The Pharma Innovation Journal 2019; 8(7): 252-256

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.03
TPI 2019; 8(7): 252-256

www.thepharmajournal.com
Received: 04-05-2019
Accepted: 06-06-2019

M Malarkodi
Department of Soil Science and Agricultural Chemistry
Tamil Nadu Agricultural University Coimbatore, Tamil Nadu, India

M Elayarajan
Water Technology Centre
Tamil Nadu Agricultural University Coimbatore, Tamil Nadu, India

K Arulmozhiselvan
Department of Soil Science and Agricultural Chemistry
Anbil Dharmalingam Agricultural College and Research Institute
Tamil Nadu Agricultural University Tiruchirappalli, Tamil Nadu, India

B Gokila
Department of Soil Science and Agricultural Chemistry
Tamil Nadu Agricultural University Coimbatore, Tamil Nadu, India

Correspondence
M Malarkodi
Department of Soil Science and Agricultural Chemistry
Tamil Nadu Agricultural University Coimbatore, Tamil Nadu, India

Long-term impact of fertilizers and manures on crop productivity and soil fertility in an alfisol

M Malarkodi, M Elayarajan, K Arulmozhiselvan and B Gokila

Abstract
Permanent Manurial Experiment (PME) was started in Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India during 1909 to monitor the impact of continuous fertilization on crop yield sustainability and soil quality in Alfisol. From 2008 onwards the treatments of PME were revised to eighteen and sunflower - maize cropping sequence is being followed under irrigated condition. The study conducted during 2018 revealed that continuous application of 100% NPK + FYM @ 12.5 t ha^{-1} increased the seed yield of sunflower by 21.7 % and grain yield of maize by 11.6 % over 100% NPK besides sustained yield to the greater extent compared to other treatments. Optimal (100% NPK) and 100% NP fertilizers gave comparable crop yields, soil fertility status indicating the lower response to applied K fertilizer as the soil is rich in available K status. The sustainable yield index (SYI) values indicated that sunflower yields were more sustainable than maize. Continuous addition of 100% NPK + FYM at 12.5 t ha^{-1} improved soil organic carbon and available nutrient status whereas imbalanced fertilization and unfertilized control decreased the most, results unsustainable yields and soil fertility. Carbon stock during 2018 was highest in integrated addition of 100% NPK + FYM (16.1 Mg ha^{-1}) and lowest in unfertilized control (8.65 Mg ha^{-1}). The study emphasis the importance of balanced and integrated application of fertilizers and manures for enhancing soil quality and sustaining crop productivity.

Keywords: Permanent manurial experiment, sustainable yield index, carbon stock, nutrient availability

1. Introduction
Soil is a key natural resource and soil health is the integrated effect of management on most soil properties that determine crop productivity and sustainability (Sharma *et al*., 2005) [1]. Continuous cultivation with high yielding varieties and high analysis fertilizers is unavoidable in Indian Agriculture, which accelerated the mining of nutrients from soil. Since large amount of nutrient has to be applied to soil in chemical form which may have impact on soil properties and soil productivity in long term. Conducting a long-term experiment at fixed site with continuous cropping will help to monitor the changes in soil quality and crop yields sustainability and also guide strategies for fertilizer management and minimize environmental degradation. The maintenance of the soil health is essential not only for maximizing agricultural production but also vital for sustaining the higher productivity levels in crops (Velu and Subramaniam, 2012) [2]. A judicious combination of organic amendments and inorganic fertilizers is widely recognized strategy of integrated nutrient management (INM) to sustain crop productivity and improve soil fertility (Manna *et al*., 2005) [3].
The earliest long-term experiments called Permanent Manurial Experiments were started at Rothamsted Experimental Station, Harpenden, Herts, England between 1843 and 1856 by J.B. Lawes and J.H. Gilbert and are known as 'Rothamsted Classical Experiments'. These experiments were neither replicated nor randomized. These experiments have been continued for more than 150 years and have yielded most valuable information for adoption of an efficient approach for managing the crops and cropping system (Elayarajan *et al*., 2013) [4]. Based on the Rothamsted model, the Permanent Manurial Experiment (PME) of Tamil Nadu Agricultural University (TNAU) started during the year 1909 remains successful among a few of permanent manurial experiments, which are being continued for more than 100 years in India and abroad. The principal aim of this experiment was to evaluate the long-term effect of inorganic and organic manuring on crop productivity and soil health.

2. Materials and methods
2.1. Experimental details
The present study, part of an ongoing nationally renowned, well recognized, monumental and

a century old Permanent Manurial Experiment (PME) of TNAU, Coimbatore, India (11° N latitude, 77° E longitude and an elevation of 426.7 m above mean sea level) in red sandy loam soil belongs to Palathurai soil series (*Typic Haplustalf*) in 50 cents area. Soil analysis data during 1974 indicated that the experimental soil was non saline, alkaline reaction, low in organic carbon (1.8 g kg^{-1}), available N (147 kg ha^{-1}), available P (3.58 kg ha^{-1}) and high in available K (381 kg ha^{-1}). Since 2008, sunflower – maize cropping sequence is being followed under irrigated condition with improved management practices.

2.2. Treatment details

The experiment included two crops per year, sunflower hybrid (CO 2) raised during summer (February-May) and maize hybrid (COHM 6) raised during kharif (July-October) with eighteen treatment combinations with plot size of 100 m^2. The treatments are T_1, Control (unfertilized and unmanured); T_2, 100% N alone; T_3, 100% NK; T_4, 100% NP; T_5, 100% NPK (old dose); T_6, 100% PK; T_7, 100% K alone; T_8, 100% P alone; T_9, 100% NPK (revised dose); T_{10}, 100% NPK + Farmyard manure (FYM) @ 12.5 t ha^{-1}; T_{11}, Farmers practice; T_{12}, No manure no crop; T_{13}, STCR-IPNS; T_{14}, FYM (Nitrogen equivalent basis (NEB)); T_{15}, Poultry manure (NEB); T_{16}, Residue mulch; T_{17}, FYM (Every year for two crops); T_{18}, (Every even year for two crops).

2.3. Crop management

The recommended fertilizer levels of 60:90:60 kg NPK ha^{-1} for sunflower and 250:75:75 kg NPK ha^{-1} for maize supplied through urea, single superphosphate (SSP), and muriate of potash (MOP) for all treatments. In the treatments T_{10}, T_{13}, T_{17} and T_{18}, well-decomposed farmyard manure @ 12.5 t ha^{-1} (air-dry basis) with average moisture content of 6 per cent and nutrient composition of 0.5% N, 0.28% P and 0.56% K was broadcasted to each crop 20 days before sowing on the surface and intermixed immediately in soil. In the treatment T_{13}, nutrients were added based on the soil test values with targeted yield of 30 q ha^{-1} for sunflower and 70 q ha^{-1} for maize. In the T_{14} and T_{15} treatments, well decomposed FYM (0.5% N) and poultry manure (2.2% N) were applied on N equivalent basis to both the crops. In the T_{16} treatment, the residue of previous crop was chopped and applied as mulch to each crop 20 days before sowing. The FYM and poultry manures were collected from the Department of Farm Management of the University.

2.4. Plant and soil sampling and analysis

At harvest during 2018, seed, stover yield of sunflower and grain, stover yield of maize were recorded and expressed in kg ha^{-1}. Average yields of both crops were made of the yield data for each fertilizer treatment over 10 years. Based on this, sustainable yield index (SYI) of the individual crop was calculated by the following Eq. (1) (Singh *et al*. 1990) [5]:

$$\textbf{Sustainable yield index (SYI)} = \frac{\overline{Y} - \sigma}{Y_{max}} \qquad (1)$$

where, $\overline{Y}$ was average yield of a treatment, σ was treatment standard deviation, and Y_{max} was maximum yield in the experiment over ten years.

Soil samples were collected from the 0 to15 cm soil depth in each plot after the harvest of maize crop during 2018 and analyzed for various physico chemical and chemical properties by following standard procedures. pH and EC were determined in soil:water (1:2.5 ratio) extract by potentiometric and conductometry methods respectively (Jackson 1973) [6]. Available soil N was determined by the alkaline-$KMnO_4$ method (Subbaiah and Asija 1956) [7], available P was determined by sodium bicarbonate ($NaHCO_3$) extraction and subsequent colorimetric analysis (Olsen *et al*., 1954) [8], available K was determined using an ammonium acetate extraction followed by emission spectrometry (Stanford and English 1949) [9] and soil organic carbon was determined by chromic acid wet digestion method (Walkley and Black 1934) [10]. The SOC stock for a layer of thickness 15 cm was calculated using the following equation Eq. (2) (Lal *et al*., 1998) [11].

$$\text{SOC stock (Mg C ha}^{-1}) = (\text{Conc.} \times \text{Bd} \times \text{D} \times 10^4 \text{m}^2\ \text{ha}^{-1})/100 \qquad (2)$$

where, Conc. equals SOC concentration (%), Bd is the bulk density (Mg m^{-3}), D is the depth in meters. Being a century old experiment and because of larger plot size the analytical data does not require statistical analysis.

3. Results and discussion

3.1. Grain yield

The data on sunflower and maize yields in the year 2018 and sustainable yield index (2009–2019) over 10 years are presented in Table 1. In 2018, continuous application of nutrients under Integrated Nutrient Management (INM) as 100% NPK + FYM (T_{10}) has achieved the highest grain yield of sunflower and maize recording 2465 and 7593 kg ha^{-1}, respectively followed by STCR-IPNS (2427 and 7398 kg ha^{-1}, respectively) which might be due to the sustained fertility by the continuous addition of nutrients both in organic and inorganic forms. The yield increase in INM recorded was 21.7% for sunflower and 11.6% for maize hybrid over 100% NPK (T_9), indicates that an integrated supply of nutrients resulted in the most sustainable yields of sunflower and maize. The results are in confirmation to the findings of Ram *et al*. (2016) [12]. Practice of STCR-IPNS (T_{13}) enhanced grain yield to the tune of 402 kg ha^{-1} in sunflower and 596 kg ha^{-1} in maize compared to 100% NPK (T_9). Application of FYM acts as source for growth and multiplication of microorganisms which would have helped to mineralize the nutrients from organic form to inorganic form.

In both crops, non-inclusion of K in 100% NP recorded the comparable yield as that of 100% NPK indicating the possibility of reducing K recommendation to crops in the soils of similar nature. Similar findings were reported by Arulmozhiselvan *et al*. (2015) [13]. Application of N alone (T_2), K alone (T_7) and P alone (T_8) did not record marked increase in the yield of crops when compared to 100% NPK (T_9). Continuous manuring such as residue mulching (T_{16}), application of FYM on every year (T_{17}) and even year (T_{18}) recorded comparable yield with T_2, T_7 and T_8. Insufficient and unbalanced application of nutrients either in organic and inorganic forms might be the reason for decline in yield. Continuous skipping of fertilizers in control (T_1) drastically reduced the grain yield of sunflower by 62.2% and maize by 86.7% compared to 100% NPK (T_9). Continuous cropping over a period of 41 cropping cycles without fertilizers (control) reduced the grain yields of rice considerably from 27.8–60.5% to that of wheat (1.9–35.3%) with respect to initial yields (Manna *et al*. 2005) [3].

3.2. Stover yield

Stover yield of sunflower varied from 1337 to 4254 kg ha^{-1} and of maize varied from 1487 to 12012 kg ha^{-1} (Table 1). The highest stover yield of sunflower (4254 kg ha^{-1}) and maize (12012 kg ha^{-1}) were registered in the STCR-IPNS practice (T_{13}) followed by 100% NPK + FYM (T_{10}) treatment which recorded stover yield of 4129 kg ha^{-1} in sunflower and 11023 kg ha^{-1} in maize. Higher dry matter production coupled with greater utilization of nutrients might be attributed to higher stover yield in the above said treatment than other treatments. Unbalanced and organic manure alone applied plots did not result in better stover yield when compared to 100 % NPK and INM practice. The lowest yield of 1337 kg ha^{-1} in sunflower and 1487 kg ha^{-1}in maize were recorded in control (T_1) followed by N alone plot (1352 kg ha^{-1} and 2334 respectively) which might be due to insufficient nutrient supply to the plants by intensive cropping without addition of external source of fertilizers and manures.

Table 1: Effect of long-term fertilizer application on grain, stover yield and sustainable yield index (SYI) of sunflower and maize crops

Treatments	Year (2018)						Over the years (1909-2018)	
	Grain yield (kg ha^{-1})		% increase or decrease over 100% NPK (T_9)		Stover yield (kg ha^{-1})		SYI	
	Sunflower	Maize	Sunflower	Maize	Sunflower	Maize	Sunflower	Maize
T_1	766	907	-62.2	-86.7	1337	1487	0.559	0.088
T_2	814	1272	-59.8	-81.3	1352	2334	0.539	0.084
T_3	1423	2997	-29.7	-55.9	2462	5019	0.600	0.297
T_4	1975	6370	-2.5	-6.4	3400	8455	0.506	0.578
T_5	2065	6418	2.0	-5.6	3583	9012	0.601	0.551
T_6	1542	3277	-23.9	-51.8	2674	4989	0.383	0.269
T_7	1124	2714	-44.5	-60.0	2023	4237	0.574	0.244
T_8	1312	2969	-35.2	-56.4	2312	4781	0.463	0.163
T_9	2025	6802	-	-	3509	8964	0.605	0.571
T_{10}	2465	7593	21.7	11.6	4129	11023	0.612	0.556
T_{11}	1845	5211	-8.9	-23.4	3071	7169	0.385	0.454
T_{13}	2427	7398	19.9	8.8	4254	12012	0.579	0.536
T_{14}	1822	5109	-10.0	-24.9	3160	7982	0.458	0.501
T_{15}	2122	6376	4.8	-6.3	3485	8892	0.423	0.426
T_{16}	974	3122	-51.9	-54.1	1648	4367	0.569	0.310
T_{17}	1223	3208	-39.6	-52.8	2092	5092	0.615	0.320
T_{18}	1076	2588	-46.9	-62.0	1830	3674	0.538	0.314

3.3. Sustainable yield index

Sustainable yield index (SYI) helps to establish the minimum guaranteed yield that can be obtained relative to maximum observed yield. The nearness of the SYI to 1 implies the closeness to an ideal condition that can sustain maximum crop yields, whereas deviation from 1 indicates losses to sustainability (Reddy *et al.* 1999) [14]. Among the crops, the SYI was higher for sunflower than maize (Table 1). In maize, the SYI was highly varied between treatments whereas in sunflower variation between treatments was minimum. Among the treatments, application of 100% NP recorded the maximum SYI of 0.578 in maize and FYM application every year recorded the maximum SYI of 0.615 in sunflower, whereas the most reduction was recorded in the control and N alone in maize (0.088 and 0.084, respectively). Kang *et al.* (2005) [15] also reported the similar results for 29 years of long-term fertilizer experiment in corn-wheat system conducted on Typic Ustochrept soils.

3.4. Soil pH and Electrical conductivity (EC)

The data on soil pH and EC are presented in Table 2. Continuous fertilization and manuring slightly influenced the soil pH over years. The treatments which received organic manures either alone or in combination with NPK *viz*., T_{10}, T_{13}, T_{14}, T_{16}, T_{17} and T_{18} recorded lower pH (<8) compared to treatments which received only inorganic nutrients (>8) may probably due to organic acids released during decomposition of organic matter resulting lower pH. Electrical conductivity of the soil was not influenced by the long term addition of fertilizers or manures (Table 2). Similar findings were also reported by Arulmozhiselvan *et al.* (2015) [13].

3.5. Soil organic carbon

Soil organic carbon (SOC) content improved over the initial status, even in the control plots. The gain in SOC content under the control plots of this study was due to annual C addition from the biomass of both crops (Bhattacharyya *et al.*, 2009) [16]. The conjoint application of 100% inorganic fertilizer with FYM brought about a significant increase in the SOC content of soil than the unfertilized and unmanured control (Table 2). Continuous adoption of INM or STCR-IPNS enhanced the SOC content from 3.2 g ha^{-1} during 1974 to 7.95 g kg^{-1} in INM and 7.84 g kg^{-1} in STCR-IPNS practice during 2018. Plot under 100% NPK + FYM contained 56.5% and 108% higher SOC content than NPK and control plots, respectively most probably due to increased yields of roots and plant residues, and the direct application of organic matter through FYM (Mandal *et al*. 2008) [17].

Balanced fertilization maintained soil organic carbon more than 5 g kg^{-1}, whereas buildup was noticed when FYM is included in NPK (>6 g kg^{-1}). Treatment received NPK (T_9) alone had 33 per cent more SOC than control which might be due to enhanced root residue addition to the soil under continuous cultivation. This is in conformity with the findings of Li *et al.* (2013) [18] who reported that the balanced fertilization enhanced SOC content compared to unbalanced fertilization.

3.6. Carbon stock

The carbon stock over years was highest for 100% NPK + FYM (16.1 Mg ha^{-1}) followed by STCR-IPNS ptactice (15.99 Mg m^{-3}) and lowest for unfertilized control (8.65 Mg ha^{-1}) (Table 2). The INM and STCR-IPNS plots contained 47.7 and 46.7% higher SOC stock than 100% NPK plot. Addition of more root biomass to soil with time due to improved physico-chemical properties and biological environment suitable for crop growth resulted in higher carbon accumulation. Many studies have shown that materials with higher lignin content such as FYM result in more carbon accumulation (Bhattacharyya *et al*., 2011; Brar *et al*., 2015; Ghosh *et al*., 2018) [19-21].

3.7. Available nitrogen

The greatest available N was recorded under the 100% NPK plus FYM treated plot (271 kg ha^{-1}) which was on par with STCR-IPNS practice (268 kg ha^{-1}). The greater availability of N may be through direct addition of FYM, which might have helped in multiplication of soil microbes, ultimately enhancing the conversion of organically bound N to mineral form (Tolanur and Badanur 2003) [22]. Omission of N from the schedule drastically reduced N availability in soil by 79 kg in PK, 86 kg in K alone and 82 kg in P alone treatments as compared to 100% NPK. The availability of N was depleted in unfertilized control (T_1) by 42.8% compared to 100% NPK application (T_9) might be due to continuous cropping without fertilization.

3.8. Available phosphorus

There was a substantial build-up of available P content over the years. Available P recorded the highest (36.48 kg ha^{-1}) in the treatment that received application of poultry manure on N equivalent basis (T_{15}) followed by INM (31.68 kg ha^{-1}) and STCR-IPNS (30.82 kg ha^{-1}) practices (Table 2). Higher amount of P released during the decomposition of PM when applied continuously on N equivalent basis which resulted in higher build up of available P than other treatments. The result is in line with the findings of Elayarajan *et al*. (2013) [4]. Whereas, omission of P in the fertilizer schedule and unfertilized control had lower available P status when compared to P received treatments might be due to exploitation of P from soil by continuous cropping.

Table 2: Effect of long-term fertilizer application on physico chemical and chemical properties in post harvest soil of maize during 2018

Treatments	pH	EC (dS m^{-1})	SOC (g kg^{-1})	SOC stock (Mg ha^{-1})	Available nutrients (kg ha^{-1})		
					N	P	K
T_1	8.14	0.30	3.82	8.65	128	6.62	435
T_2	8.18	0.25	4.40	9.77	212	8.76	456
T_3	8.16	0.24	4.54	9.94	218	9.62	598
T_4	8.20	0.28	5.02	10.84	228	18.24	488
T_5	8.16	0.23	5.06	10.85	238	23.86	646
T_6	8.08	0.29	4.72	10.27	145	16.75	615
T_7	8.08	0.28	4.40	9.70	138	9.15	634
T_8	8.18	0.28	4.52	9.83	142	19.87	497
T_9	8.10	0.26	5.08	10.90	224	22.4	668
T_{10}	7.98	0.28	7.95	16.10	271	31.68	754
T_{11}	8.22	0.25	4.48	9.68	212	16.64	532
T_{12}	8.20	0.28	3.60	8.26	138	8.96	514
T_{13}	7.97	0.29	7.84	15.99	268	30.82	692
T_{14}	7.65	0.22	7.25	14.68	224	21.07	634
T_{15}	8.15	0.25	6.78	13.93	236	36.48	662
T_{16}	7.96	0.24	5.62	11.97	176	15.64	528
T_{17}	7.56	0.19	7.06	14.19	212	17.73	556
T_{18}	7.70	0.20	6.23	12.62	204	15.89	557

3.9. Available potassium

The highest value of available K 754 kg ha^{-1} was observed in INM practice (T_{10}) followed by STCR –IPNS (692 kg ha^{-1}) (Table 2). The increase in the availability of K through addition of FYM may be due to the decomposition of organic matter and release of nutrients. The beneficial effect of FYM on the available K is also due to the reduction of K fixation and release of K due to interaction of clay with organic matter. Unbalanced fertilization and skipping of K in N (T_2), NP alone (T_4), P alone (T_8) and control (T_1) may be attributed to the higher uptake of K by crops resulting in depletion of K in the absence of K addition. This finding was in corroboration with Arulmozhiselvan *et al*. (2015) [13].

4. Conclusions

Present investigation revealed that under high intensive cropping system recommended dose of 100% NPK + FYM @ 12.5 t ha^{-1} was found to be a viable option for restoring soil organic carbon and nutrient turnover, thereby improving the availability of nutrients in soil, maintaining soil quality, and helping to achieve sustainable productivity of sunflower and maize crops for the long run under irrigated situation. In soils rich in available K, application of 100% K is not necessary, instead a maintenance dose of 50% K can be followed for sunflower and maize crops. Continuous application of nitrogenous fertilizers alone and unfertilized control were markedly reduced the yields and soil fertility. Therefore, judicious application of inorganic and organic nutrients in an integrated manner is essential for proper nutrient supply and sustaining crop productivity in a long-term sunflower-maize cropping system.

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