Effect of long term nutrient managements on maize (*Zea mays* L.) yield and soil fertility under maize – sunflower cropping sequence in an alfisol

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Abstract: The present investigation was carried out to evaluate the effect of long term nutrient managements on maize yield and soil fertility in the on-going century-old Permanent Manurial Experiment of Tamil Nadu Agricultural University, Coimbatore during 2020. The post-harvest soil after harvest of 169th crop of maize was analyzed for physicochemical and chemical properties. Results revealed that the continuous adoption of STCR-IPNS practice has achieved the highest grain yield of 8213 kg ha^{-1} which was on par with NPK + FYM treatment (7618 kg ha^{-1}) besides sustaining yield to a greater extent. Application of inorganic fertilizers alone registered pH > 8.0 whereas the application of fertilizers and manures and application of manures alone registered pH < 8.0 in soil. Among the treatments, continuous application of NPK+FYM and STCR-IPNS improved the cation exchange capacity, organic carbon content and available nutrient status in the soil whereas unbalanced fertilization and unfertilized control decreased the most, resulted in degraded soil fertility. The results indicated that the combined application of inorganic and organic fertilizers maintained higher soil fertility.

Key-Words: Permanent Manurial Experiment, maize, SYI, SOC, nutrients

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 [1]. Several long term fertilizer studies have indicated that the prolonged use of chemical fertilizers accelerated degradation of soil and a decline in crop productivity [2]. The physical, chemical and biological properties that enable soils to perform a wide range of functions are related to soil fertility. Since the soil functions are not directly measurable, appropriate physical, chemical and biological properties, are selected to indirectly measure how well each function is being performed. Long term experiments could be more useful for studying the changes in soil properties and processes over time and for obtaining information on the sustainability of agricultural systems for developing future strategies to maintain soil health [3].

The earliest long term experiments called “Rothamsted Classical Experiments” have yielded the most valuable information for the identification of most efficient nutrient management for sustaining the soil health and crop productivity. Based on the Rothamsted model, the Permanent Manurial Experiment (PME) of Tamil Nadu Agricultural University (TNAU) started during the year 1909 remains successful over 110 years in India and abroad. To evaluate the long term effect of inorganic fertilizers and manures on maize yield and soil fertility, the present investigation was carried out in the on-going PME with long term nutrient management and continuous cropping in an Alfisol.

2 Materials and Methods

2.1 Experimental site

The present study was carried out during 2019-2020, is a part of an on-going project of the century old Permanent Manurial Experiment (PME) located in Tamil Nadu Agricultural University, Coimbatore, India to assess the effect of long term nutrient management on maize yield and soil fertility after harvest of maize crop (169th crop). The experiment details and soil characteristics (analyzed during 1974) are given in Table 1.

Table 1. Experiment details and soil characteristics

Details	PME, TNAU, Coimbatore
Year of establishment	1909
Location	Tamil Nadu Agricultural University, Coimbatore
Area	50 cents
Geographical	11°N, 77°E

coordinates	
Altitude	426.7 m
Max and Min temperature	34.3°C and 21.7°C
Annual rainfall	674.2 mm
Climate type	Semi-arid sub-tropical
Cropping sequence	Maize – Sunflower
Cropping situation	Irrigated
Soil texture	Sandy loam
Soil series	Palathurai
Soil classification	*Typic Haplustalfs*
Initial soil characteristics	
pH	8.30
Electrical conductivity (dS/m)	0.25
Soil organic carbon (g/kg)	1.80
Available N (kg/ha)	147
Available P (kg/ha)	3.58
Available K (kg/ha)	381

2.2 Treatment details

The experiment included two crops per year, sunflower (June-October) and maize (November-February). The treatments are T_1, Control (unfertilized and unmanured); T_2, 100% N; T_3, 100% NK; T_4, 100% NP; T_5, 100% NPK; T_6, 100% PK; T_7, 100% K; T_8, 100% P; T_9, 100% NPK + Farmyard manure (FYM) @ 12.5 t ha^{-1} (INM); T_{10}, Soil test crop response – Integrated nutrient supply system (STCR-IPNS); T_{11}, Farmyard manure (FYM) @ 12.5 t ha^{-1}. The hybrid maize CO 6 was sown during December 2019 and harvested during April 2020. The recommended dose of N, P_2O_5 and K_2O 250:75:75 kg ha^{-1} was applied to maize. The sources of N, P and K used were urea, single super phosphate and muriate of potash, respectively for all the treatments. For treatments T_9, T_{10} and T_{11}, well-decomposed farmyard manure (FYM) at 12.5 t ha^{-1} (fresh-weight basis) with an average nutrient composition of 0.5% N, 0.23% P and 0.53% K was broadcasted 20 days before sowing and mixed with soil. For treatment $T_{10,}$ Soil Test Crop Response-Integrated Plant Nutrient Supply (STCR-IPNS), based on the soil test values and targeted yield of 90 q ha^{-1} the quantity of NPK was calculated and applied.

2.3. Plant and soil sampling and analysis

At harvest during 2020, grain, straw yield of maize was recorded and expressed in kg ha^{-1}. Average yields of maize crop were made of the yield data for each fertilizer treatment over 10 years. Based on this, sustainable yield index (SYI) of the maize crop was calculated by the following equation [4]:

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

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 upper 15 cm soil depth in triplicate from each plot after the harvest of maize crop during 2020. In each plot, ten sub-samples were collected and pooled together as a composite sample. Soil pH and EC were determined in soil:water (1:2.5 ratio) extract by potentiometric and conductometry methods respectively [5]. Cation exchange capacity was estimated by the method as described by Piper [6]. Available soil N was determined by the alkaline-$KMnO_4$ method [7], available P by sodium bicarbonate ($NaHCO_3$) extraction and subsequent colorimetric analysis [8], available K by using an ammonium acetate extraction followed by emission spectrometry [9], available S by turbidimetry method as outlined by Chesnin and Tien [10] and soil organic carbon was determined by chromic acid wet digestion method [11].

2.4 Statistical analysis

The data were analyzed by using analysis of variance (ANOVA) and mean comparison by LSD as suggested by Panse and Sukhatme [12] at 5 percent significance level for concluding on the influence of various treatments.

3 Results and discussion

3.1 Grain and straw yield

Continuous adoption of STCR-IPNS practice has achieved the highest grain yield of 8213 kg ha^{-1} which was on par with NPK + FYM treatment (7618 kg ha^{-1}) (Table 2). This might be due to the sustained soil fertility by continuous addition of FYM and NPK fertilizers and effective utilization of applied nutrients which increased sink capacity and nutrient uptake by maize. Similar results were also reported by Meena *et al*. [13]. The STCR-IPNS (T_{10}) proved its superiority by recording 27.6 per cent increase in grain yield over NPK (T_5). Non-inclusion of K in 100% NP (T_4) recorded the comparable grain yield as that of 100% NPK (T_5) might be due to high available K status of the soil indicating the possibility of reducing K recommendation to maize crop in the soils of similar nature. Similar findings were reported by Arulmozhiselvan *et al*. [14] and Malarkodi *et al*. [15]. Plots received single nutrient alone showed grain yield reduction of 80 per cent for N alone, 54 per cent for P alone and 58 per cent for K alone treatments as compared to balanced application of NPK. Continuous skipping of fertilizers in control (T_1) drastically reduced the grain yield by 86 per cent when compared to NPK (Table 2). This is in line with the findings of Manna *et al*. [16] who stated that continuous cropping over a period of 41 cropping cycles without fertilizers 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.

The highest straw yield was registered in the STCR-IPNS (13335 kg ha^{-1}) followed by NPK+FYM (110595 kg ha^{-1}) treatment (Table 2) which might be attributed to improved physical and chemical properties of soil due to FYM addition. Higher dry matter production coupled with greater utilization of nutrients in these treatments might be attributed to higher straw yield over other treatments. The lowest yield was recorded in control (T_1) followed by N alone (T_2) which might be due to insufficient nutrient supply to the plants by intensive cropping without addition of external source of fertilizers and manures. The findings were in corroboration with Arulmozhiselvan *et a*l. [14].

3.2 Sustainable yield index (SYI)

The sustainable yield index (SYI) was highly varied between treatments (Table 2). Among the treatments, application of NP (T_4) recorded the maximum SYI of 0.584 while the N alone treatment (T_2) had minimum SYI of 0.077. The SYI was >0.5 in the treatments which received optimum NP> NPK+FYM> NPK> STCR-IPNS every year whereas, the lowest SYI was recorded in the N alone and control plots (<0.1) indicating that the optimum fertilization is essential to improve and sustain the crop yields [17]. Similar results were also reported by Ram e*t al*. [2] and Mithiladevi *et al*. [18].

3.3 Physico-chemical properties

Continuous fertilization and manuring significantly influenced the soil pH over the years (Table 3). The treatments which received organic manures either alone or in combination with NPK *viz*., T_9, T_{10} and T_{11} recorded lower pH (<8.1) compared to treatments that received only inorganic nutrients (>8.1). The decrease in pH in the FYM applied treatment may probably due to organic acids released during the decomposition of organic matter resulting in lower pH. Similar findings were also reported by Ling *et al.* [19] and Malarkodi *et al*, [15]. The electrical conductivity of the soil was not significantly influenced by the long-term addition of fertilizers or manures. Combined application of NPK+FYM recorded the highest CEC (28.17 Cmol (p^+) kg^{-1}) followed by STCR-IPNS practice (26.47 Cmol (p^+) kg^{-1}). Among the inorganic treatments, continuous application of balanced dose of NPK registered the highest CEC (23.16 Cmol (p^+) kg^{-1}) than the treatments received unbalanced fertilization (Table 3). Both colloidal nature of organic and mineral surface contributed to CEC of the soil this might attribute the highest CEC under integrated application inorganics and organics in NPK+FYM and STCR-IPNS treatments [20]. The unfertilized and unmanured control (T_1) recorded the lowest CEC (15.76 Cmol (p^+) kg^{-1}).

3.4 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 the annual C addition from the biomass of both crops [21]. 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 3). Continuous adoption of NPK+FYM or STCR-IPNS enhanced the SOC content from 1.8 g ka^{-1} during 1974 to 8.99 g kg^{-1} in NPK+FYM and 8.95 g kg^{-1} in STCR-IPNS practice during 2020 and was on par with each other. Plot under NPK + FYM contained 45% and 115% higher SOC content than NPK and control plots, respectively most probably due to increased root biomass and plant residues, and the direct application of organic matter through FYM [22]. Balanced fertilization maintained soil organic carbon at more than 6 g kg^{-1}, whereas a buildup was noticed when FYM was integrated with NPK (>8 g kg^{-1}). Treatment received NPK (T_5) alone had 49 per cent more SOC than control which might be due to enhanced root residue addition to the soil under continuous cultivation. This confirms with the findings of Li *et al*. [23] who reported that balanced fertilization enhanced SOC content compared to unbalanced fertilization. Continuous application of FYM alone @ 12.5 t ha^{-1} over 110 years had 26 per cent higher SOC over NPK treatment (T_5). Use of FYM stimulates microbial activity resulted enhanced polysaccharides production and stabilization of organic matter in soil which attributed the higher SOC under FYM alone (T_{11}) treatment

3.5 Available nutrient status

Great improvement was noted in available N of 26 and 20 kg ha^{-1} for NPK + FYM (T_{10}) and STCR-IPNS (T_{10}) when compared to NPK (T_5). Overall, under NPK+FYM the available N was highest (268 kg ha^{-1}) which was 10.7 per cent higher than 100% NPK, and 118 per cent higher than control (Table 3). The greater availability of available N under NPK+FYM and STCR-IPNS treatments 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 [24]. Omission of N from the schedule drastically reduced N availability in soil by 100 kg in PK, 105 kg in K alone and 96 kg in P alone treatments as compared to NPK (T_5). The availability of N was depleted in unfertilized control (T_1) by 49 per cent compared to NPK (T_5) might be due to continuous cropping without fertilization.

There was a substantial build-up of available P content from over the years (Table 3). Available P recorded the highest (31.87 kg ha^{-1}) in the treatment that received NPK+FYM, which was on par with STCR-IPNS (30.07 kg ha^{-1}) practice accounted 40 per cent and 32 per cent higher available P over NPK (T_5). The addition of organic manures may solubilize the native P at a greater rate in soil through the release of various organic acids under irrigated conditions [25]. Omission of P in N alone (T_2), NK alone (T_3) and K alone (T_7) leads to accelerated depletion of available P status due to complete exclusion of P in fertilizer schedule and exploitation of P from soil by continuous cropping [15]. Increased available P status in the treatments which received P fertilization might be due to continuous application of P over years contributes P to available pools after fulfilling phosphorus fixing capacity [26]. The availability of P was depleted in unfertilized control (T_1) by 72 per cent compared to NPK (T_5) might be due to continuous cropping without P fertilization.

The highest value of available K (715 kg ha^{-1}) was observed in NPK+FYM treatment followed by STCR –IPNS (616 kg ha^{-1}) (Table 3). The available K under NPK+FYM was 14 per cent higher than the available K in the NPK treatment. The increase in the availability of K through addition of FYM may be due to the decomposition of organic matter and release of K besides the reduction of K fixation and release of K due o the interaction of organic matter with clay [27]. Substantial decrease in available K status was observed under control (T_1) and skipping of K in N (T_2), NP alone (T_4), P alone (T_8) may be attributed to continuous crop removal and absence of external source of K fertilizer. This finding was in corroboration with Malarkodi *et al*. [15] and Mithiladevi *et al*. [18].

Available S content was significantly higher in NPK+FYM treatment (40.92 kg ha^{-1}) followed by STCR-IPNS practice (40.59 kg ha^{-1}). The increase was 65 per cent in NPK+FYM, 64 per cent in STCR-IPNS and 59 per cent in NPK treatments over control (T_1) (Table 3). The increase in available S in INM, STCR-IPNS and NPK alone might be due to single super phosphate (SSP) and FYM which contained about 12 and 0.74 per cent of S, respectively. This indicates that continuous addition of S through SSP in combination with FYM helped in the build-up of SO_4-S in the soil over years. The available S status of control plot was lower which might be due to low SOC in control plot as S is known to be an integral part of soil organic matter. The results of the present study are also conformity with the findings of Lavanya *et al*. [28] who have recorded higher available sulphur content in the long-term fertilized soils under maize-wheat cropping system in treatment, which received SSP plus manure.

4 Conclusions

Thus, it may be concluded, from the present investigation that the adoption of NPK+FYM and STCR-IPNS were found to be a viable options for restoring soil organic carbon and nutrient turnover, thereby improving the availability of nutrients in soil, and helping to achieve higher productivity of maize crop for the long run under irrigated situation. 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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Table 2. Effect of long term nutrient managements on grain, straw yields and sustainable yield index (SYI) of maize (16^{th} crop)

Treatments	Year (2019)			Over the years (1909 – 2020)
	Grain yield (kg ha^{-1})	% increase or decrease over 100% NPK (T_5)	Straw yield (kg ha^{-1})	SYI
Control	925	-85.6	1516	0.086
N	1290	-80.0	2366	0.077
NK	3014	-53.2	5047	0.292
NP	6385	-0.8	8475	0.584
NPK	6438	-	9040	0.553
PK	3295	-48.8	5018	0.281
K	2733	-57.5	4267	0.252
P	2982	-53.7	4802	0.173
NPK+FYM	7618	18.3	11059	0.562
STCR-IPNS	8213	27.6	13335	0.551
FYM	3225	-49.9	5119	0.323
SEd	435	-	337	-
CD (0.05)	908	-	704	-

Table 3. Effect of long term nutrient managements on physic-chemical and chemical properties of soil after hybrid maize (169^{th} crop) in an alfisol

Treatments	pH	EC (dS m^{-1})	SOC (g kg^{-1})	CEC [Cmol (p^+) kg^{-1}]	Available nutrients (kg ha^{-1})			
					N	P	K	S
Control	8.23	0.26	4.18	15.76	123	6.27	362	24.80
N	8.21	0.24	4.98	16.82	218	7.70	412	30.00
NK	8.20	0.26	5.12	17.57	215	8.03	575	30.49
NP	8.21	0.28	5.38	19.23	227	18.76	447	35.42
NPK	8.19	0.32	6.22	23.16	242	22.77	626	39.51
PK	8.12	0.29	5.22	21.60	142	16.33	611	33.99
K	8.11	0.25	5.16	20.50	137	8.04	607	30.64
P	8.16	0.26	5.17	22.00	146	15.33	459	37.31
NPK+FYM	7.99	0.24	8.99	28.17	268	31.87	715	40.92
STCR-IPNS	8.03	0.25	8.95	26.47	262	30.07	616	40.59
FYM	7.98	0.19	7.86	18.13	213	14.43	526	36.86
SEd	0.08	0.04	0.16	0.30	6	1.42	23	1.24
CD (0.05)	0.17	NS	0.35	0.64	12	2.95	49	2.58