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Effect of Organic Matter on Rice Nitrogen and Phosphorus Use Efficiency Under Calcareous Sodic Soil of Amibara District, Ethiopia

Bethel Nekir
Ethiopian Institutes Agricultural Research, Ethiopia

Abstract

Wastes produced from sugarcane industries are organic in nature, and it augmented the soil properties as well as improves crop yield and quality. In 2016 field experiment was conducted to investigate effect of filter cake and bagasse for nitrogen and phosphorus use efficiency of upland rice grown on calcareous sodic soils of Amibara District. The result revealed that plant nutrient use efficiency indices agronomic efficiency, agrophysiological efficiency and apparent recovery efficiency of both nitrogen and phosphorus were significantly ($P<0.05$) affected by the application of filter cake and bagasse. The maximum nitrogen was recovered at 20 t ha^{-1} filter cake followed by combined application of 10 t ha^{-1} bagasse + 20 t ha^{-1} FC that gave 45.10 % from kg quantity of nitrogen uptake per unit of kg nutrient applied. But, the minimum nitrogen recovery efficiency was recorded at 20 t ha^{-1} bagasse + 20 t ha^{-1} filter cake. The Phosphorus apparent recovery efficiency ranged from 18.55- 32.91 %. The interaction of filter cake with bagasse also highly significantly ($P < 0.01$) affected rice grain yield. It can be encouraged to use these wastes with combination of inorganic chemical fertilizers under various cropping systems to enhance nutrient availability to plant under calcareous sodic soil.

Keywords: Nutrient use efficiency; Phosphorus; Nitrogen; Bagasse; Filter cake; Calcareous.

1. Introduction

The arid region salt-affected soils have high pHe, ECe, SAR, and are calcareous which limit nutrient availability and plant growth [1], particularly in developing countries [2, 3]. In Ethiopia particularly in Amibara district soil salinity is the major factor for crop production [4-6]. Several physiological pathways have been observed to be affected by high salinity [7], at different growth stages [8, 9]. Moreover, the interactions between salinity and mineral nutrition of plants are complex [10] and this negative interaction may decrease growth and consequently nutrient use efficiency [11]. The tissues of plants growing in saline media generally exhibit an accumulation of Na^+ and Cl^- and/or the reduced uptake of mineral nutrients, especially Ca^{2+}, K^+, N, and P [12]. Nitrogen accounts for about 80% of the total mineral nutrients absorbed by plants [13] and its uptake by rice is inhibited under high soil salinity and sodicity status [14].

Moreover, presence of $CaCO_3$ directly or indirectly affects the chemistry and availability of N, P, Mg, K, Mn, Zn, Cu and Fe [13]. Vlek and Craswell [15], reported that low nitrogen use efficiency (NUE) is largely due to NH_3 volatilization that is encouraged by high soil pH. Phosphorus use efficiency (PUE) is low in alkaline and calcareous soils due to fixation of applied P0020 [16]. As a result, improving nutrient use efficiency is a worthy goal and fundamental challenge facing the fertilizer industry, and agriculture in general, particularly in arid and semi-arid regions where salinity more aggravated the problems [17]. Different authors report organic matter amended calcareous saline-sodic soils showed the highest NUE and PUE [18, 19]. Therefore, efficient and cost-effective crop production in arid and semi-arid regions; on salt affected soils demands appropriate management options that minimize salinity impacts and optimize plant nutrients use efficiency. Keep this in mind the study was designed to investigate effect of filter cake and bagasse for nitrogen and phosphorus use efficiency of rice grown on calcareous sodic soils of Amibara District.

2. Methods

2.1. Description of the Experimental Site

The study was conducted at Amibara District, located at 9°20’31" N latitude and 40°10’11" E longitude and the elevation is at about 740 m. The climate is semi-arid with a bimodal rainfall of 533 millimeters annually. The mean minimum temperature is 19.0, while the mean maximum is 34.8 ^{O}C. Annual evapotranspiration rate of Amibara district is 2829 mm. Generally, Amibara area soil described by wide-spread occurrence of salinity and sodicity problem [4-6], Heluf Gebrekidan [20] , deficiency Fe, Zn and [21] and predominantly Fluvisols (70%) followed by Vertisols occupying about 30% of the total area [22].

2.2. Soil Sampling and Analysis

Representative soil samples from experimental site were collected at depth of 0-30cm. The soil samples were air dried, grounded and sieved with 2 mm sieve, for soil organic carbon and total nitrogen analysis 0.5 mm sieve was used. Laboratory analysis was conducted following appropriate method as described in Table 1.

Table-1. Lists of selected analyzed soil chemical properties and methodology followed

Parameter	Method and Reference
pHe	Potentiometrically [23].
ECe	Saturated paste extract [23].
OM	Wet Oxidation [24]
Available P	Olsen extraction [25].
Total N	Kjeldahl digestion [26]
CEC	Ammonium acetate [27]
Ex. base (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+})	Ammonium acetate [28]
ESP & SAR	Computed [23]

2.3. Experimental Design and Treatments

The 3^2 factorial experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. Factor one was filter cake (FC) with three levels; 0 (Fc_0), 10 (Fc_{10}) and 20 (Fc_{20}) t ha^{-1} and factor two was bagasse (BG) with three levels; 0 (Bg_0), 10 (Bg_{10}) and 20 (Bg_{20}) t ha^{-1}. Treatment combinations were T1 (control), T2 (Bg0 + Fc10), T3 (Bg0 + Fc20), T4 (Bg10 + Fc0), T5 (Bg10 + Fc10), T6 (Bg10 + Fc20), T7 (Bg20 + Fc0), T8 (Bg20 + Fc10) and T9 (Bg20 + Fc20).

Filter cake and bagasse were collected from Kesem Kebena sugar factory. Well mixed representative sample was taken from both by-products and analyzed before application to assess their chemical contents. After four weeks of treatment application Nerica-4 rice variety was sown by drilling on two side of the ridge at 30cm intra-row spacing. At sowing 69 kg P_2O_5/ha was added. Two equal split application of 69 kg N/ha was added for all plot, one-half at sowing and the remaining half at active tillering.

2.4. Data Collection

Five non-boarder rice plants per plot were randomly selected from each plot for straw and seed analysis at maturity. After washed with distilled water, the samples were dried in oven at 70^{o}C for 24 hours. After drying, the plant tissue samples were ground and passed through 0.5 mm sieve for laboratory analysis [29]. At maturity the crop was harvested. Biological yield was recorded and straw and grain were separated with hand tools.

2.5. Nutrient Use Efficiency Indices

As described by Fageria and Baligar [30] and Dobermann [31] the following common nutrient use efficiency formulas were used to calculate NUE and PUE.

Agronomic Efficiency (AE): the agronomic efficiency is defined as the economic production obtained per unit of nutrient applied. It can be calculated by:

$$\text{Agronomic Efficiency (AE)} \left(\frac{kg}{kg}\right) = \frac{Gf - Gu}{Na} \quad (1)$$

Where;
Gf = Grain yield of the fertilized plot (kg)
Gu = Grain yield of the unfertilized plot (kg)
Na = Quantity of nutrient applied (kg)

Physiological Efficiency (PE): Physiological efficiency is defined as the biological yield obtained per unit of nutrient uptake. It was calculated by:

$$\text{Physiological efficiency (PE)} \left(\frac{kg}{kg}\right) = \frac{BYf - BYu}{Nf - Nu} \quad (2)$$

Where;
BYf = Bological yield (grain plus straw) of the fertilized plot (kg)
BYu= Biological yield of the unfertilized plot (kg)
Nf = Nutrient uptake (grain plus straw) of the fertilized plot, and Nu is the nutrient uptake (grain plus straw) of the unfertilized plot (kg)

Agrophysiological efficiency (APE): Agrophysiological efficiency is defined as the economic production (grain yield in case of annual crops) obtained per unit of nutrient uptake. It was calculated by:

$$\text{Agrophysiological (APE)} \left(\frac{kg}{kg}\right) = \frac{Gf - Gu}{Nuf - Nuu} \quad (3)$$

Where;
Gf = Grain yield of fertilized plot (kg)
Gu = Grain yield of unfertilized plot (kg)
Nuf = Nutrient uptake (grain plus straw) of the fertilized plot (kg)
Nuu = Nutrient uptake (grain plus straw) of unfertilized plot (kg)

Apparent Recovery Efficiency (ARE): Apparent recovery efficiency is defined as the quantity of nutrient uptake per unit of nutrient applied. It was calculated by:

$$\text{Apparent recovery (ARE)} \left(\frac{kg}{kg}\right) = \frac{\text{Nf - Nu}}{\text{Na}} \quad (4)$$

Where;
Nf = is the nutrient uptake (grain plus straw) of the fertilized plot (kg)
Nu = is the nutrient uptake (grain plus straw) of the unfertilized plot (kg)
Na = is the quantity of nutrient applied (kg).

Utilization Efficiency (EU): Nutrient utilization efficiency is the product of physiological and apparent recovery efficiency. It was calculated by:

$$\text{Utilization efficiency (EU)} \left(\frac{kg}{kg}\right) = \text{PE x ARE} \quad (5)$$

Nutrient Harvest Index (NHI): Nutrient harvest index was calculated by using the following formula [30].

$$\text{NHI} = \frac{\text{Nutrient uptake in grain}}{\text{Nutrient uptake in grain and shoot}} \quad (6)$$

2.6. Data Analysis

Statistical analysis of variance (ANOVA) was carried out using SAS version 9.4 statistical software program [32]. Significant difference between and among treatment means were assessed using the least significant difference (LSD) at 0.05 level of probability [33].

3. Result and Discussion

3.1. Initial Soil Physicochemical Properties

The results indicated that texture of the soil of the experimental site was dominated by the siltclay. On the basis of particle size distribution, the soil contained sand 15.20%, silt 42.00%, and clay 42.80% . General soil properties of study area was presented in Table 2.

Table-2. Selected physical and chemical properties study site soil

Soil properties	Unit	Result
Particle density	g cm^{-3}	2.53
Bulk density	g cm^{-3}	1.49
Total porosity	%	41.11
ECe	ds/m	4.52
pH	-	8.73
OC (%)	%	0.31
P	mg/kg	15.13
N	%	0.11
ESP	%	19.91

Table-3. Selected chemical properties of filter cake and bagasse used for amendments

Parameters	Unit	Filter cake	bagasse
pH	-	6.13	6.00
OC (%)	%	31.29	47.98
P	mg/kg	15.58	23.83
N	%	2.07	0.65
Ca	mg/kg	49.00	2.00
Mg	mg/kg	7.00	8.00
C:N	-	15.12	73.82

3.2. Agronomic Efficiency (AE)

Nitrogen agronomic efficiency and phosphorus agronomic efficiency were significantly affected by application of filter cake and bagasse as presented in Table 4 and 5, respectively. Maximum nitrogen AE (19.59 kg grain kg^{-1}N applied) was obtained in the treatment to which 20 t ha^{-1} FC applied followed by treatments where 10 t/ha FC (16.71 kg/kg) and 10 t ha^{-1} Bg + 20 t ha^{-1} FC (16.70 kg/kg). The smallest nitrogen AE (5.22 kg grain kg^{-1} nutrient applied) was obtained at 20 t ha^{-1} Bg + 10 t ha^{-1} FC (Table 4). Phosphorus agronomic efficiency also significant and maximum phosphorus AE (45.06 kg grain kg^{-1} P applied) was obtained in the treatment to which 20 t ha^{-1} FC. While, the smallest phosphorus AE (12.01 kg grain kg^{-1} nutrient applied) was recorded at treatment received 20 t ha^{-1} Bg + 10 t ha^{-1} FC (Table 5).

Table-4. Effect of filter cake and bagasse on rice nitrogen use efficiency parameters

Treatments	AE (kg·kg^{-1})	PE (kg·kg^{-1})	APE (kg·kg^{-1})	ARE (%)	UE (kg·kg^{-1})
Bg_0FC_0	-	-	-	-	-
Bg_0FC_{10}	16.71^{ab}	62.62	50.10^{a}	41.15^{abc}	26.79
Bg_0FC_{20}	19.59^{a}	54.75	39.12^{ab}	49.42^{a}	27.05
$Bg_{10}FC_0$	10.08^{bc}	90.10	28.13^{bc}	33.47^{bc}	26.64
$Bg_{10}FC_{10}$	16.69^{ab}	80.32	35.78^{b}	42.96^{ab}	35.56
$Bg_{10}FC_{20}$	16.70^{ab}	64.71	36.51^{b}	45.10^{ab}	29.63
$Bg_{20}FC_0$	10.80^{bc}	56.40	29.19^{bc}	34.78^{bc}	20.31
$Bg_{20}FC_{10}$	5.22^{c}	81.24	18.22^{c}	33.55^{bc}	25.36
$Bg_{20}FC_{20}$	8.92^{bc}	93.18	30.37^{bc}	29.40^{c}	27.40
$LSD_{(0.05)}$	8.32	NS	12.91	11.81	NS
CV (%)	34.44	29.07	22.05	17.42	30.45

Similar letters or no letters with column indicate that there is no significant difference among treatment levels, α= 0.05, based on LSD test. Where, AE (Agronomic Efficiency), PE (Physiological Efficiency), APE (Agrophysiological Efficiency), ARE (Apparent Recovery Efficiency) and UE (utilization Efficiency).

Filter cake has a higher nutrient content and more rapid mineralization rate compared to bagasse. Agronomic efficiency is usually greater at the quick mineralized material than slow mineralized material of N source. This result is in agreement with Shah, *et al.* [34] who reported agronomic efficiency and nitrogen use efficiency increased with the use of organic and mineral nutrient. The results from various studies showed consistently that the increase in phosphorus agronomic efficiency with the addition of organic matter is greatest for rice. The findings of Dotaniya [35] who evinced use of locally available organic residues, i.e. bagasse, filter cake and rice straw can be a cheaper technology to mobilize unavailable P in situ. Bronick and Lal [36] also reported the high agronomic efficiency might be due to the reason that organic manure change the soil quality, this is linked to the effects of OM content on soil structure and biological activity.

3.3. Agrophysiological Efficiency (APE)

Nitrogen agro-physiological efficiency (APE) show highly significant ($P \leq 0.01$) difference due to applied FC and Bg. The highest nitrogen APE (50.10 kg.kg^{-1}) was observed at 10 t/ha FC followed by 20 t ha^{-1} FC (39.12 kg.kg^{-1}) and the lowest (18.22 kg.kg^{-1}) was obtained from 20 t ha^{-1} Bg + 10 t ha^{-1} FC (Table 4). Significant ($P \leq 0.05$) difference was also recorded for phosphorus APE. The maximum phosphorus APE (165.37 kg.kg^{-1}) was achieved at 10 t ha^{-1} FC treatment followed by 20 t/ha FC (139.23 kg.kg^{-1}) whereas, the lowest (58.09 kg.kg^{-1}) was obtained at combination of 20 t ha^{-1} Bg + 10 t ha^{-1} FC (Table 5).

Nitrogen and Phosphorus agrophisiological efficiency due to applied sugar industry by-product filter cake and bagasse clearly influenced under salt affected soil. This might be due to applied inorganic N loss could be reduced if the ammonia pool resulting from urea hydrolysis was partly substituted by organic matter, since the uptake of nitrogen inhibited under salt affected soils. Britto, *et al.* [14], reported that uptake of N by rice was inhibited under high sodium chloride (NaCl) and sodium sulfate (Na_2SO_4) concentration in the roots, and the excess amount of absorbed Na^+ depressed NH^{4+} absorption. [37] co-composting bagasse and filter cake to widen the C/N ratio of filter cake reduced N loss to approximately 12 %. The highest agrophysiogical efficiency was due to increased grain yield and comparative increase in uptake of phosphorus from organic matter filter cake treated plot. Incorporation of bagasse, filter cake and rice straw in soil released different types of organic acids mainly oxalic acid, which reduced the labile P conversion into non-labile P in soil [38].

3.4. Apparent Recovery Efficiency (ARE)

The percentage of apparent N and P recovery efficiency significantly varied with organic matter applied. The maximum N recovery (49.42 %) was achieved at 20 t ha^{-1} FC. But, the minimum N recovery efficiency (29.40 %) was obtained at 20 t ha^{-1} bagasse + 20 t ha^{-1} FC (Table 4).

Table-5. Effect of filter cake and bagasse on rice phosphorus use efficiency parameters

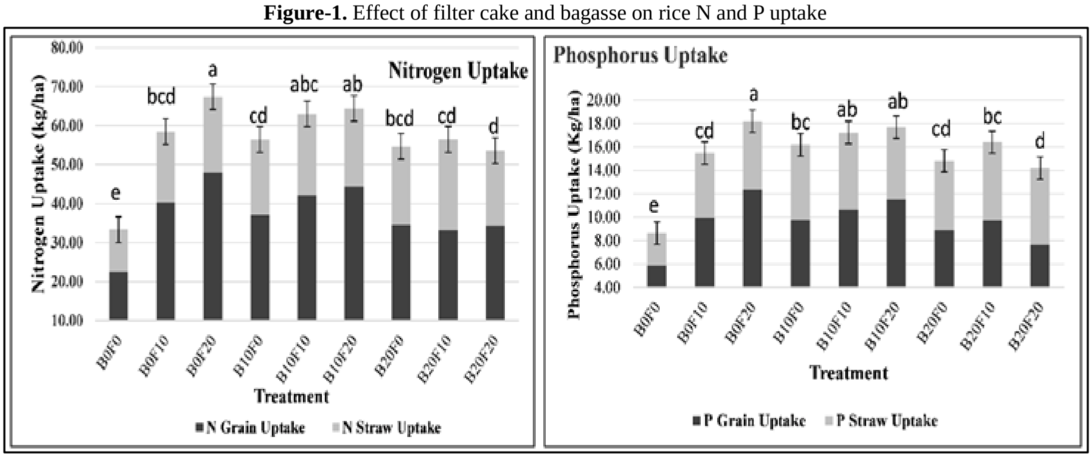
Treatments	AE (kg·kg^{-1})	PE (kg·kg^{-1})	APE (kg·kg^{-1})	ARE (%)	UE (kg·kg^{-1})
Bg_0FC_0	-	-	-	-	-
Bg_0FC_{10}	38.44^{ab}	177.69	165.37^{a}	22.80^{cde}	43.75
Bg_0FC_{20}	45.06^{a}	193.02	139.23^{ab}	32.91^{a}	62.21
$Bg_{10}FC_0$	23.19^{bc}	245.61	92.89^{bc}	25.16^{bcd}	61.26
$Bg_{10}FC_{10}$	38.38^{ab}	278.52	129.34^{ab}	28.67^{abc}	81.78
$Bg_{10}FC_{20}$	38.41^{ab}	226.78	127.59^{ab}	30.21^{ab}	68.15
$Bg_{20}FC_0$	24.84^{bc}	216.07	114.73^{ab}	20.62^{de}	46.71
$Bg_{20}FC_{10}$	12.01^{c}	231.43	58.09^{c}	25.88^{abcd}	59.93
$Bg_{20}FC_{20}$	20.52^{bc}	348.00	111.20^{ab}	18.55e	63.02
LSD $_{(0.05)}$	19.15	NS	51.29	6.11	NS
CV (%)	36.33	24.55	24.97	13.70	32.51

Similar letters or no letters with column indicate that there is no significant difference among treatment levels, α= 0.05, based on LSD test. Where, AE (Agronomic Efficiency), PE (Physiological Efficiency), APE (Agrophysiological Efficiency), ARE (Apparent Recovery Efficiency) and UE (utilization Efficiency).

The Phosphorus ARE ranged from 18.55- 32.91 %. The highest Phosphorus ARE (32.91 %) and the lowest (18.55%) were found at treatments with 20 t ha^{-1} filter cake and with 20 t ha^{-1} bagasse + 20 t ha^{-1} FC, respectively (Table 5).

Sodic soil with high pH favor nitrogen volatilization and als o calcareous sodic soil encourage precipitation of phosphorus in the form of calcium phosphate. However, application of organic matter could improve these adverse properties thereby increase nutrient recovery efficiency. When compared the recovery efficiency of the two byproduct filter cake has showed better result than bagasse. The reason for low nitrogen recovery of bagasse rate was organic input in the form of cellulose provided favorable conditions for microbial growth and increased the microbial biomass, which consequently caused N retention by microbial immobilization. Muhammad and Khattak [39], reported that filter cake which had high organic matter and N contents could have increased the N uptake. The result is in agreement with Sarwar, *et al.* [40] who reported that when compared with control treatments indicated that fertilizer use efficiency had increased with increasing filter cake. Delgado, *et al.* [41] and EI-azab, *et al.* [42] also reported increase in the recovery of applied P due to a positive effect of the application of organic in calcareous soils. Incorporation of bagasse, filter cake and rice straw in soil released organic acids mainly oxalic acid, which reduced fixation of P [38]. Moreover, statistical analysis result implies that both nitrogen and phosphorus nutrient uptake were significantly affected due to applied organic byproduct. Rice grain and straw nutrient uptake (nitrogen and phosphorus) were high at treatment sole application of filter cake Fig.1

Figure-1. Effect of filter cake and bagasse on rice N and P uptake



3.5. Nutrient Harvest Index

Nutrient harvest index were significantly affected and the highest nitrogen harvest index (70.75) was obtained from application 20 t ha^{-1} FC, while the lowest NHI (57.91) was obtained from combined 20 t ha^{-1} bagasse + 10 t ha^{-1} FC. As shown in the Table 5 the highest PHI (67.86) was achieved from untreated plot, whereas plot that received a combination of 20 t ha^{-1} bagasse + 20 t ha^{-1} filter cake gave the lowest phosphorus harvest index (53.85).

Table-6. Interaction effect of filter cake and bagasse on nitrogen and phosphorus harvest index

Bagasse level	Nitrogen harvest index (%)			Phosphorus harvest index (%)		
	Filter cake level					
	0	10	20	0	10	20
0	67.22[a]	68.29[a]	70.75[a]	67.86[a]	64.11[abc]	67.73[a]
10	65.90[ab]	65.53[ab]	64.10[a]	60.27[bc]	61.81[bc]	65.13[ab]
20	58.10[bc]	57.91[c]	63.72[abc]	59.44[cd]	59.12[cd]	53.85[d]
LSD (0.05)	7.13			3.43		
CV (%)	6.28			3.20		

Interaction means followed by the same letter within each column and row for the parameters are not significantly different at α= 0.05, based on LSD test

3.6. Grain Yield and Grain Harvest Index

The interaction of filter cake with bagasse showed highly significant ($P \leq 0.01$) difference on rice grain yield. The highest grain yield (3.53 t ha^{-1}) was obtained at application of 20 t ha^{-1} filter cake. However, the lowest grain yield (2.18 t ha^{-1}) was recorded from the control `.

Table-7. Interaction effect of filter cake and bagasse on rice grain harvest index and grain yield

Bagasse level	Grain harvest index (%)			Grain yield (t ha^{-1})		
	Filter cake level					
	0	10	20	0	10	20
0	26.67[d]	34.92[a]	35.12[a]	2.18[d]	3.33[ab]	3.53[a]
10	28.66[cd]	31.06[bc]	32.07[ab]	2.87[bc]	3.33[ab]	3.33[ab]
20	30.45[bc]	25.50[d]	27.77[bc]	2.92[bc]	2.54[cd]	2.79[bc]
LSD (0.05)	3.41			0.56		
CV (%)	6.50			10.90		

Interaction means followed by the same letter within each column and row for the parameters are not significantly different at α= 0.05, based on LSD test.

Based on the interaction analysis the highest GHI (35.12 %) was obtained from 20 t ha^{-1} FC followed by 10 t ha^{-1} FC (34.92). While, the lowest GHI (25.50 %) was recorded from treatment 20 t ha^{-1} bagasse + 10 t ha^{-1} FC and statistically at par with the control (26.67 %) (Table 7).

The study indicated a general tendency of improvement in harvest index and grain yield of rice with sole and combined application of filter cake and bagasse, and a good result was obtained at filter cake applied treatment. The reasons for higher yield in filter cake was due to low C: N ratios and higher intrinsic nutrient contents. Same result reported by Shehzadi, *et al.* [43] who study on low C:N ratio filter cake and produce high wheat yield, while high C:N ratio maize straw failed to produce good result. Seth, *et al.* [44], who utilized 15 t ha^{-1} of composted sugar industry waste (filter cake) in sodic soil to evaluate soil properties and rice growth and found that the filter cake significantly increased the grain yield. The same result reported by Shah, *et al.* [45]. Similar to grain yield GHI was also more affected by filter cake than bagasse. This result agrees with Jamil and Qasim [46] who found that organic matter increase GHI. This trend is contrary with harvest index of lentil that was not significantly affected by either NPK or filter cake treatments [47].

4. Conclusion

Nitrogen and Phosphorus are among the macro-nutrients their uptake and assimilation is being severely affected by salinity/sodicity in arid and semi-arid areas of the world. Combined application of filter cake and bagasse significantly ($P \leq 0.05$) affected agronomic, agrophysiological, apparent recovery efficiency of N and P and rice grain yield. Maximum recovery of N (49.42%) and P (32.91%) was obtained from 20 t ha^{-1} FC and minimum N (29.40%) and P (18.55%) from 20 t ha^{-1} bagasse + 20 t ha^{-1} FC application. Generally, combined use of chemical fertilizer and filter cake and bagasse improve the efficiency of chemical fertilizer and thus reduce their use in order to improve crop productivity as well as sustaining soil health and fertility. Generally, comparison of the effects of the two sugar industry byproducts reveals that the effect of bagasse was not as conspicuous as that of filter cake particularly on nutrient use efficiency and rice growth and yield parameters.

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