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Review

Dynamics of nutrients of aquatic crop (Gorgon nut or Makhana) under different systems of cultivation-A review

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To improve the productivity of any kind of land, the crop diversification is the need of the time. In order to enhance the land productivity, the lowlands were used to adopt crop diversification technology and integrated farming system. Integrated farming system (IFS) is also in operation at scattered places wherein farmers have been using excreta of livestock and droppings of poultry for fish culture and replenishment of nutrient to the soil which gets exhausted by crops. However, the yield potential of field-based Makhana cultivation was recorded to be higher than the pond-based Makhana (*Euryale ferox* Salisb.) cultivation under IFS model. This is attributed to the more efficient harvesting of Makhana seed from under the water in the shallow agricultural field system due to lesser depth of water as compared to deep pond-based Makhana cultivation under IFS system. Pertaining to the improvement of soil fertility, the key of success may be rested on the selection of efficient cropping systems and integrated assessment of various cropping systems in the wetland ecology. The major finding is that *E.ferox*-water chestnut-berseem is found to be the most judicious cropping system pertaining to improvement of soil fertility.

Keywords: Cropping systems, *Euryale ferox* Salisb, integrated farming system, plant essential nutrients, nutrient uptake, nutrient contribution, soil fertility.

INTRODUCTION

The rice-wheat cropping system is the most important cropping system of the Indo-Gangetic Plains of India. Likewise, it also occupies about 63.50 lakh ha in Bihar. During the last one decade, the rice wheat system has started showing the signs of stress with production of fatigue and deterioration of soil health (Yadav *et al*., 1998). This is especially true for areas where a continuous rice-wheat rotation predominates and system diversity is low (Fujisaka *et al*., 1994). In case of north Bihar condition, the people of this region are fortunate enough to have a vast area under wetlands (*kidneys of the landscape*) and chaur (waterlogged), where, high value aquatic crops like Makhana and water chestnut found to be naturally growing in plenty and they are getting a handsome economic return from this. Further, it is well known that rice-wheat cropping system cannot be followed in the wetland areas as these areas are found to be waterlogged for a long period. However, some wetland areas are found to be suitable to take wheat after Makhana or water chestnut after draining the water into other places. But most of the wetlands do provide opportunity to drain its water to somewhere thus wheat cannot be taken after rice or Makhana or water chestnut. Under these circumstances, the farmers have been advised to take rice before Makhana vis-à-vis to integrate Makhana with water chestnut and fish components in the same lowland waterlogged/chaur areas to get good return as the wetland have fairly flat areas of rich organic soil that is highly productive. By being one of the most biologically productive natural ecosystems, wetlands are the only places which have the potential to inhabitat some endangered and rare species of some flora (*E.ferox*) and fauna (fish).

Euryale ferox Salisb. (Nymphaeaceae) known as gorgon nut or fox nut or *makhana* is an annual aquatic and emergent macrophytic herb, and its populations have declined throughout its distribution range (Eastern India, China, Korea, Eastern Russia and Japan) (Schneider *et al*., 2003). Indian Populations are located at the north-eastern edge of the distribution range, particularly in north-eastern Bihar (In an area of 13,000 ha), where 80% of India's total production occurs (Mishra, 1998; Jha et al., 2012). The northeastern part of India has chains of rivers, intersected with many tributaries and canals. This has made possible a saucer-shaped wetlands ecosystem bounded by land. Categorically, wetlands are lands transitional between terrestrial and wet areas, where the soil is frequently waterlogged during rainy months (permanently, semi permanently or temporarily), the water table is usually at or near the surface or the land is inundated by varying depths of water. Wetlands within the state of Bihar are attributed mainly to the complex fluvial geomorphology of the gangetic tributaries which have over a period of time created a number of natural depressions and cut-off meanders. Known variously as mauns, chaurs and taals, these wetlands are a characteristic features of the inter fluvial regimes of gangetic plains which are completely inundated during momsoon, shallow with a miximum depth of 1.5m, and mostly dry by March-June. Kabartaal (in Bagusarai), Khusheshwarsthan (in Darbhanga), Berialla (in Vaishali), Vikramsila Dolphin Sanctuary (in Bhagalpur) and Motijheel (in east Champran) are some of the major wetlands of the state. Euryale ferox, rice and water chestnut are the major crops of the wetland. *Euryale ferox* is one of the most popular and economically important food crops of wetland.

E. ferox was primarily considered a crop of deep water pond, swamps and ditches (4-6' depth) worldwide. However, in India, it is grown in deep water pond as well as in shallow (0.5-2 ft depth) agricultural fields and ponds. It is a plant of tropical and subtropical climate. For its proper growth and development, the conducive range of air temperature is 20-35°C, relative humidity 50-90% and annual rainfall 100-250 cm (Mandal *et al*., 2010). Being a popular aquatic crop, it has heavy water requirement. Thus, assured availability of irrigation water is the prime need for its cultivation. Moreover, it also needs permanent standing water throughout its growth period. *E.ferox* can be characterized as a genus monotypic, diploid having chromosome number 2n = 2x = 58. It is an exclusively self-pollinated and absolutely seed propagated plant in which fertilization takes place at an early stage of their development. Pollination occurs via cleistogamy resulting in inbreeding and a low level of heterozygosity (Kumar *et al*., 2016). The germination of *E. ferox* seed is of hypogeal type (Kumari *et al*., 2014). Upon the germination, the cotyledons and hypocotyls of seeds remain in the soil. It has thick fibrous roots comprising 3-5 clusters each consisting of about 15 rootlets. The roots are thick, long (40-50 cm), fleshy and fibrous in nature and also have a number of air pockets. The plant has rhizomatous stem. The rhizome is characterized as short thick and erect. Fully developed leaves are orbicular in shape, large (diameter: 0.50-1.5 m), floating in nature and born on 0.30-1.5 m long petiole. The colour of the upper surface of leaf appears to be green while the lower one looks deep purple. Both surfaces are covered by numerous thorns (stout hooked prickles in joints of dorsal veins). Flowers are characterized by bright purple in colour, long pedicel, consisting of fleshy and goblet-shaped thalamus (04 nos.) and covered with dense and sharp prickles. Fruits are big and spheroidal in shape, whitish brown outer skin, protuberant in appearance and densely covered with sharp prickles. The fruit is described as berry, large (5-8 cm diameter), spongy, spiny and crowned with persistent sepals. Each fruit has 20 to 200 seeds (weight varies from 50-250 g). The fresh seeds are lumpy, and surrounded by streaked bright red arils, and keep on floating on water surface until the red aril gets ruptured. Thereafter, the seeds get settled in the mud and finally acquired black colour. Seeds (diameter: 0.5-1.5 cm) are enough bold and have a hard outer covering.

It has nutritional and medicinal properties and supports cottage industry. The beneficial effect of cultivation of *Euryale ferox* on soil fertility has been noticed by Jha and Datta (2003) and Singh *et al*. (2014). They reported that the content of organic carbon, phosphorus have immensely increased due to sole cultivation of *Euryale ferox*. *Trapabispinosa* taken as one of the other aquatic crop in the cropping rotation pattern is an annual floating emergent macrophyte, characterized by a worldwide distribution in aquatic ecosystems. It is popularly known as singhara or *paaniphal.* In India, it is mainly grown in Madhya Pradesh, Uttar Pradesh, Bihar and Odisha. It requires standing water (depth 0.5-1.5 m) throughout its growth period i.e., from August to November in a year. Plants have a well-developed adventitious root system which helps in enhancing the absorption capacity for the nutrients directly from soil solution through root surfaces. The fishes introduced in the Makhana-based integrated farming system mode were rohu, katla, mrigal and mangur.

E. ferox is a very high economic importance crop but in the present scenario it is on the verge of extinction; thus, to save, it should be cultivated in association with other cereals or leguminous crops in agricultural fields. *E. ferox* and *T. bispinosa* are such a particular aquatic food crop which add a substantial amount of organic matter i.e., 6-10 t/ha and 2-3 t/ha, respectively (Singh, I.S. 2014; Kumar *et al*., 2013). The biomass yield of makhana, growing in ponds in India, is positively correlated with N, K, and organic C, with the electrical conductivity of the soil, and with the contents of N, K, P, Na, Cl, HCO^{3-}, Ca + Mg, and SO_4^{-2} (Dutta and Jha, 1984; Dutta *et al*., 1986). Dutta *et al*. (1986) also found that the constituents of the water phase of makhana pond were more closely related to the biomass yield of Makhana than those in the solid phase. Most of the constituents in the water had more highly significant correlation coefficients with biomass yield than those of soil. The soil properties were either not related at all or only weakly related. These factors and the aquatic nature of the plant indicated that mass flow was the main mechanism of nutrient uptake for this crop, for which organic matter decomposition was the main source of nutrient supply. The high value of the correlation coefficient of yield with ammonium indicated the probability that *E. ferox* take up nitrogen in the ammonium form. Bicarbonate, pH and temperature were the other factors found to be closely related to biomass production. Micronutrients due to the reducing environment induced high availability and concentration in plants more than average and hence showed negative correlation.

A typical grayish-black-to black coloured soil dominated by clay (mucky type) is the main characteristic feature in low-lying areas of this zone. Indeed, organic matter is comparatively high, but, due to anaerobic condition prevailing for many months during wet season, it is partially decomposed. The soil status may further be improved if same period is allowed for quick decaying of such waste materials during post-wet months under aerobic conditions. In this region, one of the most conventional practices by farmers is to utilize this resource-rich humus soil for the succeeding arable crops. This practice not only saves a substantial amount of fertilizer N including other important essential elements but also improves the physical condition of the soil. Soil organic matter is a major terrestrial pool for C, N, P, S, and the cycling and availability of these elements are constantly being changed by microbial immobilization and mineralization (Hillel 1991). Under crop cultivation, changes in soil organic matter status would determine the dynamics of alluvial soil quality of wet lands. In addition to *E. ferox*, the other components crops too would certainly add an appreciable amount of organic matter to soil. Jha and Dutta (2003) had reported about the chemical changes in soil under *E. ferox* plants growing in naturally existing ponds. The *E. ferox* cultivation was found to be highly beneficial in increasing the content of available P and K which is helpful in maintaining the resilient properties of soil (Singh *et al*., 2016). Besides this, the organic material contributed by preceding crop to the succeeding crop growing in a particular rotation has an ability to incorporate nitrogen and may offer opportunities to increase and sustain productivity of all kinds of crops. Carter et al. (2002) reported that crop rotation can have a major impact on soil health, due to emerging soil ecological interactions and processes that occur with time. These include improving soil structural stability and nutrient use efficiency, and soil organic matter levels. Crop rotations can also increase nitrogen availability when nitrogen-fixing legumes are included (Galantini *et al*., 2000). Pulses taken in cropping system as one of the component can assist in soil improvement, particularly when used as green manure crops when the whole plant is plowed down into the soil. Fixed nitrogen and in some cases phosphorus is made available to subsequent crops, and the added organic matter contributes to improved soil structure. Varvel (2000) also reported that judicial crop rotation systems are more effective at reducing long-term yield variability than monoculture systems, and can increase total soil C and N concentrations over time, which may further improve soil productivity.

Nutrient contribution pattern through makhana (*Euryale ferox* Salisb.) cultivation to the soil system

E. ferox has been identified as one of the most important aquatic crop whose cultivation is highly beneficial for soil-water-plant continuum and human kinds as it contributes a lot of organic matter to the soil (Since its whole biomass gets incorporated in the soil at its maturity.) and it provides nutritionally important most of the essential elements such as P, Fe and Zn in higher quantities as compared with other cereal and leguminous crops (Kumar *et al*., 2013). The importance of makhana in relation to improvement of soil fertility has shown that biomass on decomposition adds approximately 34.35, 56.04, 40.71, 27.26, 13.31, 0.10 and 1.16 kg/ha nitrogen, phosphorus, potassium, iron, managanese, copper and zinc, respectively to the soil (Table1). The total uptake of these nutrients made by *E. ferox* is 69.42 kg/ha/yr N, 64.44 kg/ha/yr P, 55.59 kg/ha/yr K, 29.27 kg/ha/yr Fe and 12.39 kg/ha/yrMn.The maximum contribution of nutrients is made by leaf and root organs of the *E. ferox*. If the amount of N, P and K which is actually going to be added in the soil is explained in terms of quantities of artificial fertilizers; the soil is being replenished every year with an amount of 70 kg urea, 285 kg single super phosphate (SSP) and 67 kg potash. Thus, it can be easily estimated that a handsome amount of money which might be incurred on the purchase of these artificial fertilizers could be saved by the cultivation of makhana in agricultural fields. The removal of N, P, K, Fe, Mn, Cu and Zn by the seeds material from the soil is recorded as 35.07, 8.40, 2.52, 2.016, 0.08, 0.02 and 0.26 kg/ha, respectively. The uptake and removal amount of other nutrients from the soil is very less as it does not take part in effectively affecting the fertility status of soil.

Roots of aquatic plants absorb from the sediments and accumulate high concentrations (Baldantoni *et al*., 2004). Even if shoots and /or leaves of submerged plants accumulate lower concentrations of micro elements than roots, they may reliably provide information chiefly on water quality over short period’s equivalent to leaf age. Collins *et al.* (2005) examined the root and shoot concentrations of elements in four perennial wetland species over two seasons in mesocosm wetland system designed to remediate water from a coal pile run off basin. Deep wetlands in each system contained

Table 1. Nutrient contribution through makhana (*Euryale ferox*) plants to the soil.

Plant parts	Dry wt. kg/ha	N kg/ha	P kg/ha	K kg/ha	S kg/ha	Fe kg/ha	Mn kg/ha	Cu kg/ha	Zn kg/ha
Leaf	4750	14.72	22.80	19.00	0.95	10.45	4.75	0.038	0.50
Petiole	1690	4.05	7.77	6.42	0.17	3.85	1.67	0.01	0.13
Root	4240	11.87	16.96	23.32	0.42	10.19	4.45	0.04	0.039
Fruit sheath	1548	3.71	8.51	4.33	0.31	2.77	1.44	0.01	0.14
Total contribution	**12228**	**34.35**	**56.04**	**53.07**	**1.85**	**27.26**	**12.31**	**0.10**	**1.16**
Seed	2100	35.07	8.40	2.52	0.84	2.016	0.08	0.02	0.26
Total uptake	**14328**	**69.42**	**64.44**	**55.59**	**2.69**	**29.27**	**12.39**	**0.12**	**1.42**

Myriophyllum aquaticum and *Nymphaea odorata* shallow wetlands contained *Juncus effuses* and *Pontederiacordata*. Shoot elemental concentrations differed between plants of deep and shallow wetlands, with higher Zn, Al, and Fe concentrations in plants in shallow wetlands and higher Na, Mn, and P concentrations in plants in deep wetlands Root and shoot concentrations of most elements differed between species in each wetland type.

Comparison of fertility status of soils under makhana pond and makhana field based IFS model

As compared with the initial status, a general increase in status of organic carbon, available N, P, K, Fe, and Mnis observed in the soils of both the Makhana based integrated farming system under pond and field conditions. Further, the soil condition pertaining to the soil reaction (pH), electrical conductivity (EC), concentrations of available N and K is also found to be almost similar under both the Makhana based IFS systems. The organic carbon content of pond soil (0.52%) is 28.88% higher than the field soil (0.37%). Pond soil registered 25 per cent higher available phosphorus (20 kg/ha) than the field soil (15 kg/ha). The pond soil also recorded 20.00%, 21.42%, 17.83% and 23.33% higher concentrations of Fe (35 mg/kg), Mn (14 mg/kg), Cu (1.85 mg/kg) and Zn (0.30 mg/kg), respectively than the field soil [Fe (28 mg/kg), Mn (11 mg/kg), Cu (1.52 mg/kg) and Zn (0.23 mg/kg)].

Soil nutrient status of seven years old makhana+fish pond

The soils of the seven years old makhana+fish pond have exhibited the soil properties as pH 6.98, EC 0.25 dS m^{-1}, organic carbon 0.52%, Av. N 250 kg ha^{-1} , Av. P 27 kg ha^{-1} and Av. K 424 kg ha^{-1}. 45 mg/kg Av. Fe, 18 mg/kg Av. Mn, 1.87 mg/kg Av. Cu and 0.37 mg/kg Av. Zn. The above soil properties revealed the fact that makhana cultivation maintained the soil reaction in slightly acidic to neutral condition which is caused due to continuous flooding of soil and deposition of organic matter and its decomposition in the soil. The electrical conductivity was also recorded far below the hazardous level. The organic carbon has also got double than its initial contents in the soil. The makhana cultivation was found to be highly beneficial in increasing the content of available phosphorus and potassium contents which is helpful in maintaining the resilient properties of soil. Puste and Das (2001) studied the optimization of aquatic-terrestrial ecosystem in relation to soil nitrogen status for the cultivation of fish and aquatic food crops of the Indian subtropics. The study revealed that the physico-chemical properties of soils (pH, organic C, organic matter, available N,P, and K) as well as quality of water (pH, EC, BOD, COD, CO_3^{2-}, HCO_3^-, NO_3^- N,SO_4^{2-} S, and Cl^-) growing fish makhana and water chestnut was remarkably influenced by different moisture regimes and exhibited a significant improvement of soil health. They found that the amount of organic C, available N, P, and K content were found significantly highest in the treatment were makhana was grown under alternate flooding and drying situation with a depth>2 m as compared to other treatment. Such enrichment of soil fertility, particularly in available N and P content, might be due to the accumulation of considerable amounts of biomass and fish excreta and their subsequent decomposition in situ in the soils.Thephysico-chemical characteristics of soil (textural class, pH' organic matter, ammonical nitrogen, nitrate nitrogen, available nitrogen, phosphorus and potassium) are most important and contributed a significant improvement due to cultivation of aquatic crops such asWater chestnut (*Trapabispinosa* Roxb), makhana (*Euryale ferox*Salisb) and water lily (*Nymphaea spp*.) (Puste, *et al*., 2005). The general characteristics of pond soil are given in table 2.

Dynamics of nutrients under makhana and makhana-based cropping systems grown in inceptisols of northern Bihar under field condition

Singh *et al*. (2014) evaluated the five new cropping systems in North Bihar under field condition. They reported that nutrient uptake and productivity generally increased with increasing cropping intensity. Positive residual effects of makhana (Gorgon nut) and berseem (Egyptian clover) were observed on improvement of soil

Table 2. General characteristics of pond soil (Saturation extract).

Period of sampling	pH 1:2 Soil: water	EC (dS/m)	Org. C (%)	Total N %	P (ppm)	K (ppm)
Growth initiation (Nov-Feb.)	7.3 (7.1-7.4)	0.50 (0.47-0.51)	0.82 (0.78-0.88)	0.081 (0.079-0.084)	14.9 (13.7-16.5)	155.7 (153.7-158.2)
Grand growth summer (March-July)	6.9 (6.7-7.0)	0.59 (0.56-0.64)	0.94 (0.88-1.04)	0.089 (0.086-0.093)	17.0 (14.5-18.6)	180.3 (163.4-184.4)
Plant decomposition rains (July-October)	7.5 (7.4-7.7)	0.46 (0.46-0.47)	0.76 (0.74-0.78)	0.079 (0.077-0.081)	13.8 (11.2-16.6)	150.5 (145.4-155.6)

properties such as available nitrogen (N), available phosphorus (P) and available potassium (K). Makhana-berseem cropping system was observed to be added the highest amount of available nitrogen and available phosphorus to the soil while, the maximum addition of available potassium was made by makhana-wheat cropping system. In terms of nutrient uptake, makhana-berseem cropping system was found to be recorded the highest remover of nitrogen (382 kg/ha) and potassium (205 kg/ha) while the highest removal of phosphorus from the soil system was recorded by makhana-water chestnut cropping system (89 kg/ha).

In an another set of experimentation pertaining to an investigation of dynamics of nutrients under ten Makhanabased cropping systems under field condition Singh et al. (2015) analyzed the cycling pattern of nutrients with *E. ferox*-*E. ferox*, *E. ferox*-rice, *E. ferox*-wheat, *E. ferox*-berseem, *E. ferox*-water chestnut, *E. ferox*-rice-wheat, *E. ferox*-rice-berseem, *E. ferox*-water chestnut-berseem, *E. ferox*+fish - rice+fish and rice-wheat cropping systems. A major finding was that not only mono-cropping of *E. ferox* i.e., *E. ferox*- *E. ferox*but other *E. ferox*-based cropping systems had shown no significant impact on soil reaction and electrical conductivity of soil, while other chemical properties of soil such as organic carbon, available nitrogen (N), phosphorus (P) and potassium (K) were significantly improved due to applied cropping systems (Table3 Table3).It was observed that *E. ferox*-water chestnut-berseem cropping system appreciably increased the nutrient status of soil over other *E. ferox*-based cropping systems. *E. ferox*-water chestnut-berseem had 10-25% higher organic carbon as compared with other cropping systems. *E. ferox*-water chestnut-berseem led to 25% higher organic carbon than*E. ferox*-*E. ferox* cropping system. The highest increase in soil organic carbon content due to inclusion of berseem in the *E. ferox*-water chestnut-berseem cropping system was associated with addition of more aboveground biomass of crop residues in this system. This may be attributed to the fact that soil organic matter content and their properties are a function of agricultural practices and the kind and arrangement of plant residues returned to the soil (Ding *et al*., 2002). Intensive *E. ferox*-water chestnut-berseem and *E. ferox*-berseem cropping system leads to utilize the fallow period after harvesting of *E. ferox* and water chestnut which ultimately results in SOC improvement. Increase in SOC in cropping system with pulses as compared with the rice-wheat systems could be attributed to addition of more belowground biomass in the form of root (Ganeshamurthy, 2009).

E. ferox-water chestnut-berseem exhibited 7.86% - 27.54% higher available N,and 23.33-50% higher P than the other cropping systems, whereas the minimum N and P was found with *E. ferox*-rice-wheat and *E. ferox*-rice cropping systems.The*E. ferox*-water chestnut-berseem cropping system significantly registered 14.75% higher N than *E. ferox*-*E. ferox* cropping system. This may be owing to relatively higher addition of organic matter to the soil and inclusion of berseem, a leguminous plant incropping system capable of fixing atmospheric nitrogen into the soil. In *E. ferox*-water chestnut-berseem cropping system, the microclimate within the field was also changed by inclusion of berseem plant in cropping system and created favourable soil conditions for mineralization of native as well as applied and deposited organic matter. *E. ferox*-berseem plots had the next highest value. It may also be attributed to increased radial fluxes of O_2 from the roots of flood tolerant plants to its rhizosphere may have great impact on the biogeochemical processes of the sediment. If the O_2 release to the sediment increases, an increased rate of nitrification resulting in more available nitrate (NO_3^-) for the plants is anticipated (Andersen *et al*., 2006).

Similarly, in addition, dense beds of roots of *E. ferox* and water chestnut may increase the rate of release of dissolved phosphate from sediment, due to presence of locally favourable pH caused by inorganic carbon dynamics (Singh *et al.*, 2014). Kozlowski (1984) also reported that in some alkaline soils that are relatively low in phosphorus (P), flooding may cause an increase in P availability in soil. Ponnamperuma (1980) and Goswami (1979) are of the opinion that the reduction of ferric phosphate is the chief cause of the increase in the availability of soil phosphorus. The increase in soluble and extractable phosphorus as a result of continuous flooding is well documented. It has usually been attributed to the reduction

Table 3. Mean values of chemical properties of soil under different cropping system.

Cropping systems	pH	EC (dS m^{-1})	Org. C. (%)	Av. N (kg/ha)	Av. P (kg/ha)	Av. K (kg/ha)
E. ferox-*E. ferox*	7.25	0.15	0.60	260	22	219
E. ferox-wheat	7.50	0.16	0.71	269	18	214
E. ferox-rice	6.50	0.20	0.65	210	15	220
E. ferox-berseem	6.73	0.20	0.70	281	23	215
E.ferox-water chestnut	7.25	0.21	0.73	268	20	240
E. ferox-rice-wheat	7.51	0.18	0.70	206	19	213
E. ferox-rice-berseem	7.20	0.18	0.72	238	18	210
E.ferox-water chestnut-berseem	7.43	0.25	0.80	305	30	235
E. ferox+Fish-rice+fish	6.77	0.26	0.65	221	16	210
Rice-wheat	7.48	0.24	0.48	248	20	215
P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
$LSD_{0.05}$	0.052	0.023	0.080	8.994	4.171	4.695

LSD, least significance differenceat P = 0.05

of ferric phosphate to the more soluble ferrous form, and to the hydrolysis of phosphorus compounds. The increase in pH as a result of submergence is also considered to aid in the solution of Fe and Al phosphate (Patrick and Mikkelsen, 1971).

The *E. ferox*-water chestnut-berseem cropping system significantly registered 6.80% K higher than *E. ferox*-*E. ferox* cropping system. The availability of higher concentration of potassium in the soils with E.ferox-water chestnut –berseem cropping may be attributed to the reducing conditions caused by flooding result in a larger fraction of the potassium ions being displaced from the exchange complex into the soil solution. The release of a relatively large amount of ferrous and manganous ions, and the production of ammonium ions result in displacement of some of the K ions from the exchange complex to the soil solution. According to Goswami *et al*. (1971), under submerged conditions, an ion exchange can take place as a result of the increase in Fe and Mn, thus raising the concentration of potassium in soil solution. Brinkman (1970) believed that Fe could replace various kinds of base ions from the surface of soil colloids.

The status of micronutrient content of soil due to *E. ferox*-based cropping systems

According to the critical limit of 4.5 mg/kg soil of Lindsay and Norvell (1978), the soils were sufficient in available iron (Table4). Among all the cropping systems, *E. ferox*-water chestnut-berseem was found to be recorded the highest Fe content (43 mg/kg). However, the cropping system could not register significantly higher Fe content over *E. ferox*-*E. ferox* (38 mg/kg), *E. ferox*-water chestnut (41 mg/kg) and *E. ferox*+fish-rice+fish (38 mg/kg) cropping systems. Moreover, *E. ferox*-rice (34 mg/kg), *E. ferox*-berseem (34 mg/kg), and *E. ferox*-rice-berseem (33 mg/kg) cropping systems registered almost similar increase in available iron (Fe) content over its initial status (28 mg/kg). Pertaining to the improvement in available contents of manganese (Mn), it was found that the effect of *E. ferox*-*E. ferox* (14.00 mg/kg), *E. ferox*-rice (14.50 mg/kg), *E. ferox*-water chestnut (14.00 mg/kg) and *E. ferox*+fish-rice+fish (13.45 mg/kg) was at par. *E. ferox*-water chestnut-berseem noted to be significantly more efficient cropping system in improving the status of manganese (Mn) than *E. ferox*-wheat (11.00 mg/kg), *E. ferox*-berseem (11.30 mg/kg), *E.ferox*-rice-berseem (9.27 mg/kg) and *E. ferox*-rice-wheat (8.13 mg/kg) (Table 4). The higher availability Fe and Mn with *E. ferox*-water chestnut-berseem cropping system may be attributed to variation in prevalence of anaerobic condition of the soil system due to cultivation of aquatic nature of crops like *E. ferox* and water chestnut. It might also be due to accumulation of higher organic matter to the soil which results in higher biological activity. The organic carbon due to its affinity to influence the solubility and availability of iron by chelation (with phytosiderophores) effect might have protected the iron from oxidation and precipitation, which consequently increased the availability of iron. Mn availability to plants depends much on soil pH, soil redox potential and microbiological activities in soils. Since soil in a waterlogged state is subject to low redox potentials, under which Fe and Mn are mobilized in ferrous and manganous forms in soil solution i.e. transformation of insoluble compounds into soluble ones and, therefore, increased the availability of these elements in the soil.

In case of Cu, it is an established fact that the availability of Cu is drastically reduced in organic matter rich soils; as insoluble organic fractions of humus bind Cu tightly and fixes this nutrient in an unavailable form causing Cu deficiency. According to Mandal (1984), in general, the solubility of Cu and Zn in submerged soils is influenced by the changes in electrochemical properties, the reduction of Fe and Mn oxides and production of organic complexing agents in soils. In the light of these facts, it is

Table 4. Mean values of available micronutrient content of soil under different cropping system (Mean data).

Cropping systems	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)
E. ferox-E. ferox	38	14.00	0.85	0.24
E. ferox-wheat	28	11.00	0.87	0.26
E. ferox-rice	34	14.50	0.80	0.13
E. ferox-berseem	34	11.30	1.65	0.26
E. ferox-water chestnut	41	14.00	1.16	0.28
E. ferox-rice-wheat	31	8.13	1.55	0.24
E. ferox-rice-berseem	33	9.27	1.82	0.35
E. ferox-water chestnut-berseem	43	15.15	1.66	0.30
E. ferox+Fish-rice+fish	38	13.45	1.68	0.20
Rice-wheat	25	12.00	1.66	0.36
P value	0.0015	0.0115	<0.0001	<0.0001
$LSD_{0.05}$	7.653	3.755	0.375	0.054

LSD, least significance differenceat P = 0.05

observed that the *E. ferox*-water chestnut-berseem cropping system could not record the highest Cu and Zn content in the soil. The solubility is lower because of the formation of hydroxides, carbonates and sulphides and also due to reaction with soluble silica. Such flooding condition during the cultivation of *E. ferox* and alternate wetting and drying condition during rice cultivation and drying during the cultivation of berseem favours the availability of Cu and Zn concentration in soil with *E. ferox*-rice-berseem cropping system. Chesworth (2008) and 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 availability, at least for zinc.

CONCLUSIONS

The above works revealed the fact that soils of pond based IFS model are recorded to be more fertile than the soils of field-based Makhana cultivation of under IFS system. However, when productivity potential of Makhana production only is compared between the two systems i.e. Makhana production under deep water pond and under shallow agricultural field, it was found that productivity of Makhana under shallow field was one and half to two times higher than pond system. The pond-based Makhana cultivation under the IFS system is more popular among the farmers because farmers are able to get comparatively higher economic returns and diverse type of products at lesser investment than field based IFS systems. Pertaining to the dynamics of nutrients under different Makhana-based cropping systems, *E. ferox*-water chestnut-berseem is found to be the most judicious cropping system pertaining to improvement of soil fertility.

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