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Validation and Demonstration of Integrated Soil Fertility Management Technologies for Maize Crop on Nitisols of Jimma, Southwestern Ethiopia

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Abstract

Application of organic and inorganic fertilizers is essential for sustainable production of crops. This combined effect of organic and inorganic fertilizers on growth and yield of maize (*Zea mays* L.) in Jimma Zone, South western Ethiopia was evaluated for two consecutive years (2018/19 and 2019/20). Present study investigated that effect of organic and inorganic fertilizers on maize and their residual impacts on soil physico-chemical properties. Soil fertility depletion is the most pressing development challenge in the Ethiopian agriculture for sustainable crop production. Land degradation and associated soil fertility depletion has been recognized as a major biophysical root cause for the declining per-capita food production in Ethiopia. There is now a need to adapt and employ sustainable soil fertility management practices. The objectives of this study are to validate and demonstrate Vermicompost/compost with inorganic fertilizer to enhance crop and soil productivity for sustainable production and to popularize and disseminate integrated soil fertility management to end users. For instance, the combined application of organic and NP fertilizer significantly increased yields of maize over inorganic or organic fertilizer alone. From the result of the study, application of 50% Vermicompost +50% Recommended NP may be recommended for increasing maize grain and bio-mass yield particularly in the study area. This will greatly benefit farmers in area where supply of inorganic fertilizer is low and cases where farmers cannot afford the cost of high fertilizer input. However, application of Recommended NP ha^{-1} can also bring about increase in the yield of maize. The combined application of chemical and organic fertilizers increases soil water holding capacity and nutrient cycling, and improve crop productivity. In general, improving the overall soil health in the country not only enhances agricultural productivity and hence resulting in better livelihoods and positively influencing the national economy at large.

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Growth, maize, organic, vermi-compost, yield.

Introduction

Maize (*Zea mays* L.) is the most important cereal worldwide (Ashraf *et al.,* 2016a). Many factors like soil fertility, imbalanced nutrition, disturbed soil properties, cultivars being grown, weed infestation etc. limit its yield worldwide. Different management practices are adopted to increase and optimize the maize yields. For example, use of organic manures alongside inorganic fertilizers often lead to increased soil organic matter (SOM), soil structure, water holding capacity and improved nutrient cycling and helps to maintain soil nutrient status, cation exchange capacity (CEC) and soils biological activity (Saha *et al.,* 2008) Although chemical fertilizers are important input to get higher crop productivity, but over reliance on chemical fertilizers is associated with declines in some soil properties and crop yields over time and causes serious land problems, such as soil degradation (Hepperly *et al.,* 2009). Therefore, an integrated use of inorganic fertilizers with organic manures is a sustainable approach for efficient nutrient usage which enhances efficiency of the chemical fertilizers while reducing nutrient losses (Schoebitz and Vidal, 2016). Synergistic effects of organic manures with inorganic fertilizers accumulate more total nitrogen in soils (Huang *et al.,* 2007), but sole application of farm yard manure (FYM) resulted in increased yield of maize (Anatoliy and Thelen, 2007), higher SOM content (44%), improved soil porosity (25%) and 16 times more water holding capacity (Gangwar *et al.,* 2006). Decline in soil fertility is the major constraint to agricultural production and food security in Ethiopian farming systems. Farmers have very limited capacity to invest in fertilizers or soil conservation measures. As a result, yields are low and many farmers are forced to put fallow and marginal lands into production to meet their food needs (Tilahun, 2004). Crop response to fertilizer inevitably declines with decline in land quality, partly due to unbalanced nutrient applications.

Although organic fertilizers are useful for ameliorating physical and chemical properties of the soil, inorganic fertilizers are popular for their ease of application, early crop response, and ease of transportation as they are less bulky (Nyalemegbe *et al.,* 2012). Thus, identification and application of the proper fertilizer mix is essential for improving soil health and agricultural productivity. Kumwenda *et al.,* (1996) suggested that the low level of inorganic fertilizer use and declining soil organic matter (OM) levels contribute most to loss of soil fertility in Africa. Inorganic fertilizers containing nitrogen (N), phosphorus (P) and potassium (K) provide an important means to improve soil fertility. However, applications of inorganic fertilizers by many subsistence farmers in Africa are well below the rates recommended for their crops because they are too expensive for farmers to afford (Kasozi, 2005).

Organic fertilizers provide an option for supplementing inorganic fertilizer application to improve soil condition and nutrient availability. According to Rutunga *et al.,* (1998), locally available inputs such as farmyard manure, and tree and shrub biomass, may be a realistic option for improving soil fertility in Sub-Saharan Africa. In addition to providing nutrients, organic fertilizers improve the physiochemical characteristics of the soil, potentially reducing soil erosion and improving water holding capacity, so also increasing the efficiency of nutrient use. Therefore, integrated use of organic and inorganic fertilizers is crucial to enhance production and productivity of crops so as to supply ever increasing world's population with sufficient food (Gomiero, 2016; Tilman *et al.,* 2011; White *et al.,* 2012). Compost is often viewed as resilient way of improving soil fertility by improving soil physical properties and increasing soil organic carbon, total nitrogen, sulfur and phosphorus nutrients (Saison *et al.,* 2006). However, the use of farmyard manure (FYM) for domestic energy consumption and crop residue removal for animal feeding greatly affects soil fertility in the study area.

Since subsistence farmers have very low financial resources to afford the prices of inorganic fertilizers and organic matter(OM) is slow in its nutrient release, it is necessary to seek for affordable and less risky nutrient management practices (Bohlool *et al.,* 1992) that contain necessary ingredients for superior performance (Bibi *et al.,* 2010). Many research findings have shown that neither inorganic nor organic fertilizers alone can result in sustainable productivity (Tadesse *et al.,* 2013). These scenarios necessitate the use of integrated nutrient management in maize production since combined use of organic and inorganic fertilizers builds ecologically sound and economically viable farming systems (Rajeshwari, 2005 and Negassa *et al.,* 2007). This study was carried out to validate and demonstrate Vermicompost/compost with inorganic fertilizer to enhance crop and soil productivity for sustainable production and to popularize and disseminate integrated soil fertility management to end users.

Materials and Methods

Treatments and Experimental Design

The experiment was conducted with maize in Gomma and Omonada districts, Jimma Zone, Southwestern Ethiopia in two consecutive years (2018/19-2019/20) main cropping season on permanent plot. The field experiment was conducted on soil group Nitisols (FAO, 2006). Organic fertilizer was prepared from locally available materials (tree leaves, soybean residues, maize residues, cow dung and ash). The organic fertilizer was stored for three months in a pit and protected from rain and direct sunlight using a plastic sheet. The organic fertilizer was analyzed for total N by the micro-Kjeldahl digestion, distillation and titration method (Jackson, 1958). This allowed the treatment rate to be calculated based on the N content (0.98% by weight) of the organic fertilizer.

The experimental fields were prepared using a local plow (maresha) according to farmers' conventional farming practices. The fields were ploughed two times to a depth of 15-20 cm and furrows were constructed at third. Improved maize variety of Bako hybrid (BH-661) was used as a test crop at Omonada and Limmu at Gomma district which is high yielder as compared to other improved maize varieties in the study area was used as a test crop. A plant spacing of 80 cm (inter-row) and 50 cm (intra-row) was used. Two seeds of maize were planted per hill at rate of 20-25 kg ha^{-1}. Other appropriate agronomic management practice was followed uniformly across treatments and farmers' fields. The experiment was laid out using a randomized complete block design 10 m by 9.6 m plot size and replicated across five farmers per district. To avoid cross-contamination of treatments, the plots were separated by one meter. Seven days before planting, organic fertilizer was uniformly spread on each plot and incorporated into the soil manually using a hand hoe. Diammonium phosphate (DAP) and half of urea were applied at planting time and the remaining half of urea was top-dressed 45 days after planting.

Compost preparation and analysis

Compost was prepared from decomposable materials of maize husk, soybean residues, leaves of trees, ashes, cow dung and top soil which were turned every month. The nutrient contents of compost such as total N and available P value were tested in the laboratory after compost was matured. Total N was analyzed by micro-Kjeldahl method (Jackson, 1958) and available phosphorus was determined using the Bray-II (Bray and Kurtz, 1945) method.

Harvesting and determination of grain and biomass yield

Harvesting was done after the crop has reached physiological maturity and the cobs have dried through monitoring the grain moisture content. All the plants in the net-plot were cut at the soil surface and total stover fresh weights determined in the field. The cobs were then harvested in such a way that the husk still remain on the plant. The cobs were counted and the weight of the total number of cobs was determined. Grain and Stover yields were determined by harvesting the entire net plot area of 11 rows x 8.1 m (leaving out 2 rows from each end) and converted into kilogram per hectare. Grain yield was adjusted to 12.5% moisture level; whereas stover yield was weighed after leaving it in open air for seven days. The total dry matter yield, grain yield (at 12.5% moisture content), and harvest index were calculated as a ratio of grain yield to total biological yield.

Results and Discussion

Organic fertilizers and soil enhancers are used for their organic matter contribution and nutrients, mainly N and P (Fuente *et al.,* 2006) since around 98% N (Castellanos *et al.,* 2000) and 33 to 67% total P (Ortiz y Ortiz, 1990) found in soils are associated with organic matter.

Organic matter decomposition rate and nutrient regeneration are regulated by a series of factors including environmental conditions, hydrological regime, substrate quality, soil microbial biomass, and electron receptor availability (McLatchey and Reddy, 1998). Moreover, compost must be "mature" to decrease the risk of crop growth and yield reduction due to N immobilization caused by a high C/N ratio.

According to Fricke and Vogtmann (1993), compost must have a C/N ratio of 18 or less for production purposes and to prevent N competition in plants and soil microorganisms. Immature compost can also contain high organic acid concentrations that interfere with root function, and therefore, have an impact on plant growth (Wolkowski, 2003). In addition, compost is considered as a slow release nitrogen fertilizer because it only mineralizes a fraction of total N, estimated at 2% in a crop cycle (Castellanos *et al.,* 2000; Sikora and Szmidt, 2005). Given these results, the need arises to carry out fraction analysis of soil N compounds, as well as their relationship with cumulative N removal in plants.

Soil Fertility Status after maize Harvest

The result of the analysis of soil revealed that soil pH, organic carbon and total nitrogen varied across cropping seasons (Table 2 and 3). The observed seasonal variation may be due to the history of soil fertility of the experimental sites, which were selected from the different sites at the Gomma and Omonada districts.

The combined application of organic fertilizers with inorganic NP showed slight increase in soil pH after crop harvest in the study areas with significant difference. The soil is low in PH, low in OC and total nitrogen, these low contents of TN and OC could be attributed to the effect of intensive cultivation. Similarly, Saik *et al.,* (1998) and

Negassa and Gebrekidan (2003) revealed that cultivation of land results in the reduction of OC and total N.

In the 2018/19 cropping season, soil pH after maize harvest ranged from 5.15-5.46, which was moderately acidic (Table 2 and 3). Application of conventional and vermi compost did not significantly affect the soil pH though there is a slight increase when compared to the Rec.NP plot. This might be due to buffering capacity of the organic matter by releasing some organic compounds that fix H^+, AL^{+3} and other cations (Palm *et al.,* 1997).

Soils with a high amount of organic matter due to the addition of organic materials have high cation exchange capacity (CEC) and buffering capacities to stabilize soil pH (Abera *et al.,* 2015). Organic carbon and nitrogen content also showed little variation due to treatment applications (Table 2and 3), but as per the classification, these values are found under moderate ranges (Pam and Brian, 2007).

In the 2019/20 cropping season, however, the soil chemical properties of the experimental site after maize harvesting were completely different as compared with 2018/19 due to differences in the rainfall amount and distribution that might have affected organic matter decomposition. Soil pH ranged from 5.28–5.48, which was also moderately acidic (Table 2 and 3). Organic carbon content of the soil was not improved from the previous year.

Grain yield and total above ground dry biomass

Grain and bio-mass yield of maize were substantially affected by organic and inorganic sources of nutrients (Fig. 2 and 3). The highest maize grain and biomass yield (5234.2 kg ha^{-1} and 15337 kg ha^{-1} respectively) were obtained from the application of 50% VC and half the recommended rate of NP and P followed by full dose of recommended rate of NP from inorganic fertilizer resulting in 5126.65 kg ha^{-1} grain and 14536.55 kg ha^{-1} biomass yields respectively at Gomma district.

Therefore, combined application of organic and inorganic fertilizers is considered a good option to enhance nutrient recovery, plant growth and ultimate yield otherwise higher N and P application rates are required to attain better yield in maize (Mubeen *et al.,* 2013). Further, these results are also in concurrence with Negassa *et al.,* (2001) who found that corn yield was increased by 35% when combined (inorganic and organic) nutrients were applied. Shisanya *et al.,* (2009) also reported similar results with improved growth and yield related attributes in cotton and maize, respectively.

Combined application of organic and inorganic nutrient sources improved synergism and synchronization between nutrient release and plant recovery thus resulted in better crop growth and yield (Huang *et al.,* 2010). Kibunja *et al.,* (2010) reported that total dry matter of maize was higher in treatment combinations of inorganic and organic fertilizers than chemical fertilizers alone.

But at Omonada district the highest mean grain and bio-mass yield(5237.51 kg ha^{-1} and 10763.9 kg ha^{-1} respectively) were recorded from full dose of Rec. NP fertilizer while the lowest grain and biomass yield (4162.76kg ha^{-1} and 9767.5kg ha^{-1} respectively) were obtained from application of 50% VC and 50% Rec. NP. The application of 50% CC with 50% N and P has also given comparable grain and biomass yield as compared to application of 50%CC+50%Rec.NP from inorganic fertilizer.

Although organic fertilizers are useful for ameliorating physical and chemical properties of the soil, inorganic fertilizers are popular for their ease of application, early crop response, and ease of transportation as they are less bulky (Nyalemegbe *et al.,* 2012). Bayu *et al.,* (2006) and Makinde and Ayoola (2010) stated that high and sustainable crop yields are only possible with integrated use of mineral fertilizers with OM.

Similarly, Dilshad *et al.,* (2010) reported that combined use of organic and inorganic fertilizers improved grain yield. Lampkin (1992) indicated that use of compost over several seasons increased maize yields by 40-60% but 80-95% in combination with inorganic fertilizers.

Harvest Index

The harvest index represents the proportion of plant biomass allocated into grains; it describes the plant capacity to allocate biomass (assimilates) into the formed reproductive parts of the plant (Wnuk *et al.,* 2013). Harvest index is the partitioning of dry matter by plant among biological and economic yield (Shafi *et al.,* 2012). Also, the harvest index can be defined as been the physiological efficiency and ability of a crop for converting the total dry matter into economic yield (Sharif *et al.,* 2009).

Fig.1 Gomma and Omonada district-Jimma Zone, Oromia National Regional State.

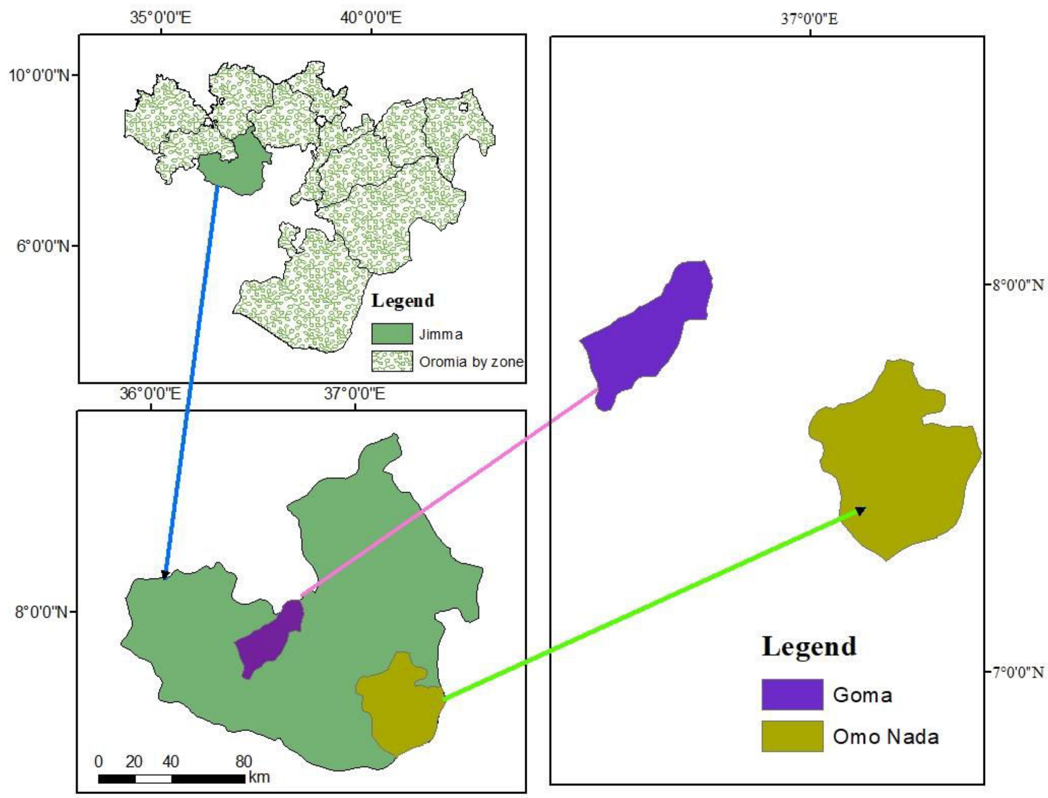


Table.1 Chemical composition of the soil organic amendments used in the study

Type of compost	Results/Parameters tested	
	Available P(ppm)	Total Nitrogen (%)
Cattle manure vermi compost	12156.06	1.235
Conventional compost	12409.44	0.283

Table.2 Effect of different soil fertility management treatments on soil chemical properties after harvesting maize in Gomma

No	Treatments	Results/parameters				
		2018/19		2019/20		
		pH(H_2O)	OC (%)	pH(H_2O)	TN (%)	OC (%)
1	Recommended NP	5.33	2.20	5.34	0.16	1.60
2	50% Recommended NP + 50% conv. compost	5.46	2.10	5.48	0.16	1.61
3	50% Recommended NP + 50% vermi compost	5.46	2.12	5.41	0.20	1.60

Fig.2 Mean effect of organic and inorganic fertilizer on maize grain and bio-mass yield at Gomma.

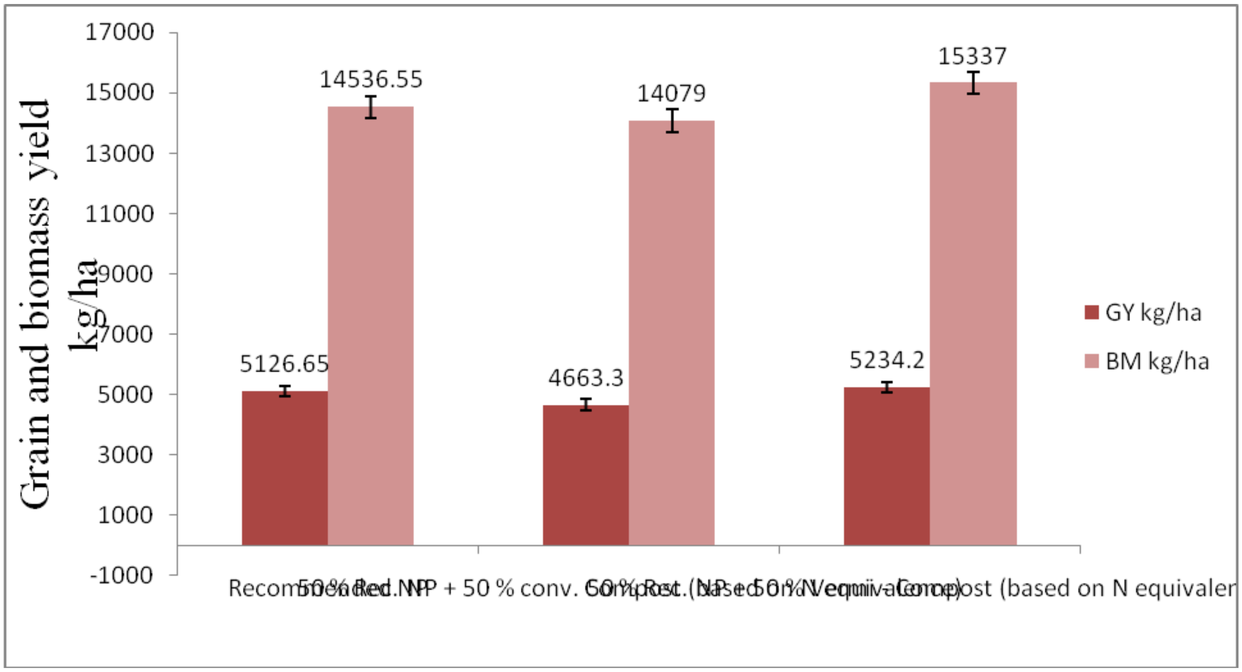


Fig.3 Mean effect of organic and inorganic fertilizer on maize grain and bio-mass Yield at Omonada district.

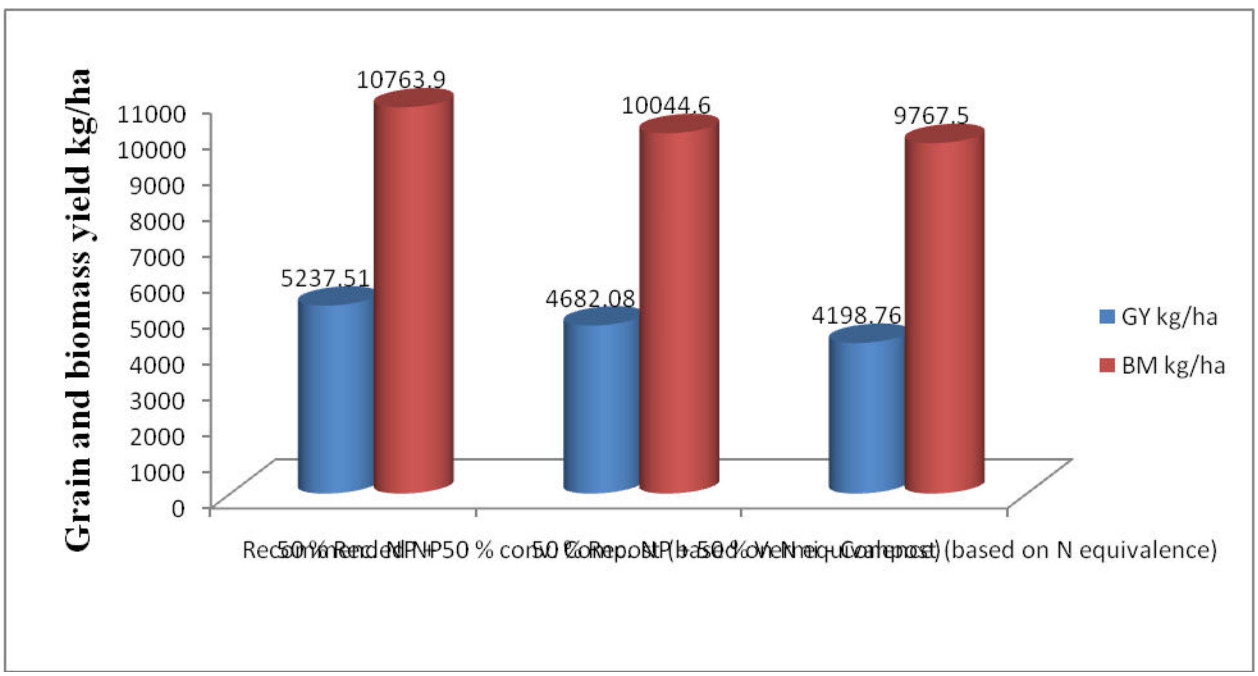
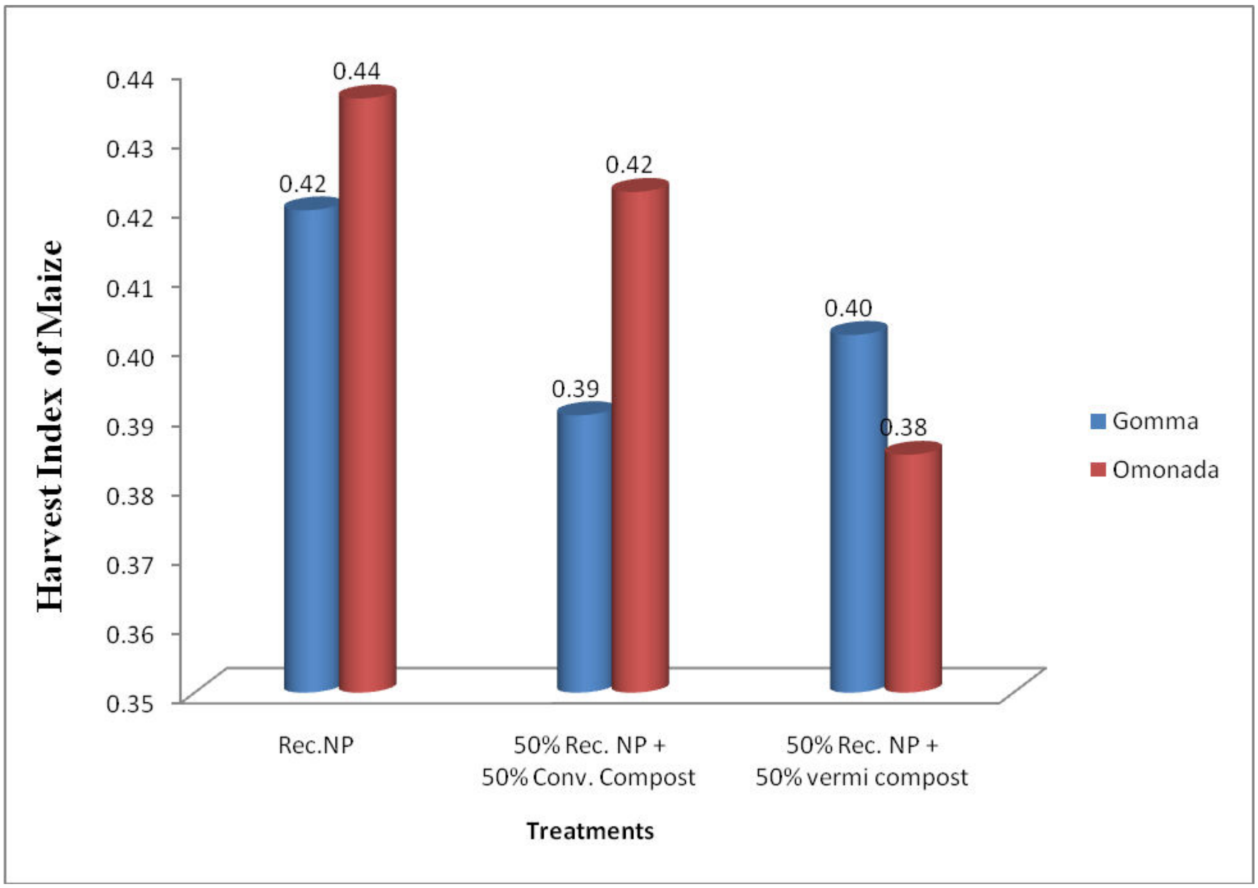


Table.3 Effect of different soil fertility management treatments on soil chemical properties after harvesting maize in Omonada

No	Treatments	Results/parameters				
		2018/19		2019/20		
		pH(H_2O)	OC (%)	pH(H_2O)	TN (%)	OC (%)
1	Recommended NP	5.15	1.67	5.28	0.118	1.36
2	50% Recommended NP + 50% conv. compost	5.36	2.02	5.44	0.16	1.06
3	50% Recommended NP + 50% vermi compost	5.19	1.90	5.32	0.124	1.19

Fig.4 Harvest Index of Maize as affected by application of organic and inorganic fertilizers at Gomma and Omonada.



Harvest index (HI) can be calculated as the ratio of grain yield (Y) and the total above ground biomass (B) at maturity (Huehn, 1993), than one could estimate the yield (Y) by multiplying the above-ground biomass (B) with harvest index (HI), and finally the above ground biomass (B) by dividing the yield (Y) with the harvest index (HI):

Above-ground biomass represents the crop's accumulated photosynthesis products while harvest index represents the efficiency of the crop to convert photosynthesized products into an economically valuable form (Kawano, 1990). Among the cereal crops, maize has the highest grain yield potential. In order to explore the high potential of maize plants to produce grain yields it is necessary to know and even more important to understand how the harvest index is influenced by the different environmental factors and management practices. The results on the maize harvest index for the two districts are given in fig. 4. Higher harvest index were recorded from Recommended NP fertilizer while the lowest harvest index was recorded from application of 50% Rec.NP and 50% vermi-compost. Maximum harvest index (0.44 and 0.42) was recorded from Recommended NP fertilizer application at Omo-Nada and Gomma respectively, followed by 50% Rec.NP and 50% conventional compost at both sites.

Combined application of organic and inorganic fertilizers is necessary for sustainable production of crops including maize. Maize growth and yield are adversely affected under organic and inorganic nutrient applications. Generally, soil productivity and health may be more sustainable with the integrated application of vermi-compost/conventional compost and inorganic fertilizers than with the use of inorganic fertilizers alone. From the results of the current experiment, it could be concluded that combined applications of 50% recommended N and P as inorganic fertilizer plus 50% vermi-compost organic fertilizer (treatment 3) provided the highest grain yield, while the lowest yield was recorded from plots treated with 50% recommended N and P as inorganic fertilizer plus 50% conventional compost organic fertilizer (treatment 2) at Gomma district. At Omonada the highest grain and bio-mass yield were obtained from application of recommended NP while the lowest grain and bio-mass yield were recorded from 50 % recommended NP + 50 % Vermi - Compost (based on N equivalence). Use of mineral fertilizer is efficient and gave greater yield increase in the year of its use than did equivalent nutrient amounts applied as vermi-compost/conventional compost. Mineral fertilizer had, however, little or no residual effect on yield levels, despite increasing the availability of some nutrients in the soil. Importantly, these trials demonstrate that, in addition to increasing the inputs of OM to the soil, and so reducing long-term soil degradation, ISFM can be an economically viable way of managing crops that also provide better economic gain to the farmer in the short term. It is important to point out that further studies are needed to evaluate the effect of periodic inputs and distinct fertilization rates based on organic fertilizers and the availability of their nutrient contents, as well as the effect of incorporating organic fertilizers in the soil in the medium- and long-term.

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