RESEARCH ARTICLE

EXPERIMENTAL APPROACH FOR IMPROVEMENT OF SOIL FERTILITY BY DOSE ADMINISTRATION OF CHEMICAL AND ORGANIC FERTILIZERS IN KHARIF RICE FIELD

Suvendu Dey[1], Shubhadhip Dasgupta[2], Sudeshna Mandal[2] and Sudha Gupta[1]*

[1]Pteridology and Palaeobotany Section, Department of Botany, Kalyani University, Kalyani-741235, West Bengal, India
[2]All India Coordinated Research Project (AICRP) on Soil Test and Crop Response Correlation, Directorate of Research, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, West Bengal, India.
Email: sudhaguptain@gmail.com

Received-06.04.2018, Revised-23.04.2018

Abstract: Experimental approach was taken up by dose administration of chemical *(CDCF-chemical dose commonly used by farmers; CDRA-chemical dose recommended by Agriculture Dept., Govt. of WB)* and organic fertilizers *(ODAC-organic dose using Azolla and cow-dung and ODAO-organic dose by using Azolla only)* in Kharif rice field at Chandipur, North 24 Parganas district of West Bengal in two consecutive years (2015 and 2016) for continuous monitoring of the soil fertility by analyzing different physicochemical properties *(texture, water holding capacity, moisture content, pH, EC, organic carbon, organic matter, total Nitrogen, available Nitrogen, Phosphorous, and Potassium)* of soil applicable for measurement of soil health. The comparative assessment of the studied soil parameters depict that among all the administered doses, presently proposed organic fertilizer dose of *Azolla* (900kg/hectare land) and cow dung (3150 kg/hectare land) is proved best for enhancing soil fertility over the years and this should be promoted for sustainable rice farming.

Keywords: *Azolla*, Cow dung, Green revolution, Organic matter, Total Nitrogen, Water holding capacity

INTRODUCTION

The grain productivity was tripled by increasing only 30 % cultivated land area due to 'Green Revolution' in India (Pingali, 2012; Sangha, 2014). Application of high doses of chemical fertilizers and pesticides, uses of high yielding hybrid crop varieties, and improved agricultural methods and practices were actually the basis of 'Green Revolution'. But, the continuous and long-term application of such chemical fertilizers, pesticides and high yielding varieties impart adverse effects on soil fertility (Wagner, 1997; Ladha *et al*., 2000; Mazid and Khan, 2014; Yadav *et al*., 2014), productivity and environmental safety (Wagner, 1997; Madhusoodanan and Sevichan, 1992; Mazid and Khan, 2014). As such, Green Revolution has failed to prove its sustaining ability in agricultural practices in the country for long term benefit (Shiva, 1991). Despite the adverse consequences, knowingly or unknowingly, the farmers across the country including West Bengal are enduring same practices with increased doses to achieve the expected productivity and this practice is somehow reducing the soil health over the years (Wagner, 1997; Ladha *et al*., 2000). Application of organic matter or bio-fertilizer is one of the sustainable ways for improving soil health and fertility (Wagner, 1997; Awodun, 2008; Dong *et al*., 2012; Rivaie *et al*., 2013). With view to it, an experimental approach has been conducted in Kharif rice (commercial high yielding Pratiksha rice variety) field at Chandipur, North 24 Parganas district of West Bengal, India during the years 2015 and 2016 for comparative assessment of soil fertility by administering chemical and organic fertilizers doses.

MATERIALS AND METHODS

Experimental field plot

The field experiment was performed at Chandipur belonging to North 24 Parganas district of West Bengal, India during Kharif Season (July to November) in 2015 and 2016 in a routinely practiced rice field located at 22º49'8.764" North and 88º47'8.682" East in the tropical sub-humid zone of eastern India. The soil of growing rice field was alluvial with efficient drainage facilities.

Experimental field set-up

The experimental field set-up encompassed five treatments having three replications each using randomized block designing (RBD) method. The treatments were control, without any fertilizer (CTRL), chemical fertilizer dose- commonly used by farmers (CDCF), chemical fertilizer dose-recommended by Department of Agriculture, Government of West Bengal (CDRA), organic dose-presently used by *Azolla* and cow dung (ODAC), and organic dose- presently used by *Azolla* only (ODAO). Urea, single super phosphate, and muriate of potash were applied as the sources of nitrogen (N), phosphorous (P), and potassium (K) respectively for CDCF and CDRA treatments. The doses for CDCF and CDRA were in combination of N, P, and K in the ratio of 138:72:180 and 120:60:60 respectively per hectare of land plot. Initially, 60% of both P, and K and 1/3rdof N were used as basal fertilizer dose during land preparation; after 20-25 days of

*Corresponding Author

transplantation of rice, the remaining 40% of P, K and 1/3rd of N was applied and finally the rest 1/3rd of N was added in the field as final dose again after 20-25 days. In both types of organic doses (ODAC and ODAO), about 450 kg wet mass of *Azolla*/hectare was administered in twice (after 7 days and after 45 days of plantation) whereas additionally 3150 kg of cow dung was applied once for ODAC set-up only during land preparation.

Applied species of Azolla as bio-fertilizer

The *Azolla* species used as bio-fertilizer was *Azolla microphylla* as it contains higher amount of macro and micro nutrient than *Azolla pinnata* (Wagner, 1997) and it can easily grow in the area having suitable heat tolerant capacity; even it can resist the direct sunlight in summer (Choudhury and Kennedy, 2007). The applied *Azolla microphylla* plant was allowed to grow along with rice plant for three weeks and then turned down in the field.

Rice variety taken for experiment

The rice variety taken for experimental farming was Pratiksha (IET-15191) [http:// www.matirkatha.net] which is a locally popular, high yielding commercial variety released in the year 2005 by Indian Council of Agricultural Research (ICAR), Government of India. The cultivation time of the chosen rice variety is kharif season (July/August - November). Healthy seedlings of 28 days old were transplanted by maintaining 24x20 cm spacing. Usual agronomic management practices adopted by the farmers in that area were followed until the harvesting of the crop.

Sampling

Before preparation of experimental field plots, soil samples in three replications were collected randomly from entire field for comparative assessment with each tested plot after farming in two consecutive kharif seasons in the years 2015 and 2016. Top soils (0-15cm) were collected from all three replicas of each treated plot separately after harvesting of the crop in each individual season.

Studied parameters

Collected soil samples were analyzed for different physicochemical attributes of soil namely, total nitrogen (TN), available nitrogen (AN), available phosphorus (AP), available potassium (AK), organic carbon (OC), organic matter (OM), electrical conductivity (EC), potential of hydrogen (pH), moisture content (MC), water holding capacity (WH) and soil texture (ST).

Methods

The TN and AN of the soils were estimated with the help of Kjeldahl digestion (make: KELPLUS, Model KEL VAC) and distillation apparatus (Model DISTYL- EMS) following method of Subbarao and Ravisankar (1962). The pH and EC were determined in dilution with distilled water in the ratio of 1:5 and measured through digital pH and conductivity meter respectively. AK was determined through Flame photometric method (Toth and Prince, 1949) and Olsen method (Olsen et al., 1954) was applied for estimation of AP. The OC of the soil was quantified by volumetric method as suggested by Walkley and Black (1934). The soil texture was determined following the methodology suggested by the American Society for Testing and Materials (ASTM, 1998). All data were statistically assessed one-way analysis of variance (ANOVA) to determine significant variations between and among the experimental designs.

Table 1. Values of studied chemical parameters of soils in different treatments through consecutive years and the calculated CD value

Treatment	Potential of hydrogen ion (pH)			Electrical Conductivity (EC) (dsm^{-1})			Organic matter (OM) (%)			Organic Carbon (OC) (%)			Available Nitrogen (AN) (kg/ha)			Available Phosphorous (AP) (kg/ha)			Available Potassium (AK) (kg/ha)			Total Nitrogen (TN) (kg/ha)		
	Initial value	2015 (Nov.)	2016 (Nov.)	Initial value	2015 (Nov.)	2016 (Nov.)	Initial value	2015 (Nov.)	2016 (Nov.)	Initial value	2015 (Nov.)	2016 (Nov.)	Initial value	2015 (Nov.)	2016 (Nov.)	Initial value	2015 (Nov.)	2016 (Nov.)	Initial value	2015 (Nov.)	2016 (Nov.)	Initial value	2015 (Nov.)	2016 (Nov.)
CTRL	6.93 ± 0.01	6.43 ± 0.05	6.22 ± 0.12	0.07 ± 0.00	0.14 ± 0.01	0.32 ± 0.00	1.56 ± 0.28	1.52 ± 0.09	1.59 ± 0.08	0.90 ± 0.16	0.88 ± 0.05	0.92 ± 0.04	250.96 ± 5.64	240.61 ± 8.96	212.15 ± 5.64	20.19 ± 2.35	19.50 ± 0.83	16.71 ± 0.68	254.32 ± 9.92	242.85 ± 17.11	221.13 ± 6.90	3172.40 ± 35.56	3141.60 ± 26.67	2997.87 ± 22.38
CDCF	6.93 ± 0.01	6.29 ± 0.07	6.24 ± 0.04	0.07 ± 0.00	0.17 ± 0.01	0.32 ± 0.01	1.56 ± 0.28	1.90 ± 0.15	1.98 ± 0.12	0.90 ± 0.16	1.10 ± 0.09	1.15 ± 0.07	250.96 ± 5.64	248.59 ± 3.42	307.88 ± 9.33	20.19 ± 2.35	28.20 ± 1.40	32.34 ± 0.90	254.32 ± 9.92	328.80 ± 12.24	355.93 ± 5.42	3172.40 ± 35.56	3747.33 ± 13.58	3773.00 ± 53.35
CDRA	6.93 ± 0.01	6.23 ± 0.08	6.25 ± 0.02	0.07 ± 0.00	0.16 ± 0.01	0.30 ± 0.01	1.56 ± 0.28	1.79 ± 0.15	1.93 ± 0.12	0.90 ± 0.16	1.04 ± 0.09	1.12 ± 0.07	250.96 ± 5.64	272.95 ± 5.64	306.58 ± 14.69	20.19 ± 2.35	26.82 ± 0.77	30.30 ± 0.95	254.32 ± 9.92	301.84 ± 11.38	345.63 ± 4.93	3172.40 ± 35.56	3506.07 ± 31.22	3557.40 ± 17.78

ODAC	6.93 ± 0.01	6.21 ± 0.03	5.99 ± 0.03	0.07 ± 0.00	0.16 ± 0.02	0.46 ± 0.07	1.56 ± 0.28	2.28 ± 0.14	2.60 ± 0.06	0.90 ± 0.16	1.32 ± 0.08	1.51 ± 0.04	250.96 ± 5.64	282.01 ± 4.66	301.41 ± 5.64	20.19 ± 2.35	25.87 ± 0.73	28.86 ± 0.36	254.32 ± 9.92	334.17 ± 14.00	352.16 ± 4.21	3172.40 ± 35.56	4250.40 ± 26.67	4327.40 ± 26.67
ODAO	6.93 ± 0.01	6.17 ± 0.09	6.23 ± 0.05	0.07 ± 0.00	0.15 ± 0.00	0.34 ± 0.02	1.56 ± 0.28	2.03 ± 0.10	2.21 ± 0.10	0.90 ± 0.16	1.18 ± 0.06	1.28 ± 0.06	250.96 ± 5.64	265.19 ± 6.85	278.13 ± 3.42	20.19 ± 2.35	23.84 ± 0.56	25.49 ± 0.94	254.32 ± 9.92	313.23 ± 10.97	328.38 ± 5.78	3172.40 ± 35.56	3593.33 ± 40.09	3619.00 ± 17.78
CD Value at 5% level	-	**0.15**	**0.18**	-	**0.04**	**0.10**	-	**0.42**	**0.35**	-	**0.24**	**0.21**	-	**18.67**	**27.95**	-	**2.82**	**1.99**	-	**45.26**	**19.16**	-	**82.70**	**109.0**

Table 2. Values of studied physical parameters of soils in different treatments through consecutive years and the calculated CD value

Treatment	Soil moisture content (%)			Soil water holding capacity (%)			Soil texture								
							Gravel			Sand			Fine		
	Initial value	2015 (Nov.)	2016 (Nov.)	Initial value	2015 (Nov.)	2016 (Nov.)	Initial value	2015 (Nov.)	2016 (Nov.)	Initial value	2015 (Nov.)	2016 (Nov.)	Initial value	2015 (Nov.)	2016 (Nov.)
CTRL	6.43 ± 0.13	2.71 ± 0.23	11.86 ± 0.37	83.60 ± 0.69	81.47 ± 0.35	83.20 ± 0.46	0.00	0.00	0.00	77.76 ± 0.56	69.38 ± 0.53	77.16 ± 0.34	23.24 ± 0.35	30.62 ± 0.97	22.84 ± 0.81
CDCF	6.43 ± 0.13	3.54 ± 0.24	11.88 ± 0.39	83.60 ± 0.69	84.40 ± 0.40	84.80 ± 0.23	0.00	0.00	0.00	77.76 ± 0.56	93.66 ± 1.15	74.76 ± 0.63	23.24 ± 0.35	6.34 ± 0.31	25.24 ± 0.58
CDRA	6.43 ± 0.13	3.04 ± 0.11	12.20 ± 0.15	83.60 ± 0.69	86.00 ± 0.83	85.87 ± 0.35	0.00	0.00	0.00	77.76 ± 0.56	89.51 ± 1.01	71.40 ± 0.64	23.24 ± 0.35	10.49 ± 0.81	28.60 ± 0.40
ODAC	6.43 ± 0.13	3.38 ± 0.10	11.38 ± 0.16	83.60 ± 0.69	86.80 ± 1.22	87.33 ± 0.58	0.00	0.00	0.00	77.76 ± 0.56	83.22 ± 0.90	68.20 ± 0.25	23.24 ± 0.35	16.78 ± 0.50	31.80 ± 0.56
ODAO	6.43 ± 0.13	3.34 ± 0.13	12.13 ± 0.37	83.60 ± 0.69	85.73 ± 0.35	86.80 ± 0.83	0.00	0.00	0.00	77.76 ± 0.56	83.62 ± 0.46	68.50 ± 0.42	23.24 ± 0.35	16.38 ± 0.51	31.50 ± 0.52
CD Value at 5% level	-	**0.56**	**1.07**	-	**2.06**	**1.72**	-	-	-	-	**2.37**	**1.36**	-	**2.35**	**0.90**

RESULTS AND DISCUSSION

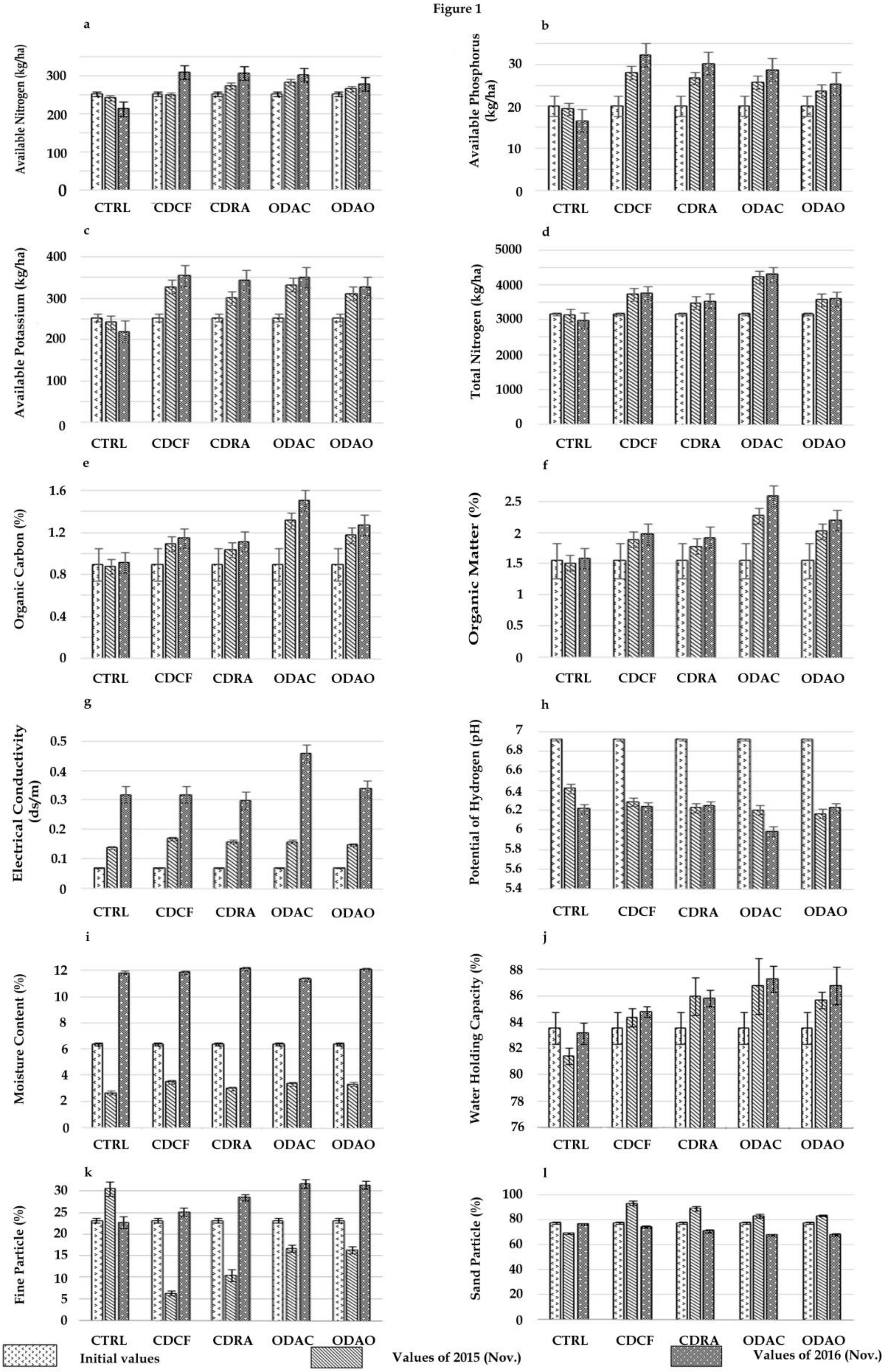
Values of the studied soil attributes are presented in the Tables 1, 2 and in Figure 1. Results highlight that in most of the cases, the physico-chemical parameters varied significantly ($p<0.05$) between and among the soil treatments with different chemical and organic fertilizer doses as well as with that of control soil.

AN value in soil is 250.96 ± 5.64 kg/ha at the initiation of experiment but after two years of experiments it is found to change differentially through various treatments. In untreated soil (CTRL), quantification of AN is found to decrease steadily to 212.15 ± 5.64 kg/ha whereas the maximum increase of AN is observed in CDCF treated soil (307.88 ± 9.33 kg/ha). In CDRA, the AN value (306.58 ± 14.69 kg/ha) is rather similar to CDCF. Interestingly, the AN value in ODAC treated soil (301.41 ± 5.64 kg/ha) is also not found to differ significantly from CDCF and CDRA. The organic treatment ODAO yield 278.13 ± 3.42 kg/ha AN which varied significantly ($p<0.05$) than control as well as CDCF, CDRA but not in ODAC. Therefore, the proposed organic dose ODAC possesses potentiality for increasing soil available nitrogen in an organic manner.

AP is found to differ significantly ($p<0.05$) in various treatments in both the years of experiments. The initial value of phosphorus in untreated soil is 20.19 ± 2.35 kg/ha and after two years of experiments it is reached to 32.34 ± 0.90 kg/ha (60.18 % increase) in CDCF and 30.30 ± 0.95 kg/ha (50.07 % increase) in CDRA. Thus, the present organic treatment performed (ODAC) also demonstrated good improvement of soil fertility by increasing the percentage of phosphorus (42.94 %) in soil with respect to initial untreated soil. However, ODAO treatment is not sufficient to enhance the range of AP in soil from medium to high grade.

The amount of AK in the experimental field originally was 254.32 ± 9.92 kg/ha which is considered to be medium in rating as per Mandal et al. (2016). Following two years' of experiments it enhances in rating in all categories of soils treated with organic fertilizer as well as with inorganic chemical fertilizers. The maximum increase is recorded in CDCF (39.95 %) followed by ODAC (38.47 %). Such an increase is rather higher in CDRA (35.90 %). ODAO treatment shows 29.12 % of increase over the initial value. Similar observation is also reported earlier by Hove (1989), Ram et al. (1994), Wagner (1997) among others.

Figure 1


a
Available Nitrogen (kg/ha)
b
Available Phosphorus (kg/ha)
c
Available Potassium (kg/ha)
d
Total Nitrogen (kg/ha)
e
Organic Carbon (%)
f
Organic Matter (%)
g
Electrical Conductivity (ds/m)
h
Potential of Hydrogen (pH)
i
Moisture Content (%)
j
Water Holding Capacity (%)
k
Fine Particle (%)
l
Sand Particle (%)
CTRL
CDCF
CDRA
ODAC
ODAO
Initial values
Values of 2015 (Nov.)
Values of 2016 (Nov.)

TN is directly related with soil organic matter. In the present investigation, two categories of organic treatments are applied in the form of direct application of *Azolla* and cow dung. The maximum TN is found 4327.40 ± 26.67 kg/ha in the ODAC treatment showing 36.41 % increase in relation to the initial value followed by CDCF (18.93 % increase) and ODAO (14.08 % increase), thereby supporting earlier reports of Singh and Singh (1987), Ram et al. (1994), Ladha et al. (2000) among others.

Percentage of OC and OM are initially high in the experimental field but both these parameters varied significantly (p<0.05) among different treatments. The maximum increase reaches to 1.51± 0.04 % in ODAC followed by ODAO (1.28± 0.06 %). Rise of OC and OM are always observed higher in organic treatments (Singh and Singh, 1987; Singh and Singh, 1990; Satapathy, 1993 and Ram et al., 1994) rather than chemical treatments and similar tendency is also noted in the present investigation. Percentage of escalations are 67.78%, 42.22%, 27.78% and 24.44% in ODAC, ODAO, CDCF and CDRA treated soils respectively but the soil of CTRL is found to be reduced in respect of both OM and OC (2.22 %) after two years' cultivation. The organic carbon also shows the similar trend which is concomitant with the views of Singh and Singh (1987).

EC values of soils in all sets are always < 1.0 throughout the experimental periods, which indicates that the soils are in normal range (Mandal et al., 2016). The values measured in soils of different treatments are not varied significantly excepting for ODAC set in 2016.

The soil pH differs significantly (p<0.05) only in ODAC with respect to other treatments in 2016; while in 2015, CTRL is differed with others. Present experiment suggests that application of cow dung and *Azolla* makes soil slightly acidic, corroborating Ram et al. (1994), although it contradicts with Awodun (2008).

MC of soils did not show significant changes in different treatments during the experimental period; however, in 2015, the CDCF and the organic doses ODAC, and ODAO treated soils show significant increase with respect to control.

WH of soils varied significantly (p<0.05) in both the years (2015 and 2016). The initial value of water holding capacity is noted to 83.60 ± 0.69 % but it is changed in different treated soils after two years of experiments, reaching maximum of 87.33 ± 0.58 % in (ODAC) treatment followed by ODAO. The maximum increase of 4.46 % over initial value is found in ODAC whereas it is 1.44% and 2.72 % in CDCF and CDRA respectively. In CTRL, 0.48 % decrease over the initial value is observed.

The physical characteristics of the soils (ST) such as percentage of gravel, sand and fine are found to show significant variations (p<0.05) in differently treated soils. The percentage of fine increases steadily in the soils treated with organic fertilizers than the soils treated with chemical fertilizers and this change may be due to addition of humus in the soils and it definitely affects the soils in positive direction in long run.

Azolla incorporation in rice field improves the release of nitrogen and other nutrient sources (Tung and Shen, 1985; Wagner, 1997) apart from enhancing phosphorus uptake by the rice plants (Mian and Azmal, 1989). The present investigation highlights the significance of organic treatments with the application of *Azolla* and cow dung in rice field over the chemical treatments for enhancing soil fertility thereby supporting Wagner (1997). *Azolla* is reported to possess great potassium accumulating ability in low potassium environment (Hove, 1989) and hence the organic matters of the species improve soil available potassium pool. Soil fertility is also influenced by humic substances formed during the decomposition of organic matter (Bhardwaj and Gour, 1970). Continuous applications of organic matter along with its residual effect (Mahapatra and Sharma, 1989; Ladha et al., 2000) improve soil fertility by increasing organic carbon, organic matter, total nitrogen, available NPK, water holding capacity and finally by improving soil texture (Hove, 1989; Singh and Singh, 1990; Satapathy, 1993; Ram et al., 1994; Wagner, 1997; Dong et al., 2012; Yadav et al., 2014).

CONCLUSION

The present study suggests that the application of *Azolla* as organic manure has positive effects in improving soil fertility but the combined application of *Azolla* and cow dung demonstrated pronounced effects. The soils of the investigated rice field plot and its surroundings in Chandipur area in North 24 Paarganas district of West Bengal are with high organic matter but with low nitrogen content and this problem might be overcome by sustainable application of *Azolla* and cow dung. As such, the present proposed organic dose of *Azolla* (900 kg/hectare land) and cow dung (3150 kg/hectare land) can be successfully applied in the cultivated fields in the locality for improving soil health as well as for promoting sustainable rice farming.

ACKNOWLEDGEMENT

The authors acknowledge the financial help provided by University of Kalyani. The kind help provided by Prof. Niharendu Saha, Department of Agricultural Chemistry and Soil Science, Bidhan Chandra Krishi Viswavidyalaya and Prof. Animesh Kumar Datta of Botany Department, University of Kalyani is gratefully acknowledged.

REFERENCES

Awodun, M.A. (2008). Effect of *Azolla* (*Azolla* species) on physic-chemical properties of soil. *World Journal of Agricultural Sciences*, 4: 157-160.

ASTM International Standards World Wide (1998). ASTM D422- standard test method for particle size analysis of soils. http:// www.astm.org/standards/D422. htm.

Bharwaj, K.K.R. and Gaur, A.C. (1970). Effect of humic and pelvic acid on growth and efficiency of nitrogen fixation by *Azotobacter chroococcum. Folia Microbiologica*, 15(5): 364-367.

Choudhury, A.T.M.A. and Kennedy, I.R. (2007). Nitrogen fertilizer losses from rice soils and control of environmental pollution problems. *Soil Science and Plant Analysis*, 36(11-12): 1625-1639.

Department of Agriculture, Government of West Bengal, http:// www.matirkatha.net

Dong, W., Zhang, X., Wang, H., Dai, X., Sun, X., Qiu, W. and Yang, F. (2012). Effect of different fertilizer application on the soil fertility of paddy soils in red soil region of Southern China. *PLoS ONE*, **7**(9): e44504. https://doi.org/10.1371/journal.pone.0044504.

Hove, C.V. (1989). *Azolla* and its multiple uses with emphasis on Africa. Food and Agriculture Organization. Rome, Italy.

Ladha, J.K., Dawe, D., Ventura, T.S., Singh, U., Ventura, W. and Watanabe, I. (2000). Long-term effects of urea and green manure on rice yields and nitrogen balance. *Soil Science Society of America Journal*, 64: 1993-2001.

Madhusoodanan, P.V. and Sevichan, P.J. (1992). *Azolla microphylla* Kaulfuss: An economically important biofertilizer for paddy fields of Kerala. *Journal of Economic and Taxonomic Botany*, 16: 73-76.

Mahapatra, B.S. and Sharma, G.L. (1989). Integrated management of *Sesbania*, *Azolla* and urea nitrogen in lowland rice under a rice-wheat cropping system. *Journal of Agricultural Science*, 113: 203-206.

Mandal, B., Kole, S.C. and Bhattacharyya, K. (2016). Project report of All India Coordinated Research Project (AICRP) on Soil Test Crop Response Correlation, BCKV, Kalyani – 741235, West Bengal.

Mazid, M. and Khan, T.A. (2014). Future of bio-fertilizers in Indian agriculture: an overview. *International Journal of Agricultural and Food Research*, 3(3): 10-23.

Mlan, M.H. and Azmal, A.K.M. (1989). The response of *Azolla pinnata* R. Brown to the split application of phosphorus and the transfer of assimilated phosphorus to flooded rice plants. *Plant and Soil*, 119: 211-216.

Olsen, S.R.C., Watanabe, F.S. and Dean, L.A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Circular (United States Department of Agriculture). pp 939.

Pingali, P.L. (2012). Green Revolution: Impacts, limits, and the path ahead. *Proceedings of the National Academy of Sciences of the United States of America*, 109(31): 12302–12308.

Ram, H., Raja, P.K. and Naidu, M.V.S. (1994). Effect of *Azolla* on soil properties and yield of mungbean (*Vigna radiata* L.). *Indian Society of Soil Science*, 42: 385-387.

Rivaie, A.A., Isnaini, S. and Maryati. (2013). Changes in soil N, P, K, rice growth and yield following the application of *Azolla pinnata*. *Journal of Biology, Agriculture and Healthcare*, 3(2): 112-117.

Sangha, K.K. (2014). Modern agricultural practices and analysis of socioeconomic and ecological impacts of development in agriculture sector, Punjab, India - a review. *Indian Journal of Agricultural Research*, 48(5): 331-341.

Satapathy, K.B. (1993). Effect of different plant spacing pattern on the growth of *Azolla* and rice. *Indian Journal of Physiology and Pharmacology*, 36: 98-102.

Shiva, V. (1991). The Green Revolution in the Punjab. *The Ecologist*, 21(2): March-April.

Singh A.L. and Singh, P.K. (1987). Influence of *Azolla* management on the growth, yield of rice and soil fertility: I. *Azolla* growth, N_2-fixation, and growth and yield of rice. *Plant and Soil*, 102(1): 41-47.

Singh, A.L. and Singh, P.K. (1990). Intercropping of *Azolla* biofertilizer with rice at different crop geometry. *Tropical Agriculture*, 67: 350-354.

Subbarao, T.S.S. and Ravisankar, C. (2001). Effect of organic manures on growth and yield of brinjal. *South Indian Horticulture*, 49: 288-291.

Toth, S.J. and Prince, A.L. (1949). Estimation of cation exchange capacity and exchangeable Ca, K and Na contents of soils by flame photometric techniques. *Soil Science*, 67: 439-445.

Tung, H.F. and Shen, R.C. (1985). Studies of the *Azolla pinnata-Anabaena azollae* symbiosis: Concurrent growth of *Azolla* with flees. *Aquatic Botany*, 22: 145-152.

Wagner, G.M. (1997). *Azolla*: A review of its biology and utilization. *Botanical Review*, 63(1): 1-26.

Walkley, A.J. and Black, I.A. (1934). Estimation of soil organic carbon by the chromic acid tritation method. *Soil Science*, 37: 29-38.

Yadav, R.K., Abraham,G., Singh, Y.V. and Singh, P.K. (2014). Advancements in the utilization of *Azolla-Anabaena* system in relation to sustainable agricultural practices. The *Proceedings of the National Academy of Sciences, India, Section B: Biological Sciences*, 80(2): 301-316.