Journal of the Andaman Science Association Vol. 20(2):186-193 (2015)
ISSN 0970-4183, Printed in India
© Andaman Science Association, Port Blair (A & N Islands), India

Assessment of Soil Fertility Status For Its Sustainable Management in Nicobar Islands, India

T.P.Swarnam*, **A.Velmurugan, S.K.Pandey, Tulsi Pawan Sai, R.Sarojini and M.N.V.Laxmi**
ICAR-Central Island Agricultural Research Institute
Port Blair – 744105, India
**Corresponding author Email : swarna_8@yahoo.com*

ABSTRACT

Surface soil samples (0-15cm) were collected from Nicobar group of Islands, India to assess the fertility status by following stratified random sampling procedure. Soil properties viz., pH, EC, organic carbon, available nitrogen, phosphorus, potassium, DTPA extractable iron, manganese, zinc, copper and hot water soluble boron were determined for grouping the soils into different fertility classes. The results indicated that the soils of Car Nicobar and Katchal were nearly neutral with calcareous soils in some places, whereas acid soils were found in Champin, Kamorta and Great Nicobar islands. There was no significant difference in distribution of organic carbon, available nitrogen, and potassium status across the islands. However, among the different land uses, significantly higher available nitrogen was observed in forest and potassium in wasteland whereas the status of micronutrients did not vary significantly. Based on the critical limits of fertility rating for various nutrients, the soil fertility of the islands can be generalized as high in organic carbon, iron, manganse, low to medium in available N, P and boron, medium to high in K, zinc and copper. Based on the fertility status crop specific manures and fertilizer recommendations were made for sustainable agricultural production in Nicobar Islands.

Key words: Soil fertility, organic carbon, micronutrients, tropical islands

INTRODUCTION

Soil is a vital natural resource, the knowledge of its characteristics and nutrient status is essential for developing specific management practices for maximizing agricultural production. Soils greatly differ in their morphological, physical, chemical, mineralogical, and biological characteristics exhibiting spatial variations. Since these characters control the response of soil to management practices, it is essential to have information about these characters for selecting management options. The major nutrients such as nitrogen (N), phosphorus (P) and potassium (K) are taken up by crops in large quantities from soil therefore, it is essential to replenish them to maintain the nutrient balance. At the same time, indiscriminate use of land results in gradual decline in nutrient supplying capacity of soil both macro and micronutrients apart from decline in soil organic matter content leading to nutrient imbalances and soil fertility degradation (FAO, 1998). It is often observed that soil properties are strongly influenced by soil management systems and changes in land use (Hulugalle et al., 1997). It is, therefore, essential that nutrient supplying capacity of the soil should be regularly monitored to maintain and ensure sustainability of agriculture.

Unlike the mainland India, soils of Nicobar group of Islands are less studied and many of the islands are remotely located. Most of the inhabitants are tribals and practice low input, rainfed agriculture. The tropical climate also favours high rate of weathering and leaching of nutrients from soils (Velmurugan et al., 2015). In order to increase the agricultural production it is vital to assess the soil resource status of these islands. In view of these a study was carried out to assess the soil resource status with a focus on soil fertility parameters in different land uses of Nicobar group of Islands. This was intended to use such information for optimizing the use of soil resource and ensuring sustainable agricultural production.

MATERIALS AND METHODS

The study area

The Nicobar group of Islands are part of the union territory of Andaman and Nicobar Islands, India that are scattered in Bay of Bengal between 6°-10° N latitude and 92°- 94° E longitude with a total area of 1841 km^2. The Nicobar group is having 22 islands of which 12 are inhabited and are divided into three distinct groups viz., northern, central and southern group of islands having distinct geomorphology and land use pattern (Fig. 1). The Car Nicobar has almost flat terrain having low relief surrounded by coral reefs and shallow seas. In central group,

Nancowry and Kamorta, have a hilly terrain covered with grass, forming undulating terrain. Katchal is slightly hilly in the centre but has a remarkable flat area. Chowra is almost flat, except for a hill which is located at its southern tip. In Great Nicobar the land is very irregular, having steep hills and valleys. In Car Nicobar and Nancowry group of Islands the major land use/cover are plantations, home gardens, natural forest and waste lands. In Great Nicobar rice and pulses are grown in coastal plains and plantations in upper slopes of the hills.

The agro-climate is typified by tropical condition with little difference between mean summer and mean winter temperatures. The annual rainfall of the islands is 3,000 mm which covers the annual PET demand except for small seasonal water deficit of 300–400 mm during the dry period (January to March). The relative humidity varies from 79% to 89%, the maximum and minimum temperature ranges from 27 to 33° C and 21 to 25° C, respectively. The daily evaporation rate is fairly high which cumulatively ranges from 1500 - 1800 mm per annum. The area experiences *Udic* soil moisture and *Isohyperthermic* soil temperature regime.

Soil sampling and analyses

The surface soil samples (0-15cm) were collected from four major land uses *viz*., natural forests, plantations, home gardens, and waste land from Car Nicobar, Kamorta, Champin, Katchal and Great Nicobar islands following standard procedure with four replications in each land use (stratified random sampling). Each sample was a composite of 7-8 cores, randomly collected from the area represented by a specific land use. From each site about 250 g soil was collected and mixed thoroughly to make one representative sample. The samples were air dried, ground and passed through 2 mm sieve for determination of chemical parameters. The pH and Electrical conductivity (EC) were measured by combined glass-calomel electrode and conductivity bridge respectively, in a soil water solution ratio of 1:2 (Richards, 1954). The soil organic carbon was determined by wet digestion method (Walkley and Black, 1934). The soil samples were also analyzed for mineralizable N by alkaline permanganate method (Subbiah and Asija 1956), available P (Olsen *et al*., 1954) and ammonium acetate extractable K (Jackson, 1973). The DTPA extractable micronutrients like Fe^{2+}, Mn^{2+}, Zn^{2+} and Cu^{2+} were determined by following the method of Lindsay and Norvel (1978) and hot water soluble B was determined by boiling soil in de-ionized water (1:2) and allowing refluxing for 5 minutes and then determining boron using azomethane-H in the extract (John *et al.* 1975). In addition, at representative sites soil morphological features depicting its status were recorded belonging to each great group established in an earlier soil survey (Ganeshamurthy et al., 2002).

RESULTS AND DISCUSSION

The soils of Nicobar Islands are mainly derived from sedimentary rocks like mudstone, limestone, clay stone, and associated conglomerate besides sandstone. In certain places soils are formed from plastic and magnesian clay, marls and partially serpentine rocks. The properties of soils are greatly influenced by the geomorphology of the location apart from the land use (Fig. 1). The soils of Nicobar group of Islands are classified into three orders (Entisol, Inceptisol, and Alfisols) and eight suborders and so far eight soil series have been established. The soil series occur either as single entity or as an association of two to three series in a mapping unit (Ganeshamurthy et al., 2002). The major limitations are erosion, soil acidity, low water holding capacity and poor nutrient status.

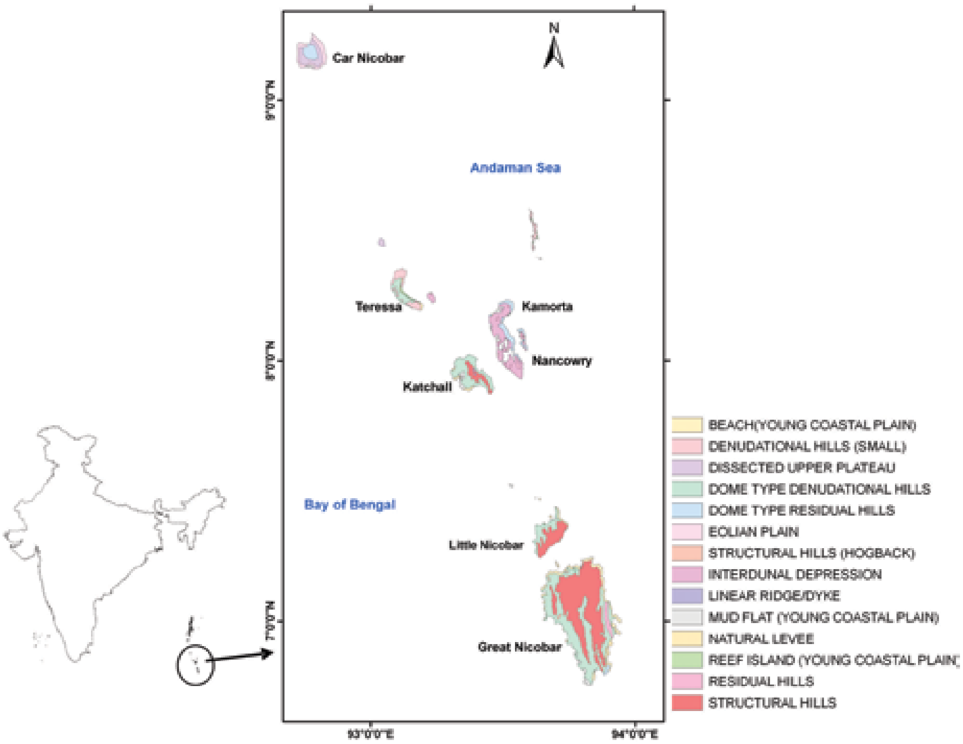

Fig 1. Location and geomorphology map of Nicobar islands

Chemical properties

The soils are acidic to neutral except in parts of Car Nicobar and Katchal where calcareous soils are found. Acid soils are found in Kamorta, Champin and Great Nicobar Islands with pH values less than 5.5 (Table 1) whereas slightly acidic to neutral soils are found in Katchal Island with average pH of 6.8 (±0.8). In Car Nicobar soils are slightly acidic to neutral and in some areas calcareous soils are found with pH values exceeding 8.0. This difference in pH was mainly due to the difference in the nature of parent material and leaching of metal cations from the soil. However, the soils are non saline and the variation was minimal (± 0.1) across the Island group irrespective of their pH. The mean values of salinity (EC) in different islands varied from 0.06 to 0.15 dS m^{-1} which is mainly due to intensive weathering and leaching of soluble salts by the rainwater as these islands experience hot and humid climatic conditions. In general, the results suggested that the values of organic carbon did not differ significantly across the Islands. The mean values of soil organic carbon in different islands ranged from 1.26 to 2.70 %. The higher organic carbon value of these Islands was mainly due to dense tropical forests/ vegetation coverage and absence of intensive agricultural practices.

Table 1. Fertility status of soils in different islands of Nicobar district

Island Name	pH	EC (dSm^{-1})	OC (%)	Available Macro nutrients ($kg\ ha^{-1}$)			DTPA micronutrients ($mg\ kg^{-1}$)				Hot water soluble B ($mg\ kg^{-1}$)
				N	P	K	Fe^{2+}	Mn^{2+}	Zn^{2+}	Cu^{2+}	
Car Nicobar	7.1 ± 0.7	0.15 ± 0.07	1.94 ± 0.34	231 ± 76	24 ± 7.2	206 ± 89	15.36 ± 5.16	6.52 ± 3.69	1.62 ± 0.50	0.83 ± 0.54	0.35 ± 0.13
Kamorta	5.2 ± 0.8	0.12 ± 0.04	1.68 ± 0.20	285 ± 145	7.6 ± 4.5	287 ± 53	23.58 ± 6.83	11.67 ± 3.33	1.61 ± 0.71	0.88 ± 0.28	0.17 ± 0.09
Katchal	6.8 ± 0.8	0.11 ± 0.02	1.26 ± 0.65	218 ± 37	16.8 ± 8.5	304 ± 146	14.3 ± 6.3	10.19 ± 3.64	0.72 ± 0.45	0.55 ± 0.26	0.32 ± 0.13
Champin	5.2 ± 0.2	0.07 ± 0.01	2.09 ± 1.07	219 ± 32	14.9 ± 4.6	297 ± 51	28.2 ± 5.2	13.3 ± 3.67	2.27 ± 0.54	1.38 ± 0.46	0.19 ± 0.12
Great Nicobar	5.1 ± 0.2	0.06 ± 0.01	2.70 ± 0.63	352 ± 45	9.7 ± 1.1	232 ± 35	21.6 ± 1.56	10.81 ± 0.60	1.78 ± 0.11	1.37 ± 0.30	0.27 ± 0.03

Macronutrients status

The available nitrogen varied from 142 to 569 kg ha^{-1} with significantly higher mean concentration in Great Nicobar (352 kg ha^{-1}) followed by Kamorta (285 kg ha^{-1}) and Car Nicobar (231 kg ha^{-1}). The available N was low in Katchal (218 kg ha^{-1}) and Champin (218 kg ha^{-1}) islands. The results indicated that 61% of the samples falls under medium fertility, while 36.6% of the samples under low fertility class. The data indicated a significant, positive correlation between organic carbon and available N ($r = 0.634^{**}$), which is in conformity with the findings of Panwar *et al.*2012. This means that major portion of soil N is in organic form and approximately with 2-3% mineralization rate this could supply a major portion of crop N requirement, sustaining the low input agriculture systems of the tribal areas.

The available P varied significantly across the Islands. The average value of available P was low (7.6 to 9.7 kg ha^{-1}) in Kamorta and Great Nicobar whereas higher amount of P was recorded in Champin, Katchal and Car Nicobar Islands (14.9 to 24 kg ha^{-1}). The P availability was primarily influenced by soil pH as evidenced from significant positive correlation between pH and available P ($r = 0.766^{**}$). Higher available P was observed in slightly acidic to neutral soils, while in strongly acid soils as in Kamorta and Great Nicobar, the available P is converted into insoluble form by various soil components especially iron and aluminium oxides making it unavailable to crops (Mahapatra *et al.*1997).

The soils of the Nicobar Islands are mostly medium in available K status with values ranging from 109 to 419 kg ha^{-1}. The mean concentration was higher in Katchal (304 kg ha^{-1}) followed by Champin (297 kg ha^{-1}) and Kamorta (287 kg ha^{-1}) islands. In Car Nicobar the available K content exhibited high variability which varied from 40 to 420 kg ha^{-1} in different locations. Potassium content was low in coarse textured soils found in Kinyuka and Kinmai villages where it varied from 40 to 140 kg ha^{-1} only. This could be due to low retention capacity of sandy soils and removal of K ions by intensive leaching.

Significantly higher N was observed in forest land followed by homegardens whereas no significant difference was observed between coconut plantation and waste land (Fig. 2A). This showed that the N fixation and recycling is higher in forest land use followed by homegardens which is well maintained with the addition of organic manures. Though there are variations in available P and K but no significant difference was observed except for higher K and P in homegardens. This is attributed to very less management of coconut gardens resulting in no difference between wasteland and forest land. Therefore, in order to enhance the coconut productivity it is essential to apply sufficient K and P to the plantations.

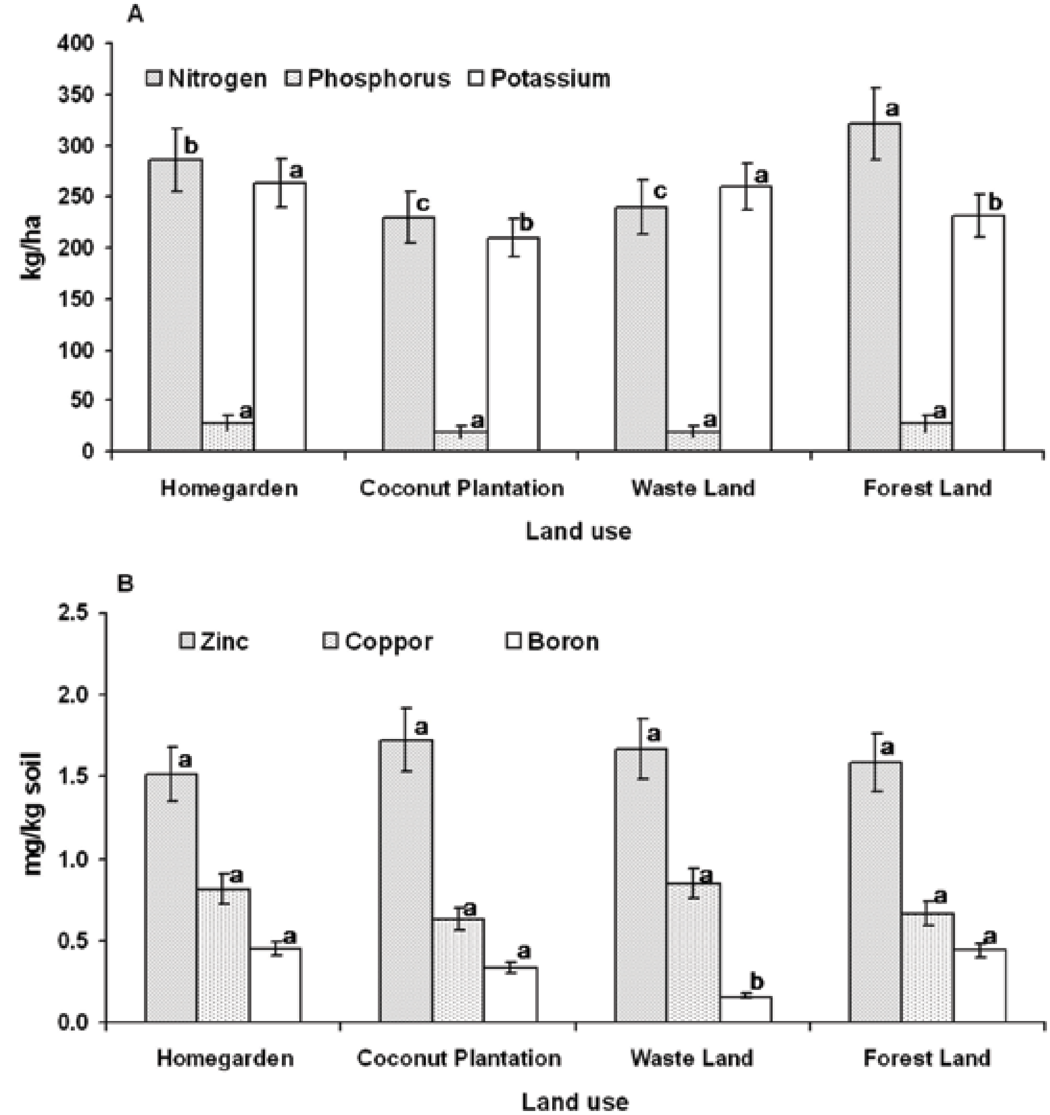

Fig. 2. Soil available nutrient status of Car Nicobar under different land use
A. Macro nutrients B. Micronutrients

Micronutrients status

The mean values of DTPA extractable Fe in Nicobar Islands varied from 14.3 to 28.2 mg kg^{-1} far exceeding its maximum critical limit of 4.5 mg kg^{-1}. Among the islands the mean concentration of DTPA-Fe^{2+} was significantly lower in Katchal and Car Nicobar. The mean concentration of DTPA- Mn^{2+} content was 10.2 to 11.7 mg kg^{-1}, with the lowest value recorded in Car Nicobar (6.5 mg kg^{-1}). In acid soils the Fe^{2+} and Mn^{2+} content were higher due to the higher solubility of oxides and hydroxides of these nutrients (Talukdar *et al.*2009). This was corroborated by a significant negative correlation observed between pH and DTPA Fe^{2+} (r= 0.718**) and DTPA Mn^{2+} (r= 0.628**), respectively.

The DTPA extractable Zn^{2+} content varied from 0.10 to 2.73 mg kg^{-1} and low mean concentration (0.72 mg kg^{-1}) was recorded in the soils of Katchal. The results also indicated that the soils are well supplied with available zinc (DTPA-Zn^{2+}) as 56.1% of samples exceeded the critical limit of > 1.5 mg kg^{-1} and only 7.3% samples were less than the deficit level (0.60 mg kg^{-1}). The DTPA extractable Zn content showed a negative correlation with pH (r = 0.299*) and positive correlation with organic carbon (r =0.295*). The higher organic carbon content of these soils might have resulted in increased surface area for ion exchange contributing to higher amount of DTPA-Zn in soils (Sharma *et al*. 2003). Due to which zinc deficiency was not observed in any of the cultivated crops supporting traditional method of soil fertility management.

The DTPA extractable Cu^{2+} varied from 0.10 to 1.89 mg $kg^{-1}$and average content was comparatively lower in Katchal (0.55 mg kg^{-1}), while higher mean values were recorded in Champin (1.38 mg kg^{-1}) and Great Nicobar (1.37 mg kg^{-1}) islands. Among the total samples analyzed, 90.2% samples falls under sufficiency range (0.2 - 0.5 mg kg^{-1}) indicating that copper is not a limiting nutrient in these islands except in few places which are mostly calcareous. The correlation studies showed a positive relationship with organic carbon (r = 0.385**) and negative correlation with pH (r= 0.459**) as that of other micronutrients. In general, the increased availability of DTPA extractable Fe, Mn, Zn and Cu under low pH and higher organic carbon was due to increased solubility of oxides and hydroxides of the respective ions (Venkatesh *et al*., 2003).

The hot water soluble boron ranged from 0.07 to 0.70 mg kg^{-1} with majority (75.6%) of the samples in sufficiency limit of 0.15 to 0.50 mg kg^{-1}. In Kamorta and Champin islands, the mean concentration was only 0.17 to 0.19 mg kg^{-1}, as against 0.27 to 0.35 mg kg^{-1} in other islands.

Among the micronutrients, the boron content was less primarily due to the acidic reaction followed by heavy precipitation (Xu *et al*.2001). Unlike other micronutrients, the hot water soluble B showed positive relation with pH, but not in a consistent manner (Tsadilas *et al*. 1994). Because, boron adsorption by soil components also increases with increase in pH and reaches a maximum in alkaline pH range. The relation between hot water soluble B and organic carbon was positive but non significant ($r=0.229^{NS}$). However, Sharma and Bajwa (1989) observed similar positive but significant correlation between hot water soluble B and organic matter.

There were no significant difference in the DTPA extractable Zn, Cu and B except for waste land which was found to have lowest B and highest Cu content (Fig. 2B). As there were no manure or micronutrients used in crop cultivation in addition to the recycling of organic wastes in the plantations, a uniform distribution pattern of micronutrient was observed.

Fertility ratings

Based on the criteria for soil fertility ratings (table 2) samples were grouped into different fertility categories. The fertility status of different islands was determined based on maximum number of samples falling in a category (table 3). The soils were high in organic carbon, available iron, and manganese in all the islands. The nitrogen and boron are in the range of low/deficient to medium/sufficient in Car Nicobar, Kamorta and Champin Islands. Phosphorus status was low to medium in all except Car Nicobar Island, medium/sufficient in potassium, and medium/sufficient to high in zinc and copper.

Table 2. Criteria for soil fertility ratings for different nutrients

Nutrients	Fertility rating for soil		
Major nutrients	**Low**	**Medium**	**High**
Organic carbon (%)	< 0.5	0.5 - 0.75	> 0.75
Nitrogen (kg ha^{-1})	< 280	280 - 560	> 560
Phosphorus (kg ha^{-1})	< 11	11- 22	> 22
Potassium (kg ha^{-1})	< 110	110 - 280	> 280
Micronurients	**Deficient**	**Medium**	**High**
Iron (mg kg^{-1})	< 2.5	2.5 - 4.5	> 4.5
Manganese (mg kg^{-1})	< 2.0	2.0 - 4.0	> 4.0
Zinc (mg kg^{-1})	< 0.6	0.6 - 1.5	> 1.5
Copper (mg kg^{-1})	< 0.2	0.2 - 0.5	> 0.5
Boron (mg kg^{-1})	< 0.15	0.15 – 0.50	> 0.50

Table 3. Fertility rating for different nutrients in various islands

Island Name	Fertility class								
	OC	**N**	**P**	**K**	**Fe**	**Mn**	**Zn**	**Cu**	**B**
Car Nicobar	H	L to M	M to H	M to H	H	H	S to H	S to H	D to S
Kamorta	H	L to M	L to M	M to H	H	H	S to H	S to H	D to S
Champin	H	L to M	L to M	M to H	H	H	S to H	S	D to S
Katchal	H	H	L to M	M to H	H	H	S to H	S to H	S
Great Nicobar	H	M	L to M	M to H	H	H	S to H	S	S

L- low, M-medium, H – high, D- deficient, S-sufficient

Nutrient management

Any intensification of agricultural activities in Nicobar Islands should ensure the sustainability of soil fertility. As the production system is organic by default in Car Nicobar and Nancowry group of Islands, it is essential to support organic production by efficiently recycling locally available organic wastes with the small holder farms. The best option is to go for vermicomposting of crop residues and animal wastes. In Nicobar Islands, plenty of plantation wastes are available in the form of coconut, arecanut leaves and their husk. From a well managed coconut garden with 175 palms ha^{-1}, nearly 14 t ha^{-1} $annum^{-1}$ organic wastes can be collected. Besides, the animal wastes like pig, goat and poultry can be collected and used for composting. As the pigs are the major farm animal found in Nicobar district, a small step to collect its waste can make significant quantum of manure which can be used for composting of organic wastes. Similarly goat can also contribute about 350 kg manure per year. Though poultry is grown under free ranging system, providing night shelters would enable collection of wastes. Similar to other animal manures, it is good source of nutrients and enhances composting of organic wastes. In addition, vermicomposting of organic wastes will support growing crops like vegetables, tubers and fruits in a semi intensive farming.

In certain areas where commercial cultivation is practised, spraying of Zinc sulphate 0.3% + 1% vermiwash at 45 and 60 days after planting of banana main crop and 45 days after cutting of mother plant for ratoon crop. In Zn deficient soils, for papaya and banana, application of Zinc sulphate @ 30-50g/plant at the time of planting is recommended. The fruits of boron deficient papaya are deformed and bumpy due to the irregular fertilization and development of seeds within the fruit. A shortage of boron also causes cracking and distorted growth in other fruits. Corrective measure is application of borax at 20 g/tree along with organic manures, at the time of planting for papaya and foliar spray of 0.2% boric acid at fourth and fifth month of planting.

CONCLUSIONS

In general, soil properties varied across the Nicobar Islands due to difference in geomorphology, parent materials, and land use. The soils of Car Nicobar and Katchal are neutral at many places and in some places calcareous soils with pH exceeding 8.0 were also noticed. In contrast, at many places acid soils are found in Champin, Kamorta and Great Nicobar. The differences in soil available P and micronutrient followed the trend in soil pH. The available P and hot water soluble Boron was low in acid soils as compared to the neutral soils of Car Nicobar and Katchal Islands. There is no significant difference in the distribution of organic carbon, available nitrogen, and potassium among the islands. Based on the critical limits of fertility rating for different nutrients the soil fertility of the islands was generalized as high in organic carbon, iron, manganese; low to medium in available N, P and boron; medium to high in K, zinc and copper. Crop specific manurial and fertilizer recommendations based on these categories are essential for sustaining agricultural production in these Islands.

ACKNOWLEDGEMENTS

The financial and material assistance provided by ICAR- Central Island Agricultural Research Institute, Port Blair are thankfully acknowledged. The authors place on record their gratitude to the Dr. S. Dam Roy, Director, ICAR- CIARI for his support and constant encouragements. We also sincerely acknowledge the support of scientists, research scholars, technical, supporting and administrative staffs of the institute.

REFERENCES

FAO, (1998). Land resources in small Island developing States, Food and Agriculture Organization of the United Nations, UNEP Report No. E/CN.17/1998/7, http://islands.unep.ch.

Ganeshamurthy, A. N., R. Dinesh, N. Ravisankar, Anil Nair & S. P. S. Ahlawat. 2002. *Land resources of Andaman and Nicobar Islands*, Central Agricultural Research Institute, Port Blair.p.

Hulugalle, N. R., L. A. Lobry de Bruyn & P. Entwistle, 1997. Residual effects of tillage and crop rotation on soil properties, soil invertebrate numbers and nutrient uptake in an irrigated Vertisol sown to cotton. *Applied Soil Ecology,* **7**: 11-30.

Jackson, M.L. (1973). Soil Chemical Analysis. Prentice Hall of India Pvt. Limited, New Delhi.

John , M.K., Chuah, H.H. & Neufeld, J.H. (1975). Application of improved azomethane H method to the determination of Boron in soils and plants. Analytical Letters 8, 550-568.

Lindsay, W.L. & Norvel, W.A.(1978). Development of a DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal* **42**, 421-428.

Mahapatra I.C., Mandal S.C., Misra C., Mitra G.N. & Panda N (1996).Acid soils of India.Indian Council of Agricultural Research, New Delhi.p270.

Olsen, S. R., C. V. Cole, F. S. Watanabe, & L. A. Dean.1954. *Estimation of available phosphorus in soils by extraction with sodium bicarbonate* (U.S. Department of Agriculture Circular 939). Washington, D.C.: U.S. Government Printing Office.

Panwar P, Sharmistha Pal, Reza S.K. & Bilap Sharma (2011). Soil fertility index, soil evaluation factor, and microbial indices under different land uses in acidic soil of Humid Subtropical India, Communications in *Soil Science and Plant Analysis,* **42**:272424-2737.

Richards, L.A.(1954). Diagnosis and improvement of saline and alkali soils (USDA Agriculture Handbook No.60), Washington D.C., U.S. Government Printing Office.

Sharma R.P., Singh M. & Sharma J.P.(2003). Correlation studies on micronutrients vis-a-vis soil properties in some soils of Nagaur district in semiarid region of Rajasthan. *Journal of the Indian Society of Soil Science* **51,** 522-527.

Sharma, H.C. & Bajwa, M.S. (1989). Different forms of boron in salt affected soils. *Journal of the Indian Society of Soil Science* **25,** 47-53.

Subbiah,B.V. & Asija, G.L. (1956). A rapid procedure for assessment of available nitrogen in soils. *Current Science* **31**:196-260.

Talukdar, M.C., Basumatary, A. & Dutta, S.K. (2009). Status of DTPA-extractable cationic micronutrients in soils under rice and sugarcane ecosystems of Golaghat district in Assam. *Journal of the Indian Society of Soil Science,* **57**(3):313-316.

Tsadilas, C.D., Yassoglou,C.S., Kosmas, C.S. & Kallianou,C.H.(1994). The availablity of soil boron fractions to olive trees and barley and their relationships to soil properties. *Plant soil* **162**:211-217.

Velmurugan, A., Dam Roy, S., Krishnan, P., Swarnam, T.P., Jaisankar, I., Singh, A.K. & Biswas. T.K. (2015). Climate change and Nicobar Islands: impacts and adaptation strategies. *Journal of the Andaman Science Association,* **20**(1):1-12.

Venkatesh, M.S., Majumdar, B., Kumar, K. & Patiram (2003). Status of micronutrient cations under various land use systems of Meghalaya. *Journal of the Indian Society of Soil Science* 51, 60-64.

Walkley, A. & Black,I.A. (1934). An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37**: 29-38.

Xu, J.M., Wang, K., Bell,R.W., Yang, Y.A. & Huang L.B. (2001). Soil boron fractions and their relationship to soil properties. *Soil Sci. Soc. Am. J.***65**: 133-138