Title
Integrated plant nutrient management on diversified cropping system in aqua-terrestrial ecosystem for yield potentiality, quality and rural sustainability

Authors
PUSTE, ANANDAMOY, DR.
DE, PRALAY, ER.
MAITY, TAPAN KUMAR, DR.

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INTRODUCTION

Among the natural resources, wetland ecosystem is one of the valuable natural gift, the swampy environment of the carboniferous produced and preserved many of the fossil fuels on which we greatly depend now, is rightly termed as *'nature's kidney'* of the world (James, 1995). Wetland ecosystem including coastal biosphere that intersected with main river systems (*Ganges, Brahmaputa, Padma, Mahanadi, Mahananda, Rupnarayan* etc.) and it's so many tributaries like oxbow lakes (*mauns, chaurs, jheels, beels, baors, nayanjali* etc.) predominant in Indian subtropics, mostly in Indo-Bangladesh regions. Categorically, these are the lands of *'low-lying flood plains'* and cover a remarkable area, comprises 25-30% (may be 40 million ha during wet months), mostly unused in north-eastern part of this sub-continent (Anonymous, 1986).

These immense valuable, well-fertile wetlands are scatteredly utilized by the rural farming community for fish culture, cultivation of aquatic food and non-food crops in neglected way (Puste, 2004). Among the aquatic food crops, deep-water rice (*Oryza sativa*), water chestnut (*Trapa bispinosa* Roxb.), makhana or fox nut (*Euryale ferox* Salisb.), water-lily (*Nymphaea* spp.) and *Colocasia* spp. are most important in respect to popularity, yield potentiality, profitability as well as acceptability to the common rural urban people of the regions. But over all productivity of the system is not encouraging due to not practicing with improvised management system for obtaining potential yield and quality of produce. Among the different management systems, application of balanced plant nutrition and its management are the integral part for optimum productivity at sustainable level, is imperative in agricultural cropping system, and more applicable to those of developing countries of the world.

To realize the significant importance of this vast unused wetland ecosystem, extensive field studies on (i) adaptability of improvised agro-techniques, along with (ii) IPNM were undertaken at farmers' level as 'on farm' TOT programs through the implementation of TDET based integrated aquaculture research projects for enhancement of productivity and quality of produce, profitability and socio-economic viability over existing system of the rural farming community at different agro-climatic zones of Indian sub-continent.

METHODOLOGY

Case studies were undertaken utilizing divergence of *'Tal'* wetland ecosystem (deep, semi-deep, temporary in NAZ, OAZ, and Coastal Zones) on a wide sector of downtrodden resource, poor to marginal farming community of Indian sub-continent. These were emphasized with the involvement of NGO's through implementation of TOT, TDET (PRA, training, technological updating demonstration-cum-improvised agro-trials) based research projects [NWDPRA (National Watershed Development Projects for Rainfed Areas), ICAR (Indian Council of Agricultural Research), DoLR (Department of land Resources), Ministry of Rural Development, Government of India] on the development of waste wetland ecosystem through the implementation of integrated management programs suited to zone-specific, viz. (i) system approach (need-based cleaning, excavation and renovation, methodological approach), (ii) IPNM utilizing organic as well as inorganic sources, and (iii) management (crop management, inter- and post-harvest care and processing, marketability etc.).

Field studies were implemented on these valuable aquatic food crops [deep-water rice (*Oryza sativa*), water chestnut (*Trapa bispinosa* Roxb.), makhana or fox nut (*Euryale ferox* Salisb.), water lily (*Nymphaea* spp.) and *Colocasia* spp.] following improvised agro-techniques at farmers' level during pre- to post-monsoon period in different categories of *'Tal'* wetland ecosystem (semi-deep, deep, marshy or temporary) in regions of this sub-continent. Including management system, a well-balanced combination of organic as well as inorganic sources of plant nutrients [T_1 – neem oilcake @ 0.1 t ha^{-1} alone as sole organic sources, T_2 – N : P_2O_5 : K_2O @ 20-60 : 30-40 : 20-40 kg ha^{-1} alone as sole inorganic sources, T_3 – combined application of neem oilcake @ 0.1 t ha^{-1} + N : P_2O_5 : K_2O @ 20-60 : 30-40 : 20-40 kg ha^{-1} as organic + inorganic sources and T_4 – T_3 + additional spraying of NPK & Zn-based micronutrients applied systematically @ 0.5% each (2.0% altogether) thrice at 20, 40 and 60 DAT (days after transplanting)], respectively applied to different crop variables, maintaining at proper dose and time, used for enhancing growth, yield attributing characters, yield potentiality, and quality of produce.

Crops were nourished initially in nursery ponds, from where it was then transplanted and established in the main wet/marshy land system, maintaining specific row to row and plant to plant spacing (25 cm to 1.5 m and 25 cm to 1.0 m, respectively) for obtaining proper plants per unit area. This started with the advent of the rainy season (June). While *Colocasia* was transplanted during mid-February. Fruits of water chestnut (consumed as immature fresh fruit), flower-stalks of water-lily and corm includes stalks of *Colocasia* (used as vegetables for preparation of different food items, curry etc.) harvested recurring. Pickings were started from August and continued up to the end of November, while, mature grain yield of deep-water rice and mature makhana seeds were harvested at a time during early part of November to first week of December. All the harvested products are highly nutritious, remunerative, and preferred mostly by the urban rural people. Besides, seeds of makhana are highly nutritious and are used for the preparation of value-added high priced popped form. Specific dose of applied inorganic fertilizer nutrients, planting variables and harvesting mode, parameters etc. of the crops used in the experiment are presented in Table 1.

Table 1. Applied dose of inorganic fertilizer nutrients, planting variables, and harvesting mode of the crops

Aquatic food crops	Specific dose of N : P_2O_5 : K_2O (kg ha^{-1})	Planting variables (row to row & plant to plant)	Harvesting of the crops	
			Mode	Parameters
Deep-water rice	50 : 30 : 30	25 cm x 25 cm	At a time	Matured grain
Water chestnut	20 : 30 : 20	1.5 m x 1.0 m	Recurring	Fresh fruits
Makhana	20 : 30 : 20	1.5 m x 1.0 m	At a time	Mature seeds
Water-lily	20 : 30 : 20	1.5 m x 1.0 m	Recurring	Flower-stalks
Colocasia	60 : 40 : 40	50 cm x 50 cm	Recurring	Corm + stalks

Besides inorganic chemical fertilizers, applied as basal (advancement of water body during peak rainy months, no chances for applying any fertilizer as top-dressing), spray was done as in treatment T_4 on the crop canopy, wherein, a sticker was used to make it more productive. Full dose of N : P_2O_5 : K_2O applied at basal except rice and *Colocasia*, where $^1/_3$ at basal and rest ($^2/_3$) in equal two splits at 20 and 60 DAT. Need-based plant protection measures were taken with bio-degradable pesticides (even with organics), especially with seed and seedling treatment as preventive measures of the crops. Initial and post experimental samples for physico-chemical properties were analyzed by Wheatston Conductivity Bridge and AAS followed the standard analytical procedure (Jackson, 1973).

Yield equivalence:

For understanding and comparison among the different crops (yield) due to their heterogeneous characteristics, it was converted as like makhana yield equivalence (MYE) in terms of production with the following formula -

$$\text{MYE (t ha}^{-1}\text{)} = \frac{\text{Total price of the crop to be compared (Rs.)}}{\text{Price of makhana t}^{-1}\text{ (Rs.)}}$$

For calculation of MYE and monetary returns, price of average produce at harvesting time were considered as follows:

Table 2. Average harvested price of the produce (Rs. t^{-1})

Aquatic food crops	Price (Rs. t^{-1})
Deep-water rice	12,000 (250.00)
Water chestnut	8,000 (167.00)
Makhana	40,000 (833.00)
Water-lily	8,000 (167.00)
Colocasia	1,750 (36.46)

Parenthesis indicates USD (1 USD = Rs.48.00)

RESULTS AND DISCUSSION

YIELD INFLUENCED BY IPNM:

Individual Crop Yield

It reveals from the results of the study zones that almost all the crop variables (deep-water rice, water chestnut, makhana, water-lily and *Colocasia*) were remarkably influenced due to the application of combined and well-balanced organic, as well as inorganic sources, of plant nutrients at basal, and subsequently, as top-dressing over the sole system (either organic or inorganic sources). Yield potentiality of the crops were performed best and exhibited highest production of rice grains (3.76 t ha^{-1}), fresh immature fruits or nut yield of water chestnut (9.93 t ha^{-1}), matured seed or nut yield of makhana (3.24 t ha^{-1}), flower-stalks of water-lily as vegetables (6.52 t ha^{-1}) and corm includes stalk yield of *Colocasia* as vegetables (86.8 t ha^{-1}) with the application of combined and balanced plant nutrients in T_4 treatment and this enhanced production was due to the positive response of their growth and yield attributing characteristics in this treatment over others (Table 3). The yield increment in T_4 treatment over others imposed in these trials adopted at the farmers' field was to the tune of 39.51 - 83.41, 23.16 - 91.70, 41.37 - 86.21, 29.55 - 54.14, and 27.61 - 110.17% in deep-water rice, water chestnut, makhana, water-lily and *Colocasia*, respectively.

MYE

Hence, the crop yields are not comparable among themselves due to their non-homogenous characteristics. However, for easy comparison it was thus converted other four food crops to equivalent yield of makhana. So, it would be more evident to compare among them now on the basis of yield equivalent of any crops like makhana (MYE), which was calculated in terms of produce value that might be reflected in integrity of the establishment of the system more confidently (Table 3).

Individually all the crops were produced less when these were raised with application of minimum level of plant nutrients, either as sole organic or inorganic. But with balanced form, all these were produced higher yield (T_4), where optimum quantity of plant nutrients including nitrogen was applied in a very rationalized way, integrated through organic as well as inorganic sources and this was produced significantly higher than that of control plots (either organic or inorganic sources). However, among the aquatic food crops, *Colocasia* produced highest MYE (3.797 t ha^{1}) followed by makhana (3.24 t ha^{1}) than that of other three crops (water chestnut, water-lily and deep-water rice (1.986, 1.304 and 1.128 t ha^{1}, respectively) due to more production and market value, obviously lucrative in the market as a food item (Table 3). Indeed, eventually *Colocasia,* as vegetables are now very popular, and seeds of makhana, and its popped-form are not only popular but now are being exported to other countries with high value, because of their nutritional quality and palatability as well. Farmers are gaining importance for the cultivation of these crops day by day in these zones, including expanding to more areas.

Table 3. Individual yield and MYE of aquatic crops as influenced by IPNM

Treatment	Individual yield (t ha^{-1})					MYE (t ha^{-1})				
	DWR	WC	Mak	WL	*Col*	DWR	WC	Mak	WL	*Col*
T_1	2.05	5.18	1.74	4.23	41.3	0.615	1.036	1.74	0.846	1.807
T_2	2.86	6.38	2.46	5.48	52.7	0.858	1.276	2.46	1.096	2.306
T_3	3.42	8.72	2.87	6.04	74.5	1.026	1.744	2.87	1.208	3.259
T_4	3.76	9.93	3.24	6.52	86.8	1.128	1.986	3.24	1.304	3.797
S.Em (±)	0.271	0.629	0.225	0.474	2.553	--	--	--	--	--
CD (*0.05*)	0.86	1.96	0.69	1.47	8.12	--	--	--	--	--

DWR, deep-water rice; WC, water chestnut; Mak, makhana; WL, water-lily and *Col*, *Colocasia* spp.

Nutritional quality

Nutritional quality of the produce was also remarkably influenced by the application of integrated plant nutrients applied on the crops and highest results of carbohydrates/starch, protein, and minerals were recorded through analyzed data in T_4 over other treatments in all the food crops (Rice – 73.6, 7.36 & 1.02%; Water chestnut – 23.6, 4.76 & 1.13%; Makhana – 77.1, 9.74 & 0.51%; Water-lily – 46.24, 8.21 & 0.62% and *Colocasia* – 4.18, 0.36, 1.23%, respectively), was probably due to the consumption of balanced food items by the plants with proper dose and time.

Production economics

After harvesting of each crop, based on the market value of the produce, GMR (Rs.ha^{-1}) was calculated and thus, it may be possible to evaluate for economic consideration of the system. In the production economics, subtracting the cost of cultivation, NP (Rs.ha^{-1}) including benefit-cost ratio (B-C ratio) was then calculated and hence, these are the right pathways to judge the acceptability of any system for adopting in a region (Table 4).

Table 4. Net profit and B-C ratio of aquatic crops as influenced by IPNM

Treat-ment	NP (in '000 Rs. ha^{-1})					B-C ratio				
	DWR	WC	Mak	WL	*Col*	DWR	WC	Mak	WL	*Col*
T_1	13.74 (286.25)	27.19 (466.46)	47.19 (983.12)	20.42 (425.42)	49.62 (1,033.7)	1.26	1.91	2.10	1.52	2.19
T_2	21.40 (445.83)	34.52 (719.17)	71.28 (1,485.0)	27.82 (579.58)	65.40 (1,362.5)	1.66	2.09	2.63	1.74	2.44
T_3	26.48 (614.17)	50.64 (1,055.0)	84.68 (1,764.2)	30.89 (643.54)	99.65 (2,076.0)	1.82	2.65	2.81	1.77	3.24
T_4	29.70 (618.75)	59.19 (1,233.1)	97.57 (2,032.7)	34.04 (709.17)	116.78 (2,432.9)	1.93	2.92	3.05	1.88	3.32

GMR, gross monetary return; NP, net profit; B-C, benefit-cost and parenthesis indicates USD (1 USD = Rs.48.00)

However, highest NP and B-C value exhibited with the use of IPNM [treatment T_4, which received combined application of neem oilcake @ 0.1 t ha^{-1} as organic + N : P_2O_5 : K_2O @

60 : 40 : 40 kg ha^{-1} as inorganic sources along with additional spraying of NPK and Zn-based micronutrients applied systematically @ 0.5% each (2.0% altogether) thrice at 20, 40 and 60 DAT over the entire crop canopy] than that of other sole and IPNM combinations applied in the experiments. Among the aquatic food crops, *Colocasia* produced highest economic value (Rs.1,16,780 ha^{1} eq. to US$ 2,432.9 and 3.32) followed by makhana (Rs.97,570 ha^{1} eq. US$ 2,032.7 and 3.05), while, lowest value was with deep-water rice (Rs.29.700 eq. US$ 618.7 and 1.93). Surprisingly, there was a NP value of 108.2 and 827.9% more in *Colocasia* over other evaluated crops in this treatment (T_4) due to synchronized favorable effect of both yield and market value of the produce. The results are more encouraging than that of controlled as well as farmers' practiced ponds, even it is more than that of 2-3 folds. Practically, at present it is more invigorating in nature and lucrative in the market of the zones day by day, particularly in the north-eastern part of the country.

CONCLUSION

Wetland ecosystem are valued entrepreneurship in the world. Vast wetland ecosystem of Indian sub-continent are subjected to waterlogging during wet months, often lying vacant without utilization. Cultivation of starch and protein rich aquatic food crops is enthusiastic, productive, especially for upliftment of rural economy in a sustainable manner. Integrated plant nutrient management is quite imperative on these aquatic beneficial crops for obtaining higher productivity and quality of produce, which makes it viable for the rural farming community.

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