The Journal of Agricultural Sciences - Sri Lanka
Vol. 18, No 3, September 2023. Pp 455-464
http://doi.org/10.4038/jas.v18i3.9705

Effect of Different Nutrient Management Systems on Yield and Yield Components of Rice Crop (*Oryza sativa* L.) in the Dry Zone of Sri Lanka

W.M.D.M. Wickramasinghe[1], W.C.P. Egodawatta[1*], D.A.U.D. Devasinghe[1], D.I.D.S. Beneragama[2], and L.D.B. Suriyagoda[3]

Received: 10^{h} April 2022 / Accepted: 01st August 2023

ABSTRACT

Purpose: *Integrated and organic nutrient management has recently become the focus in Sri Lanka for seeking better perspectives on food quality and environmentally friendly production. This study was conducted to understand the magnitude of yield and yield components under selective nutrient management systems in major cropping seasons within the transitional period of a conventional rice-based cropping system.*

Research Method: *Rice yield components and yield were measured with different nutrient management systems; conventional, integrated, and organic from Yala 2019 to Maha 2020/21. An ANOVA was carried out using the Repeated Measures MIXED model to determine the effect of nutrient management systems on yield and yield components for four continuous cropping seasons.*

Findings: *Total tillers per hill and productive tillers per hill significantly varied with conventional, integrated, and organic systems in descending order. The number of filled spikelets per panicle (43) was significantly increased, and the number of hollow spikelets per panicle (8) and thousand-grain weight (21.5g) were significantly decreased with an organic system in the Yala 2019 season only. Although the biological and expected grain yields of the Yala 2019 season were significantly higher with the conventional and integrated systems, these did not change significantly with the organic system in the last two seasons.*

Research Limitations: *Yield parameters fluctuated due to weather changes in different seasons; thus specific impacts of different nutrient managements have been masked to a certain degree.*

Originality/ Value: *The attempt to convert conventional crop production systems in Sri Lanka to organic can be effectively achieved using the integrated use of nutrients and crop rotations.*

Keywords: *Conventional, Integrated, Nutrient Management, Organic, Rice, Yield components*

INTRODUCTION

Nutrient management is a critical phenomenon for the growth and performance of a crop (Wickramasinghe *et al*., 2021). Chemical fertilizers have widely spread throughout the world after the green revolution focused on accelerating the production of crops (Ameen and Raza, 2017). The long-term application of chemical fertilizers at heavy doses damages the environment, putting the productivity of conventional systems in jeopardy (Ramchandra, 2020). A scientific understanding of crop responses is essential for seeking judicious use of alternative sources for managing crop nutrient demand.

[1] Department of Plant Sciences, Faculty of Agriculture, Rajarata University of Sri Lanka, Anuradhapura, Sri Lanka. egowcp@agri.rjt.ac.lk*
[2] Department of Plant Sciences, University of Saskatchewan, Saskatoon, Canada.
[3] Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanaka.
https://orcid.org/0000-0003-3934-6351

The recent decision to control the importation of mineral fertilizers (Sri Lanka Gazette No. 2226/48 of May 6. 2021), by the government of Sri Lanka, opened many avenues to pursue alternatives. The organic systems are expected to rely solely on organic nutrient sources; thus, the prompt supply of nutrients can be challenging for providing adequate quantities (Jouzi *et al*., 2017), which was the basis of many debates that erupted during the last few seasons. Law enforcement is taking robust actions to control mineral elements, either way, we have to accept there is no solution beyond optimizing the use of locally available organic sources as fertilizers with a better understanding of how crops perform.

The greatest challenge is to minimize the invariable responses of crops with organic inputs to changes in growth and yield determination (De Ponti *et al*., 2012; Jouzi, *et al*., 2017). During the conversion of conventional to organic farming, a detailed understanding of yield and yield parameters can be the key to executing optimal nutrient management using organic resources (Zinati, 2002). The situation is most opportune for research leading towards exploring avenues for embedding organic agriculture and making the approach a widely accepted phenomenon among Sri Lankan farmers.

The sudden switch from conventional to organic farming was unsuccessful primarily due to the rush in policy-based transformation, which could not address the ground level requirements of knowledge, support, and inputs. The efforts of farmers in such transformation should be supported with proven agronomic and management approaches for stabilizing soil quality, input generation, and socio-economic returns, in addition to committed farmers and social support. Technically, on an agronomic basis, a successful conversion to organic farming requires an approximate time of around 10 years in a tropical climate. Based on both contrasting scenarios with chemical and organic fertilizer applications, the results of this study can be used to understand the temporal performance of rice crops under different alternative fertilizer management systems, during the early transition from a conventional system to an organic system. Further, forecasting the probable outcomes of long-term organic manure application would also be supported. We hypothesized that the invariable response of crops due to swift changes in nutrient sources can be negated by combining multiple sources in the long run. The main objective of this study was to understand the response of yield and yield parameters of rice crops to seasonal changes in nutrient status during the process of converting a conventional rice-based system to organic using selective approaches. Hence, during this study, three fertilizer management systems were compared using yield and yield parameters of direct-seeded rice in the dry zone of Sri Lanka.

MATERIALS AND METHODS

This experiment was conducted within the long-term cropping systems experiment established at the farm premises of the Faculty of Agriculture, Rajarata University of Sri Lanka. The site is located at Puliyankulama in the Anuradhapura district of Sri Lanka, and it belongs to the agro-ecological region of DL1b with 8°25’18.12” latitude and 80°24’9.37” longitude. This area consists of an undulating catenary landscape (Thenabadu, 1988). The study area consists of imperfectly drained Reddish-Brown Earth soils (Soil Taxonomic Order- Alfisols, Suborder- Ustalfs, Great Group (hapludalfs) (Mapa *et al*., 2010). The study was undertaken during the first two transition years (*Yala* 2019, *Maha* 2019/2020, *Yala* 2020, *Maha* 2020/2021) of the long-term project. Seasonal rainfalls across four seasons were 181.6 mm, 962 mm, 621.7 mm, and 751.1 mm; mean monthly maximum and minimum temperatures were 32.4 °C and 24.3 °C, respectively (Figure 01.).

The nutrient management systems were defined based on the elemental N supply and the sources given in Table 01. The experiment consisted of three main input systems, which were, T_1: Conventional; 100% N applied as synthetic fertilizer application based on recommendations by the Department of Agriculture (DOA) 2013, T_2: Integrated; 50% N supply with synthetic fertilizer and 25% N supply with organic fertilizer application, T_3: Organic; No synthetic fertilizer was added and organic manure (compost) was applied to satisfy the 50% N amount of the DOA synthetic fertilizer application. Organic fertilizers, which previously calculated the nitrogen content, determined the relevant rate to get the required nitrogen content, and thereby managed the soil fertility. These N rates were decided considering the losses of N from urea and organic matter while aiming to provide adequate N for crop growth. Using this concept, we aimed to enhance the efficiency of nutrients applied and explore a sustainable nutrient management plan for rice-based cropping systems. The phosphorus and potassium rates were not standardized. The amount of these two elements depended on the quantity of organic materials used to supply N to both reduced and organic systems (Table 01.). The three treatments were established as a Randomized Complete Block Design with six replicates. The size of the plot was 90 m^2.

Pre-germinated seeds of the BG 300 rice variety were broadcast at a rate of 120 kg/ha in both the wet season (WS) and dry season (DS). The application of synthetic fertilizer was based on the DOA recommendation in 2013. Organic fertilizer was applied as a basal dressing and as the third top dressing of inorganic fertilizers. Irrigation was done as per the recommendation of DOA, and it was synchronized with the irrigation schedule recommended for that season. In case of a water shortage, additional water is pumped to maintain the inundation as per the requirement. Pest control was carried out according to the DOA guidelines for both conventional and integrated systems; however, major pests or diseases of economic impact were not reported. Weeds in the conventional and integrated systems were controlled using synthetic chemicals, while manual weeding was practiced in the organic input system.

At the time of harvesting, twelve hills were selected from each plot to count the total number of tillers and the total number of fertile tillers per hill. A total of twelve samples were cut from ground level from each plot for measuring the panicle number, the number of filled spikelets per plant, the number of hollow spikelets per panicle, and the thousand-grain yield. The expected grain yield was calculated using yield parameters. Above-ground plant parts were collected at the harvesting stage, and sampling was done by randomly placing a 50 cm x 50 cm quadrate at four locations in the plot. The harvest was threshed by hand, and all plant parts were oven-dried at 60 °C until constant weight was reached to measure crop dry matter and actual grain yield. The biological yield and Harvesting Index (HI) were calculated using equations 1 and 2.

Table 01: Treatments and their respective nutrient contents.

Nutrient management	Mineral nutrient (kg/ha)	Synthetic fertilizer rate (DOA 2013) (kg/ha)	Nutrients from organic fertilizer (kg/ha)	Organic fertilizer rate (Mg/ha)
Conventional	N - 103.5 (Urea 46%)	225 (Urea)	N – 0	0
	P - 3.9 (P_2O_5 43.7%)	55 (TSP)	P – 0	0
	K - 30.0 (K_2O 60%)	60 (MOP)	K – 0	0
Integrated	N - 51.8 (Urea 46%)	112.5 (Urea)	N – 25.9	6
	P - 1.9 (P_2O_5 43.7%)	27.5 (TSP)	P – 0.65	6
	K - 15 (K_2O 60%)	30 (MOP)	K – 52.5	6
Organic	N - 0 (Urea 46%)	0	N – 51.8	12
	P - 0 (P_2O_5 43.7%)	0	P – 1.9	12
	K - 0 (K_2O 60%)	0	K – 15	12

Biological yield = Crop dry matter + Actual grain yield…………….…………. Equation 1

$$\text{Harvesting Index} = \frac{\text{Final grain yield}}{\text{Biological yield}} \qquad \text{Equation 2}$$

Data from four seasons were analyzed to identify the impact of different nutrient management systems and cropping systems on the yield and yield parameters of rice. The data were statistically analyzed using the SAS computer program version 9.0. Count data were tested for normality and heteroscedasticity by identifying the seasons, and then the data were log-transformed to maintain the homogeneity and normality of residuals. An analysis of variance (ANOVA) was carried out using the Repeated measures MIXED model to determine the effect of nutrient management systems under different cropping systems. The season was considered a repeated factor. The means were separated using the Least significant difference (LSD) method at the 5% probability level.

RESULTS AND DISCUSSION

Weather Parameters of Seasons

The weather parameters of the two major growing seasons were different during the study period. The major (*Maha*) season received approximately 65% more rainfall than the minor (*Yala*) season. The highest rainfall was received during the *Maha* 2019/2020 and the lowest was recorded during the *Yala* 2019 season. However, the highest rainfall received in the *Yala* 2020 season is second only to the *Maha* 2019/2020 season. The monthly mean maximum temperature for all four seasons was 35-36 ºC. But the monthly mean minimum temperature was recorded at 25 ºC during the *Yala* season and around 22 ºC during the *Maha* season (Figure 01).

Yield Components

The tiller count was in a decreeing order relative to the N application; thus, a significantly lower tiller count was observed in the organic system irrespective of the season (Tables 02 and 03). The higher availability of N plays a vital role in producing a large canopy by increasing cell division, and for both conventional and integrated systems, the tiller counts were similar due to the optimization of N availability despite sources. In integrated systems, the presence of organic sources may offer more balanced nutrition to the plants, especially micronutrients, than in the conventional system, which positively affects the number of tillers in plants (Miller, 2007). The *Yala* seasons recorded a lower tiller count per hill than the *Maha* seasons (Table 03) with the direct impact of rainfall and temperature variation (Figure 01).

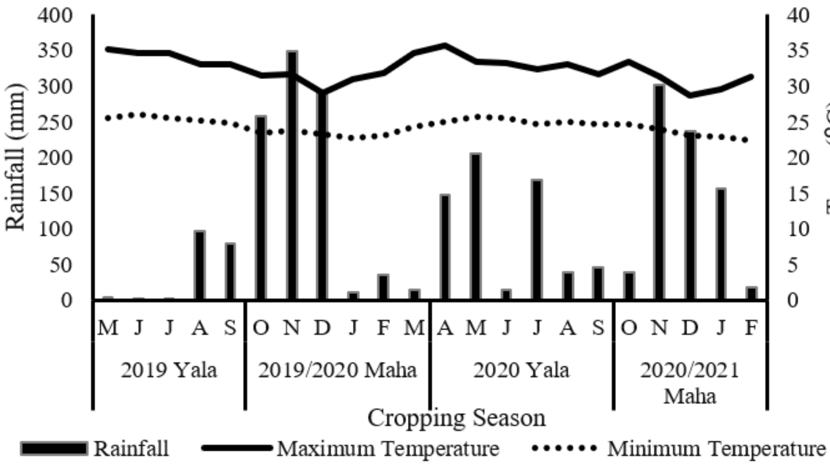

Figure 01: Monthly cumulative rainfall, monthly mean maximum, and minimum temperature in the cropping system with different nutrient management systems in *Yala* 2019, *Maha* 2019/2020 season, *Yala* 2020 and *Maha* 2020/2021 seasons.

Table 02: ANOVA table of different nutrient management and cropping season effect on rice crop.

Parameters	Nutrient management (NM)	Season (S)	NM*S
Total tillers per hill	**	**	ns
Productive tillers per hill	**	**	ns
Panicle number/m^2	ns	**	ns
Number of filled spikelets per panicle	**	**	**
Number of hollow spikelets per panicle	**	**	**
Thousand-grain weight (g)	ns	**	**
Grain yield (MT/ha)	**	**	**
Biological yield (MT/ha)	**	**	**
HI	ns	**	**

*ns-Not significant at p<0.05, ** Significant at p<0.05*

Table 03: Effect of nutrient management and cropping season on total tillers per hill, productive tillers per hill, and panicle number/m^2

	Nutrient Management			Cropping Season			
	Conventional	Integrated	Organic	*Yala* 2019	*Maha* 2019/20	*Yala* 2020	*Maha* 2020/21
Total tillers per hill	3.7^a	3.5^{ab}	3.3^b	3.2^c	4.5^a	3.0^c	3.7^b
Productive tillers per hill	2.6^a	2.5^{ab}	2.4^b	2.2^c	2.6^b	2.2^c	3.1^a
Panicle number/m^2	NA	NA	NA	296^b	190^d	454^a	255^c

Mean values followed by the same letter in each parameter are not significantly different at p<0.05 (LSD)

The productivity of rice plants is greatly dependent on the number of productive tillers rather than the total number of tillers. The number of productive tillers per hill changed significantly, as in the organic system, the numbers were low (Table 02.). The tiller number in the integrated system was similar to the mean productive tillers of the conventional and organic systems. Despite the sources and N availability, both *Maha* seasons recorded higher productive tillers than the *Yala* seasons (Table 03.).

Panicle numbers per m^2 differed significantly with cropping season only (Table 02.), hence when climatic conditions are even, excess application of inorganic fertilizer is not necessary to produce the higher number of panicles. Organic fertilizers might have provided the essential micronutrients to generate reproductive organs to compensate probable degeneration of yield components due to the inadequacy of macro elements (Rakshit *et al*., 2008; Hasanuzzaman *et al*., 2010). The panicle numbers were obtained in descending order of the *Yala* 2020, *Yala* 2019, *Maha* 2020/21, and *Maha* 2019/2020 seasons, respectively (Table 03.), thus the variability is majorly driven by weather and climate.

The other yield parameters, namely the number of filled spikelets per panicle, the number of hollow spikelets per plant, and the thousand-grain weight, were significantly influenced by the two-way interaction of the nutrient management system and cropping season (Table 02.).

The number of filled spikelets per panicle was similar across the nutrient systems in each *Maha* season (Table 04.), possibly due to optimum and favorable conditions without water stress during the *Maha* season. The conditions might have enhanced nutrient availability by improving nitrogen and other macro and micro-element absorption and the production and translocation of dry matter content from source to sink (Channabasavanna and Biradar 2001). The water-limited conditions in the first *Yala* season (Figure 01) resulted in a larger difference among nutrient management systems, and in the second *Yala* season, significantly similar numbers of filled spikelets per panicle in conventional (56) and integrated (59) systems were obtained with changes in *Yala* season weather. Although a conventional system was suddenly converted to an organic system, hollow spikelets per panicle were the lowest with the organic system in *the Yala* 2019 season. The significantly greatest hollow spikelets in the *Yala* 2020 season and lowest in the *Maha* 2020/21 season were noted (Table 04.) due to the impact of seasonal weather and water availability, which could be temporal in the long run (Figure 01).

At the beginning of the *Yala* 2019 season, the thousand-grain weight organic system was the lowest (21.5 g), which was more associated with the effect of both low nutrient levels and weather factor variation (Table 01.). The thousand-grain weight remained stable within three nutrient management systems for all seasons. The thousand-grain weight is genetically determined, and is more often stable even under stress conditions (Sarawgi *et al*., 2013). At the beginning of the study, the moisture and nutrient limitations might lead the crop to early senescence, resulting in poor grain filling. Although it had not resulted in a higher number of hollow seeds per panicle, substantial interference with grain filling was expected.

Grain Yield

The two-way interaction of nutrient management and crop season showed significant impacts on expected grain yield, biological yield, and HI (Table 02.). The higher expected grain yields of integrated (5.06 MT/ha) and conventional (4.86 MT/ha) systems were far better than the organic system (2.96 MT/ha), in the *Yala* 2019 season (Table 05.). The organic system failed to match the national average yield of 4.9 MT/ha in the *Yala* 2019 season, despite a quick transition expected to deliver some carry-over effects. The highest expected yield was recorded in conventional (7.50 MT/ha) compared to the other two input systems in *Maha* 2019/2020 season. This particular season was productive despite the level of inputs, as integrated (5.61 MT/ha) and organic (5.67 MT/ha) systems also delivered yields above the national average (Table 05.). Nutrient input or source-driven yield differences were not observed in *Yala* 2020 season and the *Maha* 2020/21 season (Table 05.), and further, the yields were more climate and weather dependent. The localized impact of weather and water availability resulted in a far below average yield compared to the national average yield of 4.55 MT/ha in *Yala* 2020, while in *Maha* 2020/21 season, the national average yield also dropped to 3.97 MT/ha. The slow release of nutrients from the organic system during the initial period resulted in low yields, and repeated application of organic matter for long periods resulted in improvements in soil fertility levels (Diacono and Montemurro, 2011; Seufert *et al*., 2012). Sufficient inputs of N, P, and K by means of long-term application continuously using organic fertilizers facilitate sufficient nutrient supply to enhance yields in organically grown crops (Surekha *et al*., 2013). Generally, a yield decline in organic systems of 40-60% with a swift change is possible during a transition period (Dabbert and Madden, 1986). Despite the early decline, with the continuous supply of organic manure, yield levels improved and reached a steady level between 60% and 80% when compared to conventionally grown crop yield levels after 4-6 years (Williges, 2004). However, due to different weather conditions, the variation of harvest obtained from such transitions can be substantial, as observed in this study.

Table 04: Effect of different nutrient management and cropping season interaction on panicle number, number of filled spikelets per panicle, number of hollow spikelets per panicle and thousand-grain weight.

	Conventional				Integrated				Organic			
	2019 *Yala*	2019/20 *Maha*	2020 *Yala*	2020/21 *Maha*	2019 *Yala*	2019/20 *Maha*	2020 *Yala*	2020/21 *Maha*	2019 *Yala*	2019/20 *Maha*	2020 *Yala*	2020/21 *Maha*
Number of filled spikelets per panicle	89^{b}	118^{a}	56^{ef}	72^{cd}	61^{de}	106^{ab}	59^{e}	74^{c}	43^{g}	104^{ab}	47^{g}	66^{c-e}
Number of hollow spikelets per panicle	19^{b}	16^{bc}	37^{a}	10^{d}	14^{bc}	15^{c}	36^{a}	10^{de}	8^{e}	15^{c}	27^{a}	9^{de}
Thousand-grain weight (g)	23.8^{a-d}	22.8^{de}	21.3^{f}	24.7^{a}	23.2^{c-e}	23.1^{cd}	21.9^{ef}	23.9^{a-c}	21.5^{f}	23.7^{b-d}	21.4^{f}	24.5^{ab}

Mean values followed by the same letter in each parameter are not significantly different at p<0.05 (LSD)

Table 05: Effect of different nutrient management and cropping season interaction on expected grain yield, actual grain yield, yield differences, biological yield and HI.

	Conventional				Integrated				Organic			
	2019 *Yala*	2019/20 *Maha*	2020 *Yala*	2020/21 *Maha*	2019 *Yala*	2019/20 *Maha*	2020 *Yala*	2020/21 *Maha*	2019 *Yala*	2019/20 *Maha*	2020 *Yala*	2020/21 *Maha*
Expected Grain yield (MT/ha)	4.86^{bc}	7.50^{a}	2.19^{d}	4.20^{c}	5.06^{bc}	5.61^{b}	2.73^{d}	4.85^{bc}	2.96^{d}	5.67^{b}	2.21^{d}	4.07^{c}
Actual Yield (MT/ha)	4.57^{c}	6.42^{a}	1.81^{g}	4.16^{cd}	4.32^{c}	5.11^{b}	2.29^{f}	3.87^{cd}	2.51^{f}	3.92^{cd}	1.63^{g}	3.21^{e}
Yield Difference (%)	6.35	16.82	21.00	0.96	17.13	9.79	19.21	25.32	17.93	44.64	35.58	26.79
Biological yield (MT/ha)	14.89^{b-e}	19.65^{a}	9.22^{f}	13.55^{de}	17.08^{ab}	16.31^{bc}	9.27^{f}	14.28^{c-e}	10.02^{f}	15.17^{b-d}	8.84^{f}	12.77^{e}
HI	0.31^{cde}	0.26^{f}	0.43^{a}	0.32^{cd}	0.34^{bc}	0.30^{def}	0.34^{bc}	0.30^{def}	0.34^{bc}	0.28^{ef}	0.38^{ab}	0.31^{cd}

Mean values followed by the same letter in each parameter are not significantly different at p<0.05 (LSD)

Yield differences between the expected and actual organic systems were higher compared to the differences between the other two systems. The yield difference between the expected and actual yield of the conventional system was less than 25% for each season, in the integrated system, the difference was less than 25% in all seasons except the *Maha* 2020/21 season. Conversely, in organic systems, the yield difference between expected and actual was more than 25% in all seasons, except the *Yala* 2019 season (Table 05.). The yield difference was mainly driven by weather, climate, and water stresses, especially in *Yala*, which is theoretically more productive than *Maha*. Despite a similar pattern of differences compared to organic and integrated systems, higher yield differences in the organic system proved the vulnerability to adverse conditions under low nutrient and poor growth situations and unexpected variability of input distribution within the organic system. The differences were also reflected by the yield components, as most of the components failed to rely upon them during the latter part of the growth due to stresses imposed by the weather and poor nutrient availability.

The biological yield of the rice crop also showed a concomitant tendency towards the final grain harvest as a long-term effect of various fertilizer applications. In season one, i.e., *Yala* 2019, conventional (14.89 MT/ha) and integrated (17.08 MT/ha) nutrient management systems achieved significantly higher biological yields compared to the organic (10.02 MT/ha) system in the *Yala* 2019 season. The absence of mineral fertilizers without improving the soil fertility to respond under organic systems resulted in the substantially poor performance of the crop. Thus, poor vegetative and reproductive growth and, hence, poor shoot dry matter accumulation and biological yield was an expectation in early seasons with the organic system (Iqbal *et al*., 2020). Afterward, in the two cropping seasons (*Yala* 2020 and *Maha* 2020/21) the biological yield was not influenced by the nutrient management systems (Table 05.).

Except for *Yala* 2020, the harvest index (HI) of crops was below 0.40 irrespective of the three nutrient management systems. The recorded HI of organic systems was subpar compared to conventional and integrated systems. The impact of climate can be negated with low HI values for all systems in certain seasons. The lower availability of nutrients and timely unavailability in the organic system were not aiding the crop in translating the vegetative biomass into harvestable biomass. Early senescence of the crop and low efficiency of translating biomass into yield led the organic system to deliver more straw (Ladha *et al*., 2005). Despite the differences during the early transition, the organic system has improved with time towards the latter part of the study by improving the HI to an acceptable figure (Table 05.).

CONCLUSIONS

A swift transition from a conventional system to an organic system drastically changed crop performance, and it also broadened the vulnerability of crops to the fluctuation of weather. The sole organic systems were more vulnerable compared to integrated systems due to the fact that the substitution of nutrient elements was not 100%. The cumulative impact of continuous application of organic sources with both organic and integrated systems were able to counter the negatives of climate and nutrient deficiencies even at the very early stages of this conversion process. Hence, a judicious transition using nutrient substitution and crop rotation approaches can be a key to transforming input-dependent conventional systems to solely organic or organic input-dependent in a shorter period of time than anticipated and also to mitigate the climate-dependent negatives far better than the conventional systems.

ACKNOWLEDGMENT

The research was funded by the Presidential Secretariat - Sri Lanka, which is greatly appreciated.

REFERENCES

Ameen, A. and Raza, S. (2017). Green revolution: a review. *International journal of advances in vscientific research*. 3 (12), 129-137.

Channabasavanna, A. S. and Biradar, P. D. (2001). Yield and yield attributes of transplanted summer rice as influenced by organic manures and zinc levels. *Journal of Maharashtra agricultural university*. 26, 170-172.

Dabbert, S. and Madden, P. (1986). The transition to organic agriculture: A multi-year simulation model of a Pennsylvania farm. *American journal of alternative agriculture*. 1 (3), 99-107. DOI:10.1017/S0889189300001028

De Ponti, T., Rijk, B. and Van Ittersum, M.K. (2012). The crop yield gap between organic and conventional agriculture. *Agricultural systems*. 108, 1-9. DOI:10.1016/j.agsy.2011.12.004

Diacono, M. and Montemurro, F. (2011). Long-term effects of organic amendments on soil fertility. In: Sustainable agriculture. Volume 2. (Lichtfouse, E., Hamelin, M., Navarrete, M. and Debaeke, P. Eds.). Springer, Dordrecht. 761-786. DOI: 10.1051/agro/2009040

Hasanuzzaman, M., Ahamed, K.U., Rahmatullah, M., Akhter, N., Nahar, K. and Rahman, M.L. (2010). Plant growth characters and productivity of wetland rice (*Oryza sativa* L.) as affected by application of different manures. *Emirates journal of food and agriculture*. 22 (1), 46-58.

Iqbal, A., He, L., Ali, I., Ullah, S., Khan, A., Khan, A., Akhtar, K., Wei, S., Zhao, Q., Zhang, J. and Jiang, L. (2020). Manure combined with chemical fertilizer increases rice productivity by improving soil health, post-anthesis biomass yield, and nitrogen metabolism. *Plos one*. 15 (10), p.e0238934.

Jouzi, Z., Azadi, H., Taheri, F., Zarafshani, K., Gebrehiwot, K., Van Passel, S. and Lebailly, P. (2017). Organic farming and small-scale farmers: Main opportunities and challenges. *Ecological economics*. 132, 144-154. DOI:10.1371/journal.pone.0238934.

Ladha, J.K., Pathak, H., Krupnik, T.J., Six, J. and van Kessel, C. (2005). Efficiency of fertilizer nitrogen in cereal production: retrospect and prospects. *Advances in agronomy*. 87, 85-156. DOI: 10.1016/S0065-2113(05)87003-8.

Mapa, R.B., Somasiri, S. and Dassanayake, A.R. (2010). Soils of dry zone of Sri Lanka: Morphology, characterization, and classification. Soil science society of Sri Lanka, Peradeniya, Sri Lanka. 51*,* 126-147pp.

Miller, H. B. (2007). Poultry litter induces tillering in rice. *Journal of sustainable agriculture*, 31:1-12. DOI: 10.1300/J064v31n01_12

Rakshit, A., Sarkar, N.C. and Debashish, S. (2008). Influence of organic manures on productivity of two varieties of rice. *Journal of central European agriculture*. 9 (4), 629-634.

Ramchandra, P.V. (2020). A review on environment and green revolution. *Dogo rangsang research journal*. 10 (6), 213-219.

Sarawgi, A.K., Subba Rao, L.V., Parikh, M., Sharma, B. and Ojha, G.C. (2013). Assessment of variability of Rice (*Oryza sativa* L.) germplasm using agro-morphological characterization. *Journal of Rice Research*. 6(1), 14.

Seufert, V., Ramankutty, N. and Foley, J.A. (2012). Comparing the yields of organic and conventional agriculture. *Nature*. 485 (7397), 229-232. DOI:10.1038/nature11069.

Surekha, K., Rao, K.V., Shobha Rani, N., Latha, P.C. and Kumar, R.M. (2013). Evaluation of organic and conventional rice production systems for their productivity, profitability, grain quality and soil health. *Agrotechnology.* 1, 87.

Thenabadu, M.W. (1988). Soil and soil conservation in Sri Lanka. National resources, Colombo: Energy and science authority of Sri Lanka, 4-8pp.

Wickramasinghe, W.M.D.M., Devasinghe, D.A.U.D., Dissanayake, D.M.D., Benaragama, D.I.D.S., Egodawatta, W.C.P. and Suriyagoda, L.D.B. (2021). Growth physiology and crop yields of direct-seeded rice under diverse input systems in the dry zone of Sri Lanka. *Tropical agricultural research*. 32 (3), 325-337. DOI:10.4038/tar.v32i3.8496

Williges, U. (2004). Status of organic agriculture in Sri Lanka with special emphasis on tea (*Camellia sinensis* (L.) O. Kuntze) production systems. Doctoral dissertation, Ph. D. dissertation, Justus-Liebig university of Giessen, Germany. 55pp.

Zinati, G.M. (2002). Transition from conventional to organic farming systems: I. Challenges, recommendations, and guidelines for pest management. HortTechnology. 12 (4), 606-610. DOI:10.21273/HORTTECH.12.4.606.