ABNORMAL NITROGEN REQUIREMENTS OF SUGAR CANE ON THE MONTMORILLONITIC BLACK CLAY SOIL OF THE KAFUE FLATS IN ZAMBIA

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Introduction

Large scale cane growing trials on the Kafue Flats, Zambia, were initiated by the Tate & Lyle Group in September, 1963, in collaboration with the Rhodesian Selection Trust Group on the 700 acre Kafue Pilot Polder.

Soil Characteristics

The soils of the Kafue Flood Plain, which covers an area of 1.3 million acres, are some of the heaviest tropical black clays in the world, averaging 70 per cent clay, of which more than half consists of Montmorillonite. This high percentage of Montmorillonitic clay causes the soil to have very marked swelling, shrinkage and cracking properties. On wetting, the soil swells to a compact, structureless, impervious mass, and on drying out shrinkage causes extensive cracking. In an established crop this cracking may ramify through the top three feet of soil. The somewhat specialised methods of crop management evolved on these lands are governed by these physical properties. Infiltration of irrigation water depends almost entirely on cracking. The cracks allow lateral movement of water for considerable distances and up to sixty feet has been recorded. Below about four feet, the subsoil is permanently wet and virtually impermeable, so that losses through deep percolation are negligible. The severe drainage problem brought about by the characteristics of this soil when wet are overcome by growing crops either on cambered beds or on high ridges. Other relevant properties of the soil are that it is not readily leached and the pH is neutral. Free lime and gypsum are often found.

Fertiliser Requirement

Of the major nutrients, the main response is obtained from *Nitrogen* and exceptionally heavy applications are needed. Phosphates also give a positive yield improvement. No response is obtained from Potash.

It would appear that mineralisation of organic Nitrogen is severely restricted, and this prevents crops from obtaining Nitrogen from any organic matter in the soil, so that Nitrogen has to be applied as straight chemical fertiliser.

Cane Trials

By 1963 it had already been demonstrated in a small trial plot on the Polder that very high yields of cane could be obtained on these soils, the major agronomic problems to be contended with being:

(*a*) The design of *a field layout* combining a system of cheap surface irrigation with the necessity for good drainage, especially during the summer rains.

(*b*) The selection of *varieties* best suited to the conditions.

(*c*) The control of *weeds* during the summer rains when it is usually difficult, if not impossible, to keep the lands clean by conventional hand weeding methods.

(*d*) The overcoming of the excessively *high Nitrogen* requirements.

System of Cane Irrigation

Two basic systems of irrigation are being used:

(i) *Furrow Irrigation* — over graded lands at 1:600, with line lengths of 700 feet.

(ii) *Flood irrigation of level basins* — basin areas varying from 6.5 to 13.5 acres, with line lengths ranging from 400 feet to 950 feet.

Under both systems cane is grown on high and well-formed ridges resembling the Louisiana Bank System. The basin irrigation method is the easiest to manage and requires only 2 labourers to handle 10 cusecs of water.

Nitrogen Requirements

Indications from Foliar Diagnosis and Fertiliser Trials

Kerkhoven (1963) found that the nitrogen requirements for cotton, maize and rice on these soils were very high — in the region of 200-240 lb. of actual N. per acre, and for sugarcane 400-500 lb. N. For this reason all fertiliser trials laid down in 1963 and 1964 included treatments with Nitrogen levels up to 600 lb. N per acre.

The first trial laid down in October, 1963, was harvested in October, 1964.

Design:	Randomised block, 10 treatments, 5 replicates.
Plot size:	1/66 acre.
Planted:	7th October, 1963.
Variety:	Co.419.
Harvested:	26th October, 1964.
Age at Harvest:	12½ months.

Treatments

4 Levels of Nitrogen

0 lb. N per acre =	0 lb. Sulphate of Ammonia
100 lb. N per acre =	476 lb. Sulphate of Ammonia
300 lb. N per acre =	1,428 lb. Sulphate of Ammonia
600 lb. N per acre =	2,857 lb. Sulphate of Ammonia

3 Levels of Phosphate

0 lb. P_2O_5 per acre =	0 lb. Double Superphosphate.

80 lb. P_2O_5 per acre = 210 lb. Double Superphosphate.
160 lb. P_2O_5 per acre = 421 lb. Double Superphosphate.

No Potash was applied as previous experiments had shown that no response had been obtained from Potash applications.

All the Phosphate was applied at planting.

The Nitrogen treatment of 100 lb. N per acre was applied at planting. The other Nitrogen treatments received two equal dressings, half at planting and the remainder at 3 months of age.

Leaf Analysis

Leaf samples were taken on the 7th April when the cane was at 6¼ months from planting. Analysis of the leaf lamina of the middle third of 20 leaves was carried out and the content of the major nutrients was expressed as a percentage of the dry weight. The analytical results followed remarkably closely to the Nitrogen application.

For comparative purposes the *minimal* optimum levels of nutrients in cane leaves at 5 months of age are shown for Jamaica. These levels are considered by R. F. Innes to be as follows:

N — 1.80%
P_2O_5 — 0.42%
K_2O — 1.40%

If nutrient levels are below these standards it is considered that insufficient nutrient has been available to the plant and that an economic increase in yield would have been obtained from additional fertiliser.

The standards which would apply to Zambia have unfortunately not been determined.

The results of the trial, together with leaf analysis figures are laid out in Table I.

Comments

(*a*) *Leaf Analyses*

(i) Nitrogen content of leaves at the N-0 and N-100 levels showed a marked deficiency. N-300 treatments were low and only at the N-600 level was the optimum attained.

(ii) Phosphate contents were good at all levels of fertilisation, though with indication of some suppression at the higher rates of N.

(iii) Potash contents were adequate throughout.

(*b*) *Yields*

Yield data, in tons cane per acre, are summarised in Table II:

Table II

Yield in Tons Cane per acre

Treatment	P_2O_5 = 0 lb.	P_2O_5 = 80 lb.	P_2O_5 = 160 lb.	Average Nitrogen
N = 0 lb.	(40.3)	—	—	(40.3)
N = 100 lb.	46.8	48.3	51.2	48.8
N = 300 lb.	51.2	61.5	54.7	55.8
N = 600 lb.	64.7	67.9	69.4	67.3
Average P_2O_5	54.2	59.2	58.4	57.3

These results show highly significant increases in yield from N-0 up to N-600. Response to P_2O_5 shows a significant increase in yield of 5.0 T.C.A. from P-0 to P-80, followed by a very slight depression from P-80 to P-160.

(*c*) *Juice Quality*

Effects of treatments on juice quality, expressed in terms of tons cane/tons sugar ratio, are summarised in Table III.

Table I

TREATMENT lb. Nutrient per acre	LEAF ANALYSIS AT SIX MONTHS as percentage of dry weight			YIELD DATA		
	Standard Minimal Nutrient content					
$N.P_2O_5.K_2O$	N 1.80%	P_2O_5 0.42%	K_2O 1.40%	Tons cane per acre	Tons cane/ Tons sugar ratio	Tons Sugar per acre
600-160-0	1.90	0.44	1.62	69.4	8.81	7.88
600- 80-0	1.89	0.48	1.50	67.9	8.93	7.69
600- 0-0	1.90	0.49	1.64	64.7	9.27	6.98
300-160-0	1.65	0.53	1.54	54.7	8.24	6.64
300- 80-0	1.65	0.51	1.52	61.5	8.49	7.25
300- 0-0	1.61	0.57	1.58	51.2	8.57	5.98
100-160-0	1.54	0.51	1.56	51.2	8.34	6.14
100- 80-0	1.42	0.51	1.56	48.3	8.34	5.80
100- 0-0	1.39	0.52	1.56	46.8	8.37	5.59
0- 0-0	1.49	0.52	1.56	40.3	8.42	4.79

L.S.D. = 3.34 T.C.A. (at P = .05)

Table III

Tons Cane/Tons Sugar Ratio

Treatment	P_2O_5 = 0 lb.	P_2O_5= 80 lb.	P_2O_5= 160 lb.	Average Nitrogen
N = 0 lb.	(8.42)	—	—	(8.42)
N = 100 lb.	8.37	8.34	8.34	8.35
N = 300 lb.	8.57	8.49	8.24	8.30
N = 600 lb.	9.27	8.93	8.81	9.00
Average P_2O_5	8.74	8.59	8.46	8.55

These results show little variation in TC/TS ratios at the lower levels of Nitrogen from N-0 to N-300, followed by a sharp deterioration of 0.70 TC/TS from N-300 to N-600. Increasing Phosphate has shown a trend of a steadily improving TC/TS ratio from P-0 to P-160.

Conclusions

Owing to the serious effect on juice quality at 600 lb. Nitrogen, it appeared that there would be a case for reducing the level in plant cane to between 300 and 450 lb. The effect of Phosphate on juice quality was interesting, and indicated that at any level of Nitrogen from 300 to 600 lb. it would be worthwhile to apply at least 80 lb. of Phosphate per acre.

Additional Experimental Results

1. *Ratoon Fertiliser Trial* (*Co.331*), *1964 crop*

Results of a ratoon cane fertiliser trial harvested in 1964, although not statistically significant, showed up two further important trends. Treatments in this experiment included Nitrogen at 300, 450 and 600 lb. with single and split application at each level, all plots receiving a standard dressing of 120 lb. P_2O_5 and 60 lb. K_2O.

At the higher levels of Nitrogen there was a notable increase in yield coupled with a sharp deterioration in juice quality when split application of fertiliser was made. The first application was made on the 26th October, 1963, and the second on the 15th February, 1964, which is normally considered very late. It is felt that there will be a real benefit in applying Nitrogen in two stages, *provided* that the second and final application is made within three months of planting or harvesting, and before January.

Table IV

Yield in Tons Cane per Acre

Treatment	P_2O_5 = 0 lb.	P_2O_5= 80 lb.	P_2O_5= 160 lb.	Average Nitrogen
N = 0 lb.	(25.05)	—	—	(25.05)
N = 100 lb.	37.36	40.46	41.74	39.85
N = 300 lb.	45.34	45.38	48.00	46.24
N = 600 lb.	48.75	49.66	52.98	50.46
Average P_2O_5	43.82	45.17	47.57	45.51

2. *Ratoon Fertiliser Trial* (*Co.419*), *1965 crop*

The 10 by 5 randomised block N.P. trial referred to previously (see Tables I, II and III) was continued in the 1st ratoon crop, with identical treatments. The results of this trial when harvested in 1965, at 10 months of age, are summarised in Table IV and Table V.

These results show very marked increases in yield with increasing Nitrogen, with some flattening off of the response curve from N-300 to N-600. Yields increase linearly with increasing Phosphate from 0 lb. to 160 lb. of P_2O_5 per acre.

The results of the ratoon experiment, when compared with the plant yield of the same trial, show a general reduction in yields. This is probably attributable to:

(i) Inferior drainage due to flattening of ridges, which were not reformed (as is now a routine practice) in the ratoon crop.

(ii) The 1st ratoon crop was reaped at 10 months only — 2½ months younger than the plant crop.

Table V

Tons Cane/Tons Sugar Ratio

Treatment	P_2O_5 = 0 lb.	P_2O_5= 80 lb.	P_2O_5= 160 lb.	Average Nitrogen
N = 0 lb.	(8.23)	—	—	(8.23)
N = 100 lb.	8.84	8.88	9.02	8.91
N = 300 lb.	9.59	10.44	10.01	10.01
N = 600 lb.	10.08	9.99	9.95	10.01
Average P_2O_5	9.50	9.77	9.66	9.64

Increasing Nitrogen levels have caused a progressive deterioration in juice quality from N-0 up to N-300. The mean TC/TS ratio at N-600 is the same as that at N-300.

Phosphate has in this case had little effect on juice quality.

3. *Plant Cane Fertiliser Trials* (*Co.419*), *1965 crop*

Results of an 8 by 5 randomised block N.P. trial laid down in Co.419 plant cane in 1964, when harvested at 12½ months of age in 1965, are summarised in Table VI and Table VII.

Table VI

Yield in Tons Cane per Acre

Treatment	P_2O_5—80 lb.	P_2O_5—120 lb.	Average Nitrogen
N — 100 lb.	41.47	40.57	41.02
N — 300 lb.	61.29	56.62	58.96
N — 450 lb.	56.33	62.81	59.57
N — 600 lb.	68.62	68.48	68.55
Average P_2O_5	56.93	57.12	57.02

Cane yields show a progressive increase from N-100 to N-600, the most notable response being an increase of 17.94 T.C.A. from N-100 to N-300. Increasing Phosphate from P_2O_5-80 to P_2O_5-120 has not brought about any significant increase in yield.

Table VII

Tons Cane/Tons Sugar Ratio

Treatment	P_2O_5—80 lb.	P_2O_5—120 lb.	Average Nitrogen
N — 100 lb.	8.51	8.51	8.51
N — 300 lb.	9.80	9.37	9.59
N — 450 lb.	9.23	9.57	9.40
N — 600 lb.	10.18	9.91	10.05
Average P_2O_5	9.43	9.34	9.39

These figures show the usual trend of deteriorating juice quality with increasing levels of Nitrogen, with the exception of an apparent slight improvement from N-300 to N-450. Increasing Phosphate has again had little effect on juice quality.

Conclusions

The results of the trials harvested in 1965 confirm that the optimum Nitrogen level under the present system of cultivation should be in the order of *300 lb. actual N per acre.* At higher rates the yield response curve generally begins to flatten out and TC/TS ratios deteriorate. Increasing Phosphate above 80 lb. P_2O_5 per acre has not brought about any significant increases in yield or juice quality.

Drainage Depth, Interaction upon Nitrogen Requirement

During the course of the 1964/65 growing season an important physical factor influencing Nitrogen uptake came to light. This was a very critical "drainage depth" (this being defined as the depth of temporary water tables caused by flood irrigation and during heavy storms). Jelley (1964) found in other crops that not only were yields affected by a relationship between growth and depth of temporary water tables, but that there also exists a strong interaction between Nitrogen and drainage. For efficient use of Nitrogen at high yield levels, a drainage depth of 8 in. to 12 in. was indicated. This effect was clearly demonstrated in cane. Even before the onset of rains, cane on ridges where irrigation water had risen close to the crest, or cane which had been completely submerged over areas of local depression showed stunted growth, poor tillering and severe Nitrogen deficiency symptoms in spite of receiving 525 lb. N. In general, the higher the ridges are above the temporary water level, the better the growth has been. For example, a 7.25 acre basin which yielded an overall average of 72.82 tons cane per acre when harvested as plants in 1965, at 13 months of age, gave 91.99 tons cane per acre over a measured better drained local area of 2.40 acres.

Field Scale Fertiliser Applications, Costs and Cane Yields

(a) 1963/64 Crop

The basic fertiliser dressing applied to the first land planted to large scale cane trials in September, 1963, was as follows:

Nitrogen — 100 lb. N per acre (as 476 lb. Sulphate of Ammonia).

Phosphate — 160 lb. P_2O_5 per acre (as 421 lb. Double Superphosphate).

Potash — Nil.

By January, 1964, severe Nitrogen deficiency symptoms became apparent. The cane was a very pale green and tillering was poor. Leaf samples taken in this Co.419 plant cane at 3½ months of age gave the following dry weight percentage analysis:

Nutrient	N.	P_2O_5	K_2O
Standard minimal level for 3½ month cane . . .	2.00	0.44	1.42
100-160-0	1.69	0.77	1.66
Comments	Deficient	Very High	Good

In view of this, and Kerkhoven's findings referred to in Section 1, it was decided to apply a large top dressing of Nitrogen to overcome the severe deficiency symptoms and to bring the level into line with his recommendations. The crop was top dressed in February with 350 lb. N per acre (using Sulphate of Ammonia at 1,667 lb. per acre); this brought the total nutrient application up to 450-160-0. Response to the additional Nitrogen was rapid and a spectacular greening up of the yellow cane canopy was observed.

This late planted field went on to yield an average of 61 tons cane per acre when harvested at 12 months of age.

(b) 1964/65 Crop

In July, 1964, when further cane planting on the Polder was commenced, no cane had yet been harvested on these soils and it was necessary to arrive at a reasonable level of Nitrogen application based on the limited information available. On the strength of leaf analysis results from the fertiliser trial shown in Table I it was decided that the standard field dressing should provisionally be:

(i) *For plants:*

Nitrogen — 525 lb. N per acre (as 2,500 lb. Sulphate of Ammonia, half at planting, half at 3-4 months).

Phosphate — 95 lb. P_2O_5 per acre (as 250 lb. Double Superphosphate, at planting).

Potash — Nil.

Cost: £31 10s. per acre.

Plant cane receiving the above treatment went on to yield 73 tons cane per acre at 13 months of age.

(ii) *For ratoons*

Nitrogen — 525 lb. N per acre (as 2,500 lb. Sulphate of Ammonia, half after cutting, half at 3 months).

Phosphate — 76 lb. P_2O_5 per acre (as 200 lb. Double Superphosphate, after cutting).

Potash — Nil.

Cost: £30 15s. per acre.

Ratoon cane receiving the above treatment yielded 62 tons cane per acre at *only* 10 months of age.

The standard dressing already established for upland red soils was 111-76-0 (200 lb. Sulphate of Ammonia + 200 lb. Double Superphosphate at planting or after harvest, and 150 lb. Urea at 3 months) costing £6 15s. per acre, and the high cost of Nitrogen fertilisation on the Polder soils was a matter of considerable concern.

(*c*) *1965/66 Crop*

Results of the fertiliser trials harvested in late 1964 and during the 1965 cropping season indicated that a reduction in the Nitrogen application could be made to 300 lb. N per acre and a reduction in phosphate application to about 80 lb. P_2O_5 per acre. The standard field dressing for the 1966 crop (now as 1st and 2nd ratoons) was therefore fixed at:

Nitrogen — 315 lb. N per acre (as 1,500 lb. Sulphate of Ammonia, half after cutting, half at 3 months).

Phosphate — 76 lb. P_2O_5 per acre (as 200 lb. Double Superphosphate, after cutting).

Potash — Nil.

Cost: £19 14s. per acre.

The cost of fertilising at the above rates represents a reduction of £11 per acre below the 1964 ratoon cane cost, but is still about triple that incurred on nearby upland red soils — however, measured yields from well drained sections of fields, where drainage depths are adequate, have shown a yield potential of over 90 tons cane per acre in 12 months. If, by improved land preparation and management, such yields can be achieved on a commercial scale, then a fertiliser requirement of 300-80-0 would be economically justified, especially taking into account the very low cost of water application under the basin system of irrigation — within an empoldered estate — close to the perennial Kafue River.

Summary

The Montmorillonitic soils of the Kafue Flats are described, followed by notes on the agronomic aspects of cane growing on these lands, with special reference to the excessively high Nitrogen requirements indicated by early trials carried out at the Kafue Pilot Polder.

The system of cane cultivation and irrigation as practised on the Kafue Pilot Polder is briefly described.

Foliar analyses made during the 1963/64 growing season indicated a Nitrogen requirement of between 300 and 600 lb. actual N per acre. Fertiliser trials harvested in 1964 and 1965 showed that the optimum Nitrogen level could be reduced to 300 lb. N per acre.

The interaction between Nitrogen and drainage depth is discussed.

The standard dressing already established for upland red soils was 111-76-0, costing £6 15s. per acre. Following on the results of fertiliser trials harvested in 1964 and 1965 the standard field application on the Black Clay soils has been 315-76-0, using 1,500 lb. Sulphate of Ammonia (half after cutting, half at 3 months) and 200 lb. Double Superphosphate per acre, costing £19 14s. per acre — still almost triple that incurred on the upland red soils — however, given good drainage, yields of over 90 tons cane per acre in 12 months can be achieved on these lands under a very cheap system of irrigation.

Acknowledgments

We wish to record our appreciation of the assistance given by the Management and staff of the Kafue Pilot Polder and the help subsequently given by the Government of Zambia, who took over the Polder as the Kafue Irrigation Research Station in July, 1965.

The authors thank the Directors of the Ndola Sugar Company Limited for permission to publish this paper and acknowledge the help given by M. E. Johnson, the Company's Research Assistant, who carried out most of the field work on these trials during 1964 and 1965.

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Mr. R. A. Wood: It would appear that nitrogen losses are the main reason for the abnormal requirements on this soil. Large quantities of sulphate of ammonia are being applied to a neutral soil in which nitrification will be rapid. Once this occurs on a poorly drained soil in which the water table is close to the surface, nitrogen losses, resulting from denitrification under these anaerobic conditions, will be very severe. The main problem therefore is one of trying to reduce these losses, which could amount to more than 50 per cent of the nitrogen applied, by improved drainage and judicious timing of fertilizer applications.

Mr. Booth: It is felt that one reason for high fertilizer nitrogen requirements is possibly lack of mineralisation of organics.

Mr. Wood: Anaerobic conditions might cause denitrification.

Mr. du Toit: How and when is nitrogen applied?

Mr. Booth: Nitrogen is applied as sulphate of ammonia, one half at planting (placed in the furrow) or immediately after harvesting, and one half as a top dressing at three months.

Mr. du Toit: I have never before heard of such fantastic nitrogen applications and at least 80 or 90 per cent must be lost so I think that the time and method of application should be reviewed.

Mr. Booth: Trials incorporating different nitrogen carriers and using single and split applications of fertiliser are being carried out. So far these have not given any significant results, though in the case of split applications there is a trend towards higher yields coupled with deteriorating juice quality unless the second application is made within three months of planting or harvesting.

Mr. Gunn: How was sucrose calculated?

Mr. Booth: Sucrose was calculated from Brix and Pol readings taken on 20 cane samples crushed in the laboratory mill. Tons cane/tons sugar ratios were calculated from sucrose % juice using assumed Java Ratio, mill extraction and "Boiling House Recovery" figures.

Mr. Gunn: Did you worry about juice purity?

Mr. Booth: Yes, very much so.