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INVITED REVIEW

RICE PRODUCTION UNDER THE ORGANIC FERTILIZER USE POLICY IN SRI LANKA

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ABSTRACT

Rice cultivation in the country dates back to time immemorial, though the rice production was not sufficient to meet the demand with the increasing population lately. Rice breeding work started during the last phase of the colonial era and continued with the green revolution in the 1960s. As a result, the national average yield improved from 0.75mt/ha during the colonial time to 4.82 mt/ha today. Improved varieties today are highly responsive to inorganic fertilizers, high tillering and high yielding with some insect and disease resistance. However, inorganic fertilizer use in the country since the 1950s resulted in soil degradation and was further aggravated by inappropriate mechanization and weedicide use. This led the department of agriculture to recommend the use of organic matter to supplement inorganic fertilizer applications to sustain production. The situation was viewed superficially and the government took a policy decision to ban the import of inorganic fertilizer and agrochemicals without any valid research data or suitable organic alternatives for pesticides, disregarding the high shriek from the eminent scientists and paddy farmers. Ad-hoc fertilizer recommendations provided to farmers and the use of alien fertilizer formulations without any field research data locally were either rejected or used sparingly by the farming community. This huge cry was later politicized and prevented the President to change his decision, though some flexibility was approved. Policy decisions ultimately ended up in huge rice imports, amidst a shortage of foreign currency, to prevent food shortages. Organic fertilizer sources are many though their availability individually is not adequate for the rice sector. There are many compost producers whose products vary in nutritive content from producer to producer and from batch to batch of the same producer. Thus, organic fertilizer standardization and providing a single fertilizer recommendation is impossible if not time and labor intensive and financially very expensive. However, a concrete single recommendation for organic fertilizer is not possible even with extensive field experimentation. Therefore use of organic fertilizer as a basal application alone with inorganic fertilizer to meet the peak nutrient demand at several stages of rice plant growth can be a good option to sustain rice production, of course after a minimum of two season's adaptive field research. This paper reviews the *pros* and *cons* of sustainable rice production in the country under the organic fertilizer policy of the government.

Keywords: Agrochemicals, Compost, Manures, Organic fertilizers, Rice production

INTRODUCTION

Rice is the staple diet of Sri Lankans that dates back to time immemorial. The beginning of paddy cultivation in Sri Lanka, traces its root back to the proud history between 161 B.C. and 1017 A.D. and ideal climatic conditions yielded a flourishing crop, which encouraged many Sri Lankans to make paddy cultivation their way of life. A large number of wild rice germplasm collected and preserved at Plant Genetic Resource Centre (PGRC), Gannoruwa will bear witness to this. Asian rice cultigens originated mainly on the southern borders of the Himalayas and to a lesser extent in the south and south-east China. Eco-geographic races of *Indica* rice spread southwards to Sri Lanka and Malay Archipelago and northward to central and south China (Chang 1976). Most rice cultivars in collapse belong to *Indica* type and there are six wild species reported from Sri Lanka namely; *O.*

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rufipogon, O. granulate, O. nivara, O. eichingeri, O. officenalis and O. perennis. The first recorded germplasm collection in Sri Lanka was by the 'Nugawela Disawe' in 1902, which consisted of 300 varieties and was exhibited in Kandy Agri-Horticultural and Industrial Exhibition (Senadhira 1983). The island-wide collection of rice germplasm was started in 1967 by the Government Agents and District Extension workers and by the year 1972 local collectors together with IRRI staff were able to collect some 3153 rice varieties island wide (Gunawardena 1983). Ancient farmers cultivated these traditional varieties year after year, which survived through natural selection and some of the traditional rice varieties used in the country in 1930s are given in Table 1.

Traditional varieties used by the farmers several decades back are a mixed population of varieties and the mixing up of varieties was due to the cultivation of different varieties in different seasons where germination of rice seeds of the previous season contaminating. Therefore there was no one particular variety as such, but a population of plants having different heights, tillering capacities, seed sizes and also different maturity periods, which sometimes farmers remove manually and purify.

Traditional rice varieties are poor yielders [(0.75mt/ha); Dhanapala 2020)] and are tall and have less tillering, though the production was not sufficient for the country's consumption and wheat import is the order of the day even though we had a low population in the country. The characteristics of these varieties are ;

1. Most of them are tall more than 1.5 to 2 m.
2. Long droopy leaves
3. Low tillering
4. High mutual shading
5. Lacks positive yield response to added fertilizer
6. Low harvest index (HI) and leaf area index (LAI)
7. Can tolerate short spells of drought
8. High weed competitive ability

Generally, rice grain is a very nutritious source of diet and has been a prominent cereal food since ancient times. The nutritive values of some Sri Lankan traditional rice are given in Table 2. Rice is low in fat and high in starchy carbohydrates. Moreover, rice is rich in vitamins and minerals and provides an excellent source of vitamins B, E and Potassium. The amino acid balance of rice protein is exceptionally good. Besides being the main source of calories and protein, rice is an important cereal because it has the highest digestibility, biological value and protein efficiency ratio than other cereals (Nadathur *et al*. 2017). Most of our traditional varieties had not only high nutritional values (Table 2), antioxidant and medicinal values but also the potential to cope with the drastic climatic changes which are generally detrimental to paddy cultivation (Rodrigo, 2013). Further, the medicinal values of traditional rice have been experienced by Sri Lankans for decades [Anonymous, 2014].

However, with the growth of our population and increasing demand for food, rice breeding in Sri Lanka was initiated. The recorded history of rice breeding in Sri Lanka dates back to the colonial era (1819-1948) and the Ceylon Agriculture Society was involved in promoting rice production until the early twentieth century a responsibility that was taken over by the Department of Agriculture

Table 1: Rice varieties grown in 1930 and before

Age Group	Varieties
3 months	'Pachcha perumal'
3.5 months	'Heenati', 'vellai perumal'
4-4.5 month	'Vellai Illankalayan', 'Murungakayan'
5-6 months	'Podi wee', 'Muthu samba', 'Panduru wee'. 'Maa wee'

[Source :(Senadhira, 1983)]

(DOA) (Dhanapala 2020). DOA did the initial rice germplasm selection work and pure lines were identified for cultivation, which improved the rice yields and production slightly. With the pure line selection, the rice researchers were able to improve a few characteristics of these varieties to some extent such as;

1. HI (Harvest Index)
2. Yield response to added fertilizer
3. Disease tolerance
4 Drought tolerances

Varietal improvement programme in Sri Lanka

Rice improvement in the country was rejuvenated in the country with the green revolution and the release of rice variety IR 8 by the International Rice Research Institute, Philippines. The varietal improvement as the best potential strategy to overcome the limitations in rice production was surmised by Duvick (1984). Formerly, due to the lack of capital, training, facilities, and defects in the socio-economical system, the practices including the application of fertilizers, the use of new technologies were either ignored or not conceived (Walisinghe *et al.* 2010). Further, intensive land selection, timely cultivation, postharvest supervision, socio-economic development and usage of chemical control methods increased rice productivity (Dhanapala 2007). To satisfy the changing market and consumer preference, and fulfill the breeding priorities the novel varieties with enhanced and defensive traits like fast-growing, high-quality, pest resistance, disease resistance, tolerance under significant abiotic stresses like heat and drought, and fast yielding varieties were needed (Khush 1995; Peng *et al*. 2009). Initially, crop improvement was accomplished with tedious, lengthy, outdated, and subjective classical breeding techniques. However, today, the knowledge of genetics helps to identify the genes responsible for desirable traits and marker-assisted breeding (MAB) (Jiang 2013a) and to preserve valuable traits within the germplasm is possible (Sasaki 2011). Further, the DNA markers are used to monitor the allelic segregation and confirm genetic stability in MAB with a high level of accuracy (Jiang 2013a,b). During the last several decades' attempts were made to the improvement of a large number of rice varieties which adjusted to diverse agro ecology. However, increasing biotic and abiotic stresses, increasing populations, and sharply reducing natural resources especially water for agricultural purposes, push the breeders for organizing and developing improved rice varieties with higher yield potential and in combination with developments in agricultural technology, plant breeding has made remarkable progress in increasing crop yields for over a century (Xu, 2010). Xu in his review further surmised that DNA markers are being used for the acceleration of plant selection through marker -assisted selection (MAS) and genes of agronomic and scientific importance can be isolated especially on the basis of their position on the genetic map by using molecular marker technologies.

Table 2: Nutritional properties of whole grains of selected Sri Lankan traditional rice Nutritional parameter (% dry basis) (Samaranayake *et al.* 2017)

Rice variety	Suwadal	Heeneti	Nilkanda	Kurulu Thuda	Maa Wee
Moisture	13.84	13.59	13.81	13.65	13.36
Crude Protein	8.09	8.10	7.80	8.44	11.16
Crude ash	1.55	1.68	1.54	1.50	1.55
Crude fat	3.28	2.89	2.78	3.14	2.78
Total Dietary fibre	6.28	4.96	5.13	4.88	2.68
Available Carbohydrates	80.80	82.37	82.74	82.04	82.23
Sugar	2.28	2.70	2.41	2.92	5.86

[Note: Crude fat, crude protein, crude ash, total dietary fiber, available carbohydrate and sugar contents are expressed as % dry basis. Mean values in a row superscripted by different letters are significantly different at $P < 0.05$.

The rice varietal improvement programmes in Sri Lanka were initiated in 1950s focusing on the development of improved short stature, fertilizer responsive, high yielding varieties suited to the local environments. In Sri Lanka rice breeding work started with the usage of imported germplasm from neighbor countries, trying to introduce some important characters to our own traditional varieties, while making crosses with our traditional varieties. The first rice hybrids developed in the country was the 'H' series (H_4, H_8, H_{10}, etc.) bred at Rice Research Station, Batalagoda, by crossing rice variety 'Mas' with variety 'Murungakayan'. These hybrids had the same characteristics as our own traditional varieties though their yield were improved by almost double and resistance to pests and diseases also improved. Further breeding work with alien germplasm was able to introduce varieties such as Bg. 11-11, Bg. 34-6, Bg. 34-8, for commercial cultivation around the country in 1970s and their characters were;

1. Short to intermediate in height; 80-120cms
2. Short erect leaves
3. High response to added fertilizer
4. High HI and low LAI
5. Poor weed competitive ability
6. Cannot tolerate drought even for short spells
7. High water requirement
8. High susceptibility to pests and diseases
9. Poor keeping quality eg. Bg 11-11 (cannot keep for more than 6-8 months as the rice milling outturn is greatly reduced and poor eating quality manifested).

However, the main breeding emphasis in the country was to increase yield through fertilizer responsiveness, using new rice technology developed elsewhere in the world. This step in rice improvement was able to increase our rice yield potential to about 8-10 mt/ha under favourable environments, though most of these varieties were prone to high incidence of pests and diseases.

The importance of incorporating disease resistance and pest resistance came to lime light among breeders world wide as the new biotypes of different pests emerged under wide spread use of high fertilizer response rice cultivars. These varieties can tolerate medium soil stress (eg. Salinity) conditions with a yield potential of over 6 mt/ha, though under ideal soil conditions the yield potential was around 10 mt/ha. During the last few decades, we were able to introduce stress resistance to our varieties with high yields and we were able to produce very popular varieties like, Bg 352, Bg 357, At 354, Bw 453, "Keeri samba" etc. today Adoption of the above strategies from time to time however increased the production levels in the country (Table 3) to a reasonable level and the country was on the verge of self-sufficiency or self-sufficient in some production years, though not consistent. Herath *et al.* (2010) also indicated rice production in Sri Lanka has shown a remarkable growth during the last four decades but still fails to do away with wheat imports. Moreover, in the year 2019, an excess production of 800,000 mt of paddy was recorded according to reports from the Ministry of Agriculture.

Table 3: Rice production and wheat imports to the country since independence [Herath 2010]

Period	Paddy Production 000'mt	Area in 000'ha	Average Yield	Rice requirement 000'mt	Wheat Imports 000'mt
1948-56	533	450	1.4	604	203
1965-70	1199	660	2.0	577	362
1986-87	2357	843	3.2	1472	556
2007-09	3553	942	4.3	2024	965
2013	4621	1067	4.33	2267	773
2016	4420	1011	4.37	2327	877
2020	5121	1066	4.80	2686	1404

The above data shows the value of the green revolution in increasing rice production and the valiant effort of our rice breeders to achieve this goal and emerged with today's fertilizer responsive, high tillering and high yielding varieties with pest and disease resistance. Among major nutrients, recent rice varieties are highly responsive to N application more than other nutrients. Many research on the N response of local rice varieties was conducted throughout their breeding programmes and even after the recommendation for cultivation. For example, Priyadarshanee *et al*. (2015) working on Bg rice varieties with N levels from 0 kg/ha to 150 kg/ha showed that the responses to the application of nitrogen fertilizer vary among the rice varieties. Plant height, number of tiller per hill, plant greenness, dry weight of shoot, plant nitrogen content, grain yield and number of panicles per plant of four rice varieties were increased with the increasing level of nitrogen fertilizer and responded positively. Suseema *et al.* (2021) reported that plant height, number of productive tillers, panicle length, leaf colour intensity, and chlorophyll content of leaves of Ld 368 showed an increasing trend against added nitrogen from 50 kg/ha to 200 kg/ha. Further, Kumara and Hafeel (2019) working on recent 'At' rice varieties bred at Rice Research Station, Ambalantota, showed that Grain yield and yield components were significant at 100 kg N ha^{-1} and grain yield and yield components showed an increasing trend with the increased nitrogen rate from 50 to 200 kg N $ha^{-1}$of both elite breeding line At 08-1078 and variety At 362.

If not for the green revolution, our rice yields would not have improved much and we would have increased the rice production through horizontal expansion only and the country's production would have been highly insufficient for the increased population today. However, none can think of a green revolution and high rice production in the country without the use of inorganic fertilizer use. Unfortunately, inorganic fertilization in lowland rice cultivation emphasized only the three major nutrients N, P &K assuming our soils are rich in other essential nutrients, paid low emphasis, and micro- nutrients were applied when deficiencies are recognized only.

Rice plant nutrition

Plant nutrition in crops is the study of the chemical elements and compounds necessary for plant growth and is a very complex field of study (https://en.wikipedia.org/wiki/Plant_nutrition). Since the inception of scientific growing of plants, scientists surmised that plants require 17 nutrient elements for normal growth and development, which are part and parcel of plant cells, plant organs as well as appendages of all types of plants in the plant kingdom, though different species require them in different quantities. The nutrient source for the plant growth is its micro-environment and the majority of these nutrient elements are absorbed from the soil environment and a few, such as oxygen and hydrogen as water vapour and carbon in the form of carbon dioxide are absorbed from the immediate environment.

Most rice soils in the country possess these nutrient elements, which are required for the plant in different but adequate quantities and in rare situations they are either at deficient levels or toxic levels. On the other hand, even if the soil possesses some elements at toxic levels plants do not show toxic symptoms because of the fact that the soil availability is not excessive and adequately enough for the plant growth. Therefore, the nutrient availability in soil solution is more important than the quantities available in the soil. This is especially true for soil fixing nutrients such as P and K. For example, Senanayake and De Datta (1991) showed that the soils, which contain 300 ppm total phosphorus, only have a concentration of 0. 08 ppm of P in soil solution, which was adequate for normal growth of rice plants in five Philippine soils.

There are several factors which make the plant nutrients available for the plants. They are the soil concentration of a particular element (availability), soil water content, soil air, nutrient interactions, synergistic effect and antagonistic effect between nutrients and nutrient competition for absorption. There are volumes of research publications and articles published globally by various scientists on these different aspects of nutrient availability. Data in Tables 4 and 5 indicate a comparative analysis of the nutritional composition and mineral composition among traditional and present-day rice varieties respectively where there are no great differences among varieties.

Roberts *et al*. (2012) studied the nutrient concentration and removal rates in many cereal crops at different yield levels and showed that nutrient removal per unit yield was low for rice (Table 6) but it was otherwise for nutrient removal for a given particular yield. Further, Sukristiyonubowo *et al*. (2012) indicated depending on the treatments, total nutrient removal through rice grains and rice straw varied from 37.25 and 93.75 kg N, 2.99 and 8.49 kg P, 53.03 and 149.03 kg K ha^{-1} $season^{-1}$. Nutrient uptake also depends on the method of cultivation in rice and Arunbabu Talla and Jena (2014) indicated Maximum uptake of major nutrients was recorded in the System of Rice Intensification (SRI) and recorded as 62.72 and 25.13 kg ha^{-1} of N, 17.06 and 5.26 kg ha^{-1} of P and 13.04 and 101.11 kg $ha^{-1}$of K for rice grain and straw respectively. These findings clearly indicate the amounts of nutrients to be replenished by way of fertilizer to the field every season, in order to sustain the yield of improved rice varieties.

Table 4: Comparison of general nutritional composition among new improved rice varieties (%w/w) and traditional rice varieties (% dry weight).

Rice variety	AT 308	Bg 358	Bg 406	Sudu Heeneti	Suduru Samba	Pachcha-perumal	Madatha-walu
Moisture content	11.85	12.11	11.95	12.33	12.13	12.1	11.7
Ash content	0.24	1.10	0.52	1.5	1.7	1.3	1.6
Fat content	2.34	1.82	2.99	2.97	2.75	4.12	2.63
Protein content	0.63	0.74	0.69	11.52	13.27	13.16	12.08
Carbohydrate	84.94	84.23	83.85	84.01	82.28	81.42	83.69

[Source: Ajeitha and Gowri 2016; Abeysekera *et al*. 2017]

Table 5: Mineral composition of the traditional and improved rice varieties.

Mineral (ppm)	Suwandel	Kaluheenati	Kurulu thuda	BG 360	BG 352	AT 362
K	2.14	2.24	2.38	2.14	2.25	2.16
Mg	1.01	1.14	1.50	0.93	1.03	1.13
Fe	21.85	34.92	22.11	18.95	20.25	22.14
Zn	26.51	34.40	28.39	27.57	32.33	23.18
Mn	36.28	28.17	41.44	43.36	32.24	23.29
Cd	0.08	0.06	0.02	0.08	0.01	0.02
Na	0.05	0.07	0.05	0.04	0.04	0.05
As	0.05	0.04	0.03	0.06	0.05	0.02

[Source: Kulasinghe *et al.* 2018]

Table 6: : **Estimated nutrient concentrations and removal rates in the harvested portion of Arkansas row crop of rice**.

Crop (unit of measure)	Nutrient removal† (lb per unit of yield)			Yield (yield/ acre)	Removal for given yield (lb/ acre)		
	N	P	K		N	P	K
Rice (bushels)	0.57	0.30	0.16	150	86	45	24
				200	114	60	32
				250	143	75	40

[Source: Roberts *et al.* 2012]

Nutrient management approach in rice production

Thousands of soil types that exist in the world have arisen from different parent materials under diverse ecological conditions. Some are fertile, tillable and wonderfully suited for agriculture while others may need a great deal of husbandry to become useful. On the other hand, the rice plant absorbs different nutrients in different quantities at different stages of rice plant growth. For example, P is required in greater quantities at the initial vegetative stage and therefore applied basally, whereas K is required in higher quantities at the vegetative stage and the maturity stage, as such it is supplied in two split applications. Further, many other secondary and micro nutrients are absorbed by the plant throughout the crop growth without any distinct peak absorption stages.

Sustainable agriculture or regenerative farming aims to produce food and fiber on a sustainable basis and to repair the damage caused by destructive procedures of nutrient removal from soil (Fageria *et al.* 2010, Fageria and Moreira 2011). In order to replenish the nutrient removal effectively and sustainably, Rai *et al.* (2019) suggested the Four-R (4R) nutrient stewardship model for best management practices (BMP) for fertilizer application for rice. 4R nutrient stewardship is based on the principle that fertilizer should be applied meeting the following requirements:

Right type or source
Right rate or dose
Right place and
Right time

Adaptation of this model helps the growers to achieve high production sustainability of rice and to satisfy the several peak requirements of nutrients in rice plants. Although the recommendations for 4R are specific with respect to the site of application, but the scientific principles are universal.

Nitrogen in rice plant nutrition.

Nitrogen is the major nutrient most important and applied universally for high yields in many crops. The innumerable number of research publications and research conducted globally on N response of field crops and various aspects of N application, sources, rates, the fate of N and improving N efficiency will prove its importance for rice plants as well. Nitrogen is vital in plant nutrition. Plants normally contain 1-5% by weight of this nutrient and have several functions in plant growth and development.

(i) Nitrogen is an essential constituent of proteins and present in many other compounds e.g. nucleotides, phosphatides, alkaloids, enzymes, hormones, vitamins, etc. It is, therefore, a basic constituent of **"plant life."**
(ii) Nitrogen is an integral part of chlorophyll,
(iii) Nitrogen also imparts vigorous vegetative growth and dark green colour to plants.
(iv) It produces early growth and also results in a delay in the maturity of plants, when in excess.
(v) It can influence the utilization of potassium, phosphorus and other elements in plants.
(vi) The supply of nitrogen is related to carbohydrate utilization. When nitrogen supplies are optimum and conditions are favourable for growth, proteins are formed from the manufactured carbohydrates.
(vii) Excessive supply of nitrogen develops excessive succulence which results in harmful effects like lodging in grain crops.

Today all rice varieties grown globally in all rice-growing countries are highly N responsive as they were bred and released to get high yields in order to feed the ever-increasing global population. Therefore rice responds almost universally to N applications except on recently cleared virgin lands or in circumstances where other factors severely limit growth. In principle, rice-producing countries in the tropics; India, Indonesia, Thailand, Philippines and Brazil, the optimum responses are obtained at rates of 30-50 kg N/ha with 2-3 tons per hectare yields from their traditional rice varieties (Senanayake, 2021). At higher rates, tall traditional varieties tend to lodge and decrease yield. Later, with the introduction of a new plant type by IRRI in 1966 scientists completely changed the N management practices and increased rates of

N application were used in new improved varieties. Nitrogen response to rice depends primarily on non-soil factors such as plant type, solar radiation, water management, growth duration and lastly, soil properties (De Datta,1981).

The fate of N in lowland rice soils when applied causes much concern among scientists. The main problem is the N use efficiency, which is less than 60% even under the most favourable environmental conditions. One reason for this N loss is the nitrification/de-nitrification processes that take place in the thin oxidized layer at the soil surface in lowland rice soils followed by a deep reduced layer underneath. This situation is ideally suitable for the oxidation-reduction processes to operate resulting in heavy N losses. The schematic diagram given in Figure 1 clearly shows the nitrification/de-nitrification processes in lowland rice soils. Further, the loss of N through seepage and percolation below the root zone even under the most appropriate environmental conditions and best agronomic practices were heavy and appreciable (De Datta,1981).

Numerous studies were conducted locally as well as globally to increase N use efficiency and to determine the optimum rate of application. The N efficiency however is increased slightly through practices like deep placement at the reduced zone of the soil's profile or incorporation into the soil after land preparation, but the processes consume more labour for application and therefore not economical. Research conducted globally on the effect of N placement using labelled N has given the following results (Table 7).

The inorganic N changes in lowland rice soils in relation to plant uptake were studied by Buresh and De Datta (1991) found that the plant uptake takes place near the transitional zone on the reduced zone and the N losses and the N uptake had almost similar peaks as shown in Figure 2. Plant uptake of N is mainly in the ammoniacal form, whereas the N losses are mainly in the Nitrate form or oxidized form.

Nitrogen use in lowland rice cultivation in Sri Lanka during the last millennium was extremely inappropriate where farmers used an excessive amount of N and the other major elements, P and K, very sparingly in their cultivations, due mainly to their poor economy. The continuous use of this practice has made the rice soils 'sick' and without any addition of organic matter to supplement other nutrients the rice yields remained stagnant.

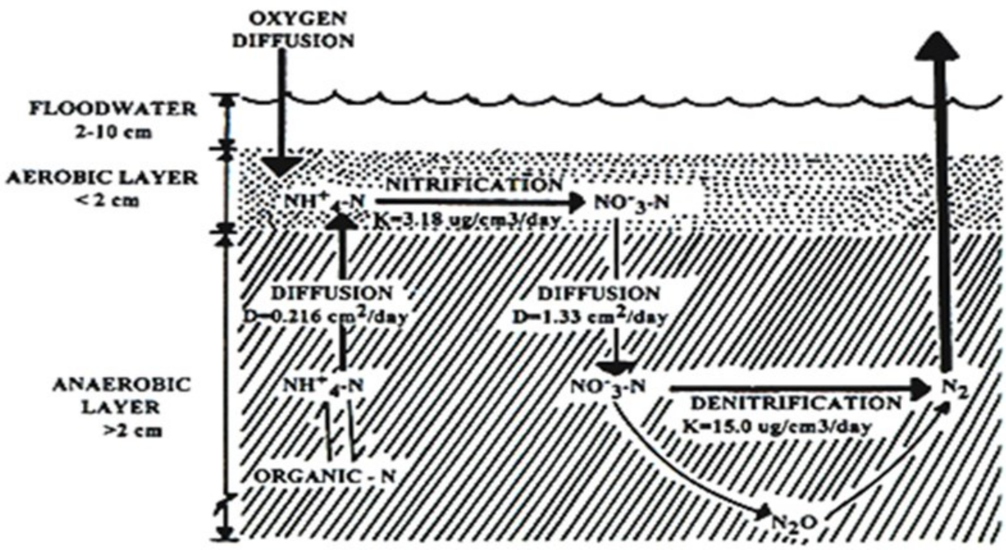

Figure 1: Nitrification and De-nitrification sequence reactions in flooded soils (Adopted from Patrick and Reddy, 1977)

Further mismanagement of other agronomic practices such as misuse of land preparation machinery and pre-land preparative application of total weed killers such as “Gramoxone” and “Round Up” contributed to the development of sandy top soils and promoted the clay particles to sink down to the traffic layer below. Therefore, the slightest increase in depth of ploughing and the addition of organic matter increased significantly the rice yields in recent years (Wickramasinghe 1999).

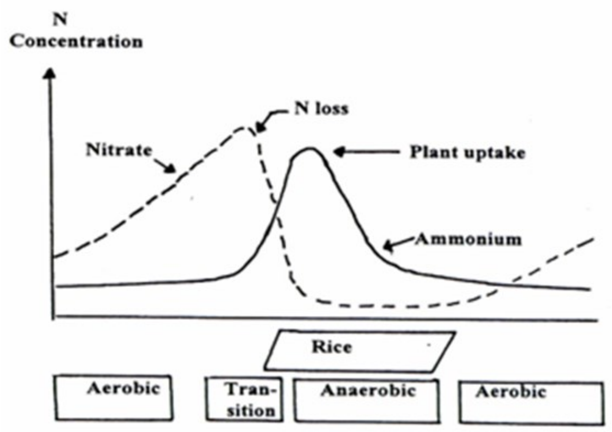

Figure 2: Inorganic N changes and plant uptake during a period of rice production (Adopted from Buresh and De Datta, 1991)

This factor is well illustrated in Table 8 where rice grown in different soil groups in several locations showed similar results indicating better root and shoot growth and shoot to root ratio under deep ploughing treatment. Therefore the N in lowland rice soils needs careful management if it were to sustain or increase rice production to meet the future demand in the country.

Rice plant response to N depends primarily on factors like plant type, solar radiation, water management, growth duration and lastly the soil properties. Further, the yield responses in short-statured present-day varieties are mainly due to panicles per unit area and the number of filled grains per panicle among yield components (Sanchez 1972). Further,

Table 7: Effect of placement of N and other methods of application on the grain yield and efficiency of fertilizer N.

Method of Application	Grain Yield (mt/ha) N sources (^{15}N labelled)			Efficiency (kg rough rice/ kg N)
	Urea	*Ammonium sulphate*	*Mean*	
Incorporated at planting	6.8	6.8	6.8	14
Placed at 10cm soil depth	8.6	8.3	8.4	43
Split Application*	7.1	7.6	7.3	23
Mean (Sources)	7.3	7.6	-	-

*30 kg N/ha at planting and 30 kg N/ha at PI.
(Source : De Datta *et al.* 1968)

Table 8: Effect of deep ploughing on some rice soils in Sri Lanka

Parameter	Thopawewa		Batalagoda		Hingurakgoda	
Soil type	**RBE**		**Alluvial**		**RYP**	
Ploughing	*Deep*	*Shallow*	*Deep*	*Shallow*	*Deep*	*Shallow*
Shoot weight (g)	10.8	6.73	5.17	4.0	52.45	33.46
Root Weight (g)	2.53	1.57	2.37	1.69	4.12	2.77
Shoot/Root ratio	4.03	4.30	2.44	2.25	12.78	12.32

RBE: Reddish Brown Earths; RYP: Red Yellow Podzolic soil
(Source: Wickramasinghe, 1999)

the new varieties have the ability to convert more N and photosynthetic food production into the grain, using a smaller straw base to produce it, than do the tall traditional varieties.

The absorption pattern of N is also important to decide how to manage N in lowland rice fields. Wada *et al*. (1986) showed that the amount of N in plants increased exponentially at the early growth stage (y=abx) and linearly at the middle and late growth stages (y=a+bx). The crossing point of the two equations coincided with the maximum tiller number stage. During the period from the neck-node initiation stage to the late stage of spikelet initiation, the magnitude of plant growth is the largest with rapidly extending leaf area. (Ando and Shoji 1984). The amount of nitrogen absorbed during this period gives the most effective contribution to the spikelet production while the recovery of top-dressed nitrogen at the neck-node initiation stage is high and almost all the top-dressed nitrogen is absorbed by the late stage of the secondary rachis branch initiation stage (Wada *et al.* 1986). This clearly shows the inadequacy of organic fertilizer use basally only to fulfill the N requirement of the rice plant in order to give high yields with improved varieties. Moreover, organic fertilizers have a low percentage of N/kg and can only provide N to the plant uniformly for a short period but in small amounts. In such a situation one has to develop varieties suitable for low N requirements in order to get sustainable good yields. Joseph (1991) indicated that a rice plant with low tillering, high grains/panicle, intermediate size leaves and somewhat horizontal arrangement are the desirable characteristics for rice varieties with low N response.

Concept of organic fertilizer use

Since the green revolution, 90% of Sri Lanka rice farmers used our improved rice varieties. These varieties are highly fertilizer responsive even though they are not much different from our traditional varieties in nutritive qualities (Table 2). However, some important traits like medicinal properties of our traditional varieties were ignored during breeding programmes. Farmers in most instances used higher rate than the recommended rate of fertilizers and also the agrochemicals for pest control. Further with mechanization, tillage practices were not done in an approved conventional way giving sufficient time for decomposition of weed growth during the fallow period and farmers used weedicides to kill the weed population before land preparation as well. All these malpractices lead the authorities to believe that some of the non-communicable diseases are due to this misuse and in 2019 H.E. President campaigned to eliminate inorganic fertilizers and synthetic pesticides. In April 2021 he "declared that the entire country would immediately switch to organic farming" banning inorganic fertilizer and agrochemical imports, yet as of February 2022, still a majority of farmers complained that they received no training in organic techniques for rice production" (Saunders 2022).

This sudden shift to organic agriculture was a herculean task for the extension agriculturists to abide by the decision and to change the farmer perception in order to sustain the production in the country, which failed miserably and ended up in a 40-50% drop in rice yield throughout the country. However, the misuse of inorganic fertilizer with fertilizer responsive varieties over several decades has resulted in degraded rice soils where the soils became sandy and nutrient retention was minimal. Some nutrient deficiencies leading to yield stagnation and / or reduction were observed and remedied but they are spotty in nature. Therefore, the government's decision to use organic matter in rice production systems was an admirable positive thinking but would have been done alone with inorganic fertilization to sustain or increase rice production to cater to the increasing population in the country. Two seasons' experience in rice production with organic fertilizer use proved beyond doubt that the intended expectations could not be achieved due to various reasons. Saunders (2022) further stated that the 2021 rice harvest failed, leading to a \$1.2 billion emergency food aid program, a \$200 million income-support program, and huge sums of money to import hundreds of thousands of tonnes of rice". However, organic fertilizer and pesticide use in the country is not a new concept and about 1% of the present-day rice farmers still use. A survey conducted by HARTI revealed (Table 9) the use of organic fertilizers and botanicals in the country either totally or in combination, in five major rice growing districts in a random sample of 60 farmers.

Timsina (2018) however identified some common myths that organic materials/ fertilizers can such as: (i) supply all required macro and micro-nutrients for plants; (ii) improve physical, chemical and microbiological properties of soils; (iii) be applied universally on all soils; (iv) always produce quality products; (v) be cheaper and affordable and (vi) build-up of a large amount of soil organic matter. Other related myths are: "legumes can use the entire amount of N_2 fixed from the atmosphere" and "bio-fertilizers increase the nutrient content of the soil. On the other hand, the common myths regarding chemical fertilizers are that they: (i) are not easily available and affordable, (ii) degrade land, (iii) pollute the environment and (iv) adversely affect the health of humans, animals and agro-ecosystems. However, it reveals that except in some cases where higher yields (and higher profits) can be found from organic farming, their yields are generally 20–50% lower than that of conventional farming. Hence considering the current organic sources of nutrients in the developing countries, organic nutrients alone are not enough to increase crop yields to meet global food demand and that nutrients from inorganic and organic sources should preferably be applied at 75:25 ratio.

Organic fertilizer sources of nutrients for rice

Organic sources of nutrients are derived principally from substances of plant and animal origin. Partially humified and mineralized under the action of soil microflora, the organic sources act primarily on the physical and biophysical components of soil fertility. These sources cover manures made from cattle dung, excreta of other animals, other animal wastes, rural and urban wastes, composts, crop residues and even green manures. The term "bulky organic manure" is used collectively for cattle dung, FYM, composts, etc. because of their large bulk in relation to the nutrients contained in

Table 9: Percentage of farmers using organic fertilizer and botanicals

Name of fertilizer	Colombo N=60	Galle N=60	Kurunegala N=60	Kegalle N=60	A'pura N=60	Average
			Average organic fertilizer %			
Compost	60	60	51	45	57	55
Poultry manure	49	15	44	23	12	29
Goat manure	10	0	5	6	2	5
Straw manure	24	46	51	66	64	50
Leaf fertilizer	20	26	41	74	41	40
Organic liquid	49	49	10	4	21	27
Cow dung	31	28	33	62	38	38
			Botanicals %			
	N=60	N=60	N=60	N=60	N=60	
Neem oil	25	65	15	31	0	27
Neem oil + Tobacco	0	0	0	8	0	2
Home made liquid	35	21	85	31	34	41
Cow urine	5	7	0	0	0	2
Neemgro	13	7	0	21	0	8

(Source: Rambukwella and Priyankara 2016) them though the concentrated organic manures, such as oil cakes, slaughterhouse wastes, fishmeal, guano and poultry manures, are comparatively richer in NPK nutrients.

Organic sources of plant nutrients are used to varying extents in all countries. In most cases, the kinds of organic manures in use in a region are determined by the organic materials that are locally available or can be generated in the area, except for commercial organic fertilizers. Crop residues and green manures, secondary products of crops, or auxiliary plants, are considered low-grade nutrients and soil fertility improving resources. Composting can sometimes increase their value as a nutrient resource. Crop residues of legumes are richer in nutrients and have a low C:N ratio, which facilitates their mineralization compared with the crop residues of cereals.

Crop residues

Crop residues represent the bulk of the crop biomass left after the removal of the main produce (grain, fruit, etc.). Most crops produce a voluminous amount of residues, e.g. straw, stalk, stubble, trash, and husks. Straw is produced in about the same and often higher amounts than grain (2–10 tons/ha). Crop residues contain a substantial proportion of plant nutrients (Table 10). However, the low N concentration of straw presents a special problem in soils containing insufficient available N. Cereal straw has a C:N ratio of about 100:1 and takes more time for decomposition whereas ratios of below 25:1 are required for microbial decomposition in order to avoid N deficiency in the next crop.

In Sri Lanka, the paddy straw incorporation programme was popularized in the country by DOA as a precautionary measure for soil degradation in the 1980-1990 era but did not continue because of the competitive demand by the paper manufacturing industry. Valachchinai Paper Factory due to the lack of raw materials for their paper manufacture offered money to the farmer and their baling machinery visited the paddy fields and removed the straw without any cost to the farmer. Hence paddy farmers opted to give their paddy straw for paper manufacturing and they got some additional income. This situation can come again with the re-opening of paper factories and if happens, paddy straw as organic fertilizer for the paddy crop will not be an option anymore.

Oil cakes

Oil-cakes represent a special type of crop residue. These are the residues left behind after oil has been extracted from an oilseed. Table 11 provides a list of the average nutrient content of common oil cakes. Non edible oil

Table 10: Nutrient composition of crop residues of some crops grown in the humid tropics.

	(kg/ha/yr)			
Crop/species	***N***	***P***	***K***	***C/N ratio***
Cowpea stem	1.07	1.14	2.54	-
Cowpea leaves	1.99	0.19	2.20	-
Rice	0.58	0.10	1.38	105.0
Maize	0.59	0.31	1.31	55.0
Oil palm (processed fibre)	1.24	0.10	0.36	-
Sesbania leaves	4.00	0.19	2.00	-
Crotolaria spp.	2.89	0.29	0.72	-
Tephrosia spp.	3.73	0.28	1.78	-
Water hyacinth	2.04	0.37	3.40	18.0
Azolla spp.	3.68	0.20	0.15	-
Typha spp.	1.37	0.21	2.38	-

[Source: https://archive.unu.edu/unupress/unupbooks/uu27se/uu27se0c.htm] cakes can be used as manure, while edible oil cakes are used primarily as cattle feed. Oil cakes have a much higher nutrient content, particularly of N and P than do normal crop residues, such as cereal straw or bulky organic manures. Owing to their low C:N ratio, these decompose at a faster rate in the soil to furnish available nutrients. However, in Sri Lanka coconut cake is produced as a byproduct in the coconut triangle area but the production is not adequate for animal feeding in the country and therefore availability of such materials for mass-scale use as fertilizer for rice crop is not possible. Other edible and non-edible oil cakes are not produced in adequate quantities because the crop cultivation extents are very limited or none.

Green manures

Green manures represent fresh green plant matter (usually of legumes and often specifically grown for this purpose in the main field) that is ploughed in or turned into the soil. Several legume plants can be used that can either be grown *in situ* and incorporated or grown elsewhere and brought in for incorporation, in which case it is referred to as green-leaf manuring. Other than N fixing field crops, some common green manures for rice are sunnhemp, Sesbania and wild indigo (*Indigofera tinctoria*) and Azolla. In Sri Lanka, DOA conducted several green manure programmes for rice with foreign-funded projects from time to time but never got popularized and the programmes collapsed with the cessation of project funds.

Table 11: Nutrient composition of different oil cakes

Oil-cakes	Nutrient content (%)		
	N	P_2O_5	K_2O
Non-edible oil cakes			
Castor cake	4.3	1.8	1.3
Cotton seed cake (un-decorticated)	3.9	1.8	1.6
Safflower cake (un-decorticated)	4.9	1.4	1.2
Edible oil cakes			
Coconut cake	3.0	1.9	1.8
Cotton seed cake (decorticated)	6.4	2.9	2.2
Groundnut cake	7.3	1.5	1.3
Rape seed cake	5.2	1.8	1.2
Safflower cake (decorticated)	7.9	2.2	1.9
Sesamum cake	6.2	2.0	1.2

[Source: https://agritech.tnau.ac.in/org_farm/orgfarm_manure.html]

Table 12: Nutrient composition of some Green Manure crops and crop residues

Green Manure	Scientific Name	Moisture %	Nutrient content (%)			
			N	P_2O_5	K_2O	S
Dhaincha	*Sesbania sp.*	80	2.51	0.92	0.92	0.2
Mung Bean	*Vigna radiata*	70	0.8	0.46	1.15	0.3
Black gram	*Vigna mungo*	70	0.8	0.46	1.15	0.3
Cowpea	*Vigna unguiculata*	70	0.7	0.34	1.15	-
Pea	*Pisum sativum*		1.97	-	-	-
Sunhemp	*Crotolaria juncea*	70	0.7	0.27	1.15	-
Leucaena	*Luicena leucucephala*		4.29	0.44	3.14	-
Azolla	*Azolla sp.*		3.68	0.46	0.34	-
Acacia	*Acacia arabica*		2.61	0.39	2.75	-

(adopted from Timsina, 2018)

Green manures can add substantial amounts of organic matter and N as well as other nutrients. The bulk of the N input through leguminous green manures comes from bacterial nitrogen fixation (BNF) and in rice culture, this can range from 70 to 90 kg N/ha/ yr in the case of *Sesbania* (Bhuiyan and Zaman 1996). The nutrient composition of some green manure crops is given in Table 12. The nutrient contribution of a green manure crop is greatest where the entire green plant is ploughed in and incorporated. However, there are limits to the use of green manuring under arid conditions because of the additional water requirement.

Green manure crops are normally grown in fallow periods or as inter-seasonal crops with the objective of sustaining soil productivity. But again as an organic fertilizer for rice crop green manure crops within fallow periods between seasons is possible in the country but unfortunately, the addition of such a manure crop cannot meet the peak nutrient requirement of rice crop during PI and Flowering periods.

Farmyard manure

Farmyard manure (FYM) is another good source and refers to the bulky organic manure resulting from the naturally decomposed mixture of dung and urine of farm animals along with the litter (bedding material). The average nutrient content of different organic manures and composts are given in Table 13. Average, well-rotted FYM contains 0.5–1.0% N, 0.15–0.20% P_2O_5 and 0.5–0.6% K_2O. The desired C:N ratio of FYM is 15–20:1. In addition to NPK, it may contain about 1 500 ppm Fe, 7 ppm Mn, 5 ppm B, 20 ppm Mo, 10 ppm Co, 2 800 ppm Al, 12 ppm Cr and up to 120 ppm lead (Pb). Often, fully or partially air-dried dung is used as FYM. During storage, organic manure is partly decomposed by fermentation, which also produces valuable humic substances. Some losses of N as ammonia do occur, but these can be reduced by the addition of about 2-percent water-soluble phosphate (Pandey, 1991)

Animal slurry

In many developed countries, because of the shifting agriculture towards intensive labour saving animal production systems, many of which do not require bedding straw, there has also been a large output of animal slurry. In large areas, the slurry is now the dominant animal manure although this can hardly be regarded as a desirable feature from an environmental point of view. Slurry from domestic animals consists of dung and urine, partly mixed with a small portion of straw and with small or large portions of water in order to improve its fluidity. It is a semi-liquid nutrient source that can be mechanically collected, stored and distributed. However, large scale animal husbandry ventures in Sri Lanka are low in number and we are not self-sufficient in milk and meat production. Hence the amount of animal slurry available in the country is highly inadequate for commercial use and as organic fertilizer for rice.

Table 13: Average nutrient content of some bulky organic manures and composts (oven-dry basis).

Type of manure	N (%)	P_2O_5 (%)	K_2O (%)
Cattle dung	0.3	0.10	0.15
Sheep/goat dung	0.65	0.5	0.03
Human excreta	1.2–1.5	0.8	0.5
Pig manure	1 -2	0.6-0.9	0.4-0.9
Farmyard manure	0.5	0.15	0.5
Poultry manure	2.87	2.90	2.35
Town/urban compost	1.5	1.0	1.5
Rural compost	0.5	0.2	0.5

(Source Tennakoon and Bandara 2010)

Compost

Although many organic waste products can be added directly into the soil, most of them have a better soil-improving effect after their decomposition through the composting process. The resulting mixed and improved products following decomposition are termed compost (Latin componere = mixing). Compost can be defined as organic manure or fertilizer produced as a result of aerobic, anaerobic or partially aerobic decomposition of a wide variety of crop, animal, human and industrial wastes. Composting has a long tradition almost everywhere in the world. Figure 3 gives a cross-section of a common compost pile showing the arrangement and composition of different layers.

Compost making does not have a complicated technology and any farmer can handle it without much problem. But the selection of quality raw materials, quantities to be used and sustaining the quality of the product are really the problems because the raw materials used can vary its nutrient content each time a compost pile is prepared. Moreover, the compost preparation for the whole rice sector in the country is very difficult and cumbersome and also cannot maintain a standard quality nutritionally hence the standard recommendation for rice. Finding adequate amounts of green raw materials in districts like Ampara, Polonnaruwa and Anuradhapura will also be a problem.

Composts commonly contain about 2 percent nitrogen, 0.5–1 percent phosphorus, and about 2 percent potassium (https://www.britannica.com/topic /compost#/media/1/130177/ 147301). Nitrogen fertilizers and manure may be added to speed decomposition. The nitrogen of compost becomes available slowly and in small amounts, which reduces leaching and can extend the availability over the whole growing season. Composts are prepared through the action of micro-organisms on organic wastes such as leaves, roots and stubbles, crop residues, straw, hedge clippings, weeds, water hyacinth, bagasse, sawdust, kitchen wastes, and human habitation wastes.

Virtually any biodegradable organic material can be composted. For making town or urban garbage compost, the organic wastes from households and other establishments should be carefully collected, separated from unsuitable materials and not contaminated with toxic substances. Department of Agriculture encouraged farmers to do

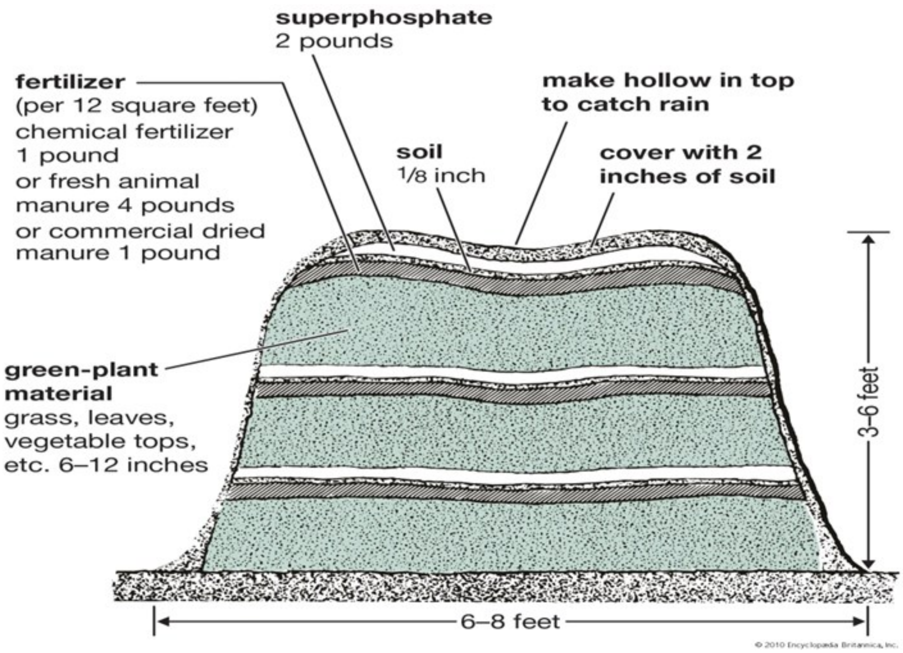

Figure 3: Cross-section of a compost pile (Adopted from Encyclopædia Britannica, Inc).

composting by having training classes and field demonstrations a few decades back but aimed mostly for upland crop cultivation. On average compost may contain 30–50 percent dry matter, 10–15 percent organic matter and the indicated amounts of plant nutrients. Ideally, compost should be rich in available plant nutrients, contain readily decomposable material and relatively stable humic substances, and have a crumbly structure, similar to humus-rich topsoil. Composts are not only nutrient source, but also effective soil amendment too.

Vermicompost

Vermicompost is ideal organic manure for better growth and yield of many plants. It can increase the production of crops and prevent them from harmful pests without polluting the environment. Joshi, *et al.* (2015) identified vermicompost as a type of organic fertilizer. It is derived by composting organic waste produced by using various species of earthworms (Blouin *et al.* 2019). It has a mixture of decomposing vegetable or food waste, bedding materials, and most importantly worm castings. This process of producing vermicompost is called Vermicomposting.

Patnaik *et al.* (2020) showed that vermicompost is an excellent organic fertilizer, with physical, chemical, and biological properties that could improve soil fertility and control crop diseases. The study of Fernandaez-Gómez *et al*. (2011) showed that vermicompost has high microbial functional diversity and the potential to be used for the treatment of pesticide pollution in agricultural production. Jahanbakhshi *et al.* (2019) demonstrated that vermicompost was a good organic fertilizer with an appropriate carbon and nitrogen ratio, acidity, as well as salinity. He *et al.* (2018) working on rice nursery seedlings in the production of mechanical transplanting rice showed seedling matrix can substantially affect the growth of rice seedlings and, consequently, influence the rice productivity. Ruan *et al.* (2021) indicated that vermicompost is a nutritive 'organic fertilizer' rich in NKP (nitrogen 2-3%, potassium 1.85-2.25% and phosphorus 1.55-2.25%), micronutrients, beneficial soil microbes like 'nitrogen-fixing bacteria' and 'mycorrhizal fungi'. Vermicompost retains nutrients for a long time and while the conventional compost fails to deliver the required amount of macro and micronutrients including the vital NKP to plants in a shorter time, the vermicompost does. Theunissen *et al.* (2010) surmised vermicompost contains plant nutrients including N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B, the uptake of which has a positive effect on plant nutrition, photosynthesis, the chlorophyll content of the leaves and improves the nutrient content of the different plant components (roots, shoots and the fruits). However, the use of vermicompost as an organic fertilizer contains all the necessary nutrient elements for rice plant at a comparatively higher rate than other organic fertilizers (Table 14) but needs production in huge quantities to cater to the rice sector of the entire country.

Liquid Fertilizers

Use of liquid fertilizers is another option suggested for conventional soil application and recommended by the organic fertilizer use policy of the government to overcome high rates of N fertilizer required by the rice plant. Advantages of liquid fertilizers are ease of handling and application, ease of blending, uniformity of application, starter and in-season application and blending with crop protection. There are many liquid fertilizer formulations prepared world over from various raw materials with nutrient compositions varying from one to another. However, the percentage of nutrients (N, P & K) in the liquid form is very low (mostly less than 5%) because the use of higher percentages will scorch the leaves. Basically, liquid fertilizers are used in crop production for correcting deficiencies of nutrients, but not as a total fertilizer input to the crop. Jim Isleib (2016) indicated that the availability of nutrients to the plant from foliar applied nutrients is short-lived and not continuous for the rest of the growing season hence foliar applications are a good way to correct mid-season deficiencies or supplement soil-applied nutrients. Kumara *et al*., (2019) working on

Nano calcite liquid fertilizer showed that a hundred ppm application of Nano calcite treatment with recommended soil added fertilizer could increase the final yield of variety At 362 approximately about 1 ton/ha. Ginting (2019) showed that liquid organic fertilizer (with 14 essential elements + growth regulators) with recommended soil application increased the rice yields from 3.82 mt/ha to 4.40 mt/ha on Indonesian rice varieties and was significant. Mahmoodi *et al.* (2020) indicated that foliar application of nutrients [nitrogen (N): 7%, phosphorus (P): 7%, potassium (K): 7%, iron (Fe): 0.05%, boron (B): 0.05%, zinc (Zn): 0.01%, manganese (Mn): 0.01%, and copper (Cu): 0.01%] was most effective when applied during two vegetative and reproductive stages to rice variety 'Sahel' in addition to the recommended fertilizer soil application.

Use of liquid fertilizer as the sole nutrient application for the rice crop is questionable because of the low nutrient analysis of major nutrients. If imported from other countries, the quality is not much different, but it is expensive. Last season there were few entrepreneurs who lack any competency in preparing liquid fertilizers came forward but failed to market their products due to many reasons. Moreover, their nutrient quality was not standardized and farmers were reluctant to use them. Further, liquid fertilizers need spraying on the leaf canopy and therefore farmer has to spend money and find labour, which are difficult to find inputs, especially in areas with extensive paddy cultivations.

Implications of organic fertilizer use

The fertilizer recommendation for crops is to provide a well-balanced fertilizer mixture in adequate amounts of all required nutrients at the particular stage of crop growth to a crop decided by intensive field research because different crops need different nutrients in different quantities and times. Hence a single blanket treatment of organic fertilizer cannot provide all the necessary nutrients in required amounts throughout the crop life for large variety of crops, especially rice. Moreover, the rice crop needs nutrients like N in very large amounts in a few stages of its growth cycle, but organic fertilizers including compost can only provide N uniformly in small amounts throughout the crop growth. Moreover, in Sri Lanka rice is grown extensively under flooded conditions and the anaerobic decomposition of added organic fertilizers cannot provide the necessary nutrition in time and required amounts to the rice plant. Figure 4 shows the growth curve of rice variety IR 42 and it shows that N is required in very large amounts during the PI stage and spikelet development stage to prevent spikelet abortion and finally the yield (Senanayake 1990). Figure 4 also shows that the recommended inorganic fertilizer split application is also inappropriate because it fails to prevent spikelet abortion

Table 14: Comparison of Nutrient composition among Compost, FYM and Vermicompost [Note: These values are subjected to changes depending on the type of organic waste]

Nutrient	Vermicompost	Farmyard manure	Compost **
N%	1.6	0.5	0.45
PO%	0.7	0.2	0.057
KO%	0.8	0.5	0.12
Ca%	0.5	0.9	1.73
Mg%	0.2	0.2	1.02
Fe ppm	175.0	146.5	467.67
Cu ppm	5	2.8	1.09
Zn ppm	24.5	14.5	8.94
Mn ppm	96.5	69	10.42
C:N ratio	15.5	31.3	N.A

[Source: http://agri.and.nic.in /vermi_compost.htm:, **Metodi Mladenov 2018] after the maximum spikelet stage. Since there is no such split application in organic fertilizer use poor spikelet formation and abortion can be expected. Further, split application of organic fertilizer at these critical stages will further reduce the N availability to the rice plant because of the temporary N deficiency situation caused by escalating microbial populations.

On the other hand, organic matter of animal origin and compost are rich sources of weed seeds and the application of these manures increases the weed density and thereby causes competition for nutrients, space and sunlight with the crop. Unfortunately the ban of weedicides by the government and the lack of labour in agriculture, farmers do not have a proper answer to curb the weed situation in their rice fields. Further, huge yield drop, sky rocketed input prices (fertilizer and agrochemicals) experienced reducing the income of farmers will force them to go out of rice cultivation in coming seasons.

Liebig's law of the minimum

Organic fertilizer will provide uniform availability of majority of nutrients for the crop but cannot compensate for the peak requirements of crop growth. Plant is unable to complete a normal life cycle without the availability of all 17 elements in adequate amounts and time. This is in accordance with Justus von Liebig's law of the minimum. Liebig’s law of the minimum, often simply called Liebig's law or the law of minimum, is a principle developed in agricultural science by Carl Sprengel (1840) and later popularized by Justus von Liebig. It states that growth is dictated not by total resources available, but by the scarcest resource (limiting factor). The law has also been applied to biological populations and ecosystem models for factors such as sunlight or mineral nutrients and this law has been confirmed worldwide. This law not only instrumental in deciding yields of crops but the necessity and proved the importance of well balanced, research-based fertilizer recommendations for the sustenance of crop yields. However, the exception to the rule is parasitic plants and carnivorous plants which absorb the nutrient elements from the host and the specially designed appendages respectively. Therefore according to this law, one can presume that organic fertilizer use in

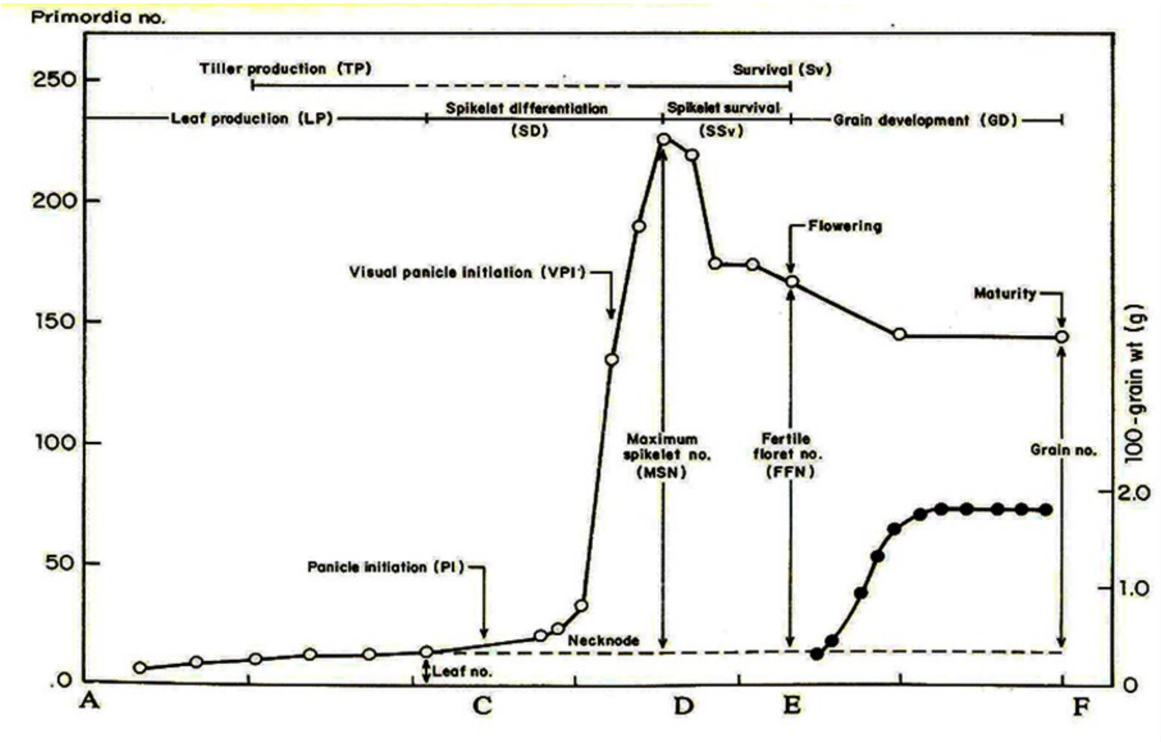

Figure 4: Growth Curve of New Improved Rice Variety IR 42 (Senanayake 1990)

rice cultivation will most probably limit the rice yields due to major nutrient 'N' which is required in large amounts for new improved fertilizer responsive rice varieties.

Lack of appropriate varieties

Our traditional varieties (actually mixed populations instead of varieties) are less responsive to fertilizer application and plants could manage with whatever the nutrients are available and gave reasonable yields. This was possible as the lowland rice ecosystem was undisturbed before the green revolution and atmospheric fixation, soil fixation, microbial fixation and input from rainwater, all in all, contributed to the nutrient requirement of the rice crop. Since the green revolution with increasing population, the rice production in the country was not enough to meet the demand and was able to produce high yielding high fertilizer responsive rice varieties through conventional breeding and to reach near self-sufficiency recently. However, breeders did not give due consideration to other favourable/valuable characteristics of traditional rice varieties. The present day rice varieties cannot sustain yield under low application of fertilizer and therefore cannot use in organic fertilizer use programme. This was clearly shown when rice production dropped by 25-50% of the previous seasons. Therefore, if we were to go for crop production under organic fertilizer use then identification of high yielding low fertilizer responsive rice varieties are of paramount importance while maintaining pest and disease resistance already achieved even though such a programme will take several years to produce results.

Peak nutrient requirement of rice plant at PI stage

Rice plant in general has three major growth stages vegetative, Reproductive and maturity stages where the time period of relevant growth stages vary with the age group of rice (Senanayake, 1990). The reproductive stage normally coincides with the maximum growth stage and has a very high demand for nutrients, especially N. Senanayake (1990) observed that during the reproductive stage of IR 42 (Figure 4) the total number of spikelet primordia produced increased to 218 from 15 at the end of the vegetative stage in 25 days. This will work out to a very high growth rate of about 01 primordia differentiated every 3 hrs and each of these primordia bears millions of independent cells. Differentiation of cells requires large amounts of N as it is involved in many biological reactions and in chromosome duplication, DNA particles, amino acids etc. which are the building blocks of cells. He further observed that even with the recommended soil application of inorganic N fertilizer there was about 20% primordial abortion within the plant, which was assumed to be due to a lack of adequate mineral nutrients and/or carbohydrates. Thus, if we use organic fertilizers as a basal application, the peak N requirement for rice plant at the PI stage is impossible to meet because of the low % of N (about 1-5%) found in organic fertilizers. As suggested by some scientists, this could be compensated by foliar application of N, then the farmers have to give a round of N spray very frequently, because of low N content in liquid fertilizers and its short stay, which is an impossible task for poor farmers. The end results will be a higher rate for primordial abortion ending up in very poor yields. Moreover, split application of organic fertilizer is also detrimental to rice crop because of the population explosion of N fixing microbes, setting up temporary N deficiency in the soil, which can affect rice crop growth and yield.

Standardisation of organic fertilizer

Standardization of organic fertilizer and recommendation for rice appears to be the most thought-provoking thing on earth. This is because sources of organic fertilizers are many with limited availability, the nutritive value of the products varies from season to season and batch to batch and each one of them individually cannot meet the country's demand. Thus, the only option available is compost making in an organic fertilizer use rogramme. However, the compost produced by one person is different from the other in nutrient composition, due to differences in raw materials, quantities used, time for compost making nutrient composition of raw materials, etc. Moreover, the required quantities for the whole rice sector even at the rate proposed by the ministry of agriculture (01 ton/acre), in an ad-hoc manner, is enormous and to have them season after season is still questionable, because of the unavailability of enough raw materials. There are many organic fertilizers proposed by researchers using raw materials given in Table 13, and their availability in the country is limited. Moreover, there are no research findings up to date on what materials to mix, how to mix, what proportions to prepare compost and the rate of application of compost for rice. Therefore, the biggest problem with organic fertilizer use and more appropriately compost is the standardization and to propose a blanket recommendation for rice.

All these individual and man-made organic fertilizers vary in their constitution from one batch to another depending on many variables such as feeding habits and nutrient composition of feeds in animal-based organic fertilizers and the case of green manures the soil fertility, fertilizer addition and also biotic and abiotic factors which again vary from season to season and year after year. Therefore if someone to do standardization and propose an organic fertilizer recommendation for rice, then the nutrient analysis needs to do batch after batch and season after season and if there are many producers, all their seasonal products need analysis individually. Moreover, field fertilizer experiments also need to be conducted season after season to come out with several recommendations as a blanket recommendation was not possible because of variability in the nutrient content of products. Thus the organic fertilizers produced in one season can only be used effectively after two seasons of research, provided the seasons behave normally and this whole process needs a colossal amount of money, time and manpower. However, all these inputs and outcomes again go waste if we do not have appropriate rice varieties to be used with the organic fertilizer use programme.

Land preparation for rice cultivation

Organic fertilizer use policy of the government also banned the import of agrochemicals altogether to the country. Ancient farmers used manual labour and/or animal power for land preparation work and by providing adequate time intervals between operations to decay the weed population by inundation and plastering bunds properly, the weeds were not a problem. Further, the tallness of traditional varieties also helped to smother any weeds germinating in the field after sowing. Moreover, farmers chopped down all the available plants and tree branches around their fields and added them to the field well ahead of land preparation and were the only fertilizer added to the field externally though some people added Bone-ash as a phosphorous source. Traditional farmers are the poorest of the poor and they were almost in hand to mouth level of subsistence. This situation prompted the next generation to leave rice cultivation and look for white color jobs even though rice yields were increased tremendously with the green revolution. Therefore, farmers due to lack of labour force resort to the mechanization of land preparation and land preparation work were done improperly and also hastily sometimes, due to lack of an adequate fleet of machinery at the time of need. Using mechanized land preparations farmers resort to “short Cuts” where they either used mud wheels or rotovator only twice within a spell of 7-10 days to prepare their land for seed sowing. This practice by farmers disregards the recommended use of implements, where soil churning at very high speeds leads to removing clay and silt particles from the root zone and getting settled on the hard pan below. Hence rice soils got degraded and became sandy in nature due to this type of machinery misuse.

Moreover, inappropriate land preparation season after season coupled with the short stature of present-day varieties, weeds became a problem and hard to control unless farmers use synthetic weedicides. Thus, due to high weed populations, farmers used to apply total weed killers before land preparation. Moreover, some weeds developed resistance and site specific weeds were observed in paddy fields. However, moving to organic fertilizer use and ban of total weed killers weed control became much more difficult as there were no research findings or methods identified in Sri Lanka for bio-control of rice weeds. Another problem in the use of weed killers and agrochemicals was the disturbance done to the natural rice ecosystem and not only soils got degraded but also microbial participation in plant nutrition was hampered severely.

Decomposition of organic fertilizers in lowland rice soils

When organic fertilizers or compost added to lowland rice fields the tendency is to decompose them under reduced conditions and the rate of decomposition was very much low compared to oxidized conditions. Several reviews on the biochemistry and microbial ecology of paddy soils show that anaerobic decomposition of organic matter where the final product was humus, which was later subject to some aerobic oxidation during fallow periods. This oxidation is minor, takes place rapidly, and is of no consequence in the utilization of the material on the soil. (Ponnamperuma 1972; Yoshida 1975, 1978; Watanabe and Furusaka 1980). Moreover, Saharawat (2005) surmised that several studies have indicated that there is a preferential accumulation of organic matter in tropical lowland rice soils when compost is used

Watanabe (1984). surmised that anaerobic decomposition of organic matter in flooded rice soils results in accumulation of volatile fatty acids (VFA), principally acetic, propionic, and butyric, and the subsequent decrease of VFA with a concomitant increase of CH_4 and sulfides.

Anaerobic decomposition or putrefaction of organic matter is usually accompanied by disagreeable odors of hydrogen sulfide and reduced organic compounds which contain sulfur, such as mercaptans (any sulfur-containing organic compound). Aggie horticulture (2009) indicated that the breakdown of organic compounds is by the action of living organisms and these organisms use nitrogen, phosphorus, and other nutrients to live and develop their cell protoplasm, but they reduce the organic nitrogen to organic acids and ammonia. The carbon from the organic compounds which is not utilized in the cell protein is liberated mainly in the reduced form of methane (CH_4). However, a small portion of carbon may be respired as carbon dioxide (Aggie horticulture 2009). Sah and Mikkelsen (1986) further indicated the anaerobic decomposition of organic matter significantly increased the amorphous Fe content and produced significant transformations in inorganic P fractions. The Al-P decreased and Fe-P and RS-P fractions increased, due to the anaerobic decomposition of organic matter.

Watanabe (1984) indicated anaerobic decomposition of organic matter is coupled with sequential reduction of electron-accepting agents such as NO^{-3}, $Mn^{+\ 4}$, Fe^{+3}, SO_4^{-2}, and CO_2. The extent of the reduction is regulated by the balance between the oxidizing and reducing capacities of the soil. Further, the formation and metabolism of gaseous products (H_2, CH_4, and $C_2 H_4$), NH_{4+}, VFA, nonvolatile acids, alcohols, amines, volatile compounds, and phenolic acids are also recorded (Watanabe1984). Under these circumstances split application of organic fertilizer for lowland rice needs second thought because of temporary unavailability of N and some other nutrients, if no inorganic fertilizers are used partially at least.

CONCLUSION

The above discussion shows that the use of organic fertilizer alone in rice production is not possible due to many reasons as discussed. Moreover, organic fertilizers are many though their individual availability is very low for the rice sector to use alone. There are many compost producers in the country whose products vary in nutritive content from producer to producer and from batch to batch or cycle to cycle. Thus, standardization of organic fertilizer and giving a single fertilizer recommendation is impossible, if not, time and labor intensive and financially very expensive. However, organic matter use was recommended several years back by the DOA because of soil degradation due to inappropriate use of only 3 major nutrients, N, P and K as inorganic fertilizers for many decades, inappropriate use of machinery for land preparation and misuse of agrochemicals for pest control. Therefore the use of organic fertilizer as a basal application alone with inorganic fertilizer to meet the peak demand of nutrients at several stages of rice plant growth can be considered for recommendation after two season's research at least. However, a concrete blanket recommendation for the rate of application of organic fertilizer is not possible even with extensive field experimentation.

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