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Evaluation of spatial soil fertility constraints in rice growing soils of Tirupati revenue division of Chittoor district, AP using Geographic Information System

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ABSTRACT

The present study on spatial variability of soil fertility status of rice growing soils of Tirupati revenue division of Chittor district, AP using Geographic information system (GIS) tools revealed that, soils are strongly acidic to strongly alkaline (5.40 to 8.95) with seven soil reaction classes viz., strongly acidic (5.1 – 5.5), moderately acidic (5.6 – 6.0), slightly acidic (6.1 – 6.5), neutral (6.6 – 7.3), slightly alkaline (7.4 – 7.8), moderately alkaline (7.9 – 8.4) and strongly alkaline (8.5 – 9.0) representing 0.8, 1.6, 11.2, 16.0, 25.0, 35.0 and 10.0 per cent of study area, respectively. The soils are non-saline to slightly saline (0.02 to 6.01 dS m^{-1}) with three salinity classes viz., non-saline (<2.0 dS m^{-1}), very slightly saline (2.0 - 4.0 dS m^{-1}) and slightly saline (4.0 - 8.0 dS m^{-1}) representing 84.5, 12.5 and 3.0 per cent of study area, respectively. The organic carbon was low to high (1.1 – 18.1 g kg^{-1}) representing 41.1, 18.9 and 40.0 per cent of study area under low, medium and high categories, respectively.The available N, P_2O_5 and K_2O were low to medium (75 to 527 kg ha^{-1}) representing 54.0 and 46.0 per cent ; low, medium and high phosphorous representing 11.6, 60.4 and 28.0 per cent and potassium was low to medium (39-1038 kg ha^{-1}) status was low, medium and high status representing 22.5, 58.0 and 19.5 per cent of study area, respectively.The calcium (1.8 to 25.0 cmol (p^+) kg^{-1}) and magnesium (1.8 to 25.0 cmol (p^+) kg^{-1}) were sufficient in range. The available sulphur was sufficient range in 96 per cent of study area (> 10 mg kg^{-1}). The available micro-nutrients viz., Zn, Fe, Mn, Cu and B were ranged from 0.21 to 9.11, 0.6-221.4, 0.61 to 166.4, 0.1-5.21 and 0.28 to 6.10 mg kg^{-1} with mean of 1.65, 30.7, 21.5, 1.02 and 0.73 mg kg^{-1}, respectively. The spatial analysis indicated that 78.0, 86.2, 97.7, 83.3 and 75.5 per cent of study area was sufficient in available Zn, Fe, Mn, Cu and B, respectively. The spatial analysis indicated that sodicity, low organic carbon, available nitrogen, phosphorous, potassium and zinc were among the major soil fertility constraints of rice growing soils of Tirupati district.

Key words: Spatial variability, Geographic information system, soil fertility constraints

INTRODUCTION

Rice (*Oryza sativa* L.) is the major food grain crop and more than two billion people depend on rice and value-added rice-based products for their energy requirement. It can be grown on wide variety of soils and tolerates acidic and alkaline soils. However, deep fertile clayey or loamy soils which can easily puddle and develop cracks upon drying are considered as the best. Currently the rice production was enough to feed our population as well as export requirements, since the rice annual production growth rate is 1.93 per cent higher than demographic growth of 1.04 per cent per annum. But the challenge is to feed the 1.6 billion projected population by 2050 and to provide them with nutritional security is a formidable one because of continuous degrading natural resource base, shrinking of productive land availability and water resources for rice cultivation, as our country became "water stressed nation" in 2006 and projected to become "water scarce nation" by 2050 if the present scenario continues (Singh, 2014). Hence, in future rice production likely to stabilize or even register negative growth. Due to the continuous nutrient mining through the intensive cropping with high yielding varieties, most of the soils become depleted of one or more plant nutrients. Deficiency of NPK has been well established but their excessive application, popularly of nitrogenous fertilizers has disturbed the balance of other macro and micronutrients in the soils. Improper fertilizer management further

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aggravated the problem due to which the yield has become stagnant or even decreasing in spite that increased usage of fertilizer consumption (Mathiew, 1979).

Rice is the major food grain crop being cultivated in an area of 41080 ha during *rabi* season and 10812 ha during *kharif* season in Chittoor district of A.P, out of which 70 per cent of area during *rabi* and 49.6 per cent area during *kharif* present in Tirupati revenue division. The cultivation of short stature, fertilizer responsive high yielding varieties with best management practices have resulted in higher yields and economic returns. But in recent years unfortunately the average yield remained static, rather in declining trend, inspite of all management practices such as fertilizers, selection of good varieties and control of pest and diseases. For instance, rice yields ranged from 2100 kg ha^{-1} to 5971 kg ha^{-1} with an average productivity of 3300 kg ha^{-1}, which was far lesser than the world's average productivity of 4360 kg ha^{-1} (FAOSTAT, 2014). The majority of rice area in study area was confined to two farming situations *viz.,* Canal irrigated under Araniyar, Swarnamukhi, Teluguganga ayacut area in Srikalahasti, Tottambedu, B.N. Kandriga, Varadaiahpalem, Satyavedu, Pichatur mandals and Tube well/bore well irrigated area under Pulicherla, Pakala, Chandragiri, Renigunta, KVB Puram, Pichatur, Nagalapuram and Varadaiahpalem mandals with rice- groundnut, rice-rice, rice-jowar/bajra, rice-vegetables and fallow-rice cropping systems under variable land forms and management practices. The fertility status of the given area can be delineated on the maps so as to indicate the fertility level for efficient nutrient recommendations to the crop. The soil fertility maps can be used for the soil test based nutrient management strategies (FAO, 2006). The soil fertility maps provide the readymade source of information about soil fertility status and serve as the decision making tool for successful raising of crops.

Hence, to enhance rice yields in sustainable manner detailed information on soil fertility constraints is highly essential, but such information related to rice growing soils of Tirupati revenue division of Chittoor district. However, traditional soil sample collection and interpretation methods are tedious, time taking and cost involved is higher and hence, new technological advances such as remote sensing, global positioning system (GPS) and geographical information system (GIS) which provide reliable and accurate information for resource planning and further monitoring the soil resources spatially and temporally for sustainable productivity (Shrestha, 2006).

MATERIALS AND METHODS

The study area of Tirupati revenue division consists of three sub-divisions *viz.,* Satyavedu, Srikalahasti and Tirupati and comprised of fifteen mandals *viz.,* 1.Satyavedu, 2. Varadaiahpalem, 3. Nagalapuram, 4. Pichatur (Satyavedu sub- division), 5. Srikalahasti, 6. Tottambedu, 7. B.N. Kandriga, 8. K.V.B. Puram, 9. Yerpedu (Srikalahasti sub-division), 10. Tirupati (U), 11. Tirupati (R), 12. Chandragiri, 13. Renigunta, 14. Pakala and 15. Pulicherla mandals (Tirupati sub-division) and falls under southern agro climatic zone (NARP-AP-3) and southern plateau and ills zone (Planning commission of India - X) and geographically located between 13.28 to 14.00 N latitude and 78.88 to 80.13 E longitudes with an elevation etween 53 m and 183 m above mean sea level (MSL). The study area has sub-tropical type of climate with an average annual rainfall of 934 mm. The onset of S.W monsoon commences during first week of June and continues till third week of September, whereas N.E monsoon enters first week of October continues up to last week of December. The S.W monsoon (June – September) receives 438 mm (47%) and N.E monsoon (October to December) receives 396 mm (42.3%) rainfall.

Soil samples from 241 representative rice growing soils at 0-15 cm depth by duly recording their latitudes and longitudes with the help of global positioning system (GPS) and depicted in Fig.1. Soil samples were processed for laboratory analysis by drying under shade, pounding with wooden pestle and mortar and passed through 2 mm sieve. Soil fertility parameters *viz.,* soil reaction, E.C, organic carbon, available nitrogen, phosphorous, potassium, calcium, magnesium, sulphur and DTPA extractable micronutrients were analyzed by following the standard procedures (Table:1).

Table1: Standard protocols adopted in soil analysis

S.No.	Analytical property	Method	Reference
1	Water holding capacity	Keen Raczkowaski box method	Piper (1966)
2	Soil reaction (pH)	Potentiometry: using soil water suspension of 1:2.5 ratio	Jackson (1973)
3	Electrical conductivity	Conductometry using soil water suspension of 1:2.5 ratio	Jackson (1973)
4	Organic carbon	Chromic acid wet digestion method	Jackson (1973)
5	Available nitrogen	Alkaline permanganate method	Subbaiah and Asija (1956)
6	Available phosphorous	Colorimetry method (JascoV -530 UV/Visible spectrophotometer)	Olsen *et al.* (1954)
7	Available potassium	Neutral normal ammonium acetate method (Systronics flame photometer 128)	Jackson (1973)
8	Available sulphur	Turbidimetric method (0.15 % $CaCl_22H_2O$)	Cottenie *et al.* (1979)
9	Exchangeable Ca and Mg	Complexometric titration - Versenate method	Kanwar and Chopra (1976)
10	DTPA extractable Micronutrients (Fe, Mn, Zn and Cu)	DTPA extract through atomic absorption spectrophotometer (VARIAN AA240FS).	Lindsay and Norvell, (1978)
11	Boron	Hot water extraction	Keren (1996)

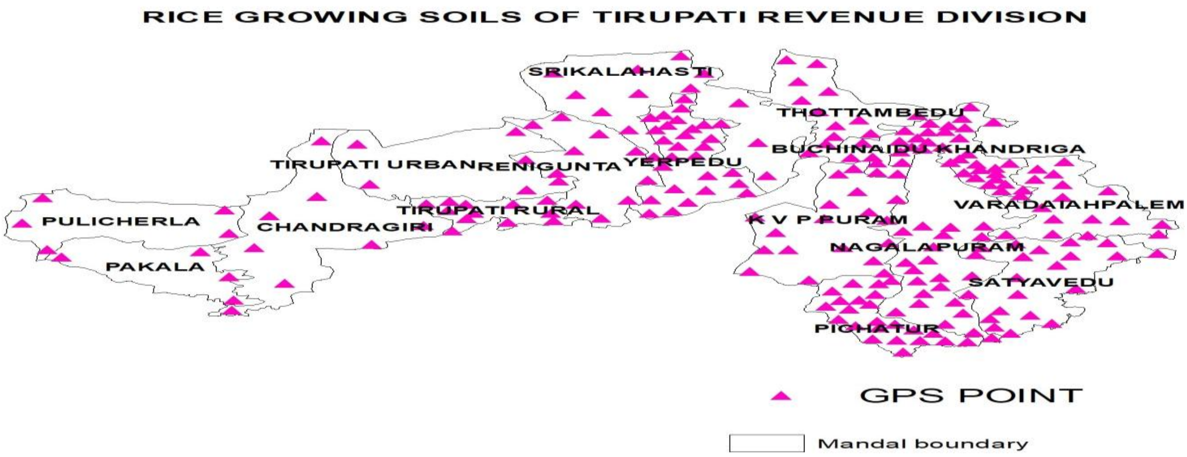

Fig. 1: GPS locations of soil samples collected from rice growing areas

The latitude and longitudes of sample sites of soil were collected in study area by using a hand-held GPS instrument (GARMIN-GPS60CSx). The GPS technology proved to be very useful for enhancing the spatial accuracy of the data integrated in the GIS. The *Arc* GIS *ver.* 10 software was used in this study. Based on the location data obtained, prepared point feature showing the position of samples in MS excel format and linked with the spatial data by join option in Arc Map. The spatial and the non-spatial database developed are integrated for the generation of spatial distribution maps. Soil spatial variability maps were prepared by the interpolation of point data. Initially, geo referenced soil test results for all properties such as pH, EC, available N, available P, available K, available sulphur and micro-nutrients (Fe, Zn, Mn, Cu and B) were plotted using ARC software. Soil test values were grouped into different zones based on the cut off values representing the mean ± one SD (Standard Deviation). Subsequently, the point data was interpolated to create a continuous surface. The interpolation technique used was ordinary Kriging.

RESULTS AND DISCUSSION

1. Soil Reaction

The rice growing soils were categorized into seven soil reaction classes *viz.,* strongly acidic (5.1 to 5.5), moderately acidic (5.6 to 6.0), slightly acidic (6.1 to 6.5), neutral (6.6 to 7.3), slightly alkaline (7.4 to 7.8), moderately alkaline (7.9 to 8.4) and strongly alkaline (8.5 to 9.0) with an extent of 275, 550, 1925, 5336, 8902, 12852 and 3314 ha representing 0.8, 1.6, 11.2, 16.0, 25.0, 35.0 and 10.0 per cent of study area, respectively. The majority of rice area was grouped under moderately alkaline class with an extent of 12852 ha followed by slightly alkaline class with an extent of 8902 ha, whereas the lowest area was under strongly alkaline with an extent 275 ha only (Fig.2).

2. Electrical Conductivity

The spatial analysis of rice growing soils using GIS tools indicated the presence of three salinity classes *viz.,* non-saline (0.0-2.0 dS m^{-1}) very slightly saline (2.0-4.0 dS m^{-1}) and slightly saline (4.0-8.0 dS m^{-1}) with an extent of 28040, 4143 and 951 ha representing 84.5, 12.5 and 3.0 per cent of the study area, respectively. The majority area was rouped under non-saline class with an extent of 28040 ha (Fig.3)

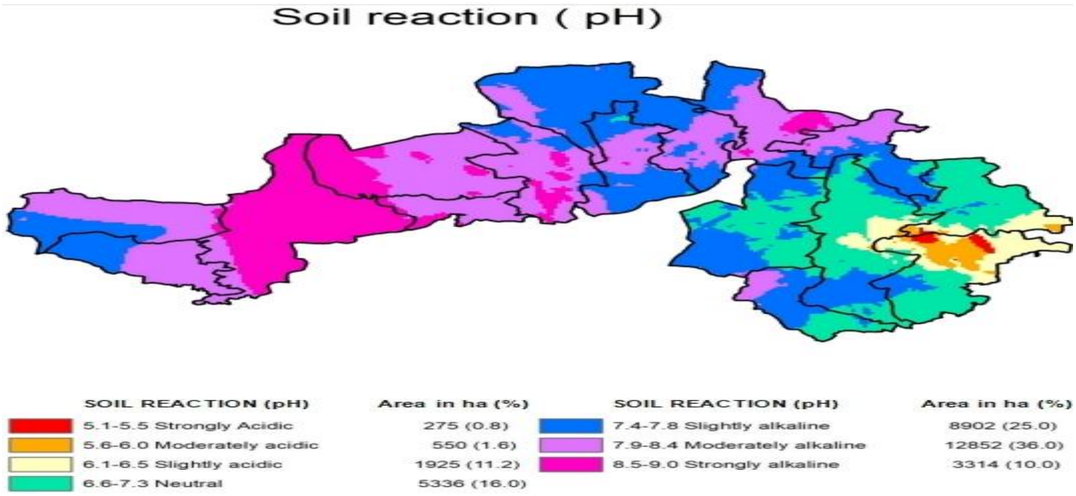

Fig. 2: Soil reaction status of rice growing soils of Tirupati revenue division

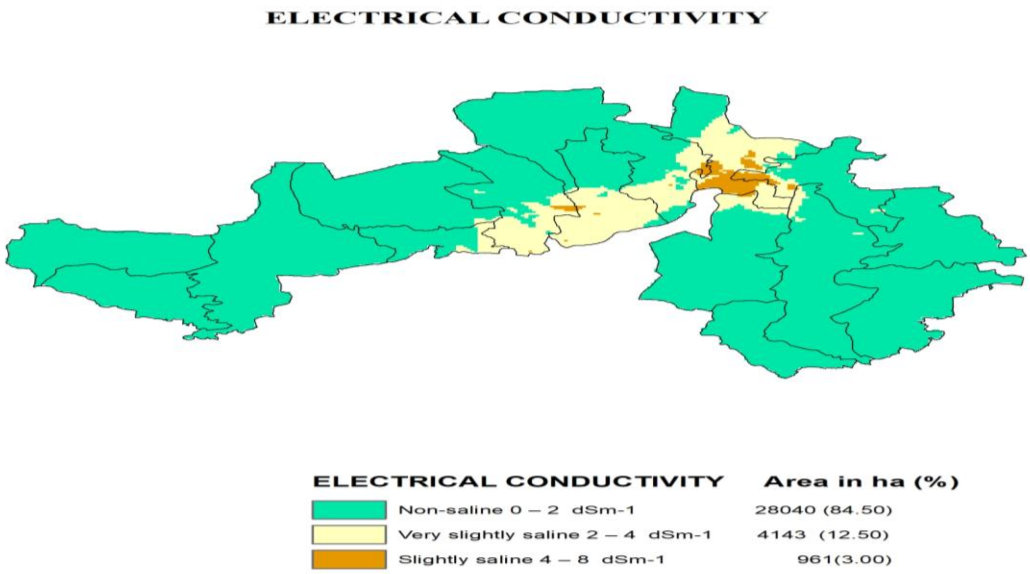

Fig. 3: Soil E.C status of rice growing soils of Tirupati revenue division

3. Organic Carbon

The rice soils of Tirupati division were low to high (1.1 – 18.1 g kg^{-1}) organic carbon with mean, standard deviation and CV of 7.0 g kg^{-1}, 0.39 and 5.70 per cent, respectively. The spatial analysis revealed that the study area was grouped under low, medium and high categories with an extent of 13609, 6297 and 13258 ha representing 41.04, 18.98 and 39.98 per cent of rice cultivated area, respectively (Fig.4). The majority of soils rice area evidenced with low status of organic carbon

(13609 ha) and the low organic carbon content was mainly due to decomposition of applied organic matter due to tropical climate coupled with limited on no application of organic manures due to non availability of organic manures (Mohan *et al.,*2021). for increasing organic carbon content in surface soil application of vermicompost is the best practice over FYM application (Priyanka *et al.,* 2016).

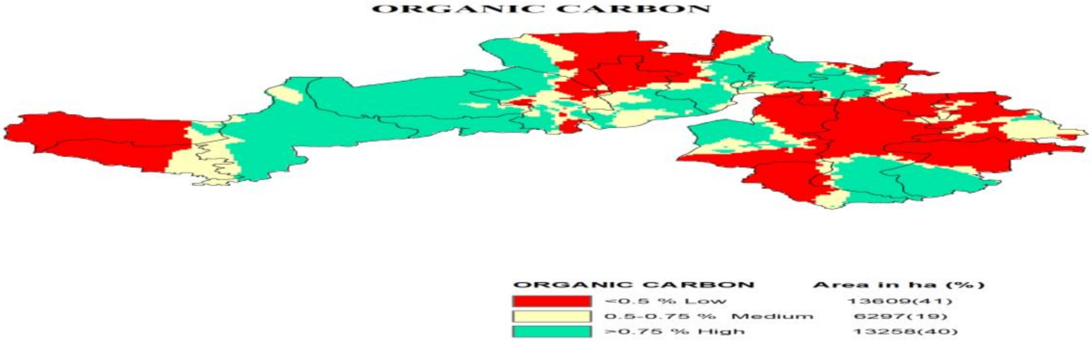

Fig. 4: Soil organic carbon map of rice growing soils of Tirupati revenuedivision

4. Macro and secondary nutrients

The available nitrogen in soils of Tirupati division was ranged from low to medium (75.0 to 527.0 kg ha^{-1}) with mean, standard deviation and CV of 241.2 kg ha^{-1}, 88.0 and 36.5 per cent, respectively. The spatial analysis indicated that the soils were under low and medium category of available nitrogen classes with an extent of 17898 and 15246 ha representing 54.0 and 46.0 per cent of the study area, respectively (Fig. 5). Available phosphorous content in rice growing soils of Tirupati division was low to high (7.7 to 349.8 kg ha^{-1}) status with mean, standard deviation and CV of 66.6 kg ha^{-1}, 50.0 and 75.2 per cent, respectively. The available phosphorous is under low, medium and high status with an extent of 3845, 20019 and 9280 ha, representing 11.6, 60.4 and 28.0 per cent of rice growing soils, respectively. The majority of area was under medium status (20019 ha) and whereas the lowest area was under low status (3845 ha) (Fig. 6).

The available potassium was ranged from low to high (39.0 to 1038 kg ha^{-1}) with mean, standard deviation and CV of 236.1 kg ha^{-1}, 154.8 and 65.6 per cent, respectively. The spatial analysis indicated low, medium and high status with an extent of 7457, 19223 and 6464 ha representing 22.5, 58.0 and 19.5 per cent, respectively. The majority of area was grouped under medium status (19223 ha) and whereas the lowest area of 6464 ha was grouped under high status (Fig. 7). The available sulphur content was ranged from deficient to sufficient (2.7 to 184.3 mg kg^{-1}) with a mean value of 38.8 mg kg^{-1}. The standard deviation and CV of 28.8 and 74.2 per cent, respectively. The available sulphur in majority of study area was grouped under sufficient range (>10 mg kg^{-1}) with an extent of 31818 ha representing 96.0 per cent of the study area(Fig. 8). Similarly, nutrient mapping was also done by Indhuja *et al.,* 2024.

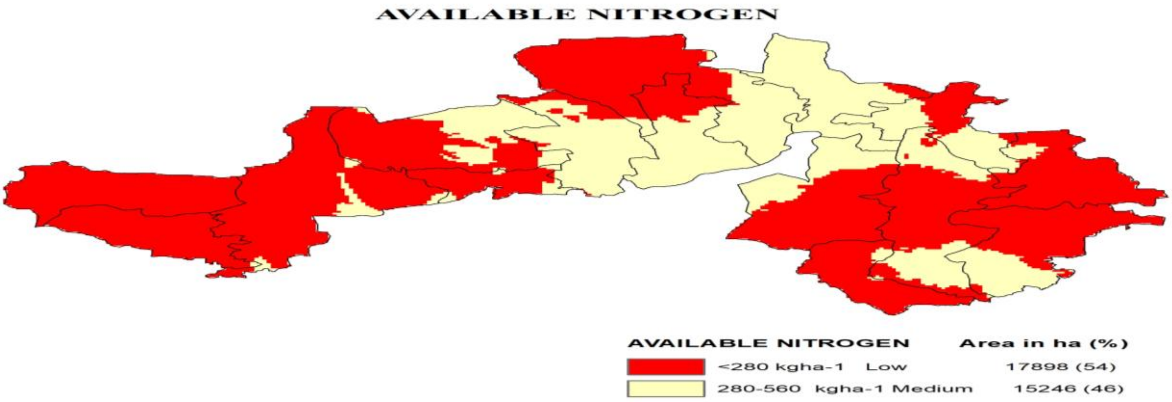

Fig. 5: Soil available nitrogen in rice growing soils of Tirupati revenue division

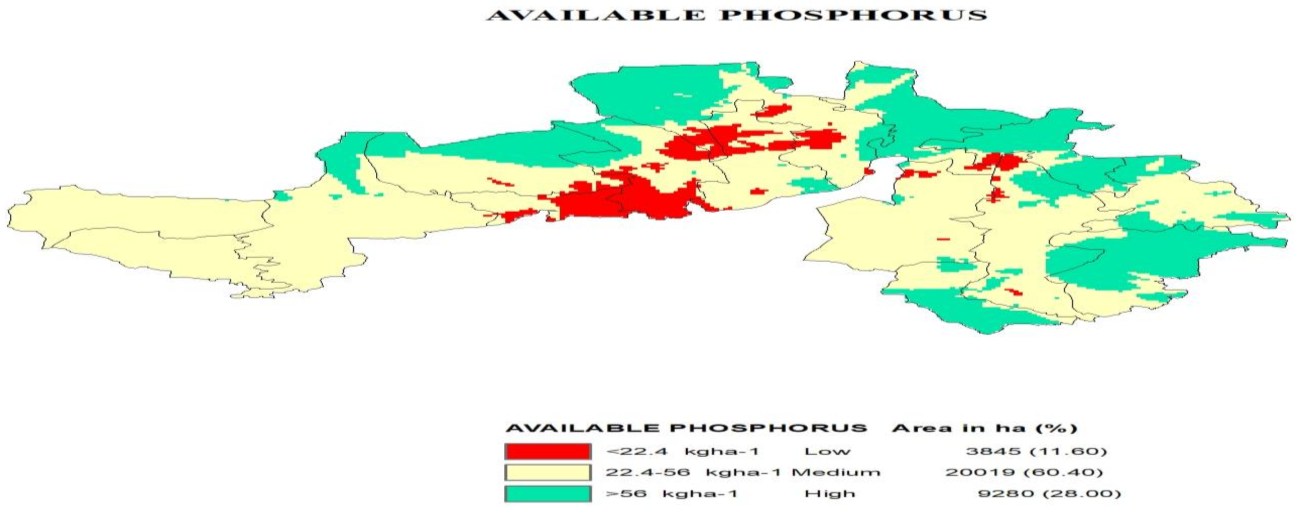

Fig. 6: Available phosphorous in rice growing soils of revenueTirupati division

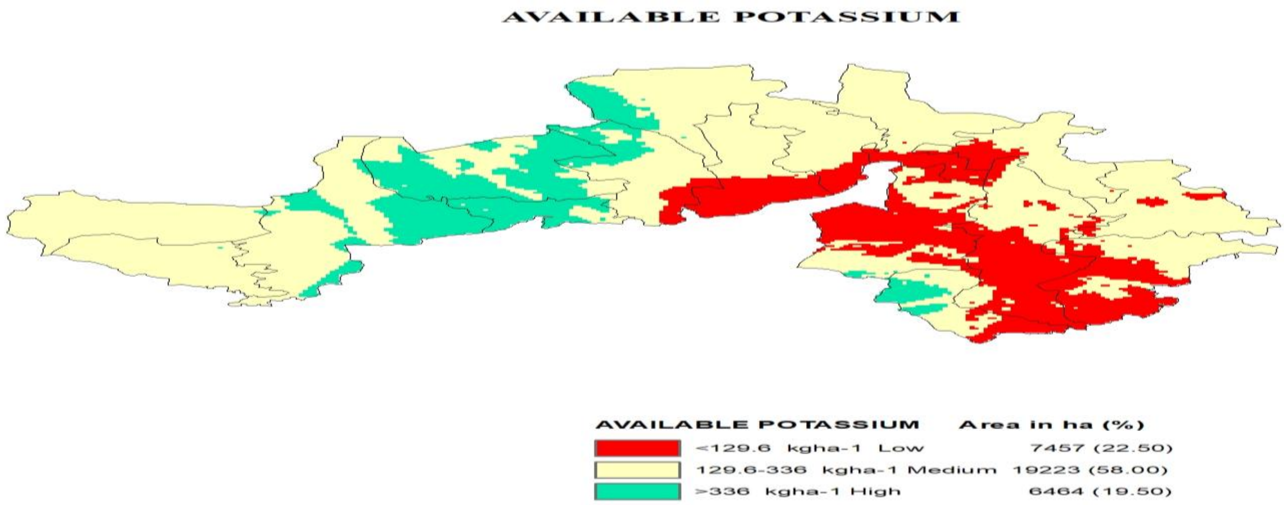

Fig. 7: Available potassium in rice growing soils of Tirupati revenue division

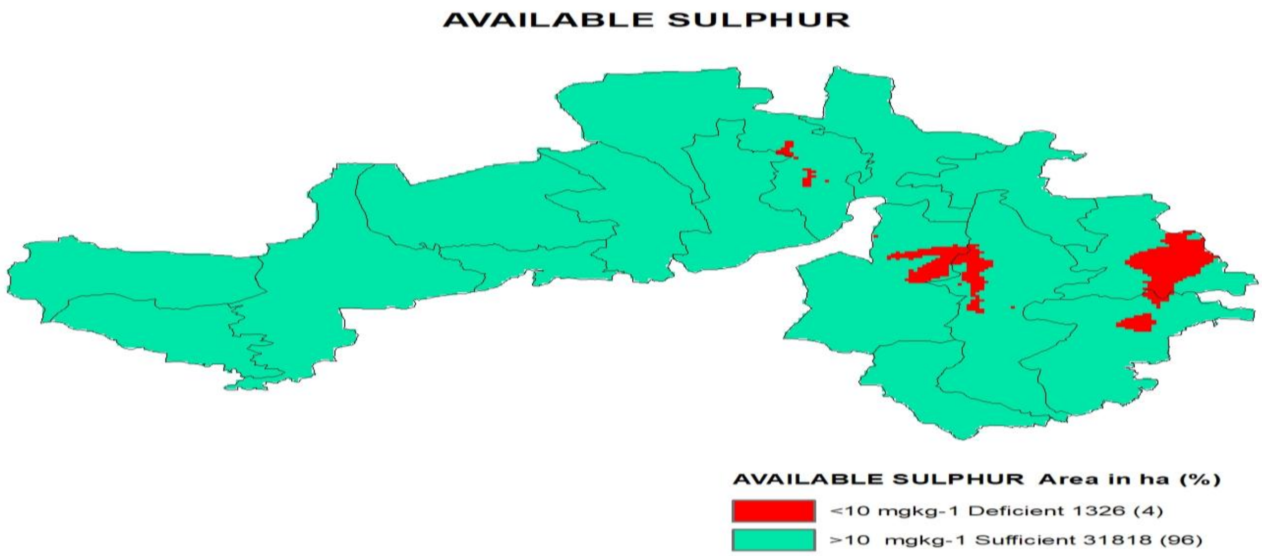

Fig. 8: Available sulphur in rice growing soils of Tirupati revenue division

5. Available Micronutrients

The available zinc content of the study area was ranged from deficient to sufficient (0.21 to 9.11 mg kg^{-1}) with mean, standard deviation and CV of 1.65 mg kg^{-1}, 1.65 and 99.8 per cent, respectively. The spatial analysis of available zinc in rice growing soils of Tirupati division using GIS indicated that major area of 25862 ha categorized under sufficient range (> 0.6 mg kg^{-1}) representing 78.0 per cent of the study area whereas, 7292 ha representing 22.0 per cent area was deficient range (> 0.6 mg kg^{-1}) (Fig. 9).

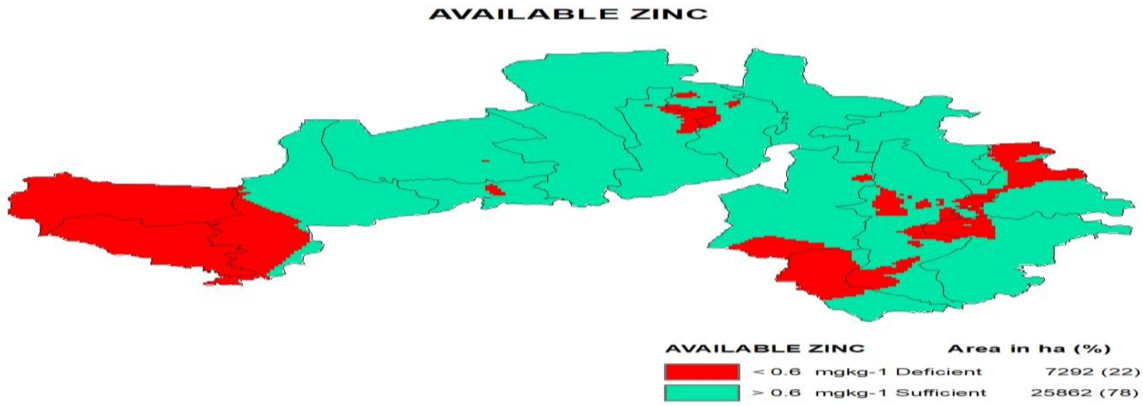

Fig.9: Available zinc status in rice growing soils of Tirupati revenue division

The available iron status in rice soils was deficient to sufficient (0.6 to 221.4 mg kg^{-1}) with mean, standard deviation and CV of 30.7 mg kg^{-1}, 40.4 and 131.2 per cent, respectively. The spatial analysis indicated that 86.25 per cent of soils were in sufficient range (>4.5 mg kg^{-1}) with an extent of 28584 ha and whereas only 13.75 per cent soils with an extent of 4560 ha area was grouped under deficient range (<4.5 mg kg^{-1}) (Fig. 10).

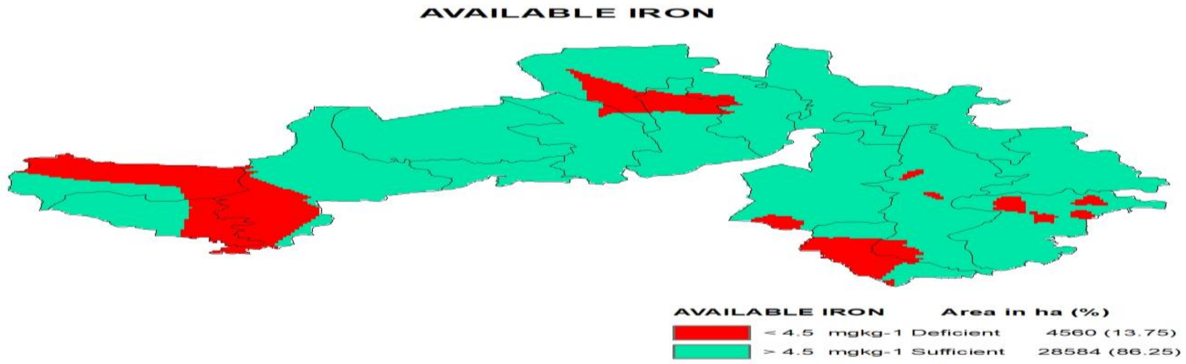

Fig. 10: Available iron status in rice growing soils of Tirupati revenue division

The DTPA extractable manganese content was ranged from deficient to sufficient (0.61 to 166.4 mg kg^{-1}) with a mean value of 21.5 mg kg^{-1}. The standard deviation and CV of 32.1 and 149.0 per cent respectively. The spatial mapping of available manganese revealed that 32393 ha of study area was under sufficient range (>1.0 mg kg^{-1}) representing 97.7 per cent whereas, 751 ha area was grouped under deficient range (<1.0 mg kg^{-1}) representing 2.3 per cent rice cultivated area of the division (Fig. 11).

The DTPA extractable copper content in rice soils of Tirupati revenue division was deficient to sufficient range (0.01-5.21 mg kg^{-1}) with mean, standard deviation and CV values of 1.02 mg kg^{-1}, 0.91 and 89.3 per cent, respectively. The spatial mapping of available copper in rice growing soils of Tirupati division revealed that major extent of area was under sufficient range (>0.2 mg kg^{-1}) with an extent of 27604 ha representing 83.3 per cent whereas, 5540 ha area was grouped under deficient range (>0.2 mg kg^{-1}) representing 16.7 per cent rice cultivated area of the division (Fig. 12).

The available boron content in soils of Tirupati division was deficient to sufficient range (0.28 to 6.10 mg kg^{-1}) with mean value of 0.73 mg kg^{-1}. The standard deviation and CV values of 0.57 and 77.9 per cent, respectively. The spatial mapping of rice growing soils of Tirupati division indicated that majority of area was categorized under sufficient range (>0.5 mg kg^{-1}) with an extent of 25190 ha representing 75.5 per cent of study area. Whereas, 24.5 per cent of soils were grouped under deficient range (<0.5 mg kg^{-1}) with an extent of 7954 ha (Fig. 13).

Fig. 11: Available manganese status in rice growing soils of Tirupati revenue division

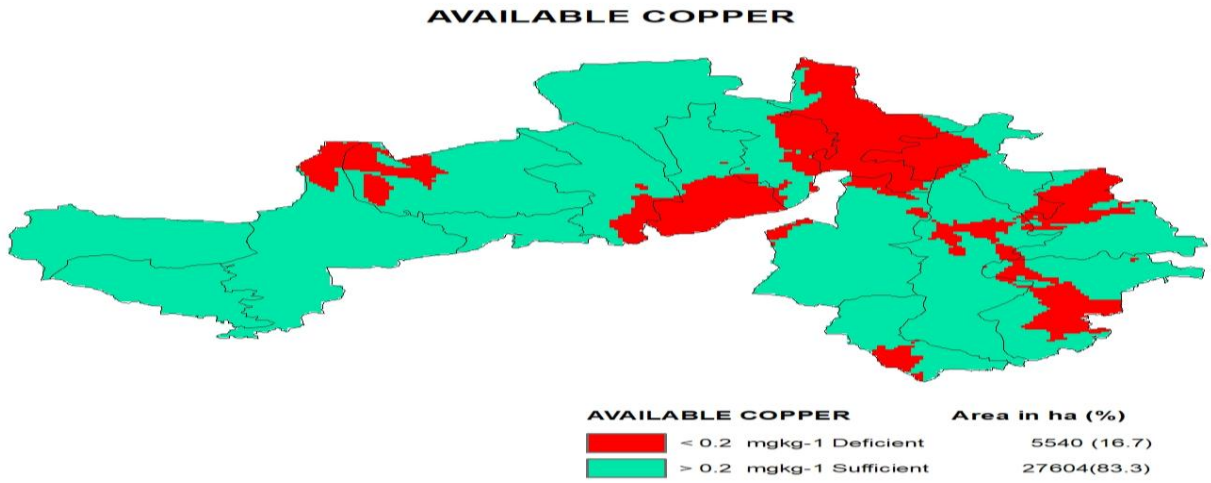

Fig. 12: Available copper status in rice growing soils of Tirupati revenue division

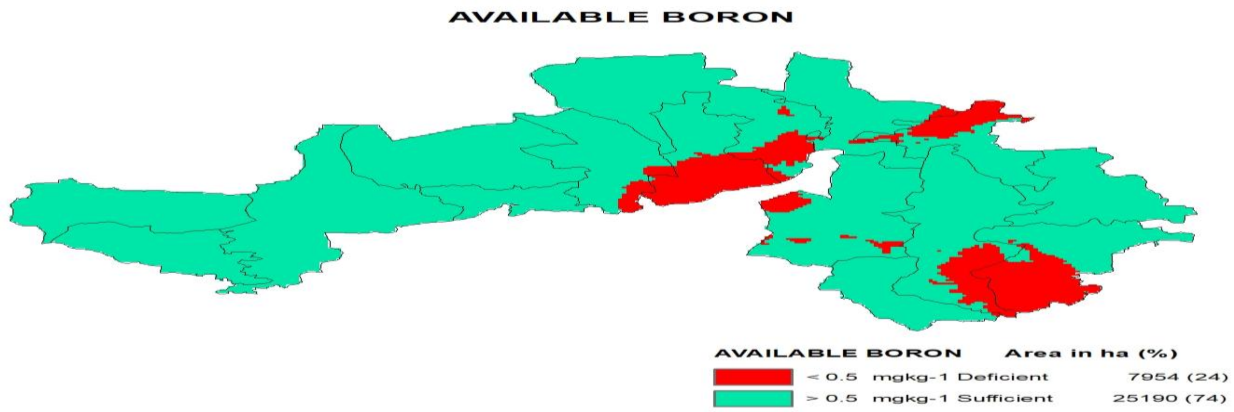

Fig. 13: Available copper status in rice growing soils of Tirupati revenue division

CONCLUSION

The rice growing soils were analyzed for soil fertility related constraints for higher productivity of rice crop. The major study area (77%) is neutral to moderately alkaline (6.6-8.4) and 10% of study area is alkali soils, hence application of gypsum and growing of daincha as green manure crop was recommended. The soils are non saline to slightly saline and observed very limited area (3%) is having salinity problem. About 41 percent study area was low in organic carbon status. The major study area was low to medium in available nitrogen (100%), phosphorous (72%), potassium (80.5%). The available sulphur was sufficient in range except in limited area (4%). The DTPA extractable micro nutrients *viz.,* zinc, iron, copper were deficient in 22%, 13.7%, 16.7 %, respectively and available boron was deficient in 24% of rice growing soils and hence soil application or foliar spraying of respective micro nutrients was recommended for higher rice yields. In conclusion adoption of integrated nutrient management with recommended chemical fertilizers and FYM application for sustainable rice yields.

REFERENCES

FAO. (2006) Plant nutrition for food security: A guide for integrated nutrient management. *Fertilizer and Plant Nutrition.* Bulletin **16**.FAO, Rome.

FAOSTAT. (2014) Food and Agriculture Organization of the United Nations, Rome, Italy. Available at: http://faostat.fao.org.

Indhuja, M., Mohan, M.M., Chari, M. S., Kumar, M.S. (2024) Mapping of plant nutrients in the soils of Bandarupalli and Mannasamudram villages in Yerpedu Mandal of Tirupati District: A GIS Approach. *Annals of Plant and Soil Research* **26**(2): 202-208.

Mathiew, M. (1979) Progress report. Fourth consultation on FAO fertilizer programme. Rome, Italy, Pp.4.

Mohan, M.M., Prasad, T.N.V.K.V., Madhuri, K.V.N., Reddy, P.V.R.M. Prasad, P.R. (2021) Carbon Farming and Soil Organic Carbon Pools under Different Land Use and Cropping Systems in Alfisols. *Journal of Agricultural. Science and Technology.* **23**(5): 1131-1147.

Priyanka, R., Khaddar, F.K. Bangar, K.S. (2016) Changes in status of organic carbon, available nitrogen and bacterial population in soils with organic manures. *Annals of Plant and Soil Research* **18**(4): 366-369.

Singh, A.K. (2014) Sustainable management of water resources: issues and strategies: IN efficient water management for sustainable agriculture. *Bulletin of the Indian Society of Soil Science*. **29**:1-86.

Shrestha, H.L. (2006) Using GPS and GIS in participatory mapping of community forest in Nepal. *Electronic Journal of Information Systems in Developing Countries*. **25**(5): 1-11.