	**Exchangeable K (ppm)**	**1N HNO_3Soluble K (ppm)**	**Non-exchangeable K (ppm)**	**Total K (ppm)**
Maximum	330.00	67.00	264.50	2431.00	2101.00	14707.00
Minimum	26.00	3.50	2.00	126.00	67.00	469.00
Mean	82.37	19.40	62.97	939.36	856.98	7022.63
Standard Deviation (±)	64.04	15.82	56.58	482.36	468.42	3540.25

Table 2: Range, mean and standard deviation of pools of K under midland soils of North Bihar

	Available K (ppm)	**Water soluble K (ppm)**	**Exchangeable K (ppm)**	**1N HNO_3 soluble K (ppm)**	**Non-exchangeable K (ppm)**	**Total K (ppm)**
Maximum	256.50	66.50	207.00	2322.00	2066.50	22471.20
Minimum	20.50	4.06	8.00	164.00	121.00	1347.50
Mean	81.40	18.14	63.26	976.56	895.16	7438.68
Standard Deviation (±)	57.90	12.64	50.27	464.38	451.23	4331.18

Table 3: Range, mean and standard deviation of pools of K under lowland soils of North Bihar

	Available K (ppm)	Water soluble K (ppm)	Exchangeable K (ppm)	1N HNO_3 soluble K (ppm)	Non-exchangeable K (ppm)	Total K (ppm)
Maximum	311.50	60.00	274.00	2039.00	1985.50	18562.50
Minimum	17.00	4.00	7.00	166.50	65.00	805.00
Mean	77.99	17.29	60.70	869.45	791.46	6167.37
Standard Deviation (±)	55.09	11.62	52.56	501.28	499.08	3822.77

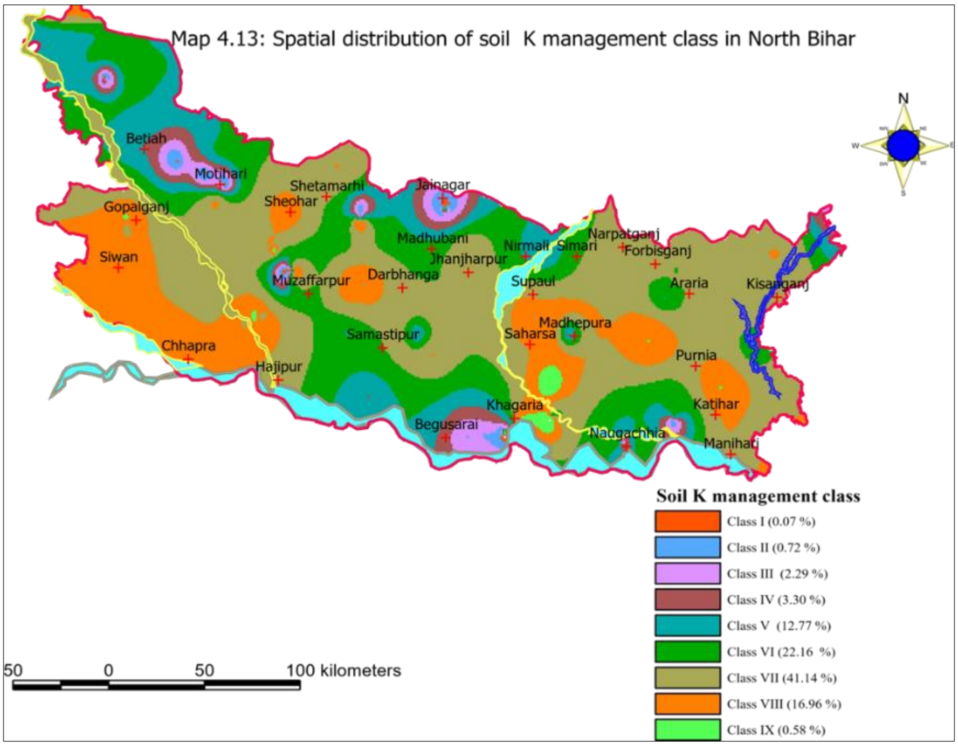
Table 4: Range, mean and standard deviation of pools of K of Soils of North Bihar

	Available K (ppm)	Water soluble K (ppm)	Exchangeable K (ppm)	1N HNO_3 Soluble K (ppm)	Non-exchangeable K (ppm)	Total K (ppm)
Maximum	330.00	67.00	274.00	2431.00	2101.00	22471.20
Minimum	17.00	3.50	2.00	126.00	65.00	469.00
Mean	80.56	18.26	62.30	928.28	847.72	6873.80
Standard Deviation (±)	58.58	13.35	52.71	480.98	471.44	3921.72

Table 5: Soil K management class in North Bihar The thematic map of soil K management class (Map 4.13) clearly reveals its spatial distribution.

Categorization of soils based on GIS	Exchangeable K	Non-Exchangeable K	Recommendations
Class I	Low	Low	K in fertilization is must
Class II	Low	Medium	K fertilization is essential
Class III	Low	High	K additions at critical stages of crops improve yield levels.
Class IV	Medium	Low	Continuous cropping needs K addition at critical stages as non-exchangeable K fraction does not contribute to plant K nutrition substantially.
Class V	Medium	Medium	Maintenance doses of K may be required for intensive cropping systems
Class VI	Medium	High	Crops may not need immediate K additions.
Class VII	High	Low	Long term cropping would need K additions after few years
Class VIII	High	Medium	K application is not required immediately.
Class IX	High	High	K application is not required.

The indicates 41.41% area under Class VII which was observed in Dharbhanga, Shitamarhi, Araria, Purnia, Katihar, Manihari, Kishanganj and Hajipur followed by 22.16% area under Class VI which was observed in Samastipur, Muzaffarpur, Madhubani, Simari and Nirmali, 16.96% area under Class VIII which is observed in Gopalganj, Siwan, Chhapra, Saharsa and Katihar, 12.77% area under Class V which is observed in Naugachhai, Begusarai, Madhubani and Nirmali, 3.30% area under Class IV which is observed in Begusari and Bettiah, 2.29% area under Class III which is observed in Motihari and Begusarai, 0.72% area under Class II, 0.58% area under Class IX and 0.07% area under Class I. Similar work was conducted by Srinivasrao and Subbarao (2010).



Map 1: Spatial distribution of soil K management class in North Bihar

Conclusion

GIS system enables a more precise approach for K fertilizer recommendations in the different soils, which vary widely in their K status as reflected by the variations in readily available K and non-exchangeable K reserves. This GIS based K mapping involved in categorizing soils for K fertility management and identified priorities for K application. Soils were categorized by including non-exchangeable K along with exchangeable K, as contribution of non-exchangeable is substantial in K removals by different production systems. Soil with low levels of both exchangeable and non-exchangeable K, K application must be done to realize full yield potential of different cropping systems.
Similarly for different categories, K recommendation has been suggested based on soil K reserve status. This categorization of soils into different groups provides a comprehensive assessment of K supply for plant uptake and better recommendation of potash application. Fertilizer recommendations evolved on the basis of soil test calibration including both exchangeable and non-exchangeable K reserves. This work resulted in the identification of the areas of North Bihar where both the readily available and non-exchangeable soil K are low and where K application is essential. Where non-exchangeable K is low to medium, continuous cultivation of crops gradually results in soil K depletion and reduction in crop yields. Further, the findings of the study may be utilized for precision agriculture in future.

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