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EFFECT OF ORGANIC AMENDMENTS AND MICROBIAL INOCULANT ON NITROGEN, PHOSPHORUS AND POTASSIUM USE EFFICIENCY OF SUGARCANE UNDER ACID TYPIC HAPLUDAND

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ABSTRACT

A field experiment was established in an acid Typic Hapludand in Isabela, Negros Occidental, Philippines from January to December 2016 to optimize the use of mudpress, bagasse ash and microbial inoculant in sugarcane production using 'Phil 2004-1011' sugarcane variety. Twelve treatments were imposed including no fertilization, with full fertilization using inorganic fertilizer, and with full fertilization + lime. The recommended N rate (RR_N) was reduced to 75, 50 and 25% with subsequent application of mud press to satisfy the full RR_N. Bagasse ash at 10 t ha^{-1} and microbial inoculant were likewise used to supplement the nutrient sources. Standard cultural practices for sugarcane production were followed. Cane yield and NPK use efficiency indices were determined and analyzed to come up with a judicious fertilization program. Integrated nutrient management practices including mudpress, bagasse ash and microbial inoculant improved cane yield, partial factor productivity and agronomic efficiency of applied N, and physiological efficiency of applied P. Application of lime resulted to better partial factor productivity and apparent recovery efficiency of applied P. Combined use of inorganic fertilizer and mudpress enhanced partial factor productivity of applied K, while addition of bagasse ash and microbial inoculant increased physiological efficiency of applied K.

Key words: amendments, microbial inoculant, nutrient use efficiency

INTRODUCTION

Application of fertilizers is an indispensable practice in sugarcane production as it augments indigenous soil nutrient supply needed for cane growth and sugar production. As in most of the sugarcane growing countries, efficient fertilization practices have contributed much to the productivity of sugarcane. It is still undeniable that nitrogen (N) is the most influential plant nutrient in global sugarcane production, as too little can impact negatively on sucrose production and too much can cause lodging, reduced cane quality and increased risk of pest and disease infestation (Meyer et al. 2007). Among the sources of N, inorganic fertilizer has been widely utilized because of its immediate effect, availability and easy handling. However, the negative environmental impact and escalating cost of inorganic fertilizer have become a public concern. This prompted farmers to recycle farm and sugar mill wastes as organic fertilizers. Mudpress or filter cake, a waste by-product from sugar factories, has a great potential to supply nutrients in addition to its favorable effects on physico-chemical and biological properties of soil (Shankaraiah and Murthy 2005). Another waste from sugar manufacturing, boiler or bagasse ash is rich in K_2O which can be used as fertilizer (Cosico 1985) and liming material due to its high pH (Vance, 1996). Despite the fertilizer and soil amendment value of mudpress and bagasse ash, their application is not widely practiced because of their relatively low nutrient content, indirect nutrient availability and difficulty in handling. These often accumulate at mill sites and generally considered a waste disposal and air pollution problem.

For sustainable sugarcane production, neither chemical fertilizers nor organic manures alone, but their integrated use is highly beneficial (Shankaraiah and Murthy 2005). Complete substitution of inorganic fertilizers by organic fertilizers is not possible to fulfil the large crop nutrient demand. This provides an impetus to develop strategy for a sound combination of different nutrient sources, which will not only improve the efficiency of both the sources but will also minimize the negative effect of over use of chemicals (Chatterjee et al. 2014).

The proper application of fertilizers concerns not only their quality, but also their quantity, as too little of the right fertilizer does not give the most economic return, while too much adversely affects the crop (Chaudhry and Corpuz 1984 as cited by Abayomi 1987). Unbalanced fertilization is also a cause of low nutrient use efficiency (NUE) (Krauss 2001). Indices of NUE include partial factor productivity, agronomic efficiency, apparent recovery efficiency and physiological efficiency (Mosier et al. 2004). Estimates of overall efficiency of applied fertilizer have been reported to be about or lower than 50% for N, less than 10% for P, and about 40% for K (Baligar et al. 2001). Previous studies suggested that commercial sugarcane varieties differ in their nutrient use efficiency particularly nitrogen (Gascho et al. 1986, Stevenson et al. 1992, Robinson et al. 2007), thus indicating a need for variety-specific N recommendations (Meyer et al. 2007). There is likewise an increasing interest in improving nutrient use efficiency of cultivated crops (Schumann et al. 1998) and this is driven by a growing public belief that crop nutrients are excessive in the environment and farmer concerns about rising fertilizer prices and stagnant crop prices (Roberts 2008).

The present study aimed to assess the cane yield and nutrient use efficiency of applied nitrogen, phosphorus and potassium in sugarcane, in terms of partial factor productivity, agronomic efficiency, apparent recovery efficiency and physiological efficiency.

MATERIALS AND METHODS

Treatments and Field Experiment

A field experiment was conducted in an acid Guimbalaon sandy clay loam classified as Typic Hapludand (Carating et al. 2014) in Isabela, Negros Occidental (10^0 10’ N, 122^0 59’ E) situated 41.86 meters above sea level. Treatments were laid out in Randomized Complete Block Design with three replications. The recommended N rate (RR_N) applied through inorganic fertilizer was reduced by 25%, 50% and 75%. This reduction in the amount of inorganic fertilizer was substituted by the application of mudpress. The amount of mudpress used to satisfy the remaining recommended N rate was computed based on its total N content. From these three combinations of inorganic fertilizer and mudpress, another two sets of treatments were made – those which were supplemented with bagasse ash at 10 t ha^{-1}, and those which were added with bagasse ash at 10 t ha^{-1} and microbial inoculant (BioGroe^{TM}) which contains plant growth promoting bacteria (PGPB). Except for the control, all treatments received the same amount of inorganic fertilizer P (105 kg P_2O_5 ha^{-1}) and K (520 kg K_2O ha^{-1}). The detailed amount of inorganic fertilizers and amendments used for each treatment is presented in Table 1. Nutrient contents of the organic amendments in terms of % N (Kjeldahl digestion), % P_2O_5 (extraction and spectrophotometry) and % K_2O (extraction and AAS) were determined and the values are shown in Table 2.

Table 1. Amount and kind of amendments and fertilizers applied per treatment.

Treatments	**Inorganic Fertilizers (kg ha^{-1})**			**Lime (kg ha^{-1})**	**Mud-press (kg ha^{-1})**	**Bagasse ash (kg ha^{-1})**	**Microbial inoculant (PGPB)**
	46-0-0	**0-18-0**	**0-0-60**				
T1 - Control (no fertilizer application)							
T2 - RR_N IF	304.35	583.33	866.67				
T3 - RR_N IF + lime	304.35	583.33	866.67	5,000			
T4 - 75% RR_N IF: 25% RR_N MP	228.26	583.33	866.67		6,363.64		
T5 - 75% RR_N IF: 25% RR_N MP + BA	228.26	583.33	866.67		6,363.64	10,000	
T6 - 75% RR_N IF: 25% RR_N MP + BA + MI	228.26	583.33	866.67		6,363.64	10,000	√
T7 - 50% RR_N IF: 50% RR_N MP	152.17	583.33	866.67		12,727.27		
T8 - 50% RR_N IF: 50% RR_N MP + BA	152.17	583.33	866.67		12,727.27	10,000	
T9 - 50% RR_N IF: 50% RR_N MP + BA + MI	152.17	583.33	866.67		12,727.27	10,000	√
T10 - 25% RR_N IF: 75% RR_N MP	76.09	583.33	866.67		19,090.91		
T11 - 25% RR_N IF: 75% RR_N MP + BA	76.09	583.33	866.67		19,090.91	10,000	
T12 - 25% RR_N IF: 75% RR_N MP + BA + MI	76.09	583.33	866.67		19,090.91	10,000	√

Thirty-six plots were prepared each having a dimension of 160m^2. Cultural and management procedures provided in the Sugar Regulatory Administration Sugarcane Production Manual (SRA-OPSI 2004) were followed. Quality cane points having 3-4 active buds were planted horizontally with buds at both sides. A population density of 40,000 stools ha^{-1} was derived by planting 4 cane points per linear meter. Ridge busting and alternate off-barring and hilling-up were practiced using animal-drawn cultivator. Water, fertilizer and pest management were practiced according to the standard agronomic methodologies of the locality. Sugarcanes were harvested 10 months after planting (February to December) upon attaining physiological maturity, when yellowing of the leaves was uniform, cane stalks turned dark purple and internodes at the terminal portion of the stalks shortened.

Table 2. Nutrient analysis of sugar mill wastes used as organic amendments.

Amendment	% N	% P2O5	% K2O
Mudpress	0.55	0.22	0.22
Bagasse ash	0.02	0.22	1.43

Data Collection and Analysis

Cane yield was obtained from the harvestable area of 108 m^2 consisting of the inner 18 furrows and excluding 4 stools on both sides of the furrow. Total soluble solid (° Brix) determination using a hand refractometer was made to monitor the maturity of cane in the field.

The following indices were computed to measure nutrient use efficiency of applied fertilizer (Mosier et al. 2004):

$$\text{Partial factor productivity (PFP)} = \frac{\text{kg crop yield}}{\text{kg nutrient applied}}$$

$$\text{Agronomic efficiency (AE)} = \frac{\text{kg crop yield increase}}{\text{kg nutrient applied}}$$

$$\text{Apparent recovery efficiency (RE)} = \frac{\text{kg nutrient taken up}}{\text{kg nutrient applied}}$$

$$\text{Physiological efficiency (PE)} = \frac{\text{kg yield increase}}{\text{kg nutrient taken up}}$$

Statistical analysis was performed by the analysis of variance (ANOVA) for randomized complete block design (RCBD) using the Statistical Tools for Agricultural Research (STAR Nebula 2013 version). The significant difference between treatment means was tested by Tukey's Duncan Multiple Range Test (DMRT) at $p \leq 0.05$ when the F-test indicated effects on the significance level of $p \leq 0.05$.

RESULTS AND DISCUSSION

Cane yield

Application of inorganic fertilizer (IF), mudpress (MP), bagasse ash (BA) and microbial inoculant (MI) significantly influenced cane yield (Table 3). The highest cane yield of 120.24 TC ha^{-1} was obtained from plots fertilized with 25% RR_N IF: 75% RR_N MP + BA + MI. Comparable cane yields were also recorded from the following treatments in descending order: 50% RR_N IF: 50% RR_N MP + BA + MI, 25% RR_N IF: 75% RR_N MP + BA, 75% RR_N IF: 25% RR_N MP + BA + MI, 25% RR_N IF: 75% RR_N MP, 50% RR_N IF: 50% RR_N MP + BA, 50% RR_N IF: 50% RR_N MP. These treatments with organic amendments and microbial inoculant can be characterized as high tonnage since yields were ≥ 100 TC ha^{-1} (SRA 2014).

Table 3. Cane yield of Phil 2004-1011 sugarcane variety applied with inorganic fertilizer, organic amendments and microbial inoculant under acid Typic Hapludand.

Treatments	**Cane Yield (TC ha^{-1}) ****
T1 - Control (no fertilizer application)	69.73e
T2 - RR$_N$ IF	93.27d
T3 - RR$_N$ IF + lime	99.39cd
T4 - 75% RR$_N$ IF: 25% RR$_N$ MP	105.08bcd
T5 - 75% RR$_N$ IF: 25% RR$_N$ MP + BA	105.39bcd
T6 - 75% RR$_N$ IF: 25% RR$_N$ MP + BA + MI	114.39ab
T7 - 50% RR$_N$ IF: 50% RR$_N$ MP	107.76abc
T8 - 50% RR$_N$ IF: 50% RR$_N$ MP + BA	110.04abc
T9 - 50% RR$_N$ IF: 50% RR$_N$ MP + BA + MI	117.09ab
T10 - 25% RR$_N$ IF: 75% RR$_N$ MP	110.95abc
T11 - 25% RR$_N$ IF: 75% RR$_N$ MP + BA	116.85ab
T12 - 25% RR$_N$ IF: 75% RR$_N$ MP + BA + MI	120.24a

***=highly significant; CV=6.61; means having same letter are not significantly different at the 5% level by DMRT*

Similar to the findings of Chatterjee et al. (2014), yield attributing characters were significantly influenced by combined application of inorganic, organic and biological sources of nutrients. Addition of biofertilizer under reduced IFs and higher organic sources showed significant positive results over uninoculated treatments. They attributed this to the production of humic acid and humic substances from organic sources which might have enhanced the soil physical condition. Also, fulvic acids released from organic sources are good source of energy for beneficial soil organisms which will have positive impact on nitrogen mineralization and mobilization. Fulvic acids likewise helped in solubilizing the reserved mineral substances making them available for plant uptake throughout the growth period. Also, organic amendments have likely increased balanced availability of essential nutrients, improved soil physical condition, and with microbial inoculant, have improved soil biological fertility status. In sugarcane production, increasing mudpress application resulted to increased cane yield (Bangar et al. 2000, Tiwari and Nema 1999, Quilloy 1983 as reported in SRA-OPSI 2004).

Nitrogen use efficiency

Among the indices of nitrogen use efficiency, treatments significantly affected partial factor productivity (PFP) and agronomic efficiency, but not the apparent recovery efficiency and physiological efficiency (Table 4). The highest crop yield obtained per unit N applied (846.74) was obtained from plots applied 25% RR$_N$ IF: 75% RR$_N$ MP + BA + MI**.** This PFP value was found comparable with those recorded from plots amended with MI, plots applied with IF and MP alone, those with 50% RR$_N$ IF: 50% RR$_N$ MP + BA and 25% RR$_N$ IF: 75% RR$_N$ MP + BA. Increasing amount of MP also resulted in improving PFP values, and the trend generally followed the order observed in cane yield data.

Partial factor productivity of applied N increased gradually with the application of higher amount of organic materials (Chatterjee et al. 2014). This indicated that application of higher amount of organic amendment can efficiently transform the applied nitrogen to economic yield. They likewise found that inoculation of biofertilizer showed marked effect on PFP.

Table 4. Efficiencies of applied fertilizer nitrogen in sugarcane production under acid Typic Hapludand.

Treatments	**Partial Factor Productivity (PFP$_{N}$)** *	**Agronomic Efficiency (AE$_{N}$)** **	**Apparent Recovery Efficiency (ARE$_{N}$)** ^{ns}	**Physiological Efficiency (PFP$_{N}$)** ^{ns}
T1 - Control (no fertilizer application)	-	-	-	-
T2 - RR$_{N}$ IF	666.19d	168.14d	8.86	18.77
T3 - RR$_{N}$ IF + lime	709.93cd	211.88cd	9.59	22.52
T4 - 75% RR$_{N}$ IF: 25% RR$_{N}$ MP	750.60abcd	252.55bcd	9.55	26.52
T5 - 75% RR$_{N}$ IF: 25% RR$_{N}$ MP + BA	742.21bcd	251.17bcd	9.90	27.52
T6 - 75% RR$_{N}$ IF: 25% RR$_{N}$ MP + BA + MI	805.54abc	314.51ab	9.05	36.01
T7 - 50% RR$_{N}$ IF: 50% RR$_{N}$ MP	769.74abc	271.69abc	9.22	30.13
T8 - 50% RR$_{N}$ IF: 50% RR$_{N}$ MP + BA	774.93abc	283.90abc	10.76	27.14
T9 - 50% RR$_{N}$ IF: 50% RR$_{N}$ MP + BA + MI	824.58ab	333.54ab	9.61	36.92
T10 - 25% RR$_{N}$ IF: 75% RR$_{N}$ MP	792.52abc	294.48abc	9.04	33.15
T11 - 25% RR$_{N}$ IF: 75% RR$_{N}$ MP + BA	822.91ab	331.88ab	11.20	29.32
T12 - 25% RR$_{N}$ IF: 75% RR$_{N}$ MP + BA + MI	846.74a	355.70a	10.29	37.25
Mean	**773.26**	**279.04**	**9.73**	**29.57**

** = significant; CV =6.57; means with the same letter suffix are not significantly different at the 5% level by DMRT*

The highest increase in crop yield obtained per unit of N applied, i.e. agronomic efficiency (AE) of 355.70 was likewise obtained from plots applied with 25% RR_N IF: 75% RR_N MP + BA + MI. Similarly higher AE was obtained from plots applied with MI and those plots receiving 50%:50% and 25%:75% combinations of IF and MP, with and without the addition of BA (Table 4). Agronomic efficiency varied remarkably with the source of nutrients and showed an increasing trend with increased level of organic materials (Chatterjee et al. 2014). Improvement in agronomic efficiency using maximum amount of organic material with biofertilizer inoculation could be due to optimum availability of N as per crop demand and reduced N loss leading to efficient uptake and utilization of applied N (Singh et al. 2008).

Apparent recovery efficiency of applied N (ARE_N), which is the ratio of nitrogen uptake with nitrogen applied, was not significantly different among treatments. ARE_N values ranged from 8.86 obtained from plots applied with RR_N IF to 11.20 from plots applied with 25% RR_N IF: 75% RR_N MP + BA. Response to applied N is higher for the ratoon crop than for planted cane, with a mean ARE_N of 30 percent on farms and 40 percent for research plots (Basanta et al. 2003 as cited by Balasubramanian et al., 2004). They further conveyed an ARE_N for planted cane to vary from 0 to 40 percent. Apparent recovery followed an increasing trend with increased level of N application through organic materials (Chatterjee et al. 2014). They found that apparent recovery is the expression of N uptake by the fertilized plants rather than the amount of N applied. Since not all of the amount of N applied is taken up by crops due to different venues of nutrient loss, the apparent recovery thus reflects the fraction that was actually taken-up and utilized by the fertilized plants.

In a similar manner, physiological efficiency (PE) values was comparable among treatments, which implies that differences in N uptake among treatments did not cause significant variation in increasing crop yield. PE values ranged from 18.77 (RR_N IF) to 37.25 (25% RR_N IF: 75% RR_N MP + BA + MI). In contrast to this finding, superior value of PE under higher organic material combination could be the result of higher yield and better conversion of source to sink (Chatterjee et al. 2014).

Phosphorus use efficiency

Treatment effects were noted on the partial factor productivity, apparent recovery efficiency and physiological efficiency of applied P, but not on the agronomic efficiency (Table 5). The highest partial factor productivity (2151.30) of applied P was derived from plots with RR_N IF + lime. This is attributed to the ability of lime in neutralizing soil acidity which in turn improved P availability (Baligar et al. 2001). This PFP value was found comparable with those obtained from plots applied with RR_N IF and plots fertilized with 75% RR_N IF: 25% RR_N MP. On the other hand, agronomic efficiency values ranged from 509.52 to 719.86 which shows that the magnitude of increase in crop yield per unit of P applied did not differ markedly. The quantity of P taken up per unit of P applied, i.e. ARE, varied with treatments where the application of RR_N IF + lime recorded the highest ARE of 2.92. This was followed by the following treatments in descending order of ARE: RR_N IF (2.65), 75% RR_N IF: 25% RR_N MP (2.60), 75% RR_N IF: 25% RR_N MP + BA + MI (2.06).

In terms of physiological efficiency of applied P, the highest magnitude of crop yield increase per unit of P taken up was obtained from plots applied with 25% RR_N IF: 75% RR_N MP + BA + MI which is 391.94.. Likewise, treatments comprising of IF + MP + BA + MI, IF + MP + BA, and IF + MP (except the 75%:25% combination) had comparably higher PE. These treatments were able to efficiently convert the nutrient taken up into biological and economic yield. The recovery of applied fertilizer P ranges from less than 10 % to as high as 30 % in the initial year of application (Ghosh et al. 2015). However, because fertilizer P is considered immobile in the soil and reaction (fixation and/or precipitation) with other soil minerals is relatively slow, long-term recovery of P by subsequent crops can be much higher.

Table 5. Efficiencies of applied fertilizer phosphorus in sugarcane production under acid Typic Hapludand.

TREATMENTS	**Partial factor productivity (PFP_P)** **	**Agronomic efficiency (AE_P)** ^{ns}	**Apparent recovery efficiency (ARE_P)** *	**Physiological efficiency (PFP_P)** *
T1 - Control (no fertilizer application)	-	-	-	-
T2 - RR_N IF	2018.76ab	509.52	2.65ab	189.59d
T3 - RR_N IF + lime	2151.30a	642.06	2.92a	218.32cd
T4 - 75% RR_N IF: 25% RR_N MP	2006.94ab	675.26	2.60ab	257.21bcd
T5 - 75% RR_N IF: 25% RR_N MP + BA	1698.80cd	574.90	2.06bc	279.11abcd
T6 - 75% RR_N IF: 25% RR_N MP + BA + MI	1843.76bc	719.86	2.06bc	353.63ab
T7 - 50% RR_N IF: 50% RR_N MP	1841.48bc	649.98	2.17bc	300.87abcd
T8 - 50% RR_N IF: 50% RR_N MP + BA	1613.49d	591.10	2.16bc	282.26abcd
T9 - 50% RR_N IF: 50% RR_N MP + BA + MI	1716.86cd	694.48	1.92bc	375.95ab
T10 - 25% RR_N IF: 75% RR_N MP	1715.42cd	637.39	1.99bc	321.71abc
T11 - 25% RR_N IF: 75% RR_N MP + BA	1571.45d	633.76	2.34abc	278.47abcd
T12 - 25% RR_N IF: 75% RR_N MP + BA + MI	1616.95d	679.26	1.77c	391.94a
Mean	**1799.56**	**637.05**	**2.24**	**295.37**

** = significant; CV =6.57; means with the same letter suffix are not significantly different at the 5% level by DMRT*

Potassium use efficiency

Partial factor productivity and physiological efficiency of applied K were affected by treatments, while comparable results were manifested in agronomic efficiency and apparent recovery efficiency (Table 6). The most efficient treatments in terms of producing crop yield per unit of K applied were those involving IF and MP regardless of proportion. The PFP values obtained from plots applied with RR_N IF and RR_N IF + lime also had higher PFP values. Increase in crop yield per unit of K applied, i.e. agronomic efficiency was not affected by treatments. On the average, a kilogram of K applied will cause a yield increase by 76.16 kg. In terms of apparent recovery efficiency, values ranged from 1.72 to 2.53 which indicates higher K recovered in plant tissue than what was applied through fertilizers and amendments. The soil had considerable level of indigenous K which were taken up by the plant in conjunction with K from external inputs. There was a significant increase in crop yield per unit of K taken up which is revealed in varying PE values. The different treatments affected the rate at which sugarcane converted the absorbed K into dry matter and cane yield. The highest PE value of 50.37 was obtained from plants fertilized with 25% RR_N IF: 75% RR_N MP + BA + MI. This would mean that a kilogram of K taken up would cause a kilogram increase in crop yield by 50 times. Statistically similar PE values were obtained from plants amended with MP, MP + BA, and MP + BA + MI. First-year recovery of applied K can range from 20 to 60 % (Ghosh et al. 2015). Potassium is generally considered to have a higher use efficiency than N and P because it is immobile in most soils and is not subject to the gaseous losses that N is or the fixation reactions that affect P.

Table 6. Efficiencies of potassium fertilizer in sugarcane production under acid Typic Hapludand.

Treatments	**Partial Factor Productivity (PFP_K)** **	**Agronomic Efficiency (AE_K)** ^{ns}	**Apparent Recovery Efficiency (ARE_K)** ^{ns}	**Physiological Efficiency (PFP_K)** *
T1 - Control (no fertilizer application)	-	-	-	-
T2 - RR_N IF	216.10abc	54.54	2.18	24.69c
T3 - RR_N IF + lime	230.28ab	68.73	2.53	26.86bc
T4 - 75% RR_N IF: 25% RR_N MP	237.09a	79.77	2.23	35.93abc
T5 - 75% RR_N IF: 25% RR_N MP + BA	187.56d	63.47	1.84	34.76abc
T6 - 75% RR_N IF: 25% RR_N MP + BA + MI	203.57cd	79.48	1.89	42.22ab
T7 - 50% RR_N IF: 50% RR_N MP	236.93a	83.63	2.16	38.77abc
T8 - 50% RR_N IF: 50% RR_N MP + BA	191.86cd	70.29	2.02	36.26abc
T9 - 50% RR_N IF: 50% RR_N MP + BA + MI	204.16cd	82.58	1.75	48.23a
T10 - 25% RR_N IF: 75% RR_N MP	237.86a	88.38	2.13	43.64a
T11 - 25% RR_N IF: 75% RR_N MP + BA	199.70cd	80.54	2.07	39.79abc
T12 - 25% RR_N IF: 75% RR_N MP + BA + MI	205.48bcd	86.32	1.72	50.37a
Mean	**213.69**	**76.16**	**2.05**	**38.32**

** = significant; CV =6.57; means with the same letter suffix are not significantly different at the 5% level by DMRT*

CONCLUSION

The findings demonstrated the potential of combined inorganic and organic sources in improving the N and K use efficiency of sugarcane. Integrated nutrient management where organic and inorganic fertilizers are used simultaneously as a source of diversifying N recorded improved nitrogen use efficiency. Application of lime resulted to better partial factor productivity and apparent recovery efficiency of applied P. Combined use of inorganic fertilizer and mudpress enhanced partial factor productivity of applied K, while addition of bagasse ash and microbial inoculant increased physiological efficiency of applied K. Integrated nutrient management through the combined use of inorganic, organic and biofertilizers increased cane yield and improved N and K use efficiency. Thus, this practice is recommended for sustainable and efficient sugarcane production.

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