THE EFFECTS OF STILLAGE (VINASSE) ON NINE RATOON CROPS OF NCo376 RECEIVING FULL IRRIGATION IN THE SOUTH-EAST LOWVELD OF ZIMBABWE

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Abstract

Stillage ranging from 0-2% concentration was applied to sugarcane via irrigation. Stillage, which contains up to 1 000 ppm N, was used as a substitute for N fertiliser and supplied between 60 and 180 kg N/ha/annum from the first to the ninth ratoon. Available soil K levels in the topsoil were also increased from 0,45 to 1,37 me% with no visible signs of potassium toxicity, despite high levels in the plant. Uptake of major elements increased with both applied stillage and N. Stillage reduced the incidence of smut but increased capping of the topsoil and clod formation at plough-out. Infiltration of water was nevertheless satisfactory. Similar results were obtained in a fifteen-year commercial trial at Triangle Estate, which showed that stillage applied at 1% concentration provided adequate P and K.

Keywords: stillage, vinasse, dunder

Introduction

Stillage, or vinasse, is the waste product of alcohol production plants which ferment molasses to produce ethanol by distillation. Triangle Ltd and Hippo Valley Estates (HVE) have plants with annual production capacities of 40 and 3,5 million litres of ethanol respectively. About 13 litres of stillage are produced for every litre of ethanol produced. Stillage is difficult to dispose of in the environment as it fouls streams and kills riverine life when discharged into waterways. Stillage contains high concentrations of potassium and nitrogen and lower amounts of other plant nutrients (unpublished data, Zimbabwe Sugar Association Experiment Station). It was decided to evaluate the disposal of stillage onto cane as a source of nitrogen and potash. Wenman and Tannock (1984) reported a cane yield increase of 7% and savings in potash, but were concerned about long term effects of stillage on the soil microflora and physical properties. The long term effects of high K on the soil were unknown and had to be monitored.

Materials and methods

Replicated trial

Stillage composition

Pre-trial analyses of representative samples of HVE stillage, collected over a nine month period in 1980, are shown in Table 1. The stillage contained high concentrations of potassium and lower concentrations of other plant nutrients such as nitrogen, phosphate, sulphur and minor elements. Vinasse from Brazil showed lower P and K concentrations and higher calcium levels (Gloria *et al.*, 1973).

Treatments

The HVE trial was sited on a siallitic PE1/P2 soil derived from gneiss (Thompson and Purves, 1978). A split-plot randomised block design with four replicates was used. The sugarcane variety NCo376 was planted in 1,5 m rows. Gross plot size was 12 rows x 50 m for stillage irrigation treatments. Gross and net plot sizes of the split plots were 12 rows x 10 m, and 10 rows x 8 m respectively. The main treatments consisted of an irrigated control (raw water without stillage) and four irrigation treatments containing stillage at concentrations of 0,25, 0,5, 1,0 and 2,0% respectively. Split-plot treatments comprised fertiliser N applied at rates of 0, 60, 120 and 180 kg N/ha.

Table 1

Comparison of HVE stillage in 1980 with results from Brazil (Gloria *et al.*, 1973)

(Concentrations expressed in mg element per litre)

Measurement	HVE	Brazil
pH	4,45	4,6
Electrical conductivity (micro S/cm)	13 500	–
Total solids (% w/v)	4,05	–
Dissolved solids (% w/v)	3,95	–
Nitrogen	<1 000	700
Phosphorus*	300 – 400	90
Potassium*	6 475	3 800
Calcium	150 – 350	1 200
Magnesium	200 – 400	400
Sulphur	1 330 – 3 000	1 200
Sodium	40 – 60	–
Iron	13 – 34	57
Manganese	1,9 – 5,6	6
Copper	0,06 – 0,82	4
Zinc	0,05 – 7,6	4

* Zimbabwe uses units of P_2O_5 and K_2O
To convert P to P_2O_5 multiply by 2,29
To convert K to K_2O multiply by 1,20

Irrigation of 60 mm was applied in the furrow when a 50 mm open pan deficit had been reached. Irrigation water inflow was measured using a 28° V-notch weir, and tail water (outflow) was measured using a Washington State College trapezoidal flume (Cackett, 1984). Irrigation treatments were maintained for nine months, followed by drying-off, which commenced about two months before harvest. In the first irrigation after each harvest, 300 mm of water was applied to all plots to bring the soil profile to field capacity and provide a small surplus for leaching.

Trial establishment and management

The trial was established in September 1981 using good quality raw water from Lake Mutirikwi (previously known as Lake Kyle), classification code C_1S_1 (Anon, 1969), with a residual sodium carbonate content of less than 1,25 me/l). Fertiliser applications to the plant crop comprised 140 kg N/ha, 44 kg P/ha and 50 kg K/ha. All subsequent ratoons received 44 kg P/ha and 50 kg K/ha per year, all applied between four and six weeks after cutting. Ratoon crop nitrogen was applied in two equal dressings at four and eight weeks after harvest. Application of the stillage treatment was started after cutback of the plant crop at nine months in June 1982. The first harvest following treatment was therefore the first ratoon crop in 1983. The trial was continued for a further eight ratoons and was terminated in June 1991 due to drought. Stillage quality was monitored throughout the trial. The composition of stillage was determined by analysis after each irrigation. The pH, conductivity, total solids and total K, as well as total N, were measured from the fifth ratoon onwards.

The following routine operations were carried out on each crop and for each plot:

- recording of disease and roguing of smut at a crop age of 8, 12, 16, 20, 28, and 32 weeks
- leaf sampling of the top visible dewlap at a crop age of 14, 18, 22, 26 and 30 weeks
- soil sampling at depths of 0-30, 30-60 and 60-90 cm before planting and thereafter annually after harvesting each crop.

Soil samples were analysed for pH, saturation paste and extract conductivities, available P, K, Ca, Mg and Na (Saunder and Meterlerkamp, 1962). The leaf samples were tested for total N, P, K, Ca, Mg and Na. Each crop was harvested at between 11,7 and 12,2 months of age. At harvest, representative millable cane stalk samples were taken from each plot for determination of pol, brix, moisture, fibre and reducing sugars. Results were expressed in terms of estimated recoverable crystal (ERC) % cane, ERC yield (t/ha), estimated recoverable fermentables (ERF) % cane and ERF yield (t/ha). Records were made of net plot cane weights, stalk numbers, diameters and lengths, and crops were rated for lodging and flowering.

The periodic non-availability of stillage and variation in stillage composition, caused by changes to production plans, meant that stillage concentrations had to be adjusted to ensure that the various treatments were maintained at the required concentration levels.

Estimation of uptake of major nutrients

Two weeks before harvesting the fourth ratoon, representative samples of cane were taken from each plot. Each sample was partitioned into leaves, tops and millable stalks which were weighed before being analysed for total N, P, K, Ca and Mg after wet digestion (Matibiri, 1986),

Commercial trial

In 1980, Triangle Ltd first applied stillage at a concentration of 1% through an irrigation system to selected cane fields. Adjacent fields of similar soil type were used as untreated controls. In this trial conventional N, P and K fertiliser was applied to fields not receiving stillage. Amounts were based on soil analysis data.

Results

Replicated Trial: HVE

Stillage dilution rates achieved

The actual mean stillage dilution rates achieved over the nine ratoons on HVE were 1,9, 1,1, 0,6 and 0,3% for the 2,0, 1,0, 0,5 and 0,25% treatments respectively.

Stillage compostion from the first to the ninth ratoon is shown in Table 2. Stillage dilution rather than composition was very variable, as the electrical conductivity and concentrations of solids, potassium and nitrogen varied on the basis of dilution.

Table 2

Range in stillage composition from first to ninth ratoon

Range	pH	Total solids (% w/v)	Total K (ppm K)	Total N* (% N)	Electrical conductivity (micro S/cm)
Mimimum	2,17	0,3	90	0,06	430
Mean	4,46	6,8	8 003	0,16	18 762
Maximum	10,48	15,4	19 700	0,38	39 500

* from fifth to ninth ratoon only

Amounts of total solids, K and N applied in stillage

The amounts of K and N applied in stillage, and the actual dilution rates achieved for each treatment, are given in Table 3.

Table 3

Amounts of total solids, K and N applied in the 2% stillage treatment (mean of nine ratoons)

Stillage concentration (% v/v)	Actual dilution (% v/v)	Stillage applied (mm)	kg/ha/annum		
			Total solids	K	N*
0,25	0,30	3,0	1 879	207	48
0,50	0,55	5,5	3 505	384	92
1,00	1,05	10,3	6 494	745	182
2,00	1,85	19,6	13 175	1 458	345

* from fifth to ninth ratoon only

Effects of stillage on soil nutrient status

The effect of 2% stillage treatment on selected properties of the topsoil are shown in Figures 1 and 2.

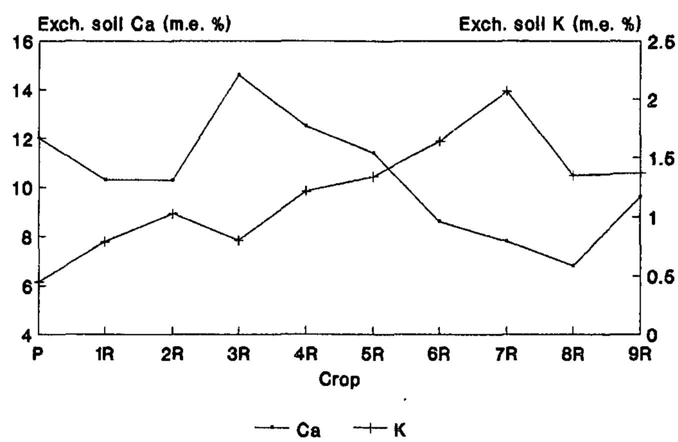

FIGURE 1: Effect of 2% stillage on soil exchangeable Ca and K levels

There was a large increase in available K from 0,45 me% in the plant crop to 1,37 me% after the ninth ratoon. However, it was apparent that in this soil type, the soil concentration at which K becomes toxic to cane, had not been reached. When the trial was terminated high yields were obtained from the 2% stillage treatment. Available Ca and Na levels, and total bases (ie K + Ca + Mg + Na) decreased over the same period. Similar trends were observed in the 30-60 and 60-90 cm soil profiles. The electrical conductivity (EC) of the soil did not appear to be affected by rainfall. The EC rose from 338 Siemens/cm at the start to 428 at the end of the trial, and the pH ranged between 6,1 and 6,6. Magnesium levels were close to 4,0 me% and sodium levels varied between 0,2 and 0,9 me%. There were no real trends over time.

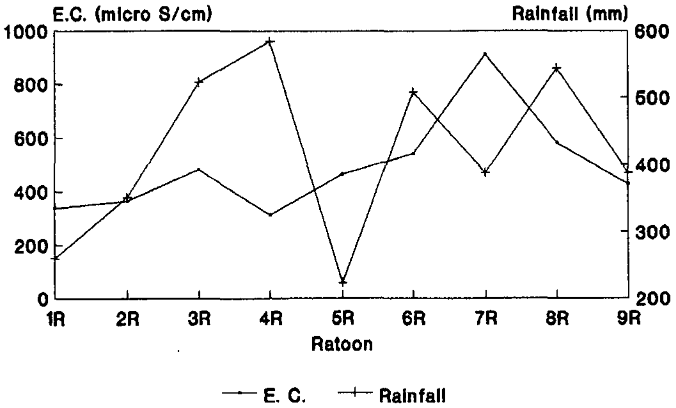

FIGURE 2: Effect of 2% stillage on soil conductivity in relation to rainfall (EC sat. extract)

Effects of stillage on physical properties of the soil

Stillage applications caused a hardening of the topsoil and increased the formation of clods. Hardening of the soil appeared to be in proportion to the amount of stillage applied. However, this occurrence did not appear to hinder penetration of the soil profile by irrigation water.

N and stillage effects on cane yield and quality of the ninth ratoon

Results for the last ratoon show benefit from stillage and the interaction with N application (see Table 4). Application of the highest concentration of stillage alone produced 111 tons cane/ha, which was significantly more than the yield from untreated plots (47 tons cane/ha) and only 21% below the highest yielding treatment, which produced 142 tons cane/ha. The response to stillage alone at 2% concentration was equivalent to the application of 120 kg N/ha with no stillage. The highest yields were produced by a combination of stillage + N.

Table 4

Interaction table for ninth ratoon: cane yield

Stillage concentration (% v/v)	Cane yield (t/ha)				
	Levels of N (kg/ha)				Mean
	0	60	120	180	
Control, no stillage	46,6	80,3	108,9	120,5	89,1
0,25	79,6	112,0	121,1	134,7	111,8
0,50	91,9	114,4	133,6	140,4	120,1
1,0	111,4	129,1	139,1	133,9	128,4
2,0	112,0	139,9	128,3	142,3	130,6
Trial mean	88,3	115,1	126,2	134,4	116,0
Significance interactions	***				
LSD P=0,05	16,7				
P=0,01	22,9				

The lowest concentration of stillage was the most effective at the highest rate of N and as concentration of stillage increased the amount of N required to maximise yield was reduced by 60 kg N/ha/annum. The highest concentration of stillage benefited from additional N.

Responses to stillage treatments

Cane quality

Except for the first ratoon, ERC and ERF % cane levels were depressed as stillage concentration increased. This trend was present but non-significant in the second, third and seventh ratoons but was significant in the other crops. Increased N levels could be a reason for the decline in quality.

Cane yield

There were no significant responses to stillage applications in the early ratoons. The first significant response occurred in the fourth ratoon when cane yields increased with amount of stillage applied. These responses continued and became more pronounced in later ratoons.

Yield of sugar and fermentables

ERC and ERF yields increased with stillage concentration. Responses were significant from the fourth ratoon onwards.

Cane quality and yield

Significantly lower cane quality was obtained with increasing levels of N in all crops. Cane yields were significantly suppressed with applications below 120 kg N/ha. Highly significant increases in ERC and ERF yields were obtained with higher levels of applied N.

Stillage dilution x nitrogen interactions

Cane quality

There were no consistent response patterns. Significant but weak interactions were obtained only in the first, sixth and seventh ratoons for ERC % cane; and only in the seventh and ninth for ERF % cane.

Yield responses

Stillage increased cane, ERC and ERF yields in all crops (see Table 5). The effects were statistically significant in all ratoons except the third. The magnitude of the interactions intensified after the third ratoon. In the absence of applied N the cane, ERC and ERF yields were boosted as the concentration of applied stillage increased. This effect was reduced at 60 kg N/ha and was absent at 120 and 180 kg N/ha.

Quality and yields obtained by applying stillage

Using the cane, ERC and ERF yields, the N benefit from irrigating with 2% stillage only was less than 60 kg N/ha in the first ratoon, but increased with advancing ratoons to a maximum of 180 kg N/ha in the eighth ratoon.

Table 5

Quality and yields obtained by applying stillage only (mean of nine ratoons)

Stillage concentration	0	0,25	0,5	1,0	2,0
Cane yield (t/ha)	57	70	80	91	100
ERC % cane	13,18	13,05	13,08	12,72	12,15
ERF % cane	13,64	13,70	13,83	13,78	13,58
ERC yield (t/ha)	7,5	9,2	10,6	11,6	12,1
ERF yield (t/ha)	8,1	10,0	11,5	12,6	13,6

Best treatment combination

The best cane yields were usually obtained with the 180 kg N/ha treatment, combined with the 2% stillage treatment. However, these high cane yields were generally offset by lower quality, when sugar and fermentable yields were considered. The 120 kg N/ha treatment combined with either 1% or 2% stillage were best, with the 1% treatment giving marginally higher ERC and ERF yields.

Uptake of major nutrients

The magnitude of uptake was influenced by yield. Uptake of nutrients from the low yielding zero stillage treatment (47 tons) to the highest stillage concentration (111 tons) showed that uptake of most elements increased by between 61 and 87%. The exceptions were potassium and magnesium, which increased by 137 and 153% respectively. In terms of leaf analysis no visual symptoms of major or minor nutrient deficiencies or toxicities were observed. K levels, however, increased with the amount of stillage applied and rose to an above normal level of 1,4%.

Smut infection levels

Smut infection was high at the start of the trial, but decreased rapidly over the first five ratoons and more slowly from the fifth to the ninth ratoon. Stillage reduced smut incidence as concentrations increased from 11 and 28%. In contrast, nitrogen increased the incidence of smut by between 4 and 11%. Laboratory investigations showed that the high nutrient content of the stillage enhanced spore germination. This possibly reduced the number of viable spores in the soil in subsequent ratoons (Anon., 1987).

Commercial trial: Triangle Estate

The data from two commercial fields showed that yields remained similar before and after stillage application. In particular, stillage resulted in savings of 22 kg P/ha/annum and 77 kg K/ha/annum in one field and 24 kg P/ha/annum and 27 kg K/ha/annum in the other. The yields obtained corresponded with the HVE trial yields. Soil analysis showed that both P and K levels increased when stillage was applied, whereas Ca and Mg tended to decrease.

Discussion

The results from the HVE trial have underlined the interaction between stillage and applied N. The rate of applied N should be adjusted on the basis of the concentration of stillage. Stillage alone produced a satisfactory yield of 112 tons cane/ha. This can be increased to 140 tons/ha with 60 kg N/ha. The soil and leaf analysis data from both HVE and Triangle indicate the benefits of stillage to both soil nutrient levels and leaf nutrient uptake. Recommendations for the future can be made by combining the results from the two trials. Application of 2% stillage and 60 kg N/ha/annum or 1% stillage and 120 kg N/ha/annum should adequately supply the P and K requirement without loss in production. The proviso would be that deep, welldrained soils are used and that infiltration of water is not impaired. The use of stillage should be monitored by carrying out regular leaf and soil analyses. Results from Australia have shown that dunder (stillage) increased cane yields and soils were capable of absorbing large and repeated applications without any serious changes, and tended to revert to their initial condition when treatment was withdrawn (Stewart and Wood, 1991). Studies on the use of vinasse (stillage) in Brazil confirmed that stillage increases the aggregate stability of soil (Mazza *et al.*, 1986). This would account for the increased tendency of the trial soils to form clods as stillage application increased. Camargo (1954) reported that vinasse increased the number of micro-organisms in the soil in Brazil and Ranzani (1956) showed improved water holding capacity. The influence of the latter effect could account for stillage reducing the effects of drought which were noticeable, particularly in the tenth ratoon.

Conclusions

The results of the trial at HVE and the commercial applications made at Triangle both show long term benefits from the use of stillage on cane. Stillage alone should be capable of producing 110 tons cane/ha on good soils. The interaction between stillage and N indicates that the best results are obtained by combining stillage treatment with additional N. The results from Triangle Ltd indicate that stillage supplies adequate P and K and that there would be no need to apply P or K when the two highest concentrations of stillage are used. A practical commercial recommendation based on these results would be to apply 1% stillage and 120 kg N with no P or K. Leaf, soil and water analyses, as well as effects on infiltration, leaching and smut, should be monitored when using stillage. Cane receiving stillage is also more resistant to moisture stress. Stillage should be considered a valuable source of N, P and K fertiliser.

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