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Soil Carbon Sequestration, Water Use Efficiency and Yield of Maize As Influenced By Organic Amendments in Irrigated Area of North-West Pakistan

Samreen Shehzadi[*1,2], Zahir Shah[2] and Wisal Mohammad[1]

[1]Nuclear Institute for Food and Agriculture (NIFA), P.O. Box. No.446, Tarnab, Peshawar, Pakistan, [2]The University of Agriculture, Peshawar, Pakistan

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Soil organic carbon (SOC) plays a vital role in terrestrial C cycle, affecting soil sustainability and its quality and environment. The soil and environmental conditions of cultivated soils in semi-arid regions are favorable for rapid decomposition of SOM resulting in high rates of C loss to the atmosphere, contributing to global warming. Application of organic amendments is an important strategy to enhance SOC storage, soil fertility, water retention, crop productivity and atmospheric C mitigation. A 2-year field experiment was conducted at the research farm of Nuclear Institute for Food and Agriculture (NIFA), Peshawar, Pakistan to study the effect of 4 organic wastes with and without NPK mineral fertilizers on SOC retention, water use efficiency (WUE) and maize yield under an irrigated wheat-maize cropping system. The wastes included municipal solid waste (MSW), filter cake (sugar industry waste), farm yard manure (FYM), and wheat crop residues. The C: N ratio of the organic wastes ranged from 8.0 in the filter cake to 100 in the wheat residues. All organic wastes were applied at a rate of 3 t C ha^{-1} alone and with a full or half dose of NPK mineral fertilizers. Soil analysis revealed that on average, filter cake and MSW as sole treatments successfully increased the total SOC content in the 0-15 cm soil layer by 7.7 t ha^{-1} and 5.8 t ha^{-1} respectively. The MSW + full NPK fertilizer treatment accumulated the highest amount of SOC (9.4 t ha^{-1}) followed by the filter cake + NPK treatments (8.2 t ha^{-1}). On average, maximum maize grain WUE (20.7 kg ha^{-1} mm^{-1}) and grain yield (4439 kg ha^{-1}) were obtained by the combined application of filter cake and full NPK followed by MSW + NPK treatment. These results indicate that among the organic wastes, filter cake and MSW have the best potential for improving SOC retention, WUE and maize yield in irrigated wheat - maize cropping systems in warm semi-arid areas.

Keywords: Soil carbon sequestration, water use efficiency, maize, Organic amendments.

INTRODUCTION

Soil organic carbon (SOC) is an important soil quality indicator as it affects physical, biological and chemical properties of soil. The prevailing soil and climatic conditions of cultivated and irrigated soils in warm semi-arid areas, however, favours the rapid mineralization and loss of SOC. This decomposition results in a loss of soil quality and aggravates C losses to the atmosphere which contribute to global warming.

Maize (*Zea mays* L.) is an important cereal crop of Pakistan grown in rotation with wheat on an area of 1.08 mha with an average grain yield of 4.0 t ha^{-1} (MINFAL, 2012). The nutrient requirements of both crops are higher and their continuous cropping , exhaustive cultivation practices and imbalanced use of chemical fertilizers enormously causes depletion in soil fertility and crop productivity (Shah et al., 2003; Mohammad et al., 2008).

Cultivated soils of Pakistan are deficient in organic matter and in essential plant nutrients (Rashid, 1994). Another major limiting factor for crop production is water availability. Moreover, the non-scientific fertilizer application practices adopted by farmers result in N and other essential nutrients losses (Iqbal et al., 1995). The low utilization of N from chemical fertilizers due to undesirable soil and environmental conditions is considered as one of the major limitations for sustainable soil fertility, crop yields and improved environment (Mohammad et al., 2006).

Conservation agricultural practices are important for improving physical conditions of soils, water use efficiency, and increasing crop yields (Kabir, 1999; Dalal and Chan, 2001). Application of different organic materials like manures, plant residues and waste materials represents an effective approach that influence soil characteristics by modifying its physical, biological and chemical properties (Van-Camp et al., 2004). It helps to mitigate climate change by transferring the atmospheric CO_2 into a more stable SOC pool. For sustainability of soil fertility and environment, it is a better option to use organic fertilizers to get maximum benefits on crop productivity. Moreover, combined application of inorganic and organic fertilizer sources sustains soil fertility and enhances crop productivity (Satyanarayana et al., 2002).

Keeping in view, the present study was undertaken to evaluate the effect of four organic wastes [Municipal solid waste (MSW), farm yard manure (FYM), sugar industry waste (filter cake), wheat residues] in the absence or presence of NPK mineral fertilizers on maize crop yield, water use efficiency and soil organic C under an irrigated condition.

MATERIALS AND METHODS

Site characterization

A two year field plot experiment (2011-12) was conducted at the Research Farm of the Nuclear Institute for Food and Agriculture (NIFA), situated at Tarnab (longitude 71°50 E, latitude 34°01 N), Peshawar, Khyber Pakhtunkhwa, Pakistan. The field site was located at an altitude of 400 m above sea level and has cool climate in winter and warm to hot climate in the summer. Soil of the experimental site was clay loam (Order: *Inceptisols*, Sub order: *Ustepts*, Soil great group: *Haplustepts*, Soil Sub group: *Udic Haplustepts*, Family: *Fine, mixed*, *hyperthermic*, *Udic Haplustepts, Taru* Soil Series (US Soil Taxonomy)), non saline and alkaline in reaction (Table 1)

*Corresponding Author's Email: sshehzadi11@hotmail.com; Tel:+92-91-2964060-62; fax:+92-91-2964059

Organic wastes collection

MSW was collected from a municipal dumping ground (Ring Road, Peshawar, Pakistan). The non-decomposable materials like plastic, glass, stone and other unwanted materials were removed prior to use. Filter cake (sugar industrial processing waste) was collected from Khazana Sugar Mill, Peshawar. In the process of cane sugar preparation, the precipitated impurities are removed by filtration to form a cake with 50 % moisture content. FYM (well rotted, from cattle source) was collected from local farmers.

Before maize sowing, wheat crop was grown under wheat- maize cropping system. Wheat residues were collected from each treatment plot after wheat harvest, and returned to same respective treatment plots after chopping into small pieces (6-8 mm), before maize sowing. The waste materials were well mixed and inverted into the soil before sowing. All organic wastes, after collection, were spread on a plastic sheet under the shade for drying. After air drying, a representative sample was taken and transferred to the laboratory. After drying in an oven at 70°C for 24 h, all waste samples were ground to a powder in a Wiley Mill and analyzed for total C (Heanes, 1984), N (Bremner and Mulvaney, 1982) and P (Soltonpour and Schwab, 1977). The results showed that the total C contents were 50%, 11%, 7% and 26% for wheat residues, FYM, MSW and filter cake respectively (Table 2). Highest N (3.40%) and P contents (1.12%) were recorded in the filter cake. The C: N ratio of organic wastes ranged from 8 in the filter cake to 100 in the wheat residues.

Experimental Design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The land was prepared by applying 0-20 cm deep cultivator plough at sowing time following by planking. After air drying and analyses, organic waste materials were applied to designated treatment plots in both seasons. Maize (Cv. Azam) was sown in the same layout after wheat harvest. Recommended row to row (75 cm) and plant to plant (9 cm) distance was maintained. The treatment plot size was

Table 1 Physicochemical characteristics of experimental soil (0-15cm)

Properties	Units	Values
Sand	%	21
Silt	%	43
Clay	%	36
Textural Class	---	Clay Loam
pH (1:2.5)	---	7.8
EC_e (1: 2.5)	dSm^{-1}	0.36
Bulk density	g cm^{-3}	1.24
Total organic carbon	%	0.88
Organic Matter	%	1.2
Total Nitrogen	%	0.07
Total mineral N	µg g^{-1} soil	42
Extractable Phosphorus (P_2O_5)	µg g^{-1} soil	11
Extractable Potassium (K_2O)	µg g^{-1} soil	80
Extractable Zn	µg g^{-1} soil	0.55
Extractable Fe	µg g^{-1} soil	7.72
Extractable Pb	ppb	0.43
Extractable Ni	ppb	0.51
Lime ($CaCO_3$)	%	19

Table 2 Chemical analysis of organic wastes

Organic Wastes	Total C	Total N	C:N	Total P	Total K	Zn	Fe
	%			%	%	µg g^{-1}	µg g^{-1}
Wheat residues	50	0.50	100	0.1	2.0	50	522
FarmYard Manure	11	0.50	22	0.37	1.20	75	630
Municipal Solid waste	7	0.72	9.7	0.25	1.25	147	627
Filter Cake	26	3.40	7.6	1.12	1.30	79	592

3 × 5 m^2. The 15 treatments included: i. Control, ii. PK only (Recommended dose), iii. Farm Yard Manure (FYM), iv. Wheat residues, v. Municipal Solid Waste (MSW), vi. Filter cake (Sugar Industrial waste), vii. NPK (Recommended dose), viii. FYM + ½ NPK, ix. Wheat residues + ½ NPK, x. MSW + ½ NPK, xi. Filter cake + ½ NPK, xii. FYM + full NPK, xiii. Wheat residues + full NPK, xiv. MSW + full NPK, xv. Filter cake + full NPK. All organic wastes were applied at a rate of 3 t C ha^{-1} (Muhammad et al., 2011). Recommended NPK (N, P_2O_5, K_2O) were applied as full (140:90:60) kg ha^{-1} and half doses (70:45:30) kg ha^{-1}.

Half doses of N and full doses of P and K were applied to maize at sowing, while the remaining half of N was applied at knee height stage. The sources for NPK were urea, TSP and SOP respectively. After maize harvesting, wheat crop was grown in November 2011 on the same plots and applied organic wastes at 3 t C ha^{-1} with and without recommended NPK fertilizer dose. The same treatments were applied to maize in Year 2 (2012). All standard agronomic practices were carried out during the experiment. Meteorological data (rainfall, temperature, humidity) during 2011-12 were collected from adjacent Agriculture Research Institute, Tarnab, Peshawar. The crop was harvested at its physiological maturity and data on stover and grain yields were recorded.

Soil analyses

After maize harvest, soil samples (0-15 cm) were collected from each treatment plot and analyzed for total organic C according to Black (1965).

Table 3. Effect of organic wastes with and without NPK mineral fertilizers on maize stover yield (kg ha^{-1}) over two growing season

Treatments†	Years		Mean
	2011	2012	
Control	13586 de	7313 d	10449f
PK	13182e	7646 d	10414f
NPK	16970 ab	17727 ab	17348 abc
FYM	15859 bc	15177 c	15518 de
FYM + half NPK	17189 ab	15960 bc	16574 bcd
FYM + full NPK	17986 a	17329 ab	17658 abc
Wheat Residues	13667 de	15152 c	14409 e
Wheat Residues + half NPK	14950 cd	16162 bc	15556 de
Wheat Residues + full NPK	16182 bc	16616 abc	16399 cd
MSW	15960 bc	17323 ab	16641 bcd
MSW+ half NPK	17196 ab	17677 ab	17436 abc
MSW+ full NPK	17784 a	18030 ab	17907 ab
Filter Cake	16168 bc	17475 ab	16821 bcd
Filter Cake + half NPK	16963 ab	17828ab	17396 abc
Filter Cake + full NPK	18146 a	18434 a	18290 a
LSD	1558	2107	1425

†= Where FYM = Farm yard manure, MSW = Municipal solid waste, Full NPK at recommended dose (140-90-60) kg ha^{-1}, half NPK at (70-45-30) kg ha^{-1}. All organic wastes were applied @ 3t C ha^{-1}.
Means sharing similar letter (s) in a column do not differ significantly at *p=0.05*

Measurement of water use efficiency

To study the effect of treatments on soil water storage, neutron access tubes were inserted down to 90 cm depth in the soil profile in each treatment plot in two replications. Before the start of experiment, neutron probe readings were calibrated with gravimetric moisture contents in soil profile in 30 cm increments. A known amount of irrigation water was applied to each treatment plot throughout the experiment. Neutron probe readings at regular interval at 30 cm increments within the soil profile were recorded from sowing through to crop harvest. The probe readings were converted to volumetric moisture contents using the bulk density of soil cores taken from each depth increment. Neutron probe readings along with meteorological observations (rainfall and temperature) were recorded regularly. The crop water use (Evapotranspiration, ET) was calculated from rainfall received and change in soil water storage to 90 cm depth, assuming no or negligible losses as runoff and drainage below the root zone. The water use efficiency was calculated according to water balance approach (Kirda, 1990).

Statistical analyses

The data were analyzed statistically according to the design through analyses of variance. The treatment means for various crop parameters were compared by LSD test using computer software Statistix 8. Contrast analyses were also performed among eight different groups.

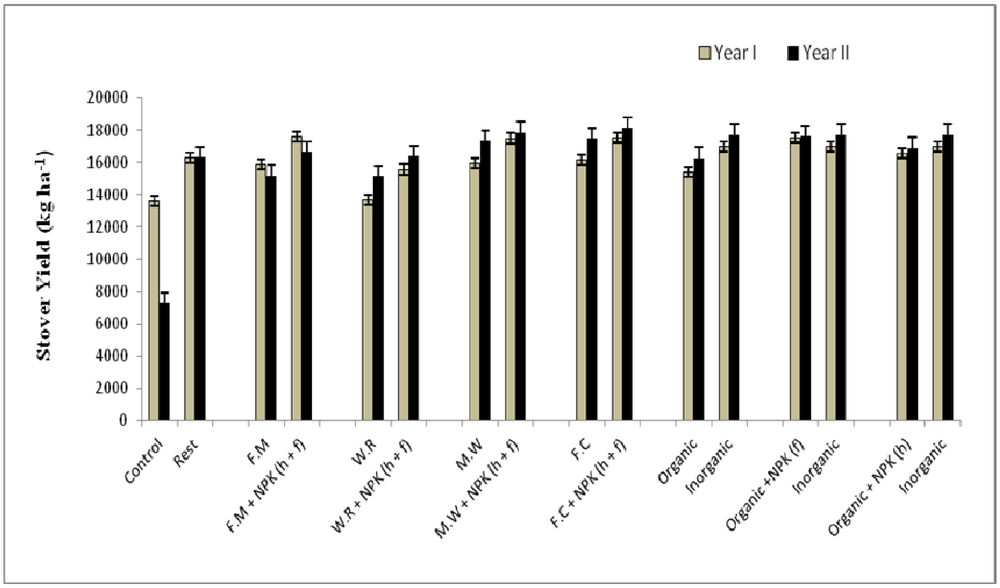
RESULTS

Stover yield

Stover yield as affected by various organic wastes alone and in combination with inorganic NPK fertilizers during two seasons are presented in Table 3. Statistical analysis of the data showed that stover yield was significantly influenced by various treatments during both seasons.

During 2011 (Year 1), application of filter cake with full NPK resulted in highest stover yield of 18146 kg ha^{-1} which was statistically similar with treatments receiving FYM + full NPK, MSW + full NPK, filter cake + half NPK, MSW + half NPK, FYM + half NPK and full NPK alone treatments. Almost the same pattern was observed during the following year 2012 where the maximum stover yield of 18434 kg ha^{-1} was recorded with treatment receiving filter cake + full NPK but this was statistically at par with other treatments receiving organic wastes (except wheat residues) along with full or half NPK fertilizers.

Among organic wastes used as sole treatments, wheat residues had the least effect on maize stover yield during



Where, F.M = Farm yard manure, W.R = Wheat Residues, M.W = Municipal solid waste, F.C = Filter cake, NPK (h+f) = NPK with half and full dose , NPK (f)= NPK full dose, NPK (h)= NPK half dose

Figure 1 Planned mean contrasts of maize stover yield

both years. However, when applied in combination with half or full NPK, it significantly increased the stover yield. The two years average data revealed that all added organic wastes improved stover yield with maximum increase occurred with filter cake (61%) and MSW (60%) treatment. Moreover, FYM caused 48% and wheat residues 38% increase in stover yield over control treatment. The data further showed that combination of organic wastes with NPK mineral fertilizers (half or full) improved the stover yield compared to organic wastes alone treatments during both years. The two years average data revealed that filter cake + full NPK treatment caused 13.6 % and MSW + full NPK 8.1 % increase in stover yield over full NPK treatment.

Planned means contrast analyses of data showed that all the organic wastes alone or in combination with NPK fertilizer resulted in significant increase in stover yield over the control treatment (Figure.1). All organic wastes along with NPK (half or full) combinations showed significant impact on stover yield than their sole treatments during 2011, however their effect was insignificant during 2012. Organic wastes along with half or full NPK combinations produced statistically similar yield to that obtained with full NPK alone treatment during both the years.

Grain yield

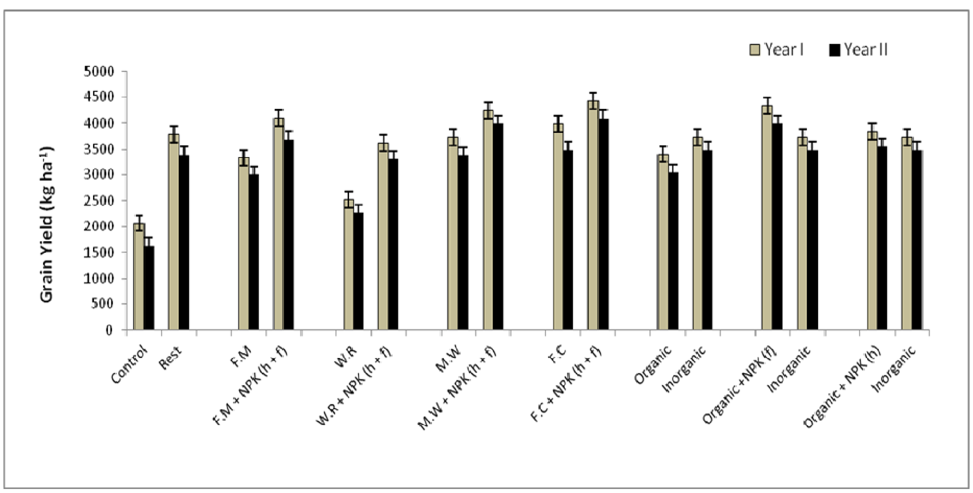
Grain yield of maize presented in Table 4 showed a significant increase with wastes alone or wastes with NPK treatments over control during both years (2011 & 2012). During 1st year, the highest grain yield of 4595 kg ha^{-1} was recorded for treatment receiving both filter cake and full NPK. The next highest grain yield of 4477 kg ha^{-1} was obtained each with MSW plus full NPK and FYM plus full NPK treatment, but this was statistically at par with that obtained with filter cake plus full NPK treatment. Interestingly the grain yields obtained with half NPK and full NPK after combining with filter cake were statistically similar. Almost the same pattern in grain yield in response to waste treatments was obtained during the 2nd year.

The two years average data revealed that the highest grain yield of 4439 kg ha^{-1} was obtained with filter cake plus full NPK which was statistically similar with 4334 kg ha^{-1} obtained with MSW plus full NPK. The data revealed that filter cake alone treatment caused 102% increase in grain yield over control. Similarly, MSW alone caused 92.6 % and FYM also caused 71.4% increase over control treatment. The least increase of 29.8% occurred with wheat residues alone treatment. The data further showed

Table 4. Effect of organic wastes with and without NPK mineral fertilizers on maize grain yield (kg ha^{-1}) over two growing seasons

Treatments†	Years		Mean
	2011	2012	
Control	2070 g	1626e	1848 h
PK	2979e	1697e	2338 g
NPK	3737 d	3484bc	3611 e
FYM	3333e	3005c	3169 f
FYM + half NPK	3909 cd	3484 bc	3697 de
FYM + full NPK	4292 abc	3883 ab	4088 bc
Wheat Residues	2525 f	2272d	2398 g
Wheat Residues + half NPK	3232 e	3030 c	3131 f
Wheat Residues + full NPK	3989 bcd	3585 b	3787 de
MSW	3737 d	3383 bc	3560 e
MSW+ half NPK	3989 bcd	3787 ab	3888 cd
MSW+ full NPK	4477 a	4191 a	4334 ab
Filter Cake	3989 bcd	3484 bc	3737 de
Filter Cake + half NPK	4242 abc	3888 ab	4065 c
Filter Cake + full NPK	4595 a	4283 a	4439 a
LSD	382.42	539.32	258.75

†= Where FYM = Farm yard manure, MSW = Municipal solid waste, Full NPK at recommended dose (140-90-60) kg ha^{-1}, half NPK at (70-45-30) kg ha^{-1}. All organic wastes were applied @ 3t C ha^{-1}.
Means sharing similar letter (s) in a column do not differ significantly at *p=0.05*



Where, F.M = Farm yard manure, W.R = Wheat Residues, M.W = Municipal solid waste, F.C = Filter cake, NPK (h+f) = NPK with half and full dose , NPK (f)= NPK full dose, NPK (h)= NPK half dose

Figure 2 Planned mean contrasts of maize grain yield

that organic wastes integrated with full NPK enhanced the grain yield by 47 % over NPK sole treatment in case of filter cake and 41% in case of MSW. The corresponding increases were 27% with FYM and 10% with wheat residues.

Contrast analyses of data on grain yield of maize are presented in Figure 2. The data reflected that all the organic wastes alone or in combination with inorganic NPK fertilizers resulted in significant (*$p \leq 0.01$*) increase in grain yield of maize over control treatment during both years. All

Table 5 Effect of organic wastes with and without NPK mineral fertilizers on water use efficiency (kg $ha^{-1}mm^{-1}$) in maize stover over two growing seasons

Treatments†	Years		Mean
	2011	2012	
Control	61.55 e	37.06 d	49.30 e
PK	52.75 f	39.95 d	46.35 e
NPK	71.29abc	92.56 ab	81.93 abc
FYM	68.33 bcd	82.14 bc	75.23cd
FYM + half NPK	71.12 abc	84.00 abc	77.56 bcd
FYM + full NPK	76.67 a	90.25 abc	83.46 ab
Wheat Residues	62.11 de	87.21 abc	74.66 d
Wheat Residues + half NPK	65.61 cde	89.64 abc	77.62 bcd
Wheat Residues + full NPK	66.17 cde	89.14 abc	77.66 bcd
MSW	69.23 bc	89.30 abc	79.26 abcd
MSW+ half NPK	72.24 abc	90.70 abc	81.47 abcd
MSW+ full NPK	74.03ab	92.05 ab	83.04 ab
Filter Cake	71.75abc	80.06 c	75.90 cd
Filter Cake + half NPK	73.75 abc	89.14 abc	81.44 abcd
Filter Cake + full NPK	77.37 a	93.73 a	85.55 a
LSD	6.65	10.90	6.81

†= Where FYM = Farm yard manure, MSW = Municipal solid waste, Full NPK at recommended dose (140-90-60) kg ha^{-1}, half NPK at (70-45-30) kg ha^{-1}. All organic wastes were applied @ 3t C ha^{-1}.

Means sharing similar letter (s) in a column do not differ significantly at *p=0.05*

organic wastes in combination with NPK (half or full) resulted in significant increase in grain yield in contrast with their sole treatments during both years. Organic wastes + half NPK produced yield statistically equal to that obtained with full NPK treatment during both years. These results suggested that filter + full NPK produced the highest grain yield followed by MSW + full NPK treatment.

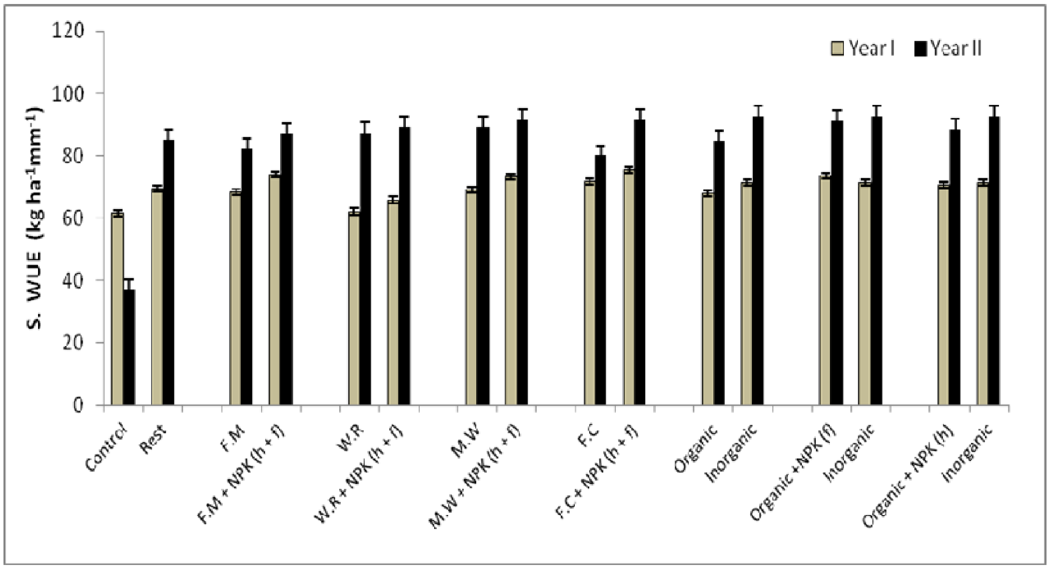
Water Use Efficiency in Stover

The results obtained on water use efficiency (WUE) in maize stover as influenced by organic wastes and NPK mineral fertilizers are given in Table 5. The data indicated that integrated use of filter cake with full NPK resulted in greater stover WUE during both years.

During 2011 (Year 1), the maximum WUE of 77.37 kg $ha^{-1}mm^{-1}$ in maize stover was obtained with integrated use of filter cake and full NPK. This was however statistically at par with that obtained with FYM + full NPK, MSW + full NPK and NPK sole treatment. Among organic wastes alone treatments, the minimum impact on WUE in maize stover was observed with wheat residues. During 2012 (Year 2), WUE in maize stover was generally greater than in year 1 particularly in the organic wastes treatments indicating that WUE in maize stover was improved by wastes with time. All organic wastes integrated with full NPK showed higher but statistically similar impact on WUE in maize straw.

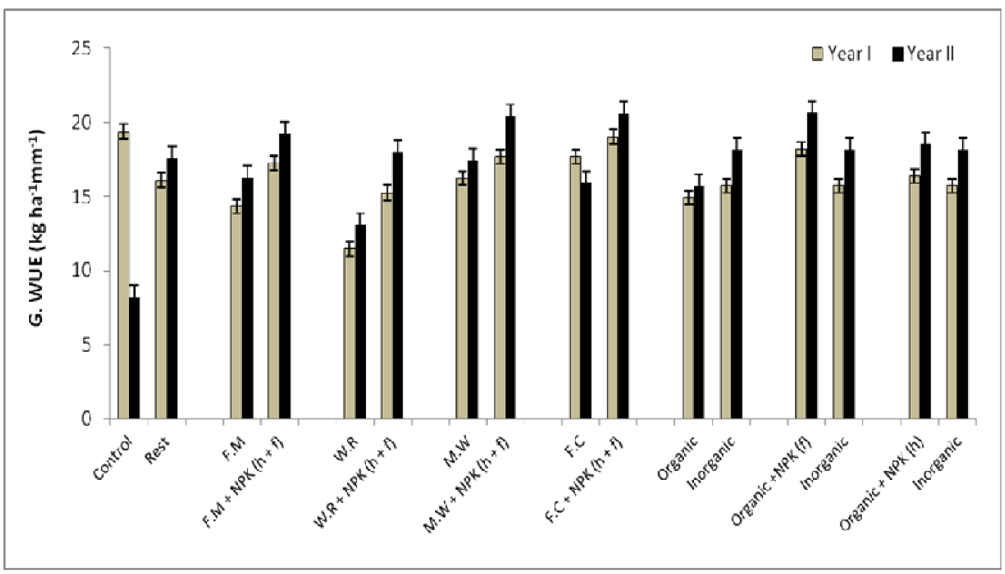
The two years average data indicated that all organic wastes as sole treatments had statistically similar effect on WUE in maize straw. The maximum WUE of 79.3 kg ha^{-1} mm^{-1} was obtained with MSW representing 60.8% increase over control. The corresponding increases in WUE were 54.0 % with filter cake, 52.6% with FYM and 51.4 % with wheat residues as sole treatments compared to control treatment.

Planned means contrast analyses (Figure. 3) showed that all wastes and NPK treatments produced significantly (*p≤ 0.01*) greater WUE in maize stover over the control treatment during both years. The data further revealed that FYM with NPK (half or full) combinations during year 1, while filter cake with NPK (during year 2) produced significant increase in straw WUE compared to their sole treatments. The data further showed that differences in WUE in maize stover between organic wastes and inorganic NPK treatments were insignificant during both years (Figure. 3). Organic wastes with half NPK combinations resulted in statistically similar impact on WUE in maize stover as NPK sole treatment.



Where S. WUE = Straw water use efficiency F.M = Farm yard manure, W.R = Wheat Residues, M.W = Municipal solid waste, F.C = Filter Cake, NPK (h+f) = NPK with half and full dose, NPK (f)= NPK full dose, NPK (h)= NPK half dose

Figure 3 Planned mean contrasts of water use efficiency in maize stover



Where G.WUE = Grain Water use efficiency, F.M = Farm yard manure, W.R = Wheat Residues, M.W = Municipal solid waste, F.C = Filter Cake, NPK (h+f) = NPK with half and full dose , NPK (f)= NPK full dose, NPK (h)= NPK half dose

Figure 4 Planned mean contrasts of water use efficiency in maize grain

Water use efficiency in grain

The results obtained regarding water use efficiency in maize grain as affected by organic wastes and NPK mineral fertilizers are presented in Table 6.

The data for Year 2011 showed that the filter cake + full NPK treatment produced the highest WUE (19.6 kg ha^{-1} mm^{-1}) in maize grain and this was statistically at par with that obtained with MSW+ full NPK (18.6 kg ha^{-1} mm^{-1}), filter cake + half NPK (18.46 kg ha^{-1} mm^{-1}) and FYM + full NPK treatment (18.3 kg ha^{-1} mm^{-1}). The data further

Table 6 Effect of organic wastes with and without NPK mineral fertilizers on water use efficiency (kg ha^{-1}mm^{-1}) in maize grain over two years

Treatments†	Years		Mean
	2011	2012	
Control	9.38 h	8.24 h	8.81 j
PK	11.92 g	8.86 h	10.39 i
NPK	15.70 ef	18.19 cdef	16.94 e
FYM	14.36 f	16.26 ef	15.31 g
FYM + half NPK	16.17 de	18.34 bcdef	17.25 e
FYM + full NPK	18.29 abc	20.22 abc	19.26 bc
Wheat Residues	11.48 g	13.08 g	12.28 h
Wheat Residues + half NPK	14.18 f	16.81 def	15.49 fg
Wheat Residues + full NPK	16.31 de	19.23 abcde	17.77 de
MSW	16.21 de	17.44 cdef	16.82 ef
MSW+ half NPK	16.76 cde	19.44 abcd	18.10 cde
MSW+ full NPK	18.64 ab	21.40 ab	20.02 ab
Filter Cake	17.70 bcd	15.96 fg	16.83 ef
Filter Cake + half NPK	18.44 ab	19.44 abcd	18.94 bcd
Filter Cake + full NPK	19.59 a	21.82 a	20.71 a
LSD	1.64	3.11	1.44

†= Where FYM = Farm yard manure, MSW = Municipal solid waste, Full NPK at recommended dose (140-90-60) kg ha^{-1}, half NPK at (70-45-30) kg ha^{-1}. All organic wastes were applied @ 3t C ha^{-1}.

Means sharing similar letter (s) in a column do not differ significantly at *p=0.05*

indicated that addition of half or full NPK mineral fertilizers to wheat residues resulted in significantly higher WUE in maize grain over wheat residues sole treatment.

During 2012 (Year 2), the data indicated that combination of organic wastes with NPK fertilizer (half or full dose) resulted in improvement in WUE in maize grain. All organic wastes in combination with full NPK treatment produced statistically identical WUE in maize grain with maximum value (21.8 kg ha^{-1} mm^{-1}) obtained with filter cake + full NPK treatment.

Among organic wastes, filter cake and MSW showed higher response during both years with 91% increase in average grain WUE followed by 73.8% increase with FYM over control The impact of wheat residues was minimum causing 39.4% increase over control. On average, the integrated use of organic wastes with full NPK improved the WUE in maize grain by 46.4% in case of filter cake, 37.9% in case of MSW, 28.5% in case of FYM and 10.2% in case of wheat residues over NPK alone treatment.

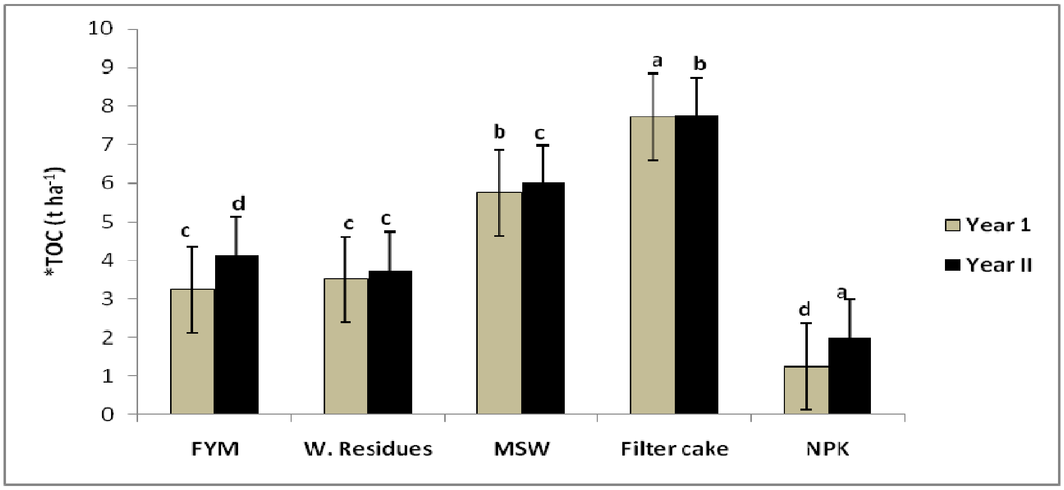
Mean contrast analyses (Figure 4) showed that combining half or full NPK with filter cake did not significantly increase the WUE in maize grain over filter cake as sole treatment during year1 but the effect became highly significant during year 2. However, wheat residues with NPK (half or full dose) produced significantly higher WUE in maize grain in contrast with wheat residues alone. The results further revealed that WUE in maize grain were significantly greater with combined use of organic wastes and full NPK treatment than that obtained with NPK alone treatment (Year 1). However, differences in WUE between organic wastes + half NPK and inorganic fertilizer were statistically similar during both years.

Soil total organic carbon

The data for soil total organic carbon (0-15 cm) after maize harvest as influenced by organic and inorganic fertilizer application are presented in figures 5 (a-c).

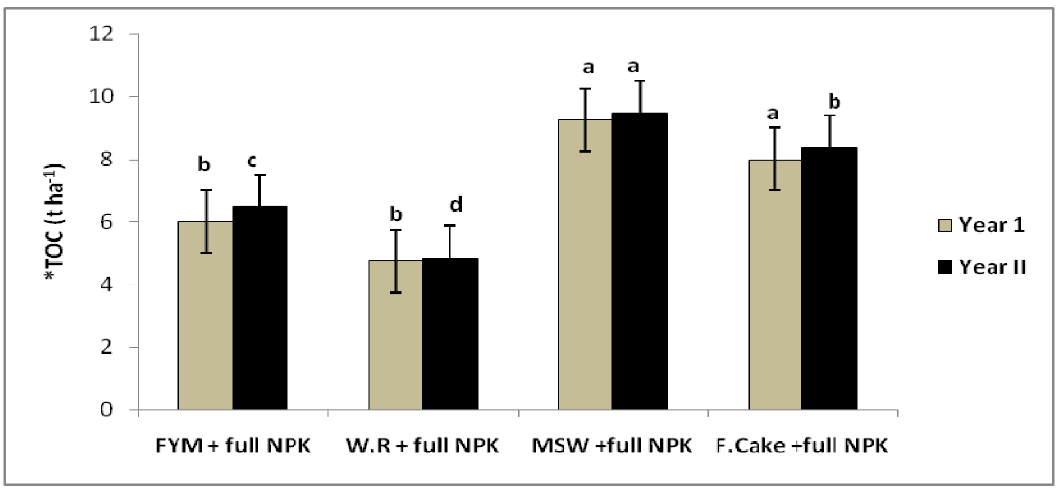
The results showed that all the sources (organic/inorganic) resulted in significant effect ($p \leq 0.05$) on total soil (SOC) content (Figure 5a). The data for Year 1 revealed that maximum total SOC were recorded in the filter cake treatment (7.7 t ha^{-1}) followed by the MSW treatment (5.7 t ha^{-1}). However; FYM and maize crop residues had statistically similar impact on total SOC. In Year 2, the highest total SOC values seen in the filter cake treatment (7.7 t ha^{-1}) followed by the MSW (6.0 t ha^{-1}), while the lowest (2.8 t ha^{-1}) was observed in the NPK treatment.

The data further revealed that during Year 1 after addition of NPK fertilizer (Figure 5b), highest soil carbon sequestration was observed in the MSW treatment with a total SOC content of 9.2 t ha^{-1} followed by statistically equal by filter cake (8.0 t ha^{-1}). Farmyard manure had 6.0 t



* = TOC (organic/inorganic fertilizer) – TOC (control) Where FYM = Farm yard manure, W. Residues = Wheat residues, MSW = Municipal solid waste, Full NPK at recommended dose (140-90-60) kg ha^{-1}

Figure 5a Soil organic carbon (0-15 cm) as affected by organic and inorganic sources after maize harvest over two growing seasons



* = TOC (Organic waste + full NPK) - TOC (full NPK) Where FYM = Farm yard manure, W.R= Wheat residues, MSW = Municipal solid waste, Full NPK at recommended dose (140-90-60) kg ha^{-1}

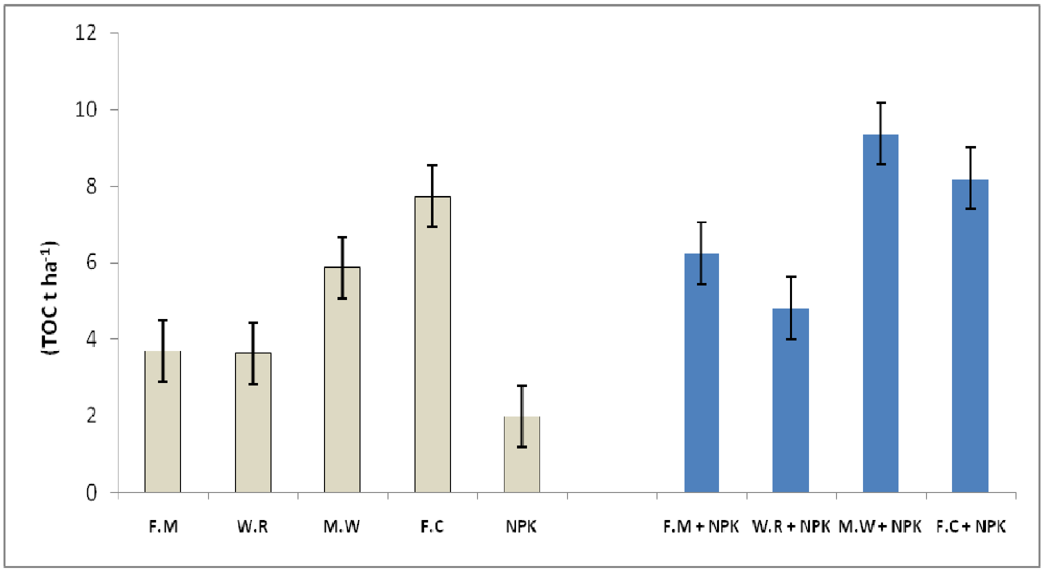
Figure 5b Soil organic carbon (0-15cm) from different organic sources as influenced by addition of NPK after maize harvest over two growing seasons

ha^{-1} while lowest SOC was recorded with wheat residues (4.7 t ha^{-1}). During Year 2, after NPK addition, total SOC was further improved with higher carbon contents by MSW (9.4 t ha^{-1}) followed by filter cake 8.4 t ha^{-1}.

The two year average data given in Figure 5c indicated that among organic wastes as sole treatments, highest increase in total SOC was recorded in the filter cake treatment (7.7 t ha^{-1}). Moreover, wheat residues and FYM had almost the same effect on soil carbon retention in the top soil (0-15 cm). The data further indicated that MSW after adding NPK accumulated significantly higher amounts of soil carbon in the topsoil compared to other organic wastes.

DISCUSSION

The data showed that municipal solid waste and filter cake significantly improved the yield of maize. Among organic wastes, the C: N ratios of MSW and filter cake were narrow (9.7 & 7.6) and thus mineralized rapidly as compared to other wastes tested in this experiment. Due to rapid



Where F.M = Farm yard manure, W.R=Wheat residues, M.W = Municipal solid waste, F.C = Filter cake, NPK* = Full recommended dose at (140-90-60) kg ha^{-1}

Figure 5c Soil total organic carbon (two years average) at (0-15 cm) depth as influenced by organic sources alone and after addition of NPK fertilizers after maize harvest

mineralization, great amount of essential nutrients were released that contributed towards higher yield. Moreover, organic wastes are good sources for enhancing the biological activity in soil (García-Gil et al., 2000; Barry et al., 2001) that may also improve the crop yield.

In this experiment, under field conditions, we observed that wheat residues with higher C: N ratio resulted in poor crop growth and ultimately resulted in low grain yields. The C:N ratio of organic manure is critical in mineralization process (Taylor et al., 1989; Trinsoutrot et al*.,* 2000) and supplying of the essential nutrients to the crops. Organic fertilizers are good sources of nutrients (Eghball et al., 2004). The literature shows that municipal solid waste contains a wide range of macro and micronutrients (Shah and Anwar, 2003) that improve plant growth and crop yields. Organic wastes not only act as a source of nutrients but also improve soil physical, chemical and biological properties (Hati et al., 2006; Saha et al., 2008) and in turn improve crop growth and yield.

Filter cake is also a good source of plant nutrients as it contains nitrogen, phosphorous, and micronutrients in large amount (Chang Yen et al*.,* 1983; Fauconnier, 1993). In addition, it is a good soil conditioner and improves soil physical, chemical and biological properties (Barry et al., 2001, De Almeida, 2011). Thus, the application of filter cake increases tolerance to stress and reduces the need of chemical fertilizers. The filter cake used in this experiment contained 3.4% total N that might have resulted in higher crop yield. The yield of various crops including maize and millet showed significant increases with filter cake additions (Rangaraj et al., 2007; Elsayed et al., 2008).

Our results showed that organic wastes integrated with full NPK mineral fertilizers produced higher crop yield than organic wastes alone. The effect was more pronounced with MSW and filter cake treatments. It is well documented that integrated use of organic and inorganic fertilizers supply balance amount of essential nutrients and increase nutrient use efficiency (Oue draogo et al*.,* 2006; Stark et al*.,* 2007). The combined application of organic wastes and chemical fertilizers is important for enhancing crop yield through improvement in soil organic fertility (Rautaray et al., 2003; Shah and Ahmad, 2006). In addition, the integrated use of organic wastes improves the efficiency of chemical fertilizers and crop productivity as well as sustaining soil health and fertility (Abedi et al., 2010).

In our experiment, the application of organic wastes improved the soil organic matter and the soil physical, chemical and biological properties. This improvement in soil properties resulted in greater straw and grain water use efficiency in maize. Our results showed that among organic wastes, filter cake and municipal solid waste produced better results. Municipal solid waste is generally applied to agricultural soils to improve their physical, chemical and biological properties. Filter cake (sugar industrial waste) also improves soil physical, chemical and biological properties (Barry et al., 2001; Vasconcelos et al., 2010). It improves soil structure, aeration, water holding capacity and porosity. Filter cake, being high in organic matter content has useful effects on improving soil physical properties such as aeration and moisture retention (Gaikwad et al*.,* 1996) and nutrient retention capacities (Sandrara, 2000; Rangaraj et al*.,* 2007; Elsayed et al., 2008). According to Duruuoha et al. 2001, filter cake resulted in greater root growth, the reason may be due to higher soil moisture content, as filter cake helps in providing greater water retention in the soil (Penatti and Donzelli, 1991).

Improvement in water use efficiency using organic fertilizers could be linked with improvement in soil physical properties like soil structure and water retention capacity (Bhagat and Verma, 1991), reduction in bulk density and increase in water infiltration (Acharya et al., 1988). Many researchers have reported improvement in soil physical properties such as water holding capacity and aggregate stability due to addition of organic wastes. (Wells et al., 2000; Odlare et al., 2008). Leon et al. (2006) found a strong correlation of total C with soil moisture content. They confirmed that high soil C contents increased the water-holding capacity mainly because of positive impact of organic matter on soil aggregation and increased water availability to plants.

Our results further indicated that combined use of organic wastes (of low C: N ratios) with NPK mineral fertilizers enhanced straw and grain WUE. As integrated use of organic and inorganic fertilizers helps in water use efficiency, enhance crop growth and sustain soil health (Shah et al., 2010). Organic fertilizers in combination with chemical fertilizers increase the inherent nutrient supplying capacity of the soil and also improve the physical properties of the soil, root growth and higher nutrient and water uptake by crops. Increased WUE caused by integrated approach could be due to vigorous biomass growth at the time when vapour pressure deficit was low, which decreased the evaporation: transpiration ratio and ultimately improved the crop transpiration efficiency (Zhang et al., 1998).

Some of the main effects of using organic amendments are increased soil organic matter and improved soil properties for crop growth (Kaur et al., 2004; Hati et al., 2006; Saha et al*.,* 2008). Organic amendments influence soil characteristics by modifying its biological, chemical and physical properties (Van-Camp et al., 2004). Our results revealed that among organic wastes, MSW and filter cake retained higher organic carbon content (0-15 cm depth) after maize harvest. The possible reasons for increasing soil organic carbon by repeated application of organic materials might be due to improvement in soil biological properties as well as the C contained in the residues themselves. Several researchers have also demonstrated that filter cake (sugar industrial waste) application to crops increased soil organic carbon, organic matter, total nitrogen and available phosphorus (Ossom and Dlamini, 2012; Elsayed et al*.,* 2008).

These findings are supported by the results of Achiba et al. (2010) who reported that the addition of organic wastes increased the total SOC from 11 g kg^{-1} in the control treatment to 21 g kg^{-1} and 33 g kg^{-1} by using 40 t ha^{-1} and 120 t ha^{-1} farm yard manure during 7 successive years. Whereas municipal solid waste application at 40 t ha^{-1}, 80 t ha^{-1} and 120 t ha^{-1} increased the soil organic carbon to 21 g kg^{-1}, 29 g kg^{-1} and 35 g kg^{-1} respectively. Our results indicated that integrated use of organic wastes and chemical fertilizers further increased the soil organic carbon content. This might be due to increased crop yield and better root growth under these treatments which improved the organic carbon in soil.

CONCLUSION

Among organic wastes, filter cake and municipal solid waste integrated with full NPK mineral fertilizer produced maximum maize grain yield, water use efficiency and retained greater soil organic carbon contents at surface (0-15cm).

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