E-ISSN: 2618-0618
P-ISSN: 2618-060X

www.agronomyjournals.com
2024; SP-7(2): 102-116
Received: 02-12-2023
Accepted: 05-01-2024

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Soil fertility mapping of soil nutrients in areas adopting rice wheat cropping system in Karnal, Haryana

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DOI: https://doi.org/10.33545/2618060X.2024.v7.i2Sb.341

Abstract
Use of high analysis fertilizers of nitrogen (N) and phosphorus (P) along with lower levels of potassium (K), meagre use of organic sources of plant nutrients, improper management of crop residues and adoption of more exhaustive rice wheat cropping system have resulted in increased deficiency of macronutrients in the soils of Haryana including Karnal district. In order to have systematic information on the spatial variation of soil pH, electrical conductivity (EC), organic carbon (OC) and macronutrients in the areas adopting rice wheat cropping system in district Karnal of Haryana, soil fertility maps were prepared using modern technologies *viz*. GPS and GIS. For this purpose 230 surface soil samples were randomly collected from all the five blocks of Karnal using GPS and analyzed at Regional Soil Testing Laboratory, KVK, Karnal during 2021-22. The results revealed that the pH of the soils of all the blocks of Karnal were neutral to alkaline in reaction ranging from 6.7-8.9. Electrical conductivity of majority of the soil samples was non-saline which ranged between 0.09 -1.34 dSm^{-1}. The OC content in soils of different blocks of Karnal *viz.* Assandh, Indri, Nilokheri, Karnal and Gharaunda ranged from 0.07-1.12, 0.07-1.03, 0.12-1.12, 0.11-0.82 and 0.10-0.79%. The OC content of majority of soil samples i.e. 72, 45, 56 and 84% was in medium range (0.40%-0.75%) in Assandh, Indri, Karnal and Gharaunda block, respectively. The available N content of all the soil samples of the district were found in deficient range. 94% samples in Assandh block, 78% of samples in Indri block, 74% of samples in Nilokheri block, 58% of samples in Karnal block and 76% in Gharaunda block were having high soil phosphorus content. Six% soil samples in Assandh, 21% in Indri, 23% in Nilokheri, 39% in Karnal and 24% in Gharaunda block were found to have medium P content in their soils. The soils of all blocks of Karnal district had K in medium range *i.e.* 46% in Assandh, 79% in Indri, 77% in Nilokheri, 69% in Karnal and 65% in Gharaunda block. The S content of all blocks of Karnal district fall under the medium category i.e. 77, 89, 84 and 87% in Assandh, Indri, Nilokheri and Gharaunda blocks, respectively. Such information regarding soil fertility status and soil fertility maps can be very useful for generating decision making support system for fertilizer scheduling of crops in a particular area.

Keywords: Soil fertility map, Blocks, Karnal, Haryana, Rice wheat cropping system

Introduction
The rice (*Oryza sativa* L.) – wheat (*Triticum aestivum* L.) cropping system (RWCS) plays a vital role in global food security as it provides staple food to the world's population (Humphreys *et al*., 2010; Laik *et al.*, 2014; Busari *et al*., 2015; Banjara *et al*., 2021) [20, 26, 6, 3]. Improving the productivity of RWCS should be our major concern to keep up with the increasing population of India, which is predicted to swell from 1.12 billion in 2008 to 1.35 billion by 2025 (UNEP, 2008) [45]. Haryana is a principal state where 95 per cent of total cultivable area is under rice wheat cropping system. The share of rice and wheat in total food grains production of Haryana has increased sharply from 50 per cent in 1966-67 to more than 90 per cent in the recent past (Swaminathan, 2002) [41]. In Haryana, rice productivity have increased from ~1,000 kg ha^{-1} in 1960-61 to 3,420 kg ha^{-1} in 2018–19 and similarly, wheat productivity have increased from ~1,200 kg ha^{-1} in 1960–61 to 4,850 kg ha^{-1} in 2018-19. However, stagnation in the productivity of rice and wheat has been observed after 2000-01.
Rice and wheat being very exhaustive cereal crops had lead to heavy depletion of nutrients in the soil, and the problem is further aggravated when farmers burn the rice crop residue left in their fields after its harvesting ending up the scope of mineralization of nutrients on decomposition of

straw. The continuous RWCS is also found to disturb the nutrient balance in the upper vadose zone (Gill, 1992; Kumar *et al*., 2022) [16, 25].

Day by day soil health is declining at an alarming rate resulting into macro as well as micro-nutrient deficiencies in the soils (Biswas and Tewatia, 1991) [5]. However, in the rice-wheat cropping system, soil organic carbon levels have been reported to decline from 0.5 percent to 0.2 percent within 30 years (Debangshi and Ghosh, 2022) [44]. The appearance of new micro-nutrient deficiencies such as iron and zinc in rice and manganese deficiency and selenium toxicity in wheat are the new hindrance in front of the sustainability of the RWCS (Chatterjee *et al*., 1987) [9].

Deficiencies of multiple micronutrients are now becoming more prevalent, 49% of Indian soils are potentially deficient in zinc (Zn), 12% in iron (Fe), 5% in manganese (Mn), 3% in copper (Cu), 3% in boron (B) and 11% in molybdenum (Mo) (Singh, 2008) [36]. High cropping intensity, burning of crop residues, imbalance fertilizer application and high yielding varieties of these two crops has resulted in to depletion in fertility of soil, which necessitates testing of soil.

Therefore, preparation of soil fertility map using remote sensing technique is a fast and efficient way of generating information about soil fertility of any region on a large scale basis which can be very helpful to the farmers and the researchers. The soil fertility evaluation is the most basic decision making tool in order to efficiently plan for a particular land use system (Havlin *et al.*, 2010) [19]. Therefore, it is very important to investigate the soil fertility status which may provide valuable information related to sustainable soil management, as well as improving the quality of field research. Keeping all these facts in mind, the present study was planned with the objective of evaluating soil fertility status and prepare soil fertility map of Karnal district of Haryana.

Material and Methods

Location

Karnal district of Haryana is better known as "Rice Bowl of India" which lies between 29°25'16.00" -29°58'01.00" N latitude and 76°22'59.00" - 77°09'22.00" E longitudes (Fig.1). Total geographical area of Karnal district is 2520 sq km which covers 5.69% area of the Haryana state. The district is bordered by the river Yamuna in the east, Panipat district in the south, Kaithal district in the west and Kurukshetra district in the north. The district is well connected by roads and railways. The Sher Shah Suri Marg (NH 1) runs through the entire length of the district. The main townships are Karnal, Indri, Assandh, Nilokheri and Ghauranda.

Agriculture and allied activities are the main occupation of the population, which is evident from the fact that about 84% of the area in the district is under agriculture. The district has good production of food grains, cereals, oilseeds and other crops. Irrigation in the district is done by surface water as well as ground water.

Climate

In Karnal, the climate is warm and temperate. The climate of the district is characterized by dry air with an intensely hot summer and a cold winter. The year may be divided into four seasons. The cold season starts by late November and extends to the middle of March. It is followed by hot season which continues to the end of June when the southwest monsoon arrives over the district. July to September is the southwest monsoon season. The post monsoon season period is from October to December.

Soil Sampling and Analysis

A total of 230 soil samples (0-15 cm depth) were collected from the farmer's fields of Karnal covering all the five blocks of district Karnal *viz.* Karnal, Indri, Assandh, Nilokheri and Ghauranda during 2021-22. Detail of number of samples collected from different blocks is provided in Table1. Soil samples were air-dried, ground and sieved through 2 mm sieve in the laboratory for the analysis of various physico- chemical properties. The soil analysis was conducted at Regional Soil Testing Laboratory, KVK, Chaudhary Charan Singh Haryana Agricultural University, Karnal. The processed soil samples were analyzed for soil pH, electrical conductivity (EC), organic carbon (OC) and available nutrients i.e. nitrogen (N), phosphorus (P), potassium (K) and sulphur (S) by adopting standard procedures. The data generated for pH, EC, OC and available N, P, K and S were categorized into low, medium and high categories based on the limits given in Table 2.

Table 1: No of soil samples collected from different blocks of Karnal District

S. No.	Block	No of samples collected
1.	Assandh	35
2.	Indri	91
3.	Nilokheri	31
4.	Karnal	36
5.	Gharaunda	37
	Total	230

Soil pH was estimated in 1:2 soil: water suspension by using digital pH meter. EC was estimated in supernatant solution of 1:2 soil: water suspension using EC meter (Jackson, 1973) [21]. OC was determined by wet digestion method given by Walkley and Black (1934). Available N was estimated by distilling soil with alkaline 0.32% $KMnO_4$ in a micro-Kjeldhal apparatus (Subbiah and Asija, 1956). Available P was extracted with 0.5 M $NaHCO_3$ (pH 8.5) and estimated spectrophotometrically at a wavelength of 660 nm (Olsen *et al*., 1954). Available K was extracted with neutral 1N neutral ammonium acetate and estimated by flame emission spectroscopy (Jackson, 1973) [21]. Available S was determined by using turbidimetric method using 0.15% solution of $CaCl_2.H_2O$ as extractant **(**Williams and Steinberg, 1969). Soil samples were collected during the year 2021-22 immediately, after the harvest of predominant wheat crop. Soil samples were collected with the help of a soil auger. Locations of all the 230 sampling sites were recorded using a handheld GPS and are presented in Figure 2.

Table 2: Criteria for Assessment of soil based on macronutrients status

Nutrients	Rating of Soil Test Values		
	Low	Medium	High
Organic C (%)	< 0.4	0.4 - 0.75	0 > 0.75
Available N (Kg/ha)	< 250	250 - 500	1 > 500
Available P (Kg/ha)	< 10	10 - 20	>20
Available K (Kg/ha)	< 125	125 - 300	> 300
Available S (Kg/ha)	< 20	20 - 40	> 40

Statistical tools

Descriptive statistical analysis was carried out to determine the mean, maximum, minimum, standard deviation, and coefficient of variation of the different variables of the data in Microsoft Office Excel Worksheet.

Mapping

The information on latitude and longitude of the soil samples collected using GPS was fed into the GIS program to generate the sampling site location map (Fig. 2). The points pertaining to soil samples having same category were grouped into a class as a polygon and the maps for nutrients were generated and digitized in Arc GIS. Thus, the soil fertility map was generated for pH, EC, OC, available N, P, K and S. These maps were used to delineate per cent area of these nutrients in different categories.

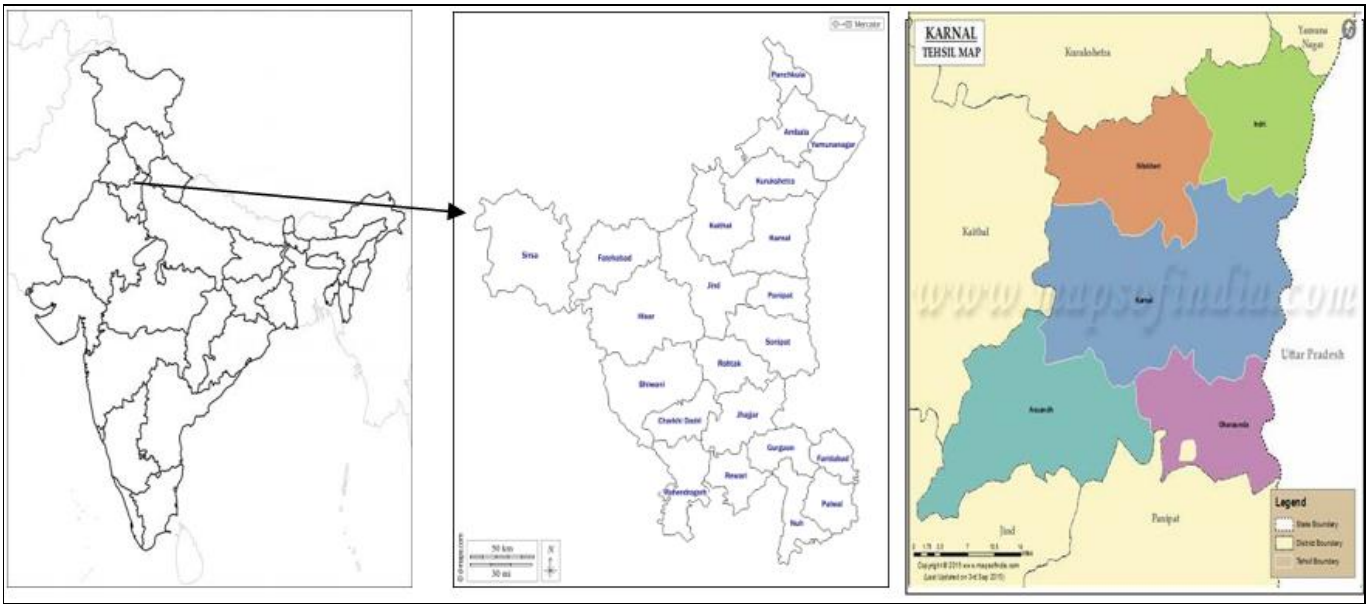

Fig 1: Location Map

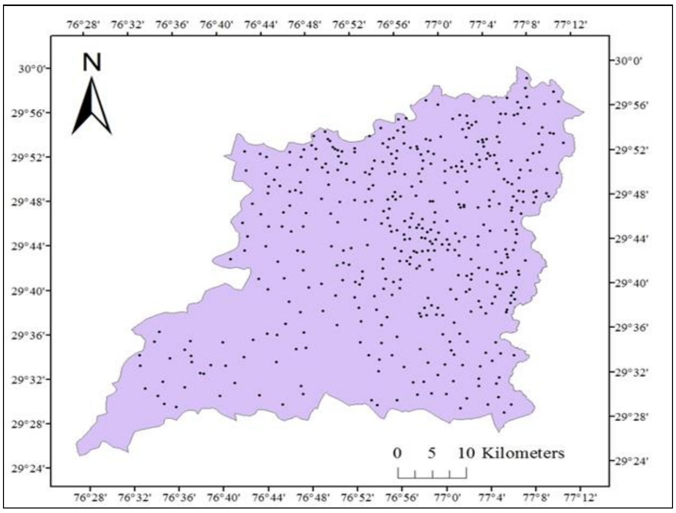

Fig 2: Soil Sample location map of Karnal district

Results and Discussion

pH status of soil samples of Karnal District

Soil pH is considered to be the "master variable" of soil chemistry due to its profound impact on countless chemical reactions involving availability of essential plant nutrients to the plants (Barrow and Hartemink, 2023) [4]. The availability of nutrients in the soil is highly associated with the pH of the soil. The uptake of ions such as Ca^{2+} and Mg^{2+} by plants increases with the increase in pH; however, micronutrient availability increases with the decrease in soil pH. More specifically, pH has a profound effect on chemical solubility and availability of essential plant nutrients along with organic matter decomposition in the soil (McCauley *et al*., 2009, Jackson and Meetei, 2018) [27, 22].

Results obtained after analyzing all the 230 samples collected across the Karnal district, it was found that the pH of Assandh, Indri, Nilokheri, Karnal and Gharaunda blocks ranged from 6.7-8.7, 7.7-8.9, 7.1-8.7, 7.9-8.9 and 7.3-8.8, respectively, indicating that the soils of all the blocks were neutral to alkaline in reaction. The presence of basic parent material or an interaction between the soil colloids and the fertilizers that were applied that led to the production of the basic cations on the soil's exchangeable complex could be the primary causes of the alkaline character of these soils. High base saturation or semi–arid environments with irregular rainfall which cause ions to accumulate in plough layer can also be the reason for alkaline nature of the soil. The neutral to alkaline pH may be attributed to the reaction of applied fertilizer material with soil colloids, which resulted in the retention of basic cations on the exchangeable complex of the soil (Gyawali *et al*., 2016; Guru Prem *et al*., 2017; Khokhar *et al*., 2022) [17, 18, 23].

Electrical conductivity status of soil samples of Karnal District

EC is a very important parameter which depicts the soil health. EC is an index of salt concentration and an indicator of electrolyte concentration of the soil solution. Ions of soluble salt in soil solution come from irrigation water and fertilizer solutions. EC of the nutrient solution is related to the amount of ions available to plants in the root zone. In general, higher EC hinders nutrient uptake by increasing the osmotic pressure of the nutrient solution and thus severely affect plant health and yield (Samarakoon *et al*., 2006; Ding *et al*., 2018) [33, 12]. The EC of the soils of Assandh, Indri, Nilokheri, Karnal and Gharaunda blocks ranged from 0.09-0.68, 0.08-0.62, 0.13-0.90, 0.10-0.67 and 0.09- 1.34 dS m^{-1} with a mean value of 0.30, 0.24, 0.40, 0.25 and 0.25 dS m^{-1} respectively. Minimum EC of 0.08 dS m^{-1} was reported in Indri block and maximum EC i.e.1.34 dS m^{-1} was reported in Gharaunda block. The normal EC of samples of Karnal may be ascribed to leaching of salts to lower horizons. At the same time, data obtained gives an idea that salinity is not a problem in the Karnal district, which indicating good quality of soil and considered suitable for agricultural purposes.

Table 3: Descriptive statistics of soil properties (n=230)

	pH	EC (dS/m)	OC (%)	N(Kg/ha)	P (Kg/ha)	K (Kg/ha)	S (Kg/ha)
Mean	8.29	0.28	0.48	153.32	26.26	258.29	31.24
Standard Error	0.02	0.01	0.01	1.72	0.64	8.19	0.57
Median	8.30	0.23	0.48	152.00	23.40	243.00	29.96
Mode	8.20	0.18	0.67	145.70	21.40	252.00	30.80
Standard Deviation	0.34	0.16	0.20	26.11	9.70	124.45	8.60
Sample Variance	0.12	0.03	0.04	681.57	94.11	15,487.78	74.03
Kurtosis	1.82	9.26	-0.06	1.37	1.92	3.00	5.77
Skewness	-0.83	2.39	0.28	0.39	1.10	1.48	1.80
Range	2.20	1.26	1.05	169.60	60.00	725.10	60.00
Minimum	6.70	0.08	0.07	79.40	8.00	28.70	16.23
Maximum	8.90	1.34	1.12	249.00	68.00	753.80	76.23
Sum	1,914.43	64.24	111.38	35,415.94	6,066.52	59,665.74	7,216.51
Count	231.00	231.00	231.00	231.00	231.00	231.00	231.00
Confidence Level (95.0%)	0.04	0.02	0.03	3.38	1.26	16.13	1.12

Similar results were reported by Gora (2013) that the EC of soil samples ranged from 0.15 to 1.15, 0.16 to 3.68, 0.12 to 1.30 and 0.07 to 1.30 dS m^{-1} with the mean values of 0.55, 0.51, 0.63 and 0.32 dS m^{-1} in Kaithal, Kurukshetra, Sirsa and Fatehabad districts of Haryana, respectively indicating that most of the samples were non-saline in nature.

Soil OC status of soil samples of Karnal District

Soil OC influences soil biological, physical and chemical properties and is found to be directly associated with better plant nutrition, particularly as a potential source of nutrients, improved soil structure, improved water holding capacity and soil buffering capacity. Therefore, soil OC plays, a central role in nutrient soil availability in the soil, strongly affecting N and S availability to the plant roots and strongly affecting P, Fe and Cu availability. Increasing OC content in soils is considered to be a main factor to increase plant yields (Canellas and Olivares, 2014) [7].

The OC content in soils of different blocks of Karnal *viz.* Assandh, Indri, Nilokheri, Karnal and Gharaunda ranged from 0.07-1.12, 0.07-1.03, 0.12-1.12, 0.11-0.82 and 0.10- 0.79% with mean values of 0.60, 0.45, 0.41, 0.42 and 0.54% respectively. In Nilokheri and Karnal blocks of Karnal district maximum samples i.e. 55 and 56% out of 31 and 36 samples respectively were found in low category of OC content in soil. However, both in Assandh and Gharaunda only 11% samples were found to have low OC content out of 35 and 37 samples, respectively. Nevertheless, majority of soil samples i.e. 72, 49, 35, 36 and 86% were found to be in medium OC category (0.40% - 0.75%) in Assandh, Indri, Karnal and Gharaunda blocks respectively.

The probable reason for low to medium organic carbon content in these areas may be attributed to good aeration of soil and high rate of organic matter decomposition under hyperthermic temperature regime which led to extremely high oxidizing conditions (Gyawali *et al.*, 2016) [18]. Due to continuous, rice-wheat cropping system since long and burning of residues after harvest might have resulted in low organic carbon in the soil over a period of time (Guru Prem *et al*., 2017) [17].

Available N status of soil samples of Karnal District

The available N content of the soils ranged from 86.0 - 249.0 Kg ha^{-1} in Assandh, 79.4 - 238.1 Kg ha^{-1} in Indri, 93.0-200.8 Kg ha^{-1} in Nilokheri, 110.3-195.84 Kg ha^{-1} and 108.0-200.6 Kg ha^{-1} in Karnal and Gharaunda with a mean value of 169.05, 147.44, 150.24, 147.41 and 160.23 Kg ha^{-1}, respectively. It is very much evident from the data presented in Table 5 that all the 35, 91, 36, 37 and 31 samples collected from Assandh, Indri, Nilokheri, Karnal and Gharaunda blocks were found to be in low range of N availability (<250 Kg ha^{-1}). In a study conducted by Antil *et al*. (2016) [1] 10 years back during 2010-11 similar results regarding N availability was reported. All the soil samples (n=2812) collected from 21 districts of Haryana state fall under low category of available N (< 250 Kg ha^{-1}). After 10 years of continuous agricultural activity same situation is prevalent in Karnal. It is a very alarming situation that in last decade N availability in Haryana soils is found to be low in all the samples analyzed although farmers of Haryana specifically Karnal apply urea injudiciously to their fields.

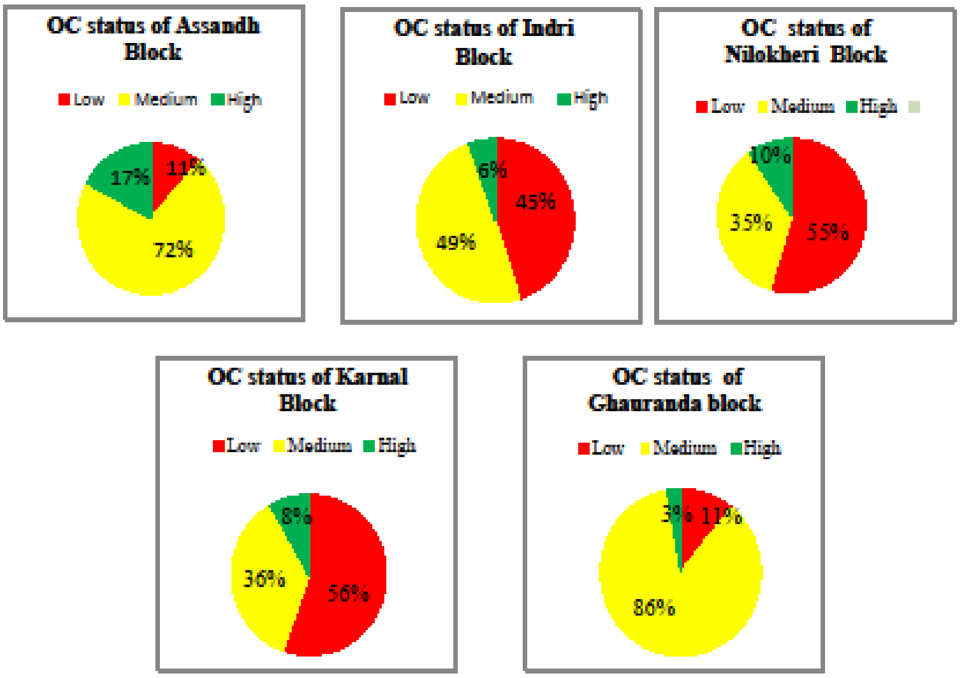

Fig 3: Soil organic Carbon status in different blocks in Karnal district (No. of Soil Samples=230)

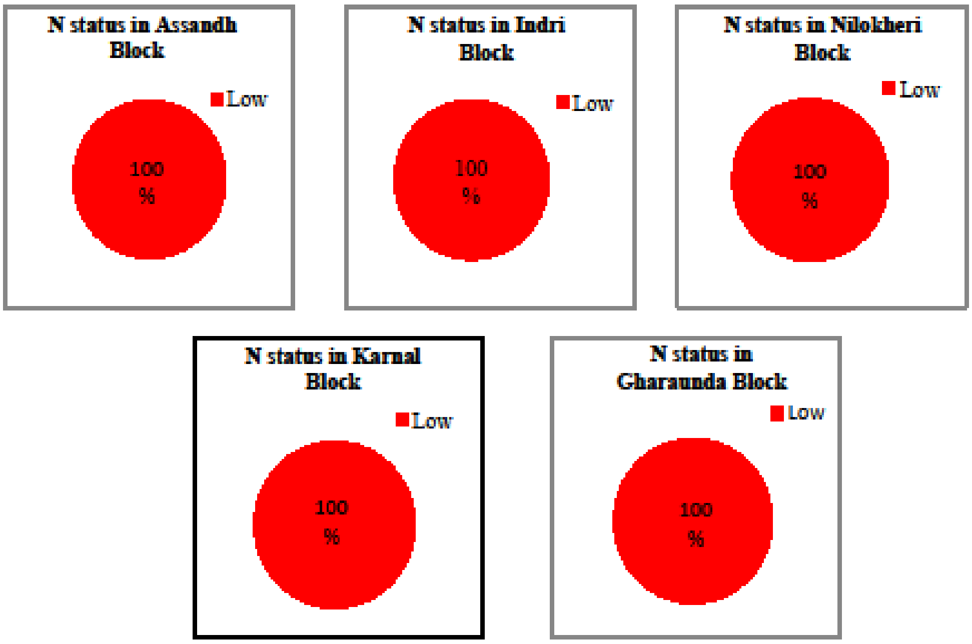

Fig 4: Soil available N status in different blocks in Karnal district (No. of soil samples=230)

Similar results were reported by Gyawali *et al.* (2016) [18] in Kaithal district and Guru Prem *et al.* (2017) [17] in Ambala District of Haryana and documented that all the samples analyzed were deficient in available N content in the soil. Haryana hardly had any soil sample with sufficient quantity of available N. Same results are reported in our study conducted in Karnal district during 2021-22. All the 230 samples analyzed fell under low category of N availability. The N deficiency could be attributed to nitrogen losses through volatilization, runoff, microbial fixation, and denitrification. A faster decomposition rate of organic materials due to the region's harsher temperatures may also contribute to less available nitrogen in the soil. Dhawan *et al.*, (2021) [11] and Dwivedi *et al.*, (2017) [13] have reported that soils of India are inherently deficient in N supply because of topographical location in subtropical/tropical climates that hinder the accumulation of soil organic matter, a primary source of N in the soil. Nitrogen (N) is the most limiting plant nutrient globally and its efficiency in field crops rarely exceeds ~40%. Low recovery of N is associated to its loss by volatilization, leaching, surface runoff, and denitrification. Gyawali *et al.* (2016) [18] has also reported that all the surface and sub-surface soils of Kaithal, Kurukshetra and Karnal to be in low category of N availability and which was attributed to loss of nitrogenous fertilizers due to leaching and volatilization processes.

Available P status of soil samples of Karnal District

The availability of soil P to plants is often limited due to the strong fixation of P species such as orthophosphate and inositol phosphate in the soil solid phase (Gerke, 2015) [15].

The P content of soils ranged from 20.0-68.0 kg ha^{-1} in Assandh, 9.0-52.2 kg ha^{-1} in Indri, 9.0-39.8 kg ha^{-1} in Nilokheri, 8.0-38.4

kg ha^{-1} in Karnal and 14.8-49.8 kg ha^{-1} in Gharaunda block with a mean value of 33.16, 25.58, 24.19, 21.28 and 27.94 kg ha^{-1}, respectively. 94% of samples in Assandh block, 78% of samples in Indri block 74% of samples in Nilokheri block, 58% of samples in Karnal block and 76% in Gharaunda block fall under high range of soil P availability i.e. > 20 kg ha^{-1}. These results clearly indicate, buildup of available P in Karnal soils. Perusal of data presented in Table 5 reveals that 6% soil samples in Assandh Block, 21% in Indri block, 23% in Nilokheri block 39% in Karnal block and 24% in Gharaunda block fall under medium range of soil P availability (10-20 kg ha^{-1}). However, not a single sample was found to have available P in low category in Assandh and Gharaunda block out of 35 and 37 samples, respectively. In Indri, Karnal and Nilokheri block only 1%, 3% and 3% samples were in low category out of 91, 36 and 31 samples.

However, almost a decade back in a survey work done by Antil *et al.* (2016) [1] it has been reported that out of 2812 soil samples 21% soil samples were found to be in low category, 44% in the medium category and 35% in high category of P availability in Haryana soils. More specifically in Karnal district out of 92 soil samples 1%, 32% and 67% samples were respectively in low, medium and high category of P availability. After 10 years of continuous rice–wheat cropping system P availability has increased in the soil.

According to the site information about the history of fertilizer application, DAP fertilizer has been used repeatedly in fertilization of different crops (mainly rice and wheat) and this may be a major reason for the higher values of available P in some rice growing areas of Haryana. Similar results were also noted by Singh (1988) [37] and Singh *et al*. (2014) [39]. The changes in the status of available P in these soils were due to continuous addition of phosphatic fertilizers. The range of available P in rice growing soils was considerably large which might be due to change in soil properties *viz.*, pH, OC content, texture and various management practices which affects the availability/fixation/ transformation of phosphorus in the soil (Gyawali *et al*., 2016) [18].

As efficiency of applied P is very low and it comes in available form very slowly and plants take up only 10-40 per cent of applied P during the growing season (Aulakh and Pasricha, 1999; Guru Prem *et al*., 2017; Khokhar *et al*., 2022) [2, 17, 23] and the rest resides in the soils as less soluble products. It is also recommended that in case of paddy, the application of DAP could be omitted, if recommended dose of it is applied to previous crop wheat.

Available K status of soil samples of Karnal District

The K content of the Assandh block varied from 79.5 - 753.8 kg ha^{-1} with a mean value of 337.64 kg ha^{-1}, Indri block varied from 79.5 - 697.3 kg ha^{-1} with a mean value of 251.82 kg ha^{-1}, Nilokheri block varied from 97.1-417.87 kg ha^{-1} with a mean value of 239.57 kg ha^{-1}, Karnal block varied from 86.3-522.2 with a mean value of 261.75 kg ha^{-1} and Gharaunda block varied from 70.0-749.0 kg ha^{-1} with a mean value of 207.89 kg ha^{-1}. The soils of all blocks of Karnal district were found to have soil K in medium range i.e. 46% in Assandh, 79% in Indri, 77% in Nilokheri, 69% in Karnal and 65% in Gharaunda block. Only in Assandh block maximum soil samples i.e. 48% were found in the category of high range of K availability. This implies that the majority of soil samples in all blocks had a medium K content. It is most likely due to the presence of K -rich parent material in the soil, such as feldspar and illite.

The amount of K removed by rice-wheat cropping system can be as high as 325 kg ha^{-1} (Table 5). Field crops generally absorb K faster than they absorb N or P or build up dry matter. The removal of K depends on the production level, soil type and whether crop residues are removed or recycled in the soil. When crop residues are retained in the field, large amounts of K gets recycled. Average K uptake per ton of grain is about 27.3 kg ha^{-1} for wheat and 25.0 kg ha^{-1} for rice (Tandon and Sekhon, 1988) [43]. Removal of K by rice-wheat system far exceeds its additions through fertilizers and recycling. Optimum application of N increased K uptake by 57% over control plots and N and P application increased K uptake by 145% (Tandon and Sekhon, 1988) [43].

Due to the continuous drain of K from soil reserve over the years without its replenishment, the deficiency of K has started appearing in certain pockets of the district, which is a serious matter of concern.

Available S status of soil samples of Karnal District

Sulphur (S) is increasingly recognized as the fourth major plant nutrient, in addition to N, P and K. S is considered as a very important constituent of some amino acids like cystein, cystine and methionine, abundantly found in oil seed crops. Most of the soils with light texture are low in available S either these soils have depleted their S reserves due to continuous cropping or may be due to regular use of S free fertilizer. Judicious application of S plays a major role in the growth and development of crops (Kopriva *et al*., 2019; Zenda *et al*., 2021) [24, 48] and now a day's sulphur is gaining considerable importance for enhancing crop yields and quality of production in the context of Indian agriculture. Since the last two decades, S deficiency has been reported globally (Kopriva *et al*., 2019) [24]. Approximately 46% of agricultural soils of India observed S.

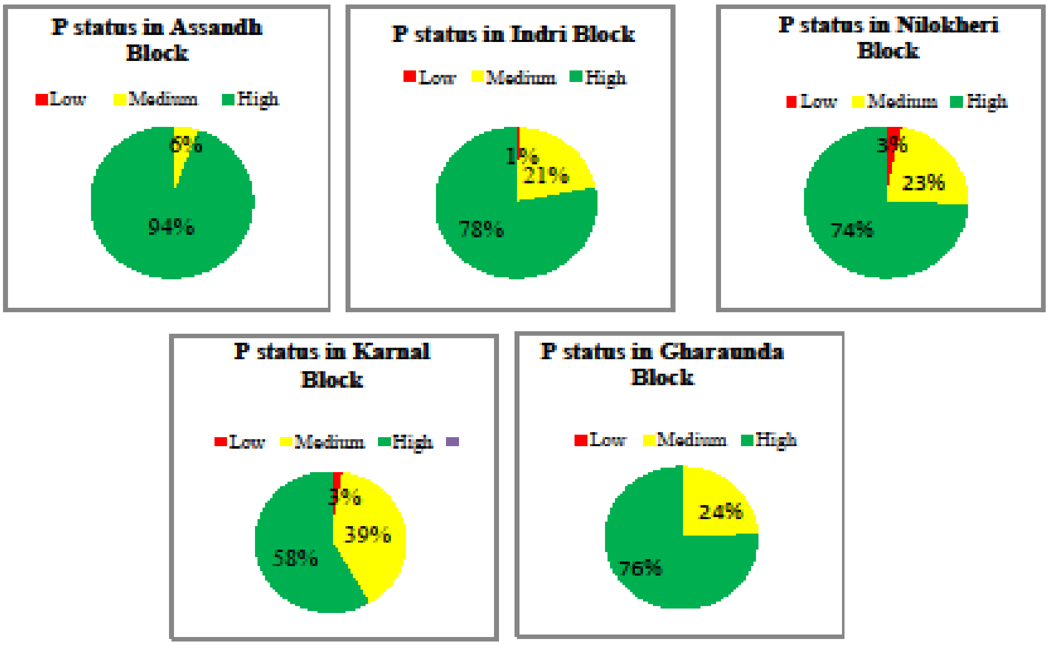

Fig 5: Soil available P status in different blocks in Karnal (No. of Soil Samples=230)

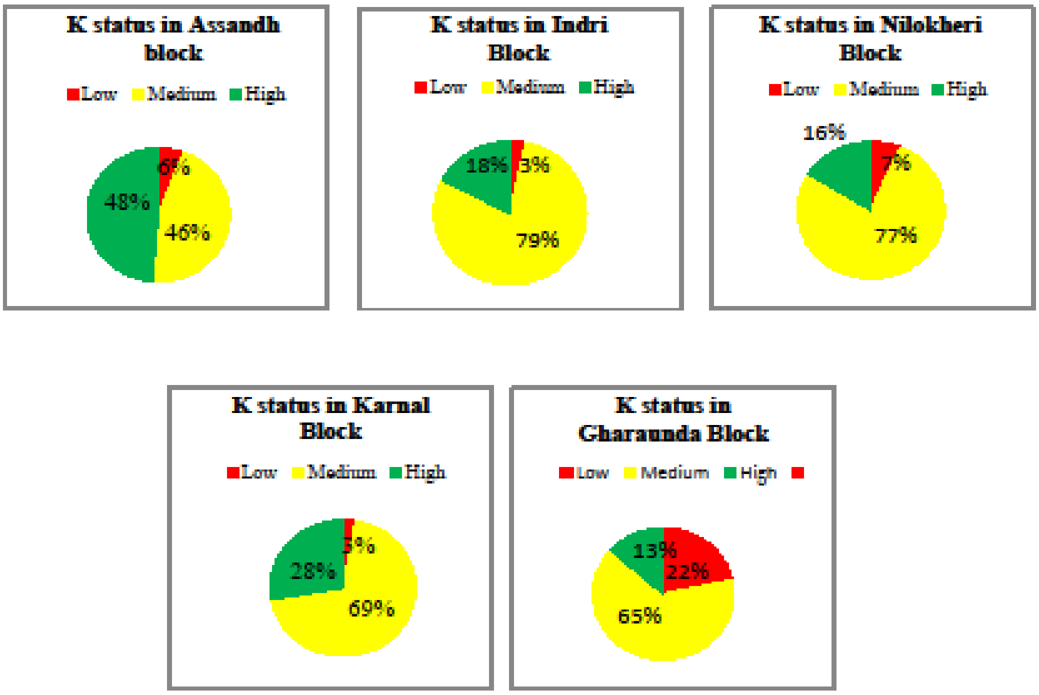

Fig 6: Soil available K status in different blocks in Karnal (No. of soil samples=230)

Table 4: Temporal changes in the nutrient status of Karnal district in last one decade

Nutrients	Low		Medium		High	
	2010-11*	2021-22	2010-11*	2021-22	2010-11*	2021-22
Organic C (%)	51(55%)	86 (37%)	41 (45%)	126 5%)	0 0 (0%)	1 18 (8%)
Available N (Kg/ha)	92 (100%)	230 (100%)	0 (0%)	0 (0%)	1 (0%)	3 0 (0%)
Available P (Kg/ha)	1(1%)	3 (1%)	29 (32%)	50 (22%)	62 (67%)	177 (77%)
Available K (Kg/ha)	0 (0%)	16 (7%)	3 (3%)	161 (70%)	89 (97%)	53 (23%)
Available S (Kg/ha)		10 (4%)		200 (87%)		20 (9%)

*Antil *et al.*, 2016 [1]

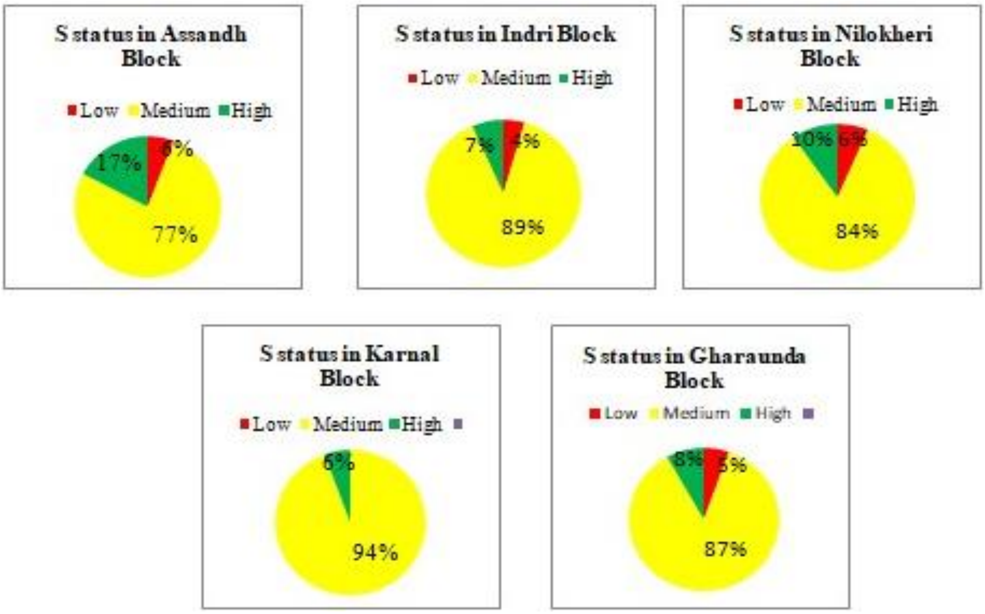

Fig 7: Available S status in different blocks in Karnal (No. of soil sample=230)

deficiency and out of them, 30% of soils are potentially deficient (Satyanarayana and Tewatia, 2009) [34]. The fast decline in available soil S is chiefly due to higher crop removal by high-yielding genotypes; high cropping intensity; poor replenishment in soil due to use of S-free fertilizers. Thus, under these situations the application of S fertilizers becomes imminent to harvest good crop yields of aerobic rice. The S content of soil ranged from 19.91-76.23, 16.8-53.9, 16.23-69.37, 22.34-54.96 and 16.8-54.72 kg ha^{-1} in Assandh, Indri, Nilokheri, Karnal and Gharaunda blocks respectively. The S content of all blocks of Karnal district fall under the medium S category i.e. 77, 89, 84 and 87% in Assandh, Indri, Nilokheri and Gharaunda blocks, respectively. This implies that most of the samples fall under the medium category of available S. In Karnal block high available S also recorded i.e. 94%. The high S status of soil may be due to the continuous application of S containing fertilizer i.e. $ZnSO_4$ in the rice-wheat cropping system which contains 10-15% S. Gyawali *et al.* (2016) [18] observed that approximately 76% of analyzed samples for available S fall under high category, while 12% area of Kaithal district was found deficient in available S.
Intensification of agriculture with high yielding varieties and multiple cropping coupled with use of high analysis sulphur free fertilizers along with restricted or no use of organic manures have accrued in depletion of soil sulphur reserve (Guru Prem *et al.*, 2017) [17]. Almost similar trend were also observed by Narwal *et al*. (2011) [29]. The higher status of available S in rice growing areas may be due to sulphur rich parent material and application of $ZnSO_4$ as a common practice for correcting zinc deficiency in rice-wheat cropping system.

Status and Distribution of Available Macronutrients in the Soil of Karnal District

When we talk about Karnal district as a whole which is better known as "Rice Bowl of India" and is famous for the production of the long-grain, aromatic basmati rice we found a wide variation in its soil nutrient fertility level when compared with the fertility level 10 years back. Data presented in Table 4 clearly reveals that during 2021-22 OC content of 55% samples were in medium range followed by 37% samples in low range. From the results obtained there is a clear indication that 8% samples had OC in high range. When we compare the results with the survey work done by Antil *et al*. (2016) [1] during 2010-11 we find that number of samples in low category decreased from 55% in 2010-11 to 37% in 2021-22. It is very satisfying to observe that number of soil samples which falls in high category of OC content, which was 0% in 2010-11 have increased to 8% in 2021-22. This shows the increasing awareness of Karnal farmers towards soil health because management of soil health involves management of soil organic carbon pool as it is the backbone of soil health. (Chappell *et al*., 2021) [8].
Table 4 clearly stipulates the available N status of our soils. Years back in 2010-11 and now in 2021-22 none of the soil sample was found to have sufficient quantity of available N. However, availability of N in the soil can be of major concern because consistently throughout the last decade all the soil samples are found to be deficient in N. Nobody can deny that farmers continue to apply urea injudiciously to their fields but there are no evidences of N build up in our soils. Similar results have been reported by Gyawali *et al.* (2016) [18] in Kaithal district and Guru Prem *et al*. (2017) [17] in Ambala District of Haryana and they also found that all the samples analyzed were deficient in available N content in the soil.
As far as available P content in Karnal soils is concerned, 177 samples out of 230 samples were found in high range accounting for 76.95%. These results clearly indicates build-up of available P content in the soil due to low nutrient use efficiency of P and above all soil pH of majority of soils in Haryana is more than 8.0 and in alkaline pH availability of P is hindered. It was found that 1.30%, 21.73% and 76.95% samples fall under low, medium and high category respectively. Ten years back (Table 4) 67 % samples were in high category of P availability which

Table 5: Percent area under low, medium and high categories of organic carbon and available macronutrients in different blocks of Karnal districts of Haryana

Organic Carbon				
Blocks	**Low (< 0.4%)**	**Medium (0.4 - 0.75%)**	**High (> 0.75%)**	**Total**
Assandh	4	25	6	35
Indri	41	45	5	91
Nilokheri	17	11	3	31
Karnal	20	13	3	36
Gharaunda	4	32	1	37
Total	86	126	18	230
Percentage	**37%**	**55%**	**8%**	
Nitrogen (kg/ha)				
Blocks	**Low (< 250)**	**Medium (250-500)**	**High (> 500)**	**Total**
Assandh	35	0	0	35
Indri	91	0	0	91
Karnal	36	0	0	36
Gharaunda	37	0	0	37
Nilokheri	31	0	0	31
Total	230	0	0	230
Percentage	**100%**	**Nil**	**Nil**	
Phosphorus (kg/ha)				
Blocks	**Low (< 10)**	**Medium (10-20)**	**High (> 20)**	**Total**
Assandh	0	1	34	35
Indri	1	19	71	91
Karnal	1	14	21	36
Gharaunda	0	9	28	37
Nilokheri	1	7	23	31
Total	3	50	177	230
Percentage	**1%**	**22%**	**77%**	
Potassium (kg/ha)				
Blocks	**Low (< 125)**	**Medium (125-300)**	**High (> 300)**	**Total**
Assandh	2	16	17	35
Indri	3	72	16	91
Karnal	1	25	10	36
Gharaunda	8	24	5	37
Nilokheri	2	24	5	31
Total	16	161	53	230
Percentage	**7%**	**70%**	**23%**	
Sulphur (kg/ha)				
Blocks	**Low (< 20)**	**Medium (20-40)**	**High (> 40)**	**Total**
Assandh	2	27	6	35
Indri	4	81	6	91
Karnal	0	34	2	36
Gharaunda	2	32	3	37
Nilokheri	2	26	3	31
Total	10	200	20	230
Percentage	4%	87%	9%	

have increased to 77% in 2021-22. There is a commonly held belief that P fertilizers are very inefficient because P use efficiency is often found to be 10-15% only. The residual fertilizer P not recovered by the crop is believed to be permanently tied-up or "fixed" in the soil in forms not available to the plants (Roberts and Johnston, 2015) [32]. Contrary to which Neue *et al*. (1990) [30] reported that 20 million hectares of world rice cultivation area are P-deficient and Muralidharudu *et al*. (2011) [28] have reported that that 61.02% of Indian soils are low in P. The K availability of the soil samples of Karnal district was also found to exhibit alarming situation. Out of 230 samples 16, 161and 53 samples were found under low, medium and high range respectively, according to the critical limits mentioned (Table 2). It was found that during 2021-22, 6.95% soil samples were in low, 70% in medium and 23.04% in high range of K availability. It is found to be very surprising that within 10 years K reserve of our soils have depleted tremendously. During 2010-11, 97% samples had high values of available K which has reduced to 23% in 2021-22. Not a single sample was found deficient in available K in 2010-11, and now in 2021-22, 7% samples have been reported to be deficient. Due to the continuous drain of K from soil reserve over the years without its replenishment, the deficiency of K has started appearing in certain pockets of the district, which is a serious matter of concern.

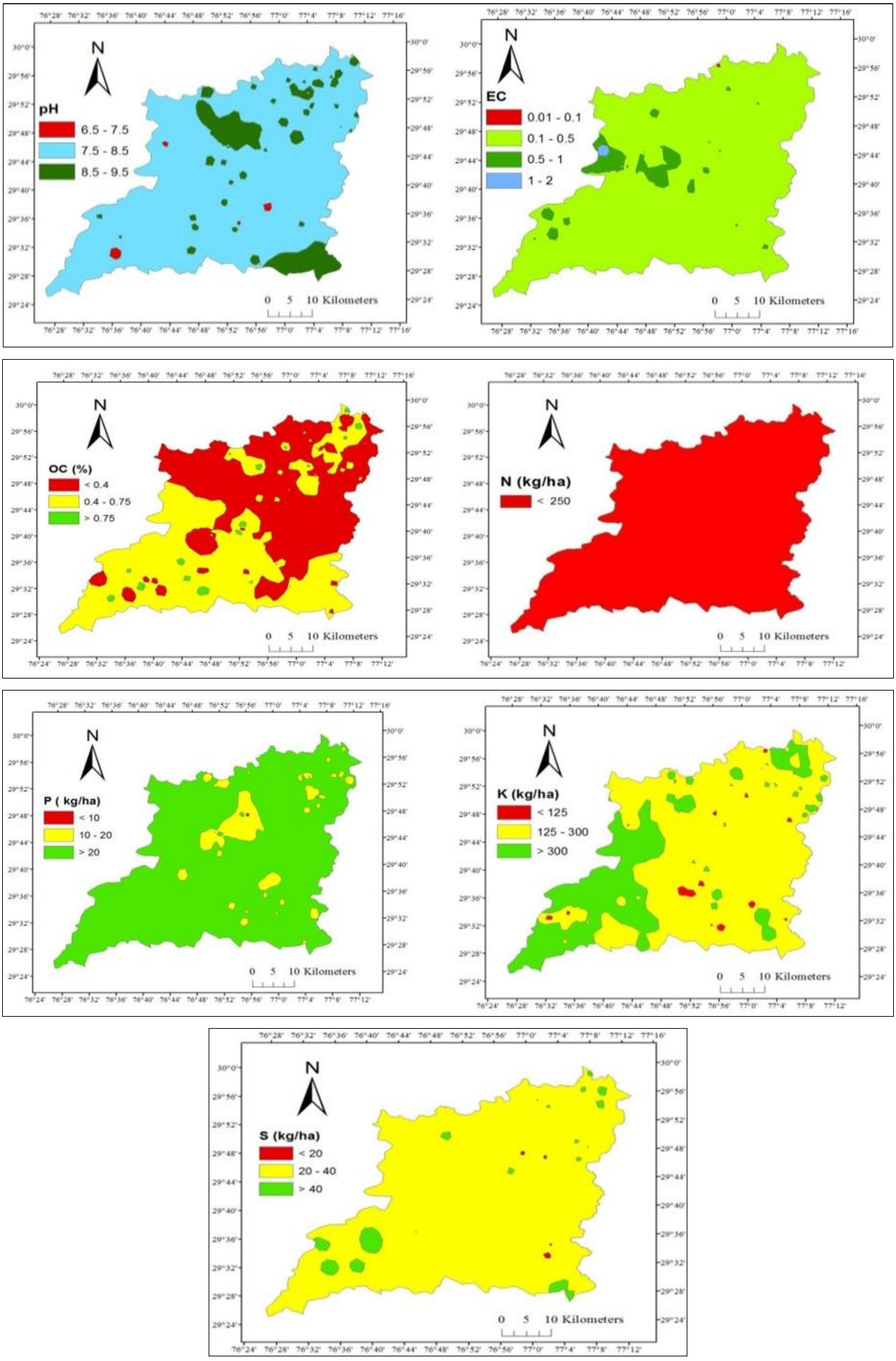

Fig 8: Status and distribution of physico chemical properties and available macronutrients in Karnal district of Haryana

Conclusions

RWCS has started showing the signs of fatigue and has put up a question mark on its ecological and economical sustainability (Garg *et al*., 2006). This is very much evident from the results achieved after the analysis of 230 soil samples collected across Karnal district of Haryana. A wide variability in availability of major nutrients and other soil properties was observed. About 37, 100, 1, 7, and 10% area of Karnal district was found deficient in organic C, available N, P, K and S, respectively. Available N was low in all the blocks of Karnal. Contrary to organic C and P, the availability of K in the soil of Karnal district adopting RWCS is exhibiting a continuous decline due to low rates of K application through fertilizers and manure. Scenerio of increasing K deficiency in the soils is mainly because K removal by the crops has exceeded the replenishment. Soil fertility maps generated using GPS and GIS technologies would be very useful for quick visualization of status of different nutrients and their remedial measures.

Hence, there is an urge to create awareness among farming communities towards soil health for which soil testing is the first step. It is truly sail by Hayne (1940) that, “If we feed the soil, it will feed us and only productive soil can support prosperous people.” Thus, maintaining soil health is not only essential for human health but it is also essential for proper ecosystem functioning and nature conservancy.

Conflict of Interest

The authors declare that they have no conflict of financial or non-financial interests that are directly or indirectly related to the work submitted for publication.

Author Contribution

Kiran Kumari: Conceptualization, Methodology, Supervision, Visualization as a major advisor.

Manisha Arya: Sample collection, complete laboratory analysis, software and formal analysis, preparation of fertility maps and pie diagrams, writing of original draft.

Ankur Chaudhary: Editing, checked and corrected the final draft.

Pankaj Singroha: Methodology, sample collection and analysis.

Ajay Baljot: Editing Methodology, sample collection and analysis. All authors contributed to the article and approved the submitted version.

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