Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2020; 9(1): 644-649
Received: 07-11-2019
Accepted: 09-12-2019

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Long term fertilizer impact on crop biomass, microbial biomass carbon, microbial biomass nitrogen and nutrient uptake of swell - shrink soil in maize under finger millet - maize cropping sequence

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Abstract

Cereal based cropping sequences are major cropping systems in India. Maize - finger millet cropping system is being followed by 44 years of continuous and long term fertilization and also it has a significant impact on yield and soil health. This investigation evaluated the effect of long term fertilizer application and intensive cropping on yield, biomass, soil organic carbon, soil microbial biomass carbon, soil microbial biomass nitrogen, and nutrient uptake of maize in sandy clay loam (*Vertic Ustropept*) soil. Application of inorganic NPK fertilizers at graded levels from 50 to 150% NPK increased the yield (Grain, Stover & Shell) root biomass, soil available major (N, P & K) and micro nutrients (Zn, Cu, Mn & Fe) SOC, SMBC and SMBN in maize. Under the integrated nutrient management practice (100% NPK+FYM), the percent increased grain yield was 15.66 in maize over 100 % NPK indicating that INM is the best way of maximize the yield continuously in intensive cropping systems. NPK + FYM (INM) treatment might have contributed directly in appreciable amounts of major and micronutrient to the soil and it would increase the growth and yield of maize. Continuous addition of N alone did not influence the soil available N and other nutrients instead reduced available N when compared to NPK treatments. Addition of fertilizer P in progressive levels such as 50, 100 and 150% NPK levels has increased the soil available P (21.02 % in maize) over 100 per cent NPK. Also, addition of different levels of K has improved the soil available K (14.13 % in maize) when compared to 100 % NPK. Addition of Zn along with NPK treatments alone showed the higher Zn and other treatments has deficient of Zn including Mn, Cu and Fe but slightly higher in INM plot in maize. SOC, SMBC and SMBN were higher in NPK + FYM treatments than other inorganic fertilized plots.

Keywords: Long term fertilization, maize – finger millet cropping system, swell shrink soil, SMBC & SMBN

Introduction

Continuous cropping system, high yielding varieties, irrigation and high analysis fertilizer accelerated the mining of nutrient other than supplied even more 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. Interest in long-term field experiments as the suitable indicators of sustainability of agriculture has increased during last few decades the world over. These experiments indicate the extent to which yield and related parameters and the quality of ecosystem can be predicted. These are also capable of serving as an early warning system to detect problems that threaten future productivity (Berzsenyi *et al*, 2000).

Primary (macro) nutrients viz., nitrogen, phosphorus, and potassium are the most frequently required in a crop fertilization schedule. Also, they are need in the greatest total quantity by plants as fertilizer. Nitrogen has a profound effect on soil fertility, crop yield and contributes to an increase in post harvest residue thus preventing the loss of soil organic matter (Wiater and Chwil, 2005) [25].

Soil P exists in various chemical forms including inorganic P (Pi) and organic P (Po). These P forms differ in their behavior and fate in soil (Turner *et al*, 2007) [21]. In the soil, applied P is partitioned into readily available (labile) and less readily available (stable) inorganic and organic forms with different desorption, dissolution, and mineralization rates that may contribute to plant P nutrition. Continuous long term application of fertilizers can lead to P accumulation in surface horizons greater than that required for optimum plant growth thus increasing the potential for P loss to surface water and cause eutrophication (McDowell *et al*, 2001) [11].

The forms of soil K in the order of their availability to plants and microbes are solution > exchangeable > fixed (non exchangeable) > mineral (Sparks, 2000). The effects of the long term intensive cropping and fertilizers on available K status in a *Haplustert* soil was that the available soil K declined over the 29 years of intensive cropping and fertilizer application even at 150 per cent NPKS (Temphare, 2002) [20].

Soil organic carbon plays a vital role for soil health management in ecosystem. In India, intensive cropping, high yielding cultivars and inappropriate fertilizer application cause severe depletion of nutrients and soil organic matter posing a serious threat to crop productivity and soil sustainability. The sound fertilizer management, particularly organic manure application, could restore crop productivity and its sustainability through improving the quality of the degraded soils (Bi *et al*, 2009) [3]. The manure application led to increased soil organic carbon (SOC) content and nutrients, improved soil porosity and structure, and increased soil microbial activity (Hao *et al*, 2008) [6].

Soil microorganisms are important driving force for the nutrient transformation and cycling of soil organic matter in soil, and also provide a substrate of available nutrients for crops (Xu *et al*, 2016) [26]. Soil microbes are directly affected by soil quality and are extremely sensitive to changes in it (Zhou and Ding 2007) [28]. They respond quickly to the application of fertilizers, altered cropping systems, and land utilization changes (Yusuf *et al*, 2009) [27]. Soil characteristics such as soil microbial biomass carbon (SMBC) and soil microbial biomass nitrogen (SMBN) have been used as indexes to assess changes in soil fertility and soil quality (Schloter *et al*, 2003) [15].

With this background, a study has been undertaken to evaluate the continuous application of mineral fertilizers along with the organics on yield, nutrient uptake and soil organic carbon properties in maize under finger millet - maize cropping sequence on black soils of *Vertic Ustropept* in Coimbatore, Tamil Nadu.

Materials and Methods

Site Description

Long Term Fertilizer Experiment (LTFE) of Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore was started during 1972 and it has crossed 47 years of continuous experimentation with three and two cropping sequence. The finger millet – maize cropping sequence was followed from 2008. The experimental soil (Periyanaicken palayam soil series) is sandy clay loam in texture and taxonomically grouped under *Vertic Ustropept*. Available nutrient status of experimental soil analyzed at 2008 showed that, low in available nitrogen (178 kg ha^{-1}), low in available phosphorus (11 kg ha^{-1}) and high in available potassium (810 kg ha^{-1}). Ten treatments are being studied in this LTFE trial, which comprises of T_1 -50 % NPK, T_2 -100 % NPK, T_3 -150 % NPK, T_4 -100 % NPK + Hand Weeding, T_5 -100 % NPK + Zn, T_6 -100 % NP, T_7 -100 % N, T_8 -100 % NPK+ FYM, T_9 -100 % NPK (-S (Single Super Phosphate as Phosphorus source)) and T_{10} - control under randomized block design.

Experimental Design and Treatments

The Maize hybrid (COHM6) was sown with 30 cm X 10 cm spacing. As per the treatment structure, twenty days before the sowing of crop farm yard manure @ 10 t ha^{-1} was applied uniformly in INM treatment plot. Hundred per cent recommended doses of P_2O_5 and K_2O and 25 per cent of N (Urea) @ 90:45:17.5 kg ha^{-1} respectively was applied basally in the main field. The remaining 50 and 25 per cent of N was top dressed on 25th and 50th DAS. Fertilizers like urea for N, single super phosphate (SSP) for P and Muriate of Potash (MOP) for K was selected as source of fertilizer nutrient. Instead of Single Super Phosphate, Di Ammonium Phosphate was used as source of P to eliminate supply of sulphur in T_9. Except T_4, other treatments received soil application of pre emergence herbicide. Routine cultural operations and needed plant protection measures were carried out at regular intervals as per the Crop Production Guide.

Grain, straw yield, shell, straw and root biomass was recorded plot wise at the time of harvest and yield per hectare was arrived in 2018-2019. Available N in soil was estimated by alkaline permanganate method (Subbiah and Asija, 1956) [18], available P by Colorimetry method (Olsen *et al*., 1954) [13], available K by Neutral Normal Ammonium Acetate method (Stanford and English, 1949) [17], and available micronutrients (Fe, Mn, Zn and Cu) were estimated by DTPA extraction followed by absorption spectrometry (Lindsay and Norvell, 1978) [9] Soil microbial biomass C (SMB-C) and N (SMB-N) were estimated by the chloroform-fumigation- extraction methods (Vance et al. 1987; Jenkinson 1988) [22, 7] and all the values were subjected to analysis of variance as mentioned by Panse and Sukhatme (1985) [14].

Results and Discussion

Effect of chemical fertilizers and organic amendments on yield and yield components of maize (kg ha^{-1})

The results revealed that, the continuous addition of progressive dosage of (50,100 &150 %) NPK fertilizers had significantly ($P \leq 0.05$) increased the grain yield along with stover, maize shell & root biomass of maize. Among the treatments, 100% NPK + FYM showed significantly higher percent increased of grain yield (13.54), stover (11.25), cob shell (15.63) and root biomass (29.20) over 100 per cent NPK fertilizers. These additions of NPK along with FYM, besides supplying some quantum of nutrients to the soil, might have also improved the soil physical properties such as porosity and lower the bulk density of the soil. The grain and stover yield of maize obtained by application of NP alone was found comparable with T_9 (100 % NPK (-S)) and T_2 (100 % NPK) which may be attributed to higher soil available potassium that would have met plants K requirement during crop growth. Continuous addition of mineral N fertilizers alone had declined the yield as well as yield parameters when compared to the combined application of NPK. This is due to continuous addition of N alone might have increased the soil acidity and it has decline the SOC and other plant available nutrients in soil. The increased yield and yield parameters of maize under the treatment T_8 (100% NPK +FYM) might be due to application of inorganic fertilizers along with farmyard manure could have encouraged the better rhizosphere environment, which would have made better nutrient availability in root zone and increased the nutrient absorption and translocation from source to sink exert a important regulative function on complex process of yield formation. This was inline with the findings of Meena *et al* (2017) [12] who revealed that, the application of K along with N and P (100% NPK) resulted in higher grain and stover yields of maize over 100% NP. Application of FYM along with the recommended dose of fertilizers recorded the highest grain and stover yield of maize.

Effect of chemical fertilizers and organic amendments on soil available nutrients (kg ha^{-1}) Soil chemical properties

Major nutrients (N, P & K)

Application of 100% NPK + FYM (T_8) was significantly influenced ($P \leq 0.05$) the soil available nutrients of N, P and K of 244, 27.28 and 767 kg ha^{-1} in Maize crop (Table 1). Application of FYM at 10 t ha^{-1} along with 100% NPK increased the available N status and increased N availability due to additional and slow release of N from manures added to soil. Continuous addition of N alone (T_7) did not influence available N remarkably instead available N was reduced when compared to NPK treatments. The highest N was recorded in 100% NPK + FYM (T_8) of 244 kg ha^{-1} in maize respectively. The increase in available N status may be due to organic manure application which would help for multiplication of microbes leading to mineralization and enhanced conversion of organically bound N into inorganic forms thus enhanced N availability to crops. Organic manures besides being a store house of nutrients also prevents the loss of nutrients by leaching. The decrease in available N status in the absolute control may be due to the continual removal of soil N in the absence of external supply of N through fertilizers and manures. There was decrement of soil available N by applying N alone (T_7) continuously due to acidifying the soil environment and lowest N (151 kg ha^{-1}) observed in control (T_{10}) plot. This result was corroborated with the findings of Dong *et al*. (2012) [4] who reported dynamic changes of soil available nitrogen significantly increased with organic manure and NPK treatments, suggesting that the long-term soil organic matter played a major role in releasing soil available nitrogen. As all the treatments except control, received nitrogen for all the crops, its availability in the post harvest soils was maintained more or less same quantity as that of initial available N value (199 kg/ha).

Regarding the P status, the lowest available P status was found in control (7.82 kg ha^{-1}) while a high value of 27.28 kg ha^{-1} was recorded for the application of FYM at 10 t ha^{-1} along with 100% NPK in the post-harvest soil of maize (Table 3). Available P status of the soil was the lowest in control due to exclusion of P fertilizers from the nutrient schedule. Available P status was significantly higher in treatments receiving P fertilizers than in the treatments without P. Higher availability of P in 100 % NPK + FYM treatment may be attributed to high residual P by low P sorption as organic anions released during the decomposition of FYM would have adsorbed on sorption sites thereby making more P availability in soil. This was in line with the findings of Varinderpal Singh and Brar Dhillon (2006) [23] who found relatively large amount of residual P in NPK + FYM treatments. Further, those treatments that received phosphatic fertilizer continuously showed P built up as compared to initial available P (12.3 kg ha^{-1})

The continuous application of inorganic nutrients and FYM significantly increased the soil available K when compared to the K skipping treatments. The highest soil K was observed in NPK + FYM of 767 kg ha^{-1} maize crops. Soil available K declined in all the treatments from the initial value (907 kg ha^{-1}) of experimental soil. Regarding the treatments, continuous addition of organic manure along with FYM and optimum K fertilization recorded higher value over control. Within the treatments, INM practice recorded higher value which might be due to mineralizing action of organic matter and release of nutrients to the soil labile pool. The decreased availability of K in N, NP and absolute control treatments may be attributed to the higher uptake of K by crops resulting in depletion of K in the absence of K addition. This was inline with the findings of Dong *et al*. (2012) [4] who revealed NPK treatment significantly increased available K content. However, irrespective of the treatments, soil potassium depletion was observed as compared to initial soil available potassium (907 kg/ha) which may be due to considerable removal of potassium by both the crops and fixation of K in clay minerals (Madaras *et al*., 2014).

Micro nutrients (Zn, Fe, Mn & Cu)

Trace elements or micronutrients (DTPA extractable) like zinc, iron, manganese and copper ranged from 0.542 - 2.257, 1.766 - 2.657, 5.484 - 6.895 and 0.818 - 1.0140 mg kg^{-1} in post-harvest experimental soil of maize respectively (Table 4). There was no significant change observed in DTPA extractable iron, copper and manganese in post harvest soil of maize. Significantly higher availability of 2.257 mg kg^{-1} of Zn was noticed in 100 % NPK + $ZnSO_4$ in the soil of maize. This might be attributed to the fact that good amount of Zn was contributed by continuous addition of $ZnSO_4$ along with 100% NPK. This was supported by the findings of Sunil Panwar *et al*. (2017) [19] who observed that soil available Zn was highly significant in 100 % NPK +FYM. The continuous removal of micro nutrients by the crops under continuous cropping of finger millet - maize cropping sequence may be attributed to lesser content of DTPA-Zn for those treatments that did not receive zinc sulphate fertilizer (Keram *et al*., 2012) [8]. While available copper, iron and manganese content were not influenced due to different treatments in the post harvest soil of maize. However, available copper and iron were found below critical values (Cu -1.2 ppm & Fe-3.7 ppm) in all the treatments which may be due to non application of these two nutrients coupled with removal of these nutrients by both the crops every year. (Singh *et al*., 2010) [16].

Nutrient uptake of maize (kg ha^{-1})

Total nutrient uptake of crop is nutrient accumulation in above ground parts, and harvest parts by the time of physiological maturity or attained maximum uptake of crops. The total nutrient uptake (Grain + Straw + Shell + Root) was significantly ($P \leq 0.05$) higher by using long term fertilization of inorganic and organic amendments and which was ranged from 49.55 to 144.27 of N, 9.52 to 27.45 of P, 62.5 to 187.30 kg ha^{-1} of K in maize crop. When compared to the treatments, the higher nutrient uptake of 144. 27, 27.45 and 187.30 kg ha^{-1} of N, P & K respectively was found in 100 % NPK + FYM followed by 150 % NPK (127.35, 25.14 & 164.80 kg ha^{-1} of N,P &K). Also 100 % NPK and 100 % NPK +Zn was on par with each other and the lowest uptake was observed in control. This might be due to application of mineral fertilizers and organic amendments directly implied on the soil available pools or plant available nutrients. These available nutrients are easily accessible by plants and significantly high accumulation of nutrients in plant parts as well as edible portion of maize. This was inline with the findings of Alan and John, (2017) [1] who revealed that, combined application of N and P mineral fertilizers could increased the grain N concentration linearly with increasing N rates with added P, but the increase of grain N content was nonlinear without P due to dilution effect. Also 100 % NPK and 100 % NPK +Zn was on par with each other and the lowest uptake was observed in control. Omission of nutrients or unbalanced nutrient application couldn't meet the nutrient accumulation in plants for proper growth, thus negatively impacting the yield output of maize (Edmeades, 2003) [5].

Continuous addition of chemical fertilizers and organic amendments on SOC (%), SMBC and SMBN (mg kg^{-1}) in post harvest soils of maize

Soil microbial biomass is being a driving force of biochemical process and pool of soil nutrients for crop growth. The long term fertilizer application along with organic manure led to a significantly increases ($P< 0.05$) of SOM, SMBC and SMBN than control which was ranged from 0.46 – 0.71 %, 191 – 282 and 19.29 – 46.15 mg kg^{-1} respectively in maize. Addition of mineral fertilizer along with organic amendments would help to increase the plant biomass yield, an increases the carbon input to soil is a main factor for higher SOM (0.71%). Also addition of FYM with mineral feriliser produces the cationic bridges with the functional groups leads to reduce the SOM solubilisation or oxidation. These SOM provide a better soil environment for proliferation of soil microbial population which would increase the SMBC (282 mg kg^{-1}) and SMBN (46.15 mg kg^{-1}). Even though, mineral fertilizer alone also given the higher plant biomass that could increased the SOC (0.62%), SMBC (262 mg kg^{-1}) and SMBN (37.92 mg kg^{-1}) but when compared the manure with mineral fertilizer, these minerals fertilizers treatments (50 % NPK, 100 % NPK & 150 % NPK) decreased the SOM and other microbial biomass like SMBC and SMBN (Li *et a*l., 2008). Because application of mineral fertilizers alone did not improve soil physical properties like aggregate stability and low bulk density, which may directly influenced the soil biological as well as physio chemical properties in soil. Though application of organic amendments provide the some extents of major and micro nutrients also addition of C input to soil. This was agreement with the findings of Wei *et al*., (2016) [24] who stated that greater SOM has observed by the application of organics + fertilizers treatments than either organics or fertilizers alone may also be attributed to increased root growth associated with additional C inputs from roots (Luo *et al*., 2015) [10].

Conclusion

Result getting from the long term fertilizer application with different treatments resulted in significant variation on the maize growth and yield components, nutrient availability (Major & Micro), total nutrient uptake (Grain + Straw + Shell + Root), SOC, Soil Microbial biomass carbon (SMBC) and Soil Microbial biomass Nitrogen (SMBN) in finger millet – maize cropping sequence in *Vertic Ustropept* in swell shrink cropping sequence. Application of recommended dose of fertilizer along with FYM maintained significant improvement in grain yield of maize, chemical properties as well as nutrient balance over the years as compared to other treatments. Among the nutrients, the study revealed that maintenance of available N, built up of P and depletion of available K was observed as compared to initial available status. Non application of micronutrients fertilizer also resulted in depletion of micronutrients in post harvest soil. Regarding the SOC and Microbial Biomass carbon and Nitrogen observed higher while applying the INM (Recommended Dose of Fertilizers + FYM) than control treatments over more than 4 decades of intensive cropping. This suggests that mineral fertilizer with organic manure shall be adopted for sustaining crop yield and soil fertility in continuous cropping system.

Table 1: Yield and yield components of maize (kg ha^{-1})

Treatment Structure	Grain Yield	Straw Yield	Shell yield	Root biomass
T_1 -50 % NPK	5055	6455	1796	531
T_2 -100 % NPK	5399	8259	1845	589
T_3 -150 % NPK	5421	8496	2012	732
T_4 -100 % NPK + HW	5330	7698	1879	646
T_5 -100 % NPK + Zn	5382	8425	2001	561
T_6 -100 % NP	5240	8277	1823	475
T_7 -100 % N	3986	6479	1714	382
T_8 -100 % NPK + FYM	6245	9306	2187	832
T_9 -100 % NPK (-S)	5151	7918	1861	715
T_{10} –control	2721	4389	977	311
SEd	125	170	45	16.5
CD (P = 0.05)	214	289	77	28.1

Table 2: Effect of continuous fertilization of soil available major (N, P & K) and micro nutrient (DTPA Extractable) in post harvest soils of maize

Treatment Structure	N	P	K	DTPA - Zn	DTPA - Fe	DTPA - Mn	DTPA - Cu
T_1 -50 % NPK	174	19.33	599	0.776	2.063	5.978	0.986
T_2 -100 % NPK	195	22.54	672	0.808	2.139	6.697	0.967
T_3 -150 % NPK	230	25.50	699	0.837	2.412	6.655	0.995
T_4 -100 % NPK + HW	202	22.78	645	0.818	2.203	6.321	0.921
T_5 -100 % NPK + Zn	213	21.68	653	2.257	2.275	6.587	0.988
T_6 -100 % NP	199	19.60	571	0.804	2.157	6.676	0.942
T_7 -100 % N	184	12.31	577	0.783	1.836	5.560	0.890
T_8 -100 % NPK + FYM	244	27.28	767	1.149	2.657	6.895	1.040
T_9 -100 % NPK (-S)	196	22.53	642	0.808	2.122	6.271	0.886
T_{10} –control	151	7.82	538	0.542	1.766	5.484	0.818
SEd	6	0.48	17	0.025	0.056	0.158	0.019
CD (P = 0.05)	10	0.81	29	0.042	0.095	0.270	0.033

Table 3: Effect of continuous fertilization on total nutrient (Grain + Straw + Shell + Root) uptake of N, P & K (kg ha^{-1}) in maize

Treatment Structure	N uptake	P uptake	K uptake
T_1 -50 % NPK	86.11	16.29	103.9
T_2 -100 % NPK	110.36	20.58	143.1
T_3 -150 % NPK	127.35	25.14	164.8
T_4 -100 % NPK + HW	109.00	20.70	133.2
T_5 -100 % NPK + Zn	121.53	22.82	151.9
T_6 -100 % NP	102.08	20.24	132.1
T_7 -100 % N	75.67	14.83	98.1
T_8 -100 % NPK + FYM	144.27	27.45	187.3
T_9 -100 % NPK (-S)	102.70	21.10	135.6
T_{10} –control	49.55	9.52	62.5
SEd	2.989	0.491	3.53
CD (P = 0.05)	5.091	0.836	6.012

Table 4: Effect of continuous fertilization on SOC (%), SMBC & SMBN (mg kg^{-1}) in post harvest soils of maize

Treatment Structure	SOC (%)	Biomass Carbon (mg kg^{-1})	Biomass Nitrogen (mg kg^{-1})
T_1 -50 % NPK	0.538	242	28.61
T_2 -100 % NPK	0.615	262	37.92
T_3 -150 % NPK	0.634	275	43.60
T_4 -100 % NPK + HW	0.630	259	39.51
T_5 -100 % NPK + Zn	0.618	276	41.16
T_6 -100 % NP	0.598	259	34.40
T_7 -100 % N	0.510	211	25.67
T_8 -100 % NPK + FYM	0.707	282	46.15
T_9 -100 % NPK (-S)	0.638	264	40.40
T_{10} –control	0.460	191	19.29
SEd	0.016	7	0.83
CD (P = 0.05)	0.027	12	1.42

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