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Effect of Different Soil Amendment Systems on Sugarcane Nutrient Uptake and Leaching

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Abstract

Different soil amendment systems has long been used in sugarcane plantations. However, the nutrient uptake and leaching under different amendment systems has not yet well studied in Ethiopia. Hence, sugarcane leaf and leachate nutrient concentrations under organic (ORG), conventional (CONV) and integrated (INT) soil amendment systems were evaluated during juvenile growth period (first five months) of sugarcane. To that end, a pot experiment with eight treatments and three replications was conducted in the Ethiopian Wonji sugarcane plantation. The treatments encompassed CONV (92 kg urea-N/ha), INT (46 kg urea-N/ha and 150 kg filter cake-N/ha) and ORG (150, 300, 450, 600 and 750 kg filter cake-N/ha) soil additions. Data were collected on leaf nutrient contents and nutrient leaching. The result showed that except in CONV, leaf N concentration was lower than the critical value in all the treatments. N leaching was higher in CONV than in ORG, whereas P leaching was contrariwise. Therefore the N fertilizing value of ORG was relatively low during juvenile growth of sugarcane where as it minimizes groundwater contamination due to N leaching. Nevertheless, P leaching under filter cake amendment can be a potential risk of eutrophication, if judicious application is not practiced.

Keywords: Nutrient Leaf Concentration, Leaching, Organic, Conventional, Integrated.

1. Introduction

For many years, the main goal of applying fertilizers was to provide nutrients to plants to increase or sustain optimal crop yield. Thus, improving fertilizer use efficiency in terms of nutrient uptake and crop yield is important to fertilizer producers and users. However, any fertilizer, whether in the natural, inorganic, or organic form, can harm the environment if misused (Chien et al. 2009)

High application rates of chemical fertilizer results in eutriphication (N and P) of ground and drainage water through leaching and runoff. These may finally end up in algal blooming and water hyacinth invasion (Hunsigi, 1993; Williams, 2005). Moreover, emission of greenhouse gases (nitrous oxides) and soils polluted with toxic heavy metals are the other consequences. Thus, recently, fertilizer use has been labeled by environmentalists as one source of polluting soil, water, and air environments.

Sustainable crop production can never be achieved by using only chemical fertilizer or only organic manure. Thus, balanced use of organic and inorganic fertilizer is very essential for the stable soil fertility where nutrient turn over in the soil plant system is faster and larger. In the case of sugarcane higher yield is obtained in the soils with sufficient level of organic matter and available nutrients (Paul et al., 2005).

To ensure proper use of fertilizer which is beneficial to both crop production and the environment, ways should be sought to achieve the newly defined goal of fertilizer use, that is, improving fertilizer nutrient use efficiency and minimizing environmental impacts. With that regard the major sources of fertilizers should be evaluated both in terms of their fertilizing capacity and environmental effect. To that end the nutrient uptake and leaching under organic, conventional and integrated soil amendments should be evaluated. Therefore, the objective of this study is to evaluate uptake and leaching of the major nutrients (N, P and K) under sugarcane cropping system.

2. Materials and Methods

2.1. Site description

The study was conducted in the Ethiopian Wonji sugarcane plantation ($8^0$31'N and $39^0$12'E). The site is located 110 km south east of Addis Ababa (Fig 2.1) at an altitude of 1540 meter above sea level. The average annual rainfall is 807 mm. while average daily minimum and maximum temperatures are 14.3^oC and $27.6\ ^oC$, respectively. The soils of the study area are predominantly heavy clay. Chemical and physical properties of the soil are given in Table 2.1.

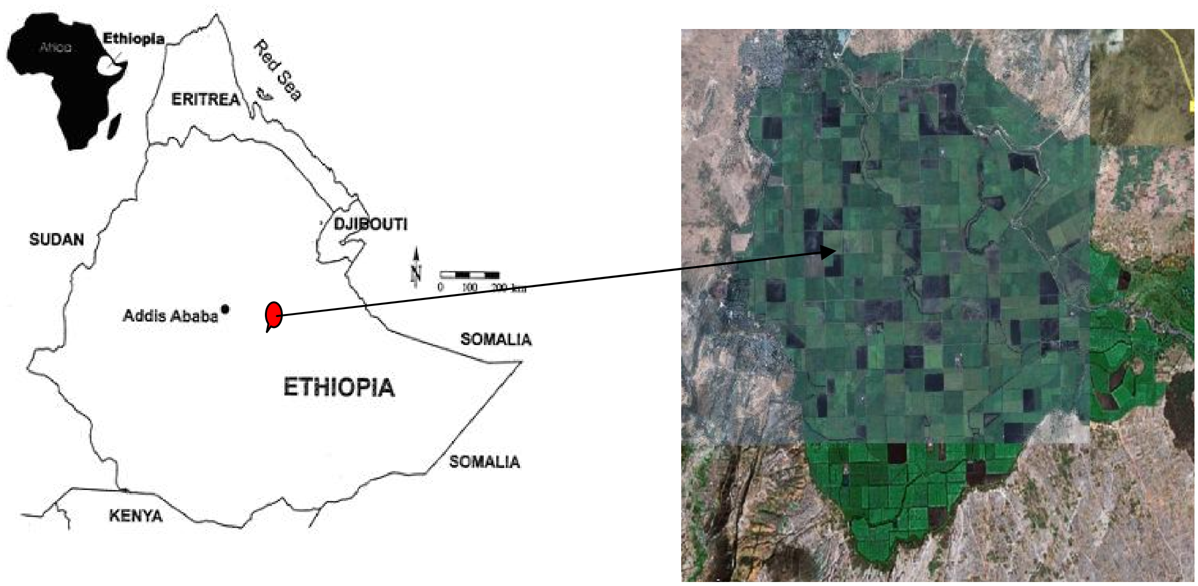

Fig 2.1. Location of the experimental site in Ethiopia and map of Wonji sugarcane plantation (the study area).

2.2. Experimental set up

A pot experiment that consisted of eight treatments, each replicated three times, was conducted in the Ethiopian Wonji Research Centre experimental site. The treatments were laid out in randomized complete block design. The designation and description of the treatments are indicated in Table 2.2.

The first treatment was a pot with no soil amendment (control). The second treatment was a pot amended with 92 kg urea-N/ha (CONV) at 9 weeks after planting (WAP) which is conventional practices in Wonji. The rate and time of application were established by several field experiments carried out in the plantation (APECS, 1987). The third treatment was a pot amended with combinations of air dried filter cake (150 kg filter cake-N/ha) and synthetic fertilizer (46 kg urea-N/ha), and thus represented integrated amendment (INT). The rate was applied based on the recommendations of Bokhtiar and Sakura (2005). The remaining five treatments were organically amended with application rates of 150, 300, 450, 600 and 750 kg filter cake-N/ha (ORG).

Table 2. 2. Treatments designations and descriptions

No	Treatment Code	Treatment	Description
1	T-1	Control	No amendment
2	T-2	CONV	92 kg urea-N/ha*
3	T-3	INT	46 kg urea-N/ha and 150 kg filter cake -N/ha**
4	T-4	ORG-1	150 kg filter cake-N/ha
5	T-5	ORG-2	300 kg filter cake-N/ha
6	T-6	ORG-3	450 kg filter cake-N/ha
7	T-7	ORG-4	600 kg filter cake-N/ha
8	T-8	ORG-5	750 kg filter cake-N/ha

*Practice of Wonji plantation (APECS, 1987)
**Recommended rate (Bokhtiar and Sakura, 2005)

2.3. Experimental Management

The pot used for the experiment was a half drum of 44 cm depth and 58 cm diameter. Five holes were drilled in the centre of the base plate of each drum so as to allow unrestricted flow of percolate after irrigation. Then the soil, which was collected from the fields of Wonji sugarcane plantation (0-30cm depth), was filled into each drum (pot). Afterwards, the specified rate of filter cake (Table 2.2) was applied on each pot and mixed with the soil. The filter cake used for the experiment was obtained from Metehara Sugar Factory. The chemical compositions of the filter cake are given in table 2.3.

The soil in each pot was pressed and equalized at 10 cm under the rim of the pot. Each pot was placed on a wooden structure which was constructed by raising 40 cm above ground. Finally, a 10 lit polyethylene vessel was placed under each pot so as to collect the leachate. In each vessel a biocide (mercuric chloride) was added in order to inhibit N transformations until the collection of the leachate.

Three sugarcane cuttings (two budded) were planted per pot at 5 cm overlap. The cuttings were obtained from sugarcane plants grown under similar environmental conditions for 10 months. The middle portion of the stalks were used to prepare the cuttings. Throughout the experiment, all the pots were irrigated with an equal amount of water. The time of irrigations was decided based on visual observations of the soil for moisture requirement. Chemical fertilizer (urea) was applied in the CONV and INT treatments at 9 weeks after planting (WAP). Other cultural activities such as weeding and cultivations were also performed as required. Finally, the cane was harvested at 21 WAP.

Table 2.3. Chemical compositions of the filter cake used for the experiment

Chemical property	Content
pH (1:5)	7.91
EC (1:5) ($mScm^{-1}$)	2.2
Organic carbon (%)	30.75
N total (%)	1.05
P Olsen (ppm)	440
C:N	30

2.4. Data Collection

Leaf sampling and analysis: At 12 WAP, four leaves (the third leaves from the top of the cane) were sampled from each pot. Three days before leaf sampling, the pots were irrigated to enhance nutrient uptake. The samples were sent to Wonji Research Directorate laboratory for analysis of leaf N, P and K concentrations.

In the laboratory, the middle 200 mm of the leaf was cut and the midribs were removed from the blades. Then, the samples were dried at $65^{O}C$ and milled. The analysis of total N was done by digesting the samples in a sulfuric-salicylic acid mixture (Buresh et al., 1982). Total P and K were analysed using dry ashing method (Chapman and Pratt, 1961).

Water sampling and analysis: Every 30 days, the amount of leachate collected from each pot was measured and a proportional sample (10% of the collected amount of leachate) was taken and stored in a refrigerator. At 16 WAP, a 500 ml leachate subsample was taken again from each of the stored sample and sent to Ethiopian water works enterprise laboratory for analysis of nitrate and phosphate concentrations.

The nitrate and phosphate concentrations in the subsamples were analyzed using cadmium reduction (Wood et al., 1967) and ascorbic acid method (Edwards et al., 1965), respectively. These methods involved additions of 1 powder pillow of NitraVer 6 nitrate reagent (Cadmium potassium pyrosulfate) and PhosVar 3 (Ascrobic acid) to a 10 mm filtered water sample for determination of nitrate and phosphate concentrations, respectively. Then, the absorbance of the mixtures were read by spectrophotometer at 507 nm (for nitrate) and at 890 nm (for phosphate) wavelengths. Afterwards, the nitrate and phosphate concentrations were computed from the standard curve of absorbance against concentration.

2.5. Data Analysis

Analysis of variances and mean comparisons (DMRT) among treatments were performed by employing Genstat software statistical packages (12^{th} edition). Standard error mean was also computed to compare leaf and leachate analytical results. Additionally, correlation between filter cake application rates and the various parameters were analysed.

3. Results and Discussion

3.1. Leaf Nutrient Concentrations

At 12 WAP, the treatments resulted in significantly different leaf N, P and K contents (P<0.05). Leaf N concentration was highest in CONV, intermediate in INT and lowest in all the ORG treatments (Table 3.1). Leaf K concentration was also highest in CONV and lowest in the maximum filter cake application rate, while intermediate in the remaining treatments. Leaf P concentrations never showed differences among the treatments except at the 300 and 600 application rates. Moreover, negative correlations were observed between the filter cake application rates and leaf N (r=-0.93) and K (r = -0.73) concentrations. However, the correlation was weak in the case of leaf P concentration (Table 3.1).

The observed negative correlations imply that higher application rates of filter cake may lead to lower available soil N and K concentrations during juvenile growth period of sugarcane. This can be attributed to the high C:N ratio (30) of the applied filter cake which probably increased immobilization while decreased mineralization. Azmal et al. (1995) also reported a negative correlation (r=-0.85) between the applied amounts of organic matter and N mineralization. Thus, the decrease in mineralization might result in the observed smaller leaf N and K concentrations in ORG treatments.

Table 3.1. Effect of conventional (CONV), integrated (INT) and organic (ORG) soil amendments (at different filter cake application rates) on leaf N, P and K concentrations (%) at 12 WAP.

			ORG (kg filter cake N/ha)						
Nutrient	CONV[1]	INT[2]	0	150	300	450	600	750	[3]r
N	1.97d	1.76c	1.52ab	1.56b	1.55b	1.42a	1.39a	1.44ab	-0.93
P	0.20ab	0.19 a	0.19a	0.21ab	0.24b	0.21ab	0.24b	0.20ab	0.26
K	2.17e	1.71cd	1.73d	1.72cd	1.47ab	1.56abc	1.62bcd	1.40a	-0.73

In rows, means followed by different letters are significantly different (P<0.05).
1 = 92 kg urea-N/ha; 2 = 46 kg urea-N/ha and 150 kg filter cake-N/ha.
3 = Correlation coefficient.

Table 3.2. Sugarcane leaf nutrient critical values and optimum ranges (McCray et al., 2006)

Nutrient	Critical value (%)	Optimum range (%)
Nitrogen (N)	1.80	2.00–2.60
Phosphorus (P)	0.19	0.22–0.30
Potassium (K)	0.90	1.00–1.60

Leaf N concentration in the control, ORG and INT treatments was lower than the critical value while the reverse was observed in CONV (Table 3.2). On the other hand all the treatments, including the control, showed higher or equal P and K concentrations than the critical values. These suggest that there might be no P and K shortages in the soil used for the experiment at 12 WAP. Meanwhile, soil N availability might not be sufficient in the control, ORG and INT treatments.

According to McCray et al. (2006) leaf analysis provides a picture of crop nutritional status and problems at the time of sampling. Accordingly, filter cake amendments may result in temporary N deficiency during early growth of sugarcane, especially, at higher application rates. This is most likely due to the slow decomposition rate of filter cake (Verma, 2004). Thus, had the leaf samples taken at the latter ages of the cane, the result might have been higher than the current amounts. Therefore, during filter cake amendments mechanisms that enhance N availability, such as composting, might be beneficial to avoid the possible occurrence of N deficiency.

The highest leaf K concentration in CONV might be resulted from the synergistic effects of N on K. The application of urea-N in the CONV might stimulate mineralization of K with concomitant increase in leaf K concentration. Conversely, the low availability of N, due to immobilization, in ORG might result in the lower leaf K concentration.

The non significant differences between the different amendments and the control in leaf P concentration were strange as a considerable increment in P Olsen was observed in the amended soils (Fig 3.3). Moreover, leaf P concentration in control was similar to the critical value. This suggests even without any amendment the soil of Wonji plantation can supply enough P during juvenile growth of sugarcane which might be attributed to the relatively smaller P demand of sugarcane. According to Landon (1984) sugarcane is among moderate P demanding crops that deficiency occurs when soil P Olsen is less than 7 ppm.

3.2. Nnutrients Leaching

N leaching: The total amount of NO^{-}_{3}-N leached per pot at 16 WAP in ORG was 45%, 65% and 68% lower than in control, CONV and INT, respectively (Fig. 3.7). The result supports the finding of Haas et al. (2002) who reported a decline in nitrate leaching by 15% and 50% upon shifting from CONV to INT and ORG, respectively. It was interesting that ORG showed less N leaching than the control. This might be due to the immobilization of N upon application of filter cake and therefore less nitrate to be available for leaching. Azmal et al. (1996) also stated that applications of organic matter with high C:N ratio could decrease mineral N. As the filter cake applied in this study had high C:N ratio and as decomposition of filter cake could take up to 3 months (Verma, 2004), the observed lowest N leaching in ORG was reasonable.

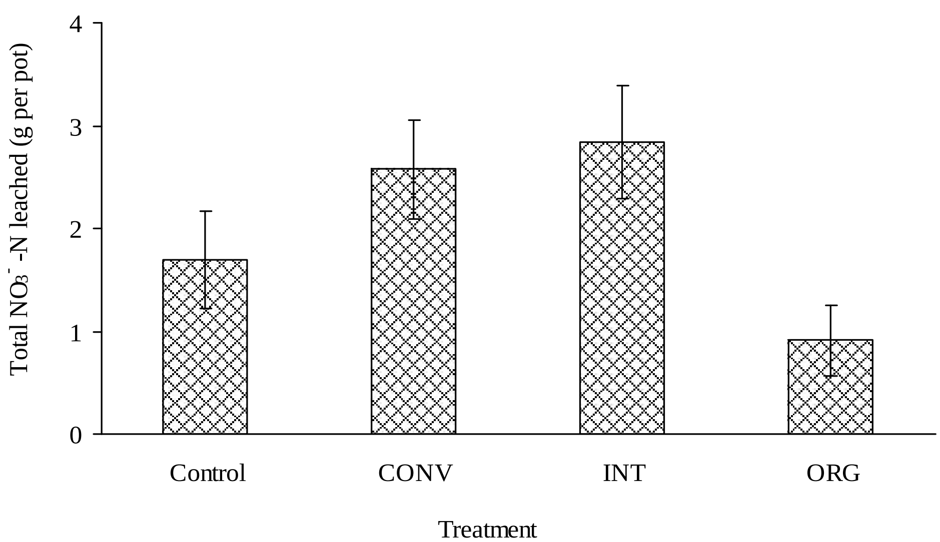

Fig 3.1. Effect of conventional (92 kg urea-N/ha-CONV), integrated (46 kg urea-N/ha and 150 kg filter cake-N/ha-INT) and organic (450 kg filter cake-N/ha-ORG) soil amendments on the total amount of NO^{-}_{3}-N (g/pot) in the leachate collected at 16 WAP. Organic fertilizer (filter cake) was applied at planting while chemical fertilizer was applied at 9 WAP. Vertical bars indicate ±SEM (standard error of mean).

From the applied N, 33.6%, 17.4% and 2.4% was lost in the CONV, INT and ORG treatments, respectively. Similar result was also found by Hartmink (2008) where he observed a 30% loss of the applied N in Australian sugarcane plantations. The highest N loss in CONV might result from the easy leaching behaviour of the applied inorganic fertilizer (urea). Due to the nitrification of ammonia in a urea fertilizer, the tendency of nitrate leaching with irrigation water is high. Earlier findings also showed that N leaching was higher in soils amended with urea than organic fertilizer. Suphachai and Kazuyuki (2009) observed that in a short term, the total amount of nitrate leaching from soils amended with urea was significantly higher than soil amended with cow manure.

It becomes apparent that the performance of ORG was far better than CONV in minimizing N leaching which is the major cause of groundwater contamination. In Ethiopian sugarcane plantations, nitrate leaching into ground water after fertilizer application is up to sixteen times higher than before application (Layo, 2010b). Thus, filter cake soil amendment is most likely the best alternative in mitigating the problem of N leaching.

P Leaching: The treatments increased P-PO_4^{3-} leaching in the order of ORG > INT > CONV and control. P leaching was 25% and 10% higher in ORG and INT, respectively, than the control; whereas CONV did not differ from the control. The highest amount of P in ORG and INT treatments might be resulted from the high P content of the applied filter cake (440ppm). The soil analysis result also shows that P Olsen content in CONV, ORG and INT was increased by three-fold, five-fold and seven-fold of the initial soil, respectively (Layo, 2010b). Thus, the observed highest leaching of P from the INT and ORG treatments was plausible.

The result suggests that the application of filter cake as organic fertilizer might lead to eutrophication problems. Cheesman (2004) also stated that leaching of most elements is greater from soil amended with filter cake than with the other materials. Particularly in Wonji and Metehara sugarcane plantations where furrow irrigation is being practiced, the potential risk of eutrophication is probably high. Thus, as leaching of P to water bodies is the major cause for algal blooming (Wade et al., 2007), utmost care should be taken during filter cake field applications.

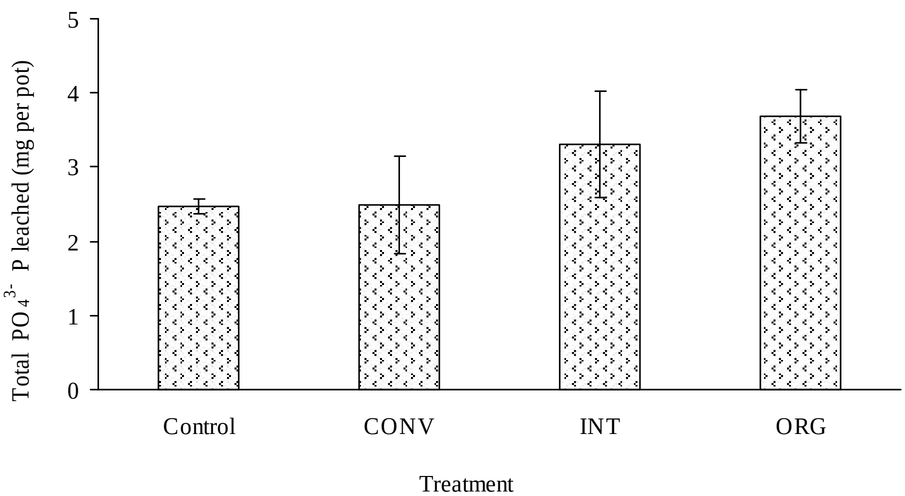

Fig 3.2. Effect of conventional (92 kg urea-N/ha-CONV), integrated (46 kg urea-N/ha and 150 kg filter cake-N/ha-INT) and organic (450 kg filter cake-N/ha-ORG) soil amendments on total amount of P (mg/pot) in the leachate collected from the pots at 16 WAP. Organic fertilizer (filter cake) was applied at planting while chemical fertilizer was applied at 9 WAP. Vertical bars indicate ±SEM (standard error of mean).

4. Conclusion

The N fertilizing value of filter cake was relatively low during juvenile growth of sugarcane as leaf N concentration was found to be lower than the critical value at 12 WAP. Therefore, during filter cake amendments mechanisms that enhance N availability, such as composting, might be beneficial to avoid the possible occurrence of N deficiency.

The ecological benefit of filter cake soil amendment in terms of N leaching was promising. Therefore, application of filter cake as organic fertilizer can minimize groundwater contamination due to N leaching which is one of the major problems in the sugarcane plantations. Nevertheless, P leaching under filter cake amendment can be a potential risk of eutrophication, if judicious application is not practiced. Thus, to reduce the risk of P eutrophication, high rates of filter cake should not be applied in fields prone to leaching and runoff. Furthermore, as environmental and soil quality deterioration are turned out to be the major problems, it is highly recommended to minimize excessive inorganic fertilizer applications. Integrated soil amendment can be used as an alternative, if organic amendment alone is not possible.

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