A CONTRIBUTION TO PLANT PHYSIOLOGICAL DIAGNOSIS

Analysis of a long-term factorial fertilizer experiment with maize on acid Hutton soil series

(With summary in Afrikaans)

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Abstract

A fertilizer formula — irrespective of its actual cost — can bring the farmer profit or loss depending on how well it satisfies the particular requirements of a particular site.

Soil analysis as complemented by plant-tissue analysis helps in determining these particular requirements. Indeed, fertilizer applications provoke complex chain reactions within the plant itself — as illustrated in this paper — that can only be observed using plant analysis. The knowledge of this 'physiological mechanism' is essential for establishing the most adequate fertilizer formula.

Soil analyses help in knowing what is 'offered' to the plant on a particular site. Plant analyses help in knowing what is 'required' by the plant on this particular site.

The complementary nature of plant and soil analyses is therefore essential to the better knowledge of this law of supply and demand between soil and plant, the correct use of which is a basis for rational ie profitable cultivation.

Introduction

There is perhaps some justification on occasion for questioning the return from fertilizer applications on farmers' lands.

A fertilizer formula, irrespective of its actual cost, can bring the farmer profit or loss depending how well it satisfies the particular requirements of a particular site.

In this paper, special attention is given to the complementary nature of plant and soil analyses as a scientific basis for the establishment of the best 'tailor-made' fertilizer application.

The material in this study is based on an NPK lime factorial experiment on a soil of the Hutton series at the Bapsfontein Research Station of Messrs African Explosives and Chemical Industries Limited. This experiment has been the subject of a number of previous investigations (Dijkhuis 1968; Djikhuis, Dudding & Clayton 1969; and Skeen, Dudding & Clayton 1972).

Experimental procedure

The experiment which consists of two replications of a 3P x 2 lime factorial with split plots to contain a 3N x 3K factorial was commenced in 1957/58 and is still in progress in a slightly altered form. The total amount of nutrients applied over the first 12 years is given in Table 1. Further details of the experiment are presented by Dijkhuis, Dudding & Clayton (1969).

Soil and leaf samples were taken from all plots in January, 1969. Soil samples were analysed for pH in N KCl, clay and organic matter content, Bray No 2 extractable P and N NH_4 OAc extractable K, Ca and Mg. Leaf samples were analysed for moisture content, N by Kjeldalh and P (NO_3 not included) K, Ca, Mg, S, Cl, Mn, Fe and Zn by X-ray fluorescence spectrometry.

Soil analysis of the 0000 plot was qualitatively as follows (actual data are presented in Table 12).

Mg very low	Organic matter 1,57: good
Ca low	pH (KCl) low
P low	Clay 23%
K low	Al excessive (Skeen et al 1972)

Physiological Diagnosis (PD) corrected indices for maize leaves (Beaufils 1971 and 1965/72) indicating plant requirements in order of importance from the 0000 plot were as follows

K : —80		Fe : + 44	
P : —70		Cl : + 243	
N : —28	S:0	Mg : + 504	
H_2O: — 16		Ca : + 548	
Zn : — 15		Mn : + 564	

Note. There was no incompatibility between the situation of Ca and Mg in soil and plant tissues. The excess observed in the tissues was the result of an abnormal accumulation most likely due to K, P and N deficiencies as will be shown later.

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TABLE 1 Total amounts of nutrients applied in 12 years (kg per ha)

As urea		As superphosphate					As potassium chloride			As lime		
	N		P	S	Ca	Mg		K	Cl		Ca	Mg
N0	0	P0	0	0	0	0	K0	0	0	L0	0	0
N1	636	P1	276	385	656	22	K1	318	318	L1	2 838	242
N2	1 272	P2	552	770	1 312	44	K2	636	636			

Results and discussion

(a) Effect of treatments on soil composition

The effects of long-term fertilizer applications on soil composition are presented in Table 2. The acidifying effect of urea is clearly illustrated by the significant decreases in pH value and extractable Ca and Mg. Both superphosphate and potassium chloride applications have significantly increased the P and K contents of the soil respectively. In addition potassium dressings decreased both P and Mg levels in the soil which although significant are small. As expected, lime applications have significantly raised the pH and Ca and Mg levels in the soil. Although not significant, there is a tendency for urea to depress soil K, lime to depress organic matter and soil P and superphosphate to increase organic matter content.

The depressive effect of urea on soil pH only reaches significance in the presence of lime (Table 3) as in its absence the pH of the soil is almost at its ultimate value at which the soil is very strongly buffered.

The interaction of P, K and lime in Table 4 shows that lime and K together tend to decrease the soil P content. The reason for this decrease could result from the greater P uptake on plots receiving both K and lime and/or as a result of the partial neutralization of the acid in the Bray extracting solution in samples receiving lime which would lead to a lower recovery of P (Dekkers, 1971). A consideration of the P uptake in terms of PD indices (Table 5) for the same interaction (PK lime) tends to show that even if KCl applications have an antagonistic effect on P uptake, lime on the contrary tends to promote this uptake.

TABLE 2 Main effect of fertilizer treatments on the chemical composition of a Hutton soil over a period of 12 years

SOIL TEST	FERTILIZER FACTOR														
	N			K			LSD*	P			LSD	LIME		LSD
	0	1	2	0	1	2	P = 0,05 P = 0,01	0	1	2	P = 0,05 P = 0,01	0	1	P = 0,05 P = 0,01
pH KCl	4,56	4,40	4,26	4,42	4,39	4,41	0,123 0,164	4,42	4,47	4,32	ns	3,93	4,89	0,242 0,379
OM (%)	1,37	1,45	1,28	1,38	1,39	1,33	ns	1,28	1,29	1,53	ns	1,46	1,27	ns
P (ppm)	40,4	37,3	40,1	41,2	38,7	37,9	2,49 3,33	15,1	34,6	68,1	12,28 19,26	43,2	35,3	ns
K (ppm)	84,2	75,8	70,9	53,4	74,3	103,3	11,08 14,78	77,5	69,7	83,8	ns	75,8	78,2	ns
Ca (ppm)	417,6	374,4	321,9	382,5	362,8	368,9	31,33 41,80	326,7	391,8	395,4	ns	194,4	548,2	62,21 83,11
Mg (ppm)	53,7	44,9	35,4	48,8	44,3	40,9	4,58 6,12	40,6	48,4	45,1	ns	23,4	65,9	9,40 12,55

*Refers to both N and K

TABLE 3 Effect of urea and lime on the pH value of a Hutton soil

	N0	NI	N2	LSD	
				P = 0,05	P = 0,01
L0	3,98	3,93	3,85	0,174	0,232
LI	5,14	4,86	4,65		

TABLE 4 Effect of superphosphate, potassium chloride and lime applications on the extractable P content (ppm) of a Hutton soil

		P0	PI	P2	LSD (rows)	
					P = 0,05	P = 0,01
L0	K0	16,3	43,3	75,0	14,47	19,31
	K1	16,2	35,7	72,8		
	K2	15,2	35,2	79,0		
LI	K0	14,7	31,2	66,7		
	K1	14,0	31,7	61,7		
	K2	14,0	30,8	53,2		

LSD (columns) P = 0,05 17,19
P = 0,01 22,93

TABLE 5 Effect of superphosphate, potassium chloride and lime applications on PD indices for leaf P

		P0	P1	P2
L0	K0	−14	55	61
	K1	−50	3	15
	K2	−51	−15	−7
L1	K0	8	61	85
	K1	−37	12	34
	K2	−55	−14	−9

(b) Effect of treatments on leaf composition and yield
The main effect of fertilizer treatments on leaf composition (expressed both on the dry matter basis and as PD indices) and current yields are presented in Table 6. Because in this particular case, all the leaf samples were taken at the same time and because the treatments had little effect on the moisture content of the leaves (although small significant differences are present), conclusions drawn from the data expressed on a dry matter basis will not be affected.

TABLE 6 Main effects of fertilizer treatments on leaf composition (1968/69) and yield

LEAF FACTOR	FERTILIZER FACTOR													
	N			K			LSD* P=0,05 P=0,01	P			LSD P=0,05 P=0,01	Lime		LSD P=0,05 P=0,01
	0	1	2	0	1	2		0	1	2		0	1	
H_2O (% FM)	71,1	71,6	71,9	71,3	71,3	72,0	0,50 0,70	71,9	71,2	71,5	ns	71,5	71,5	ns
N (% DM)	2,12	2,30	2,43	2,32	2,26	2,25	0,05 0,07	2,31	2,26	2,27	ns	2,30	2,26	ns
N (PD index)	18	28	39	62	20	3	9,9 13,2	33	28	24	ns	24	33	ns
P (% DM)	0,19	0,20	0,21	0,21	0,20	0,19	0,008 0,011	0,16	0,21	0,23	0,007 0,011	0,20	0,20	ns
P (PD index)	1	2	10	43	−4	−25	9,0 11,9	−33	17	30	13,0 20,4	0	9	ns
K (% DM)	1,65	1,53	1,47	0,98	1,60	2,07	0,11 0,15	1,76	1,44	1,45	0,19 0,30	1,65	1,45	0,16 0,24
K (PD index)	−18	−30	−50	-105	−16	22	16,5 22,0	1	−45	−54	25,5 39,9	−23	−42	ns
S (% DM)	0,24	0,24	0,25	0,26	0,24	0,23	0,008 0,010	0,25	0,24	0,25	ns	0,25	0,24	0,004 0,006
Cl (% DM)	0,65	0,66	0,63	0,54	0,68	0,72	0,04 0,05	0,63	0,66	0,65	ns	0,65	0,64	ns
Ca (% DM)	0,81	0,82	0,84	1,00	0,79	0,68	0,06 0,07	0,70	0,86	0,91	0,10 0,16	0,76	0,89	0,12 0,17
Mg (% DM)	0,34	0,36	0,36	0,45	0,34	0,27	0,04 0,05	0,31	0,37	0,38	ns	0,32	0,39	0,06 0,09
Fe (ppm)	213,8	204,7	231,6	230,3	211,9	207,8	14,25 19,01	236,2	211,4	202,4	20,04 31,42	228,8	204,6	14,6 22,8
Mn (ppm)	188	208	343	272	246	220	45 60	252	243	244	ns	317	176	126 168
Zn (ppm)	21	23	23	25	22	20	1 2	26	21	19	1 2	21	23	1 3
YIELD 1967/68 kg/ha	3 780	4 650	4 750	3 460	4 585	5 130	36,2 48,3	3 695	4 660	4 830	61,9	4 070	4 720	61,9
YIELD 1968/69** kg/ha	112	169	170	66	176	209	38,7 51,7	28	210	213	84,1 131,9	159	142	ns

*Refers to both N and K

**1968/69 was a severe drought year which caused a severe reduction in yield. Leaf samples were taken before the drought started.

TABLE 7 Effect of urea and lime on manganese content of leaves (ppm)

	N0	NI	N2	LSD P = 0,05	LSD P = 0,01
Lo	198	256	496		
LI	179	160	189	124,6	190,7
LSD	P = 0,05 63,9 P = 0,01 85,1				

TABLE 8 Effect of urea and potassium chloride on yield (1967/68) in kg/ha

	N0	NI	N2	LSD P = 0,05	LSD P = 0,01
Ko	3 495	3 422	3 462		
KI	3 837	4 960	4 972	1 338	1 786
K2	4 031	5 570	5 840		
LSD	P = 0,05 1 338 P = 0,01 1 736				

The data in Table 6 show that the effects of fertilizer treatments on leaf composition follow a logical and expected pattern. The notion of balance between nutrient elements within the plant is well illustrated as antagonistic effects (eg between K and Ca and Mg) and as synergistic effects (eg between N and P) caused by the various fertilizer applications. The acidifying effect of urea on this soil is clearly brought out by the increase in Mn and Fe levels in the leaf. The precipitation of Mn within the plant, blocks vascular tissue which limits growth, development and yield. Liming remedies this situation by reducing the solubility of Mn and Fe compounds in the soil (Table 7)

Because of severe drought in February 1969 the yields for the 1968/69 season (Table 6) are very low and for this reason yields for the previous season are also presented. The pattern of yield response to fertilizer factors is similar for both seasons despite the lack of rain which emphasizes the relative resistance to drought induced by balanced fertilization.

A significant NK interaction on yield (Table 8) shows that a response to N only occurs at an adequate level of K which according to a PD diagnosis of the 0000 plot is the most limiting nutrient factor. In this particular case the most profitable combination appears to be N_1K_2.

The PK interaction (Table 9) is only significant in the drought year 1968/69 although the same tendency is shown in 1967/68. As the supply of both P and K to the root is diffusion-controlled, the quantities of these nutrients reaching the root during the dry spell would be severely reduced as under these conditions the water films in the soil would become discontinuous and thereby reduce diffusion. Thus the higher the levels of P and K together in the soil the greater the chance the plant would have to take up more P and K and thereby increase yield.

TABLE 9 Effect of superphosphate and potassium chloride on yield (1967/68 and 1968/69) in kg/ha

	1967/68				1968/69			LSD	
	P0	PI	P2	LSD	P0	P1	P2	P = 0,05	P = 0,01
K0	3 174	3 492	3 722		27	89	82		
K1	3 700	4 880	5 200	ns	34	256	237	67,1	89.5
K2	4 228	5 600	5 595		25	283	320		
LSD	ns				LSD	P = 0,05 99,7 P = 0,01 148,1			

The antagonism between K and Ca is clearly shown in Table 10 where the K_2 level is required to eliminate the depressive effect of lime on K uptake.

TABLE 10 Effect of potassium chloride and lime on K content of leaves

	L0	Ll	LSD P = 0,05	LSD P = 0,01
Ko	1,09	0,87		
K1	1,80	1,40	0,160	0,213
K2	2,06	2,08		
LSD	P = 0,05 P = 0,01	0,220 0,329		

In order to show how imbalanced fertilization can lead to severe losses in practice a balance sheet for the 1121 and 0220 treatments is presented in Table 11. The imbalanced treatment (0220) has resulted in a loss of R111/ha over 12 years despite the fact that the P application was twice the amount of the 1121 treatment which returned a profit of + R485/ha for the same period.

Table 12 which reports and illustrates soil and leaf analysis results for some typical combinations shows how plant nutritional balance has reacted according to treatments. A diagnosis of the control plot shows that

dolomite lime is required in order to increase soil pH, Ca and Mg and to reduce Mn toxicity.

K, P, N and Zn are required with predominance of K over P and N in order to restablish the balance towards normal.

TABLE 11 Balance sheet of fertilizer costs and value of crop for two selected treatments over 12 years

Treatment	N (kg/ha/12 years)	P (kg/ha/12 years)	K (kg/ha/12 years)	Lime (kg/ha/12 years)	Total fertilizer cost/ha*	Total value of increased yield/ha*	Profit or loss/ha
1121	636	276	636	6700	R288	R133	+R485
0220	0	542	636	0	R244	R773	—R111

*1971 prices

TABLE 12 Soil and corresponding leaf analysis for some typical combinations

Treatment combinations	Soil analysis: pH in KCl; elements in ppm					Leaf analysis: H_2O% fresh matter; elements on dry matter basis											PD Schematic for NPK*			Yields over 12 years kg/ha	Yields/gains over control	
NPKL	pH	P	K	Ca	Mg	H_2O	N%	P%	K%	S%	Ca%	Cl%	Mg%	Fe ppm	Zn ppm	Mn ppm	N	P	K		Actual	%
0000	4,2	17	57	213	36	70,9	2,17	0,16	1,26	0,24	0,86	0,60	0,40	257	26	210	→	↓	↓ ↘	2 437	0	—
1110	3,7	33	66	133	21	71,2	2,31	0,22	1,43	0,25	0,79	0,77	0,35	212	20	278	→	→	↓ ↓	3 682	+1 245	+51%
2220	3,8	83	96	123	10	72,6	2,43	0,22	1,69	0,25	0,82	0,73	0,28	197	18	408	→	→	↘ ↘	4 128	+1 691	+69%
1111	5,4	29	69	544	77	71,4	2,23	0,20	1,13	0,24	0,99	0,79	0,58	214	22	186	→	→	↓ ↓	2 978	+1 541	+63%
1121	4,8	29	92	435	57	71,1	2,33	0,22	2,05	0,23	0,68	0,72	0,30	202	22	159	→	→	→	4 387	+1 950	+80%
0220	3,9	79	117	261	33	71,0	2,05	0,19	2,12	0,24	0,64	0,66	0,30	209	20	187	↓	↓	→	2 765	+3 282	+13%

*(Beaufils 1971)

Treatment 1121 is the most economical fertilizer combination (Dijkhuis et al 1969)

Treatment 0220 is one of the un-economical fertilizer combinations

The closest existing combination to satisfy these requirements is 1121 which has also proved to be the most economical one in this particular case (Dijkhuis et al 1969).

Note. Regarding treatment 0220 where an imbalanced formula containing an unnecessary amount of P was applied, the P deficency observed in the tissues of the control plot has not been corrected. Only soil P content has improved confirming the lack of uptake of this element.

Conclusions

Establishing profitable fertilizer recommendations for farmers' lands is a scientific process.

Soil analysis complemented by plant tissue analysis in each particular case — although delicate and somewhat complex — constitutes a reliable and useful — if not necessary — basis for this process.

This not only helps in knowing what is required by the plant in order to establish a treatment but also in understanding and explaining how soil and plant react to the treatment.

Opsomming

ANALISE VAN 'n LANGTERMYN FAKTORIALE BEMESTINGSPROEF MET MIELIES OP SUUR HUTTON GRONDSERIE.

Of 'n bemestingsprogram 'n wins of 'n verlies vir die boer beteken, hang af van hoe goed dit in die spesifieke behoeftes van die betrokke terrein voorsien, afgesien van die werklike koste daarvan.

Grondontledings, ondersteun deur plantmateriaalontledings, help mee om hierdie spesifieke behoeftes te bepaal. Soos hierin aangedui, ontsluit kunsmistoedienings kettingreaksies binne die plant, iets wat slegs deur plantontledings waargeneem kan word. 'n Begrip van hierdie 'fisiologiese meganisme' is noodsaaklik vir die bepaling van die mees toereikende bemestingsprogram.

Terwyl grondontledings 'n aanduiding gee van wat die plant 'aangebied' word op 'n spesifieke grond, gee plantontledings weer 'n aanduiding van wat die plant se 'behoefte' op daardie plek is.

Die komplimentêre aard van plant- en grondontledings is dus noodsaaklik vir 'n beter begrip van hierdie wet van aanbod en vraag tussen grond en plant, en die regte gebruik van hierdie wet is die basis vir rasionele, dit wil sê winsgewende, gewasverbouing.

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