Agropedology 2019, 29 (01), 51-60

Physico-Chemical Properties of Soil and Mineral Composition of Plants as Affected by Fox Nut-Based Cropping Systems

I.S. Singh*, Manoj Kumar, A.K. Thakur [1], A.K. Choudhary [2], B.P. Bhatt [2], S.P. Singh [3] and S. S. Prasad [3]

ICAR Research Complex for Eastern Region, Research Centre for Makhana, Darbhanga-846005, Bihar, India
[1]ICAR-National Institute of Natural Fibre Engineering and Technology, Kolkata- 700040, West Bengal, India
[2]ICAR Research Complex for Eastern Region, Patna-800014, Bihar, India
[3]Department of Soil Science, Rajendra Agricultural University, Pusa-848125, Bihar, India

Abstract: *Foxnut (Euryale ferox* Salisb.) is exclusively an aquatic crop and generally grown naturally in non-saline wetland areas having stagnant water. Prolonged submergence in lowlands impedes the cultivation of most field crops except few one such as rice. For enhancing the system productivity, crop diversification technology needs to be adopted in wetland/aquatic ecosystems as well. In present study fox nut-based eight different crop rotations, *viz. fox nut-fox nut, fox nut-rice, fox nut-wheat, fox nut-berseem, fox nut-water chestnut, fox nut-rice-wheat, fox nut-rice-berseem and fox nut*-water chestnut-berseem were followed consecutively for three years (2012-13 to 2015-16). The pooled data showed that *fox nut*-water chestnut-berseem cropping system had more organic carbon, available N, P and K to the tune of 25 %, 14.75 %, 26.66 % and 6.80 %, respectively over the fox nut-fox nut cropping system. The soils under *fox nut*-rice-berseem cropping system had the highest concentration of DTPA Cu (1.82 mg kg^{-1}) and Zn (0.35 mg kg^{-1}). F*ox nut* and water chestnut retained the highest tissue concentrations of the less soluble Fe and Mn and P, Cu and Zn. The results indicated that adoption of fox nut-water chestnut-berseem cropping system significantly improvedthe fertility status of soil in the aquatic low land ecosystem.

Key words: *Cropping systems, fox nut, water chestnut, rice, berseem, plant nutrients, soil fertility*

Introduction

Fox nut or Gorgon nut (*Euryale ferox* Salisb.), popularly known as makhana in India, is an important annual aquatic herb of Nymphaeaceae family. It has been widely distributed in the aquatic/wetland ecosystem of eastern India, China, Korea, Eastern Russia and Japan. In the lowland ecosystem of eastern India (parts of eastern Uttar Pradesh, Bihar, West Bengal, Assam, Chhattisgarh and Manipur), it is cultivated as a cash crop for its seeds. Bihar not only contributes 80 % of India's total production (23,000 tonnes) of makhana seeds (Jha *et al*. 2012) but it also covers 85 % of total land areas under makhana cultivation (15,294 hectares). It has attained the status of an industrial crop due to commercialization of popped form (white puffs) of its seeds. The starchy white puffs are marketed as a premium dry fruit similar to cashew nut or almond. Besides this, fox nut seeds have various medicinal properties, leading to its use in Ayurvedic and Chinese medicines (Kumar *et al*. 2015).

Traditionally considered a crop of deep-water ponds, swamps and ditches (1.20-1.80 m depth) worldwide, fox nut in India is grown in both deep-water

*Corresponding author: (Email: induciah@rediffmail.com)

pond and lowland agricultural fields with 0.15-0.60 m water depth. It is a crop of the tropical and sub-tropical climate and for its proper growth and development, the conducive range of air temperature, relative humidity and annual rainfall is 20-35°C, 50-90 % and 1000-2500 mm, respectively (Mandal *et al*. 2010). As an aquatic crop, it requires assured availability of water to be standing permanent throughout its growth period.

Besides fox nut, traditional ponds in eastern India are also used for growing another aquatic crop, called water chestnut (*Trapa bispinosa),* however, farmers grow annually only one of these two. *Water chestnut* is an annual floating emergent macrophyte and found worldwide in wetland ecosystems. In India, it is popularly known as *singhara* or *paani phal*, and is mainly grown in Madhya Pradesh, Uttar Pradesh, Bihar and Odisha. It requires standing water depth of 0.5-1.5 m throughout its growth period (August to November). Plants have a well-developed adventitious root system which enhances the absorption capacity of the nutrients directly from the soil solution through root surfaces. The timing of cultivation makes it worth-fitting in crop rotation with other aquatic crop like fox nut, especially when it is cultivated under field condition (lowland). Five major makhana based cropping systems, *i.e.,* makhana-water chestnut, makhana-berseem, makhana-rice, makhana-wheat and makhana-rice-wheat were found economically beneficial and sustainable in terms of maintenance of soil health and to increase the system productivity (Kumar *et al.* 2011).

Under crop cultivation, changes in SOM status would determine the dynamics of alluvial soil quality in wetlands (Jha and Dutta 2003). In addition to *fox nut*, other components of crops may also likely to add organic matter to the soil. Kumar *et al*. (2013) reported that fox nut and water chestnut add substantial amounts of organic matter (6-10 t ha^{-1} and 2-3 t ha^{-1} respectively) to the soil. Besides this, the organic matter contributed by the preceding crop, in a particular crop rotation, can incorporate N leading to the increased and sustained productivity of all kinds of crops. Carter *et al*. (2002) reported that crop rotation could have a significant impact on soil health due to soil ecological interactions and processes that occur with time. These include improvement of soil structural stability, nutrient use efficiency and SOM levels. Crop rotations can also increase N availability when N-fixing legumes are included in the system (Galantini *et al*. 2000). Legumes, cultivated as one of the cropping systems, can assist in soil improvement, particularly when used as green manure crops. Fixed N and in some cases, P are made available for the succeeding crops and the added organic matter contributes to the improvement of soil structure. Varvel (2000) also reported that judicious crop rotation systems are more effective in reducing the long-term yield variability than monoculture systems, and can increase total soil C and N concentrations over time that may further improve soil productivity.

The nutrient absorption capacity of aquatic and non-aquatic crops differs a lot due to differential cell growth, tissue water content, nutrient requirement and soil condition. Aquatic macrophytes, as they grow in standing water, are able to acquire nutrients from the sediment as well as the water column (Rattray *et al*. 1991). The degree to which they use these two resources is probably related to their relative available proportions. Some aquatic macrophytes are known to be efficient removers of nutrients. The tissue nutrient concentrations of many macrophytes are reported to be dependent on the concentrations of N and K in the surrounding water (Portielje and Roijackers 1995). This suggests "luxury" uptake of nutrients (particularly of N and K).

In general, the response of lowland *fox nut* to the quantum of organic matter available in the soil system is usually higher than that of other lowland crops like rice and water chestnut, primarily because of the higher requirement of N, P, K, Fe, Mn and Zn, and easy availability of these nutrients in the soil solution under water-logged condition. The information on the cyclical pattern of nutrients under *fox nut*-based cropping systems is lacking. This paper reports the effect of different fox nut-based cropping systems on the fertility status of the silty clay loam soil of the Eastern Indo-Gangetic Plains.

Materials and Methods

The field trial (2012 to 2015) was located at 26° 10' N and 85° 87' E at an altitude of 49 m above mean sea level with a mean annual rainfall of 1150 (Adwara-Kamla flood plain) of Eastern India. The experiment was conducted at the experimental farm of the Research Centre for Makhana, Darbhanga. Prior to the experiment, the field had not been under any cropping. Fox nut, rice (*Oryza sativa*), wheat (*Triticum aestivum*), berseem (*Trifolium alexandrium*) and water chestnut (*Trapa bispinosa*) were the test crops. The soils of the experimental site are silty clay loam of Inceptisol order with crumb structure. The soil-site properties, prior to the experiment, are presented in table 1.

Table 1. Initial soil-site properties of the experiment farm

Soil-site property	Value	Soil-site property	Value
Bulk density (Mg m^{-3})	1.47	Mg hardness (mg l^{-1})	5.35
Particle density (Mg m^{-3})	2.51	dissolved oxygen (mg l^{-1})	6.0
Porosity (%)	41.43	Total N (%)	0.025
Soil moisture retention capacity (%)		Total P (%)	0.012
33 k Pa	38		
1500 k Pa	20	Total K (%)	0.201
pH	7.01	Inorganic N (ug l^{-1})	400
Electrical conductivity (dS m^{-1})	0.10	Inorganic P (mg l^{-1})	5.55
Organic carbon (%)	0.40	Ca (mg l^{-1})	2.12
CEC (cmol (p+) kg^{-1})	20	Mg (mg l^{-1})	0.70
pH of irrigation water	6.6	Chloride (Cl^{-1}) (mg kg^{-1})	7.20
Electrical conductivity of irrigation water (dS m^{-1})	0.00331	Fe (mg l^{-1})	55
Alkalinity (mg l^{-1})	80	Mn (mg l^{-1})	80
Total acidity (mg l^{-1})	10	Cu (mg l^{-1})	22
Total hardness (mg l^{-1})	12.80	Zn (mg l^{-1})	40
Ca hardness (mg l^{-1})	7.45		

The three cropping seasons include a rainy or *kharif* season from July to October, a winter or *rabi* season from November to February, and summer or dry season from March to May. Rainfall during the rainy season always exceeds evaporation, while in winter and dry seasons, the reverse was the case. The experiment was laid out in a randomized block design with 30 m X 20 m plots replicated thrice. Eight cropping systems consisting of Fox nut-Fox nut, Fox nut-rice, Fox nut-wheat, Fox nut-berseem, Fox nut-water chestnut, Fox nut-rice-wheat, Fox nut-rice-berseem and Fox nut-water chestnut-berseem were compared with the mono cropping of Fox nut-Fox nut. Each cropping system was repeated thrice, resulting in two to three crops grown within three years. Land for all crops was prepared with a tractor-drawn mould board plough. Rice seedlings were 20 days old for wet season rice. For all other crops, seeds were directly sown by hand. All crops in the various cropping systems received recommended doses of fertilizer (Table 2). Need-based irrigation was given to each crop with groundwater. Yields of main and byproducts of each crop under various cropping systems were measured by hand-harvest of a 20 m^2 area in each plot at physiological maturity. All crops were cut at about 15 cm from the surface, except fox nut and water chestnut. The economic part of individual crops was separated manually after harvesting. Yields were measured for both fresh and dry weights. Sub-samples of the main product and byproduct were oven-dried to constant weight at 70°C for 72 h and ground in a Wiley mill to pass through a 1mm sieve.

Initial soil samples were collected with an auger for the 0-15 cm soil depth at 10 locations of the experimental area. After harvesting the crop, soil samples were also collected and analyzed for each crop of the cropping systems under different treatments. The samples were thoroughly mixed and passed through a 2 mm sieve and kept in poly bags for analysis of available N, P, K, Fe, Mn, Cu and Zn following standard methods as described by Jackson (1973). Plant samples were taken at physiological maturity for fox nut, rice, wheat, berseem and water chestnut during each cropping season for the determination of N, P, K, Fe, Mn, Cu and Zn in economic and byproduct parts of the plant. Nutrient contents in plant parts were measured using standard procedures (Jackson 1973). Soils with DTPA extractable Fe, Mn, Cu and Zn less than 4.5, 2.0, 0.2 and 0.6 mg kg^{-1}, respectively were considered deficient (Lindsay and Norvell 1978). Critical limits of 50, 20, 4 and 20 mg kg^{-1} were taken for Fe, Mn, Cu and Zn, respectively in deficient plant samples. All nutrient concentrations in plant samples were expressed on a dry weight basis. Mean nutrient concentrations in the plant material of each crop were calculated.

The data, recorded under laboratory and field conditions, was statistically analyzed using OPSTAT online Agriculture Data Analysis developed by the CCS Haryana Agricultural University, Hisar, Haryana, India. The details of crop cultivars and their agronomic practices adopted in the study are given in table 2.

Table 2. Details of crop cultivars and their agronomic practices

Crops	Cultivar	Duration (Days)	Inter and intra row spacing (cm)	Recommended dose of nutrients		
				N ($kg\ ha^{-1}$)	P ($kg\ ha^{-1}$)	K ($kg\ ha^{-1}$)
Fox nut	Selection-6	150	125 x 125	100	60	40
Rice	Improved variety	140	15 x 20	80	40	40
Wheat	Improved variety	115	15 x 20	60	40	30
Berseem	Improved variety	70	-	20	80	-
Water chestnut	Local	70	100 x 100	40	60	40

Results and Discussion

Physical properties of soil under different Fox nut-based cropping system

There was an improvement in bulk density of soil with Fox nut-fox nut (1.28 Mg m^{-3}), Fox nut-water chestnut (1.30 Mg m^{-3}) and Fox nut-water chestnut-berseem (1.25 Mg m^{-3}) cropping systems over its initial value (Table 3). No change in particle density could be recorded during the period of the experiment. The significant improvement in the porosity percentage over its initial value was noticed under all the cropping system except Fox nut-rice. The improvement in bulk density under these cropping systems may be attributed to the higher addition of organic matter and more soil faunal activity in the upper region of the soil (Balamurugan *et al*. 2000). Fox nut-water chestnut-berseem cropping had the highest water holding capacity of soil at 33 k Pa (46 %) and 1500 k Pa (25 %) followed by Fox nut-water. Similar findings were also reported by Aggrawal *et al*. (1997).

Table 3. Mean values of physical properties of soil under different cropping

Cropping systems	BD ($Mg\ m^{-3}$)	PD ($Mg\ m^{-3}$)	Porosity (%)	WHC at F.C. (%)	WHC at W.P. (%)
Fox nut-Fox nut	1.28	2.50	48.80	40	21
Fox nut-wheat	1.42	2.50	43.20	38	19
Fox nut-rice	1.46	2.51	41.83	37	19
Fox nut-berseem	1.40	2.50	44.00	38	17
Fox nut-water chestnut	1.30	2.51	48.20	42	21
Fox nut-rice-wheat	1.45	2.50	42.00	39	18
Fox nut-rice-berseem	1.37	2.50	45.20	38	18
Fox nut-water chestnut-berseem	1.25	2.50	50.00	46	25
C.D. (*P=0.05*)	NS	NS	0.957	3.114	1.330

There is no significant change in pH and EC of the soils under eight cropping systems (Table 4). Increased availability of nutrients was observed in Fox nut-water chestnut-berseem cropping system. Fox nut-water chestnut-berseem had the highest content of organic carbon (0.80 %) which is 8.75-25 % higher than other cropping systems. Due to the inclusion of berseem, this cropping system also added more the above-ground biomass of crop residues. Intensive Fox nut-water chestnut-berseem and Fox nut-berseem cropping system utilize the fallow period after harvesting of Fox nut and water chestnut and in-turn, improve the SOC content. Increase in SOC in cropping systems with pulses as compared with the rice-wheat systems could be attributed to the addition of more below ground biomass in the form of the root (Ganeshamurthy 2009).

Fox nut-water chestnut-berseem had 305 kg N ha^{-1} followed by Fox nut-berseem (281 kg ha^{-1}), Fox nut-wheat (269 kg ha^{-1}) and Fox nut-water chestnut (268 kg ha^{-1}), while the minimum N was found with Fox nut-rice-wheat (Table 4). Singh *et al.* (2014) reported an improved available N content in soil due to sole cropping of Fox nut and Fox nut-berseem cropping system. The highest values of available N, P and K were noticed under Fox nut-water chestnut-berseem cropping system owing to the inclusion of berseem, a N-fixer. The early decomposition of the green succulent berseem might have caused early release and availability of nutrients in the soil solution (Bellaki and Badanaur 1994) and also favouring the mineralization of organic matter.

In all the cropping systems, the available P was found to be medium ranging between 15 kg ha^{-1} (Fox nut-rice) and 30 kg ha^{-1} (Fox nut-water chestnut-berseem) (Table 4). In the Fox nut-water chestnut-berseem cropping system, the higher available soil P might be due to production of organic acids during microbial decomposition of the crop residues (Jha and Rattan 2007) and green manure in soil and decrease in soil pH. Further, dense beds of roots of fox nut and water chestnut may increase the release rate of dissolved phosphate from sediment due to the favourable pH caused by inorganic carbon dynamics (Barko and James 1998). The increase in available P might be attributed to the reduction of ferric phosphate to the more soluble ferrous form, and to the hydrolysis of P compounds. The higher accumulation of total P in soil might be from the decomposition of succulent biomass of berseem and crop residues of fox nut and water chestnut. The increased pH, as a result of submergence, also enhances the solution concentration of Fe and Al phosphate (Patrick and Mikkelsen 1971).

The available K ranged between 210 (Fox nut-rice-berseem) and 240 kg ha^{-1} (Fox nut-water chestnut) under different cropping systems (Table 4). The higher concentration of K in the soils with Fox nut-water chestnut–berseem cropping may be attributed to flooding resulting in a larger fraction of the K^+ being displaced from the exchange complex into the soil solution. Further, the crop residues of Fox nut, water chestnut and berseem might have also added K to the available pool of the soil (Kumar and Prasad 2008) and through a reduction in fixation *via* interaction of organic matter with clay (Pannu *et al*. 2001) or displacement of some of the K ions by NH^{4+}, Fe^{2+} and Mn^{2+} from the exchange complex to the soil solution.

Table 4. Mean values of chemical properties of soil under different cropping system

Cropping systems	pH	EC (dS m^{-1})	Org. C. (%)	Av. N (kg ha^{-1})	Av. P (kg ha^{-1})	Av. K (kg ha^{-1})
Fox nut-Fox nut	7.25	0.15	0.60	260	22	219
Fox nut-wheat	7.50	0.16	0.71	269	18	214
Fox nut-rice	6.50	0.20	0.65	210	15	220
Fox nut-berseem	6.73	0.20	0.70	281	23	215
Fox nut-water chestnut	7.25	0.21	0.73	268	20	240
Fox nut-rice-wheat	7.51	0.18	0.70	206	19	213
Fox nut-rice-berseem	7.20	0.18	0.72	238	18	210
Fox nut -water chestnut - berseem	7.43	0.25	0.80	305	30	235
C.D. (*P=0.05*)	0.075	0.011	N/A	12.940	4.325	34.160

Micronutrient content of soil under Fox nut-based cropping systems

The Fox nut-water chestnut-berseem cropping system had the highest Fe content (43 mg kg^{-1}) followed by Fox nut-water chestnut (41 mg kg^{-1}), Fox nut-Fox nut (38 mg kg^{-1}), Fox nut-rice (34 mg kg^{-1}), Fox nut-berseem (34 mg kg^{-1}), and Fox nut-rice-berseem (33 mg kg^{-1}) cropping systems (Table 5). As per critical limit of 4.5 mg kg^{-1} soil (Lindsay and Norvell 1978), the soils were sufficient in available Fe. The Fox nut-water chestnut-berseem cropping system had the highest Mn content, but the available Mn in this system was found to be at par with the Mn in the Fox nut-Fox nut (14.00 mg kg^{-1}), Fox nut-rice (14.50 mgkg^{-1}) and Fox nut-water chestnut (14.00 mgkg^{-1}) systems (Table 5). The higher availability of Fe and Mn in the Fox nut-water chestnut-berseem cropping system may be attributed to variation in the anaerobic condition of the soil system due to cultivation of crops like fox nut and water chestnut and accumulation of higher organic matter in the soil resulting in higher biological activity (Verma *et al*. 2005). The organic carbon, which influences the solubility and availability of Fe by chelation (with phytosiderophores) effect, might have protected the Fe from oxidation and precipitation and increased the availability of Fe during the decomposition of organic matter/crop residues (Sekhar *et al*. 2014).

The soils under Fox nut-rice-berseem cropping system contained the highest concentration of Cu (1.82 mg kg^{-1}) and Zn (0.35 mg kg^{-1}) which are 8.79 and 14.28 % higher than Fox nut-water chestnut-berseem.The lower values of Cu and Zn in the soils of the Fox nut-water chestnut-berseem cropping system could be due to the reaction with soluble silica and their lower solubility caused by the formation of hydroxides, carbonates and sulphides. The flooding condition during the cultivation of fox nut and alternate wetting and drying conditions during rice cultivation and drying during the cultivation of berseem favours the availability of Cu and Zn concentration in soil with the Fox nut-rice-berseem cropping system. Zhang *et al.* (1989) stated that the presence of comparatively higher organic matter can promote the availability of Zn, presumably by supplying soluble complexing agents. At high pH, organic matters appear to increase the availability of Zn.

Table 5. Mean values of available micronutrient content of soil under different cropping system (Mean data)

Cropping systems	Fe ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)	Cu ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)
Fox nut-Fox nut	38	14.00	0.85	0.24
Fox nut-wheat	28	11.00	0.87	0.26
Fox nut-rice	34	14.50	0.80	0.23
Fox nut-berseem	34	11.30	1.65	0.26
Fox nut- water chestnut	41	14.00	1.16	0.28
Fox nut-rice-wheat	31	8.13	1.55	0.24
Fox nut-rice-berseem	33	9.27	1.82	0.35
Fox nut-water chestnut-berseem	43	15.15	1.66	0.30
C.D. (*P=0.05*)	8.024	3.785	0.141	0.046

Chemical composition of plants

Berseem plant had the highest N content (2.96 %) while the lowest was in the fox nut (0.27 %) (Table 6). Considering 1 % as the critical limit, fox nut, rice, wheat and water chestnut were deficient in N. Biomass N concentration in flooded plants such as fox nut and water chestnut decreased significantly as flood-induced microbial denitrification in the soil reduces the supply of nitrate to plants (Gambrell *et al*. 1991).

None of the aquatic plants had P content below 0.2 %, which is considered to be the critical limit for P content. Berseem had the adequate amount of tissue-P, but rice and wheat were deficient. Rattaray *et al.* (1991) reiterated that some aquatic macrophytes are known to be efficient removers of some nutrients.

Rice (1.38 %) and wheat (1.18 %) and berseem had a sufficient amount of tissue-K. Based on critical limit of 1.0 %, fox nut and water chestnut were deficient of tissue-K. Prolonged flooding of soil decreased the concentration of K in biomass of fox nut and water chestnut, owing to lower transport of K to shoots under flooding (Ponnamperuma 1972). Deficiency of root oxygen decreases the selectivity of K^+ uptake by roots due to accumulation of excessive concentration of Fe and Mn in root tissues.

Fe and Mn were highest in the fox nut while the highest concentration of Cu and Zn was recorded in water chestnut. Considering the critical limit of Fe (50 $mg\ kg^{-1}$), the rice (35 $mg\ kg^{-1}$) and wheat (25 $mg\ kg^{-1}$) crops found to be deficient. The crops had Mn (20 to 924 $mg\ kg^{-1}$) in the tissue against the critical limit of 20 $mg\ kg^{-1}$. Uptake of Fe and Mn depends on plant species, and their availability in soils increases with flooding (Jones 1972). The higher concentrations of Fe and Mn in fox nut and water chestnut could be attributed to the excessive uptake of soluble $Fe^{2+}$and Mn^{2+} during prolonged inundation of the soil. Aquatic macrophytes differ both in their capacity to take up metals in root tissues and in the proportion of metals transferred to the above-ground parts (Lan *et al.* 1992).

Considering 4 $mg\ kg^{-1}$ (Jones 1972) as the critical limit for Cu, all the crops were found to have sufficient content of Cu in their tissues, although the soil samples were deficient in DTPA Cu content. None of the crops showed Zn below the critical of 20 $mg\ kg^{-1}$ barring berseem. Compared to the average values of the Zn concentration in plants (Rattan *et al.* 2009), fox nut, rice and water chestnut are sufficient in Zn content, but the soils were deficient in DTPA Zn. Campbell *et al*. (1988) reiterated that metals that preferentially bind to organic ligands, like Cu and Zn should be less available to rooted aquatic macrophytes when such ligands are available for binding. Guilizzoni (1991) opined that some rooted submerged plants might absorb metals directly from water when they are not readily available in sediments and/or in high concentrations in the surroundings. The positive residual impact and its contribution towards the enrichment of soil fertility of all the crops grown in

Table 6. Mean contents of inorganic elements in biomass of crops due to *Fox nut* based cropping systems

Crops	N (%)	P (%)	K (%)	Fe (mg kg^{1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})
Fox nut	0.27	0.45	0.37	2175	924	6.3	93
Rice	0.42	0.18	1.38	35	30	7.4	25
Wheat	0.48	0.16	1.18	25	20	5.5	20
Water chestnut	0.40	0.70	0.80	2113	591	16.6	300
Berseem	2.96	0.22	1.54	120	25	10.5	2.5
CD (0.05)	0.166	0.065	0.055	8.063	5.961	0.340	7.488

cropping pattern under the Fox nut-water chestnut-berseem cropping system exhibited superiority in having the higher concentration of nutrients over the other crops *vis-a-vis* other crop combinations. The concentrations of Fe, Mn, and Cu in plants had definite relationship with their availability status of soils. The results thus, indicate that soil test values corroborate with plant analysis.

Conclusion

The three years' pooled data showed that the soils, with the Fox nut-water chestnut-berseem cropping system, had higher water holding capacity than the soils with the Fox nut-fox nut and six other Fox nut-based cropping systems. This cropping system could lead to a significant increase in organic carbon, N, P, Fe and Mn contents of the soil. However, for enhancing the Cu and Zn concentrations in soil, Fox nut-rice-berseem system appeared to be the most efficient one. The crops included in Fox nut-water chestnut-berseem cropping system exhibited a maximum concentration of nutrients in their tissues. Berseem recorded the highest concentration of N, and K. Fox nut had the highest tissue concentrations of the less soluble Fe and Mn, whereas water chestnut accumulated maximum contents of P, Cu and Zn. Based on the findings, we recommend cultivating fox nut in cropping system mode must include at least one leguminous crop for the sustainable use of soil.

References

Aggrawal, P., Parashar, D.K., Kumar, V. and Gupta, R.P. (1997). Effect of *Kharif* green manuring and *Rabi* tillage on physical properties of puddled clay loam soil under rice-wheat rotation. *Journal of the Indian Society of Soil Science* **45**, 434-38.

Balamurugan, J., Kumaraswamy, K. and Rajarajan, A. (2000). Effect of *Eucalyptus citriodora* on the physical and chemical properties of soils. *Journal of the Indian Society of Soil Science* **48**, 491-495.

Barko, J. and James, W.F. (1998). Effects of submerged aquatic macrophytes on nutrient dynamics, sedimentation, and resuspension. *In* 'The Structuring Role of Submerged Macrophytes in Lakes'. (Eds. E. Jeppensen, M. Sondergaard, K. Christoffersen,) pp. 197-214. (Springer Verlag, New York)

Bellaki, M.A. and Badanur, V.P. (1994). Effect of crop residue incorporation on physical and chemical properties of Vertisols and yield of sorghum. *Journal of the Indian Society of Soil Science* **42**, 533-535.

Campbell, P.G.C., Lewis, A.G., Chapman, P.M., Crowder, A.A., Fletcher, W.K., Imber, B., Luoma, S.N., Stokes, P.M. and Winfrey, M. (1988). Biologically available metals in sediments. Publ. No. 27694, National Research Council of Canada, Ottawa, pp. 298.

Carter, M.R., Sanderson, J.B., Ivany, J.A. and White, R.P. (2002). Influence of rotation and tillage on forage maize productivity, weed species, and soil quality of a fine sandy loam in the cool-humid climate of Atlantic Canada. *Soil and Tillage Research* **67**, 85-98.

Galantini, J.A., Landriscini, M.R., Iglesias, J.O., Miglierina, A.M. and Rosell, R.A. (2000). The effects of crop rotation and fertilization on wheat productivity in the Pampean semiarid region of Argentina. II. Nutrient balance, yield and grain quality. *Soil and Tillage Research* **53**, 137-144.

Gambrell, R.P., DeLaune, R.D. and Patric, Jr. W.H. (1991). Redox processes in soils following oxygen depletion. *In* 'Plant life under Oxygen Deprivation: Ecology, Physiology and Biochemistry'. (Eds. M.B. Jackson, D.D. Davies, H. Lambers) pp. 101-117 (SPB Academic, The Hague,).

Ganeshamurthi, A.N. (2009). Soil changes following long-term cultivation of pulses. *The Journal of Agricultural Science* **147**, 699-706.

Guilizzoni, P. (1991). The role of heavy metals and toxic materials in the physiological ecology of submerged macrophytes. *Aquatic Botany* **41**, 87-109.

Jackson, M.L. (1973). *Soil Chemical Analysis*. pp. 498. (Prentice Hall of India Pvt. Ltd., New Delhi).

Jha, B.K., Kumar, L., Gupta, V.K., Singh, I.S. and Jee, J. (2012). An overview of Fox nut cultivation. *In* 'Status of Agricultural Development in Eastern India' (Eds. Bhatt *et al.*) pp. 361-369. (ICAR-RCER, Patna, Bihar).

Jha, P. and Rattan, R.K. (2007). Mineralization of carbon and P in soil as affected by soil moisture regimes and incorporation of crop residues. *Journal of the Indian Society of Soil Science* **55**, 218-221.

Jha, S.N. and Dutta, R.N. (2003). Soil-waterchemistry of Fox nut (*Euryale ferox* Salisb.) cultivation. *In* 'Fox Nut' (Eds. Mishra, R. K., Jha, V. and Dehadrai, P.V.). pp 73-84. (DIPA, ICAR, New Delhi).

Jones, R. (1972). Comparative studies of plant growth and distribution in relation to water logging: The uptake of iron and manganese by dune and dune slack plants. *Journal of Ecology* **60**, 131-139.

Kumar, L., Gupta, V.K., Jha, B.K., Singh, I.S., Bhatt, B.P. and Singh, A.K. (2013). Fox nut ki kheti ki unnat takneek. Technical BulletinNo. E-116/Patna-73. ICAR RCER, Patna.

Kumar, L., Gupta, V.K., Khan, M.A., Singh, S.S., Jee, J. and Kumar, A. (2011). Field based Fox nut cultivation for improving cropping intensity of rice fields. *Bihar Journal of Horticulture* **1,** 71-72.

Kumar, L., Choudhary, A.K., Bhatt, B.P. and Singh, K.P. (2015). Genetic divergence in makhana (*Euryale ferox* Salisb.). *Indian Journal of Horticulture* **72**, 365-369.

Kumar, B. and Prasad, R.K. (2008). Integrated effect of mineral fertilizers and green manure on crop yield and nutrient availability under rice-wheat cropping system in calciorthents. *Journal of Indian Society of Soil Science* **56***,* 209-214.

Lan, C., Chen, G., Li, L. and Wang, M.H. (1992). Use of Cattails in treating wastewater from Pb/Zn mine. *Environmental Management* **16,** 75-80.

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

Mandal, R.N., Saha, G.S. and Sarangi, N. (2010). Harvest and processing of Fox nut (*Euryale ferox* Salisb.)-An unique assemblage of traditional knowledge. *Indian Journal of Traditional Knowledge* **9,** 684-688.

Patrick, W.H. and Mikkelsen, D.S. (1971). Plant nutrient behavior in flooded soil. In 'Fertilizer Technology and Use, 2nd Edition'. (Eds. R.A. Olson,). pp. 187-215. Soil Science Society. (Amer. Inc., Madison, Wisc. U.S.A).

Pannu, R.P.S., Singh, Y., Singh, B. and Khind, C.S. (2001). Long-term effects of organic materials on depth-wise distribution of different K fractions in soil profile under rice-wheat cropping systems. *Journal of Potassium Research* **17**, 34-38.

Ponnamperuma, F.N. (1972). The chemistry of submerged soils. *Advances in Agronomy* **24**, 19-96.

Portielje, R. and Roijackers, R.M.M. (1995). Primary succession of aquatic macrophytes in experimental ditches in relation to nutrient input. *Aquatic Botany* **50**, 127-140.

Rattan, R.K., Patel, K.P., Manjaiah, K.M. and Datta, S.P. (2009). Micronutrients in soil, plant, animal and human health. *Journal of the Indian Society of Soil Science* **57**, 546-558.

Rattray, M.R., Howard-Williams, C. and Brown, J.M.A. (1991). Sediment and water as sources of N and P for submerged rooted aquatic macrophytes. *Aquatic Botany* **40,** 225-237.

Sekhar Chandra, Ch., Balaguravaiah, D. and Naidu, M.V.S. (2014). Studies on genesis, characterization and classification of soils in Central and Eastern Parts of Prakasam district in Andhra Pradesh. *Agropedology* **24**, 125-137.

Singh, I.S., Kumar, L., Singh, A.K., Bhatt, B.P. and Singh S.P. (2014). Impact of makhana (*Euryale ferox* Salisb.) based cropping systems on nutrient dynamics of Inceptisols of north Bihar. *International Journal of Agricultural and Statistical Sciences* **10**, 125-129.

Varvel, G.E. (2000). Crop rotation and N effects on normalized grain yields in a long term study. *Agronomy Journal* **92**, 938-941.

Verma, V.K., Setia, R.K., Sharma, P.K., Singh, C. and Kumar, A. (2005). Micronutrient distribution in soils developed on different physiographic units of Fatehgarh Sahib district of Punjab. *Agropedology* **15**, 70-75.

Zhang, F., Romheld, V. and Marschner, H. (1989). Effect of zinc deficiency in wheat on the release of zinc and iron mobilizing root exudates. *Journal of Plant Nutrition and Soil Science* **152,** 205-210.

Received: April, 2018 *Accepted: January, 2019*