THE MAINTENANCE OF SOIL FERTILITY WITH SPECIFIC REFERENCE TO NITROGEN, PHOSPHORUS, POTASSIUM AND LIME

(Met opsomming in Afrikaans)

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Abstract

The long-term effect of the application of nitrogen, phosphorus, potassium and lime individually and in combination on the response of maize on a Hutton soil type was studied. Annual nitrogen requirements are determined primarily by the expected yield and the results demonstrate the necessity for high N applications if sustained high yields are to be achieved.

Annual applications of P, in excess of plant requirements, brought about a gradual build-up of this nutrient in the soil, resulting in a situation where residual P eventually provided the main source of supply to plants. The soil test level for P above which no further response to applied fertilizer can be expected was shown to be of the order of 30-40 ppm (Bray No 2). Maintenance dressings are thereafter required to ensure that this level does not drop from year to year. The available information, however, does not permit an estimate to be made of what constitutes a maintenance dressing, nor does it provide an indication of the quantity of P required to raise the soil-test level from a given value to a sufficiency level of 30-40 ppm.

Responses to applied K gradually increased over the seasons despite the fact that K also showed a gradual build-up in the soil. This trend suggests that greater demands are made to fill the needs brought about by a general increase in fertility over the years. This trend in response to K emphasises the need to monitor continuously changes taking place over a period longer than one or two seasons only.

The application of lime to eliminate toxic Al had a marked effect on increasing the response to applied nutrients and thus increasing yields. The results further showed that at least three seasons were required for maximum effect and that mainteance dressings are required to prevent the regeneration of toxic Al.

Introduction

In an extensive agricultural system, fertilizer usage is generally not very high and soil testing provides a useful tool for determining fertilizer practices. Responses to applied fertilizer are usually spectacular since inherent soil fertility has been depleted by years of exhaustive cropping. With the intensification of agricultural production, greater amounts of fertilizer are used resulting in a gradual build up of available nutrients. Often no immediate responses can be measured and conventional soil testing as a diagnostic tool for determining fertilizer requirements is extended to its limit. A greater degree of sophistication and refinement is required in the interpretation of diagnostic data in order to maintain a high level of fertility management.

In determining the upper level of fertilization, economic considerations must be included in the final recommendations. The value of the expected crop increase in relation to the cost of the fertilizer must be estimated if farm profits are to be maximised. In evaluating a fertilizer programme, soil-test results must be backed by sound, well-directed research, if interpretations and judgements are to provide a recommendation that will ensure optimum economic returns.

Unfortunately the results of fertility experiments are often used for purposes not originally intended in the design, with the result that the amended objectives are seldom reached. Soil-test calibration studies are often attempted from limited results in which individual responses to applied fertilizer cannot be isolated in view of the confounding effect of residual fertilizer. Interpretation of response curves are further subject to additional error in that too few nutrient levels are included in the design. In most cases, the standard 3^3 factorial (as well as the incomplete factorial) is used as an all-purpose design but unfortunately does not lend itself to soil-test calibration studies nor does it allow optimum annual requirements to be accurately fixed.

However, in the long-term, these experiments provide invaluable guidelines for the development of a sound advisory service. Accumulation or depletion of nutrients and the development of distinct fertility patterns from selected fertilizer programmes can be followed. The objective of this paper, therefore, is to discuss the results of a long-term nitrogen (N), phosphorus (P), potassium (K) and lime factorial (on maize) with the view of assessing its value as an aid in establishing an efficient and reliable advisory service based on soil testing.

Experimental

The information presented in this paper expresses the results of a $3^3 \times 2$ NPK and lime factorial experiment which was conducted at the Bapsfontein Research Farm of African Explosives and Chemical Industries Limited (Annual Reports of Agricultural and Biological Group). The experiment was commenced in 1957/58 and is still in progress although in a slightly amended form. The results reflect the reaction and response of maize to fertilizer and lime on the Hutton soil series under an average annual rainfall of approximately 700 mm per annum.

Elemental nutrient rates applied, in kg/ha, are as follows

N0	0	P0	0	K0	0
N1	53	P1	23	K1	26,5
N2	106	P2	46	K2	53

Phosphorus, as single superphosphate, was banded at planting using a conventional row-planter while N as urea and K as potassium chloride (KCl) were side-dressed and cultivated in when the maize plants were 30 cm high. Lime was not applied at any fixed interval or rate but only as and when required as judged by soil pH measurements. Lime was applied as calcium hydroxide in 1957 (2 ton/ha), as calcitic agricultural lime in 1960 and 1961 (2 ton/ha) and as dolomitic agricultural lime in 1966 (2 ton/ha). Plant pop-

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ulation was fixed at 35 000 plants per hectare and with the exception of 1957/58 and 1958/59 hybrid maize seed was planted.

Individual plots were sampled for soil analysis to a depth of 20 cm at the end of each season. Soil P was extracted with a Bray No 2 solution (soil:solution ratio 1:7,5 and shaking time of 40 seconds) and soil K was extracted with neutral normal ammonium acetate (soil:solution ratio 1:10 and shaking time of 15 minutes). Exchangeable aluminium (Al) index (EAI) was determined according to the method of Reeve (1970) using KCl as extractant and borax as the titrant. Soil pH was measured in a 1:2,5 soil:solution ratio.

Results and discussion

Despite the fact that this soil is inherently fertile (the 'zero' plot which received no fertilizer or lime shows an 11-year average yield of 2 215 kg grain per hectare), relatively large responses were obtained from the application of N, P, K and lime individually and in combination. Dijkhuis, Dudding & Clayton (1969) summarise the average yields for the various treatment combinations over an 11-year period.

In view of the large dependence of yield on rainfall and the even greater dependence on the seasonal distribution of the rain, the fertilizer combination required for maximum yield varied from year to year. The optimum NPK combination — and consequently profitability — also varied accordingly. Although the experimental results show that on the average, a fertilizer combination comprising 53 kg N, 23 kg P, 53 kg K and adequate lime would be the most economical, it is incorrect to suggest that this combination is the most profitable in view of the large class intervals between nutrient rates. In spite of the over-riding climatological influence, clear fertility patterns developed.

Response to applied nitrogen

Response to applied nitrogen fertilizer (main effects) over eight seasons are shown in Figure 1.

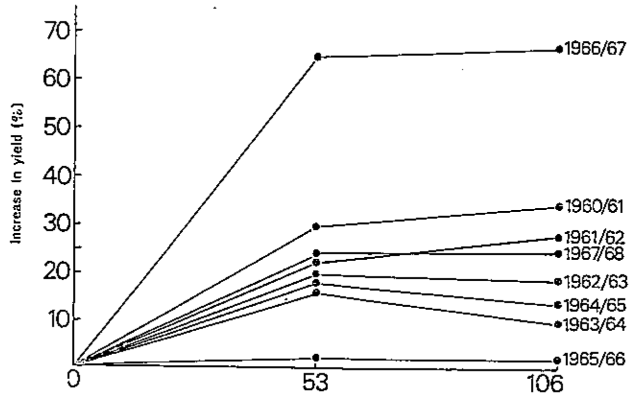

Fig 1 Yield response to applied nitrogen fertilizer (main effects)

The data suggests that no additional response can be expected above an application of 53 kg N/ha. However, specific treatment combinations can be extracted for different seasons which indicates significant response to 106 kg/ha of applied N. Unfortunately first order interactions cannot be predicted and since they do not occur to the same degree from one season to another, it is difficult to fix a precise value for N. Unlike P and K, nitrogen does not build up in soils for a very long period and it is therefore not possible to test for this element by soil analysis.

Total annual requirements are determined primarily by the size of the expected yield and the responsiveness of different soil types to applied N. According to the results presented in Figure 1, the optimum recommendation should fall somewhere between 53 kg/ha and 106 kg/ha but the level of average maximum profit can only be estimated from a critical analysis of the different interactions involved. Indeed even such a computation will fail to predict accurately an optimum level in view of the lack of sufficient nutrient levels and the wide range of rates adopted. The necessity for high N applications is nevertheless clearly demonstrated if sustained high yields are to be achieved.

Response to applied phosphorus

By various reactions which are collectively referred to as fixation, soluble P from fertilizer materials is converted to less soluble and less available forms in soil. With repeated applications, this fixed P can become a major source of supply to plants (Dunbar & Baker, 1965; Tandon & Kurtz, 1968; Place, Phillips & Brown, 1968). For this reason, long-term experiments become more and more difficult to interpret especially at the higher rates of application. During the first season, the results apply to a soil of presumably uniform and known fertility. The second year commences with plots which probably already differ in soil fertility and these differences can be expected to increase with time. Plants are now provided with two sources of available P viz residual (fixed) P and fertilizer P. The difficulty which now arises is to isolate the individual contributions from the two sources to total yield.

In situations resulting in a residual build-up of P in the soil, the fertilizer-P requirements will gradually decrease from year to year until a position is reached where optimum yields can theoretically be obtained without the addition of any fertilizer P. At this point, relatively small quantities of fertilizer P are required annually to maintain a high level of nutrient availability. This level is predetermined by both potential productivity and soil type.

In the present experiment, with the exception of one season, applications greater than 23 kg P/ha did not result in any significant yield increases. Furthermore, there appeared to be a large residual carry-over of P in the soil from one season to the next. This is reflected in the present average soil-test levels for P of 14, 46 and 75 ppm for the P_0, P_1 and P_2 plots respectively. Clearly, yields from the latter two plots became less and less dependent on applied P and the amount of fertilizer required for maximum yield and profit decreased from one season to the next.

In an endeavour to establish a critical soil-test level above which no further response to applied P could be expected, annual treatments for the P_1 and P_2 plots were amended. On one-half of the P_1 and P_2 plots the usual annual 23 kg P/ha and 46 kg P/ha application rates were given respectively, while on the remaining half these annual dressings were withheld. The object was to determine to what degree the residual soil P could alone sustain maximum yield. These amendments were maintained for two seasons and the responses to residual and applied P are presented in Figure 2.

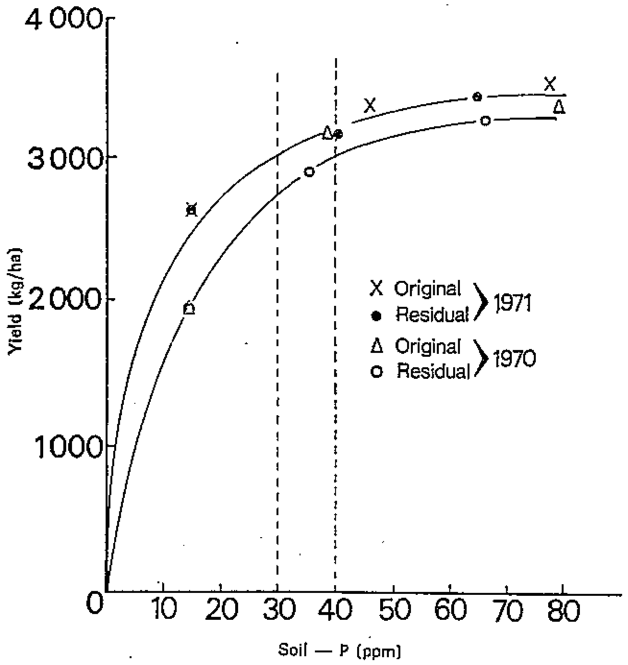

Fig 2 Relationship between soil test level for P and yield (the two lines are drawn through the 'residual' points)

In both seasons, P_1 (residual) was slightly, but not significantly lower than P_1 (original) with respect to yield. This trend persisted at the P_2 level but the difference between residual and original treatment was smaller. Clearly a position was reached where residual P provided the main source of available P and the slight difference between the 'residual' and 'original' treatments was probably due to the absence of readily-available P to the young developing plants. The application of a small quantity of P in the form of a maintenance or 'starter' may have been sufficient to achieve complete parity in yield.

Although there are insuffcent points to draw definite conclusions, an optimum level of soil P for this soil is probably in the region of 30-40 ppm. Annual maintenance applications are required to ensure that this level remains constant. The available data, however does not permit a reliable estimate to be made of what constitutes a maintenance dressing nor does it provide information concerning the quantity of fertilizer P required to raise the P level of a similar soil from a certain value to a sufficiency level of 30-40 ppm.

An annual maintenance dressing of P is definitely required since a crop of the order of 4 000 kg/ha can substantially lower the P status of the soil each year. After the first season of witholding annual P applications, the average soil test for P on high-yielding plots showed a drop of four ppm (from 35 ppm to 31 ppm) between the 'residual' and 'original' P_1 plots. This difference increased to 12 ppm on the same plots in the second season. These observations are in close agreement with the results of Farina (1971).

Response to applied potassium

In view of the confounding of results by residual fertilizer, the actual contribution of applied K fertilizer to total yield increase cannot be isolated. Calibration of soil-test data against yield increase with respect to K is therefore unfortunately not possible. Nevertheless, the long-term nature of the experiment resulted in the development of interesting trends which have a significant bearing on the maintenance of fertility especially under an intensive agricultural system.

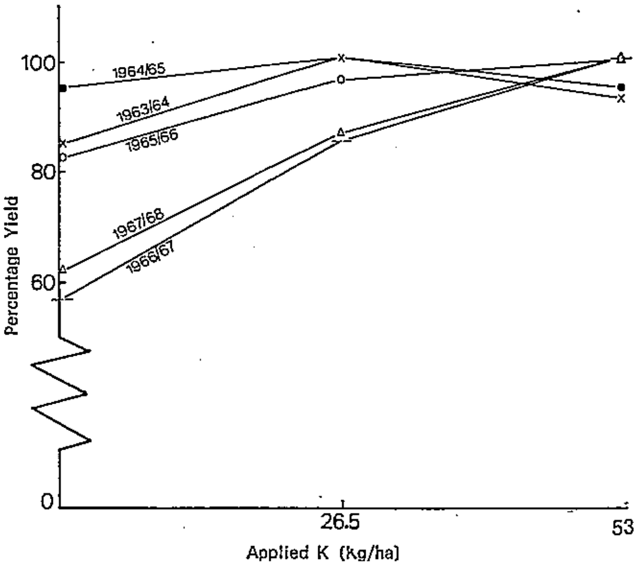

Fig 3 Yield response to applied K fertilizer at the highest levels of N, P and lime

During the initial stages of the experiment, annual responses to applied K fertilizer were not clear but later seasons showed significant responses to the second level of applied K. The development of this increased response over five consecutive seasons is clearly illustrated by the results in Figure 3.

The increased K requirement is not consistent with the average soil-test levels for this element which showed a residual build-up of K from one season to the next. These values for the K_0, K_1 and K_2 plots are 46, 62 and 88 ppm respectively (sampled in April 1971). In view of the build-up of K in the soil, the development of a response to K at the second level of application is indeed unexpected. The increase in soil-K levels may represent an increase in non-exchangeable K only which, although not immediately available, is nevertheless extractable with an ammonium acetate solution. The extracted amounts thus do not necessarily reflect availability *per se* and the results suggest that the rate of availability of soil K may be considerably improved only after the labile pool has been built up above a certain critical level.

An additional factor worthy of consideration is the greater amount of K that may have been required to fill the needs brought about by the use of high rates of N. With a general improvement in soil fertility with time and the significant contribution of N to improved yields, K requirements probably increased above original demands. Support for the effect of N on increased K demands are numerous (Munson, 1970) and the existence of a sensitive N-K balance in plant nutrition is not surprising in view of the fact that their total uptake for most crops is nearly equal. An efficient monitoring system is thus essential for the maintenance of a fertility balance since depletion could occur fairly rapidly under intensive production even on soils containing high amounts of K.

Response to lime applications

The existence of toxic quantities of Al is probably the most important factor limiting the attainment of optimum yields in acid soils. Experimental results have shown that maximum growth occurs only after exchangeable Al has been reduced to a non-toxic level (Reeve & Sumner, 1970; Kamprath, 1970). The application of large amounts of fertilizer to soils with a high-yielding potential but containing excessive quantities of soluble Al is wasteful and will result in inefficient utilization of available nutrients and soil moisture. Contrary to older concepts, the effects of a higher soil-pH value on increasing the availability of soil P and other nutrients as well as improving micro-organism activity are incidental and do not represent the main reasons for applying remedial liming treatments. Rather, the improvement of soil conditions — by the elimination of toxic Al, resulting in a growth medium more favourable for healthy root development — is the primary reason. The development of a favourable growth environment improves the foraging ability of plant roots thereby increasing the soil volume available for exploitation. The beneficial effect of liming on the uptake of plant nutrients is illustrated by an analysis of the experimental soils sampled in April 1971. These results, for P and K (averages) are presented in Table 1.

TABLE 1 Influence of lime on the uptake of phosphorus and potassium from soil

Soil-P level (ppm)			Soil-K level (ppm)		
Rate	Limed	Unlimed	Rate	Limed	Unlimed
P0	36	18	K0	42	50
P1	13	50	K1	57	68
P2	63	77	K2	83	92

The lower soil-test levels for both elements, at all rates of application, clearly show an increased nutrient removal as a result of liming. The greater removal of native and applied nutrients on the limed plots is due to improved root development under more favourable growing conditions. This is as a result of a better utilisation of available nutrients and not necessarily as a result of an increased availability *per se* of individual plant nutrients.

An analysis of five randomly-selected limed plots together with their unlimed counterparts revealed average exchangeable Al indexes of 0,03 me/100 g and 1,0 me/100 g respectively. According to Reeve et al, (1970) a value of 0,2 me/100 g represents the critical level above which Al could be expected to influence plant growth adversely. The unlimed plots contain excessive amounts of Al while in the limed plots Al has been reduced to an acceptable level.

To illustrate the financial benefits of liming an acid soil, data has been extracted from the results of seven consecutive seasons viz 1961/62-1967/68. In order to eliminate seasonal variations in response and the effects of interactions, annual optimum yields for both limed and unlimed plots were calculated. Fixed costs for N, P and K were used and since lime was not applied every season, an average cost of R2,40 per hectare per annum was allotted to all limed plots. The price of maize was fixed at R3,30 per 90,7 kg (200 lb) bag. Although the listed prices are not the ruling seasonal prices since 1961/62 it was assumed that the income/expenditure ratio had not altered significantly since that date. This information was fed through a computer.

Despite seasonal variations which resulted in a range of optimum grain yields from 1 685 kg/ha to 6 463 kg/ha it was still possible to study the contribution of lime to yield increase and profitability. Both quadratic and square-root models were fitted to the data and although widely divergent results with regard to optimum NPK combinations were obtained, results for optimum yield and maximum profits were remarkably similar. These results expressed as an average of the two models are given in Figure 4.

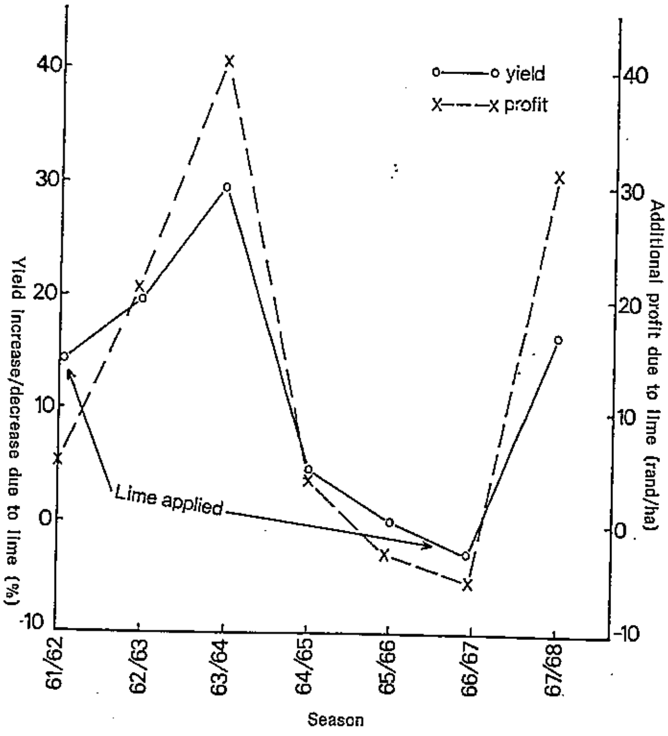

Fig 4 Effect of lime on the yield and profitability of maize

An interesting feature is the time taken for the applied lime to exert its maximum effect on yield. At least three seasons were required for complete reaction. Thereafter the residual effect decreased rapidly, presumably as a result of the hydrolysis of precipitated Al compounds leading to the re-release of protons. Any disturbance of a soil's equilibrium is only temporary since pedogenetic factors will act against any environmental imbalance in order to resume the natural equilibrium.

The application of lime in October 1966 failed to arrest the developing acidity and was too late to have any beneficial effect on the yields of the ensuing season. Considering the relative insolubility and degree of fineness of agricultural lime as well as the general inefficiency of effectively blending lime with the soil volume, a delay in reaction can be expected. This discouraging effect is more than offset by possible profitability which is directly proportional to increased response (Figure 4).

The maintenance of a soil medium favourable for unrestricted root development depends on the ability to diagnose a soil condition requiring remedial or corrective treatment. Soil analysis after the 1963/64 season clearly showed that acidity would not be a limiting factor. Consequently, according to the evidence available, no additional lime was recommended. However, the long-term residual effect of lime clearly indicated that this was incorrect and that a further lime treatment was required to maintain a low level of soil acidity. At that stage it was impossible to predict this requirement. The results of this experiment suggest that a three-year cycle should be adopted to ensure the success of a liming programme. Applications every third season need probably only consist of small dressings, designed not necessarily to reduce exchangeable acidity further but to ensure that it is maintained at a non-toxic level.

Conclusions

An attempt has been made to piece together the long-term effects of fertilizers and lime on the build-up or depletion of soil fertility. Although the results are rather limited in that they apply only to a single soil series under a specified set of environmental conditions, the development of particular fertility patterns, arising out of the long-term application of various fertilizer programmes, has a much wider significance and application.

In view of its nature and reaction in soils, N cannot be studied in the same manner as P, K and lime. Annual requirements are determined principally by expected yield and the reaction of different soils to this nutrient.

With regard to P, K and lime, the long-term build-up and residual effects emphasise the need for an efficient soil-testing system in order to monitor any changes taking place. Providing objectives are clarified when preparing a recommendation, fertility build-up and maintenance can be carefully controlled to ensure optimum nutrient uptake throughout the growing period.

Under higher levels of fertility management, depleted soils are vulnerable to sudden nutrient imbalances. Similarly, intensification can unknowingly lead to the development of nutrient deficiencies even in relatively fertile soils. Continued experimentation and soil testing become increasingly important in order to provide more meaningful interpretations of soil analytical data.

Opsomming

DIE HANDHAWING VAN GRONDVRUGBAARHEID MET SPESIFIEKE VERWYSING NA STIKSTOF, FOSFOR, KALIUM EN LANDBOUKALK

Die langtermyn-effek van stikstof-fosfor-kalium-en landboukalktoedienings alleen en in kombinasie op 'n Hutton grondserie op die groei van mielies is ondersoek. Jaarlikse stikstofbehoeftes word hooksaaklik bepaal deur die verwagte opbrengs en die resultate beklemtoon die belangrikheid van hoë stikstoftoedienings indien volgehoue hoë opbrengste gerealiseer wil word.

Jaarlikse toedienings van fosfor groter as die plant se behoeftes, het 'n stadige opbou van hierdie plantvoedingstof in die grond tot gevolg gehad sodat 'n situasie bereik word waar residuele fosfor uiteindelik die hoofbron van voorsiening vir die plant se behoeftes is. Daar is aangetoon dat geen verdere verhoging in opbrengs op toegediende bemesting verwag kan word wanneer die grond se P-ontleding 30-40 dpm (Bray No 2) bereik het nie. Onderhoudstoediening word hierna benodig om te verhoed dat hierdie peil nie van jaar tot jaar daal nie. Die beskikbare informasie is egter nie voldoende sodat 'n skatting gemaak kan word van wat 'n onderhoudstoediening behoort te wees nie. Dit gee ook nie 'n aanduiding van die hoeveelheid fosfor wat benodig word om die grond se P-ontleding van 'n gegewe waarde tot 'n bevredigende syfer van 30-40 dpm te verhoog nie.

Reaksies op toegediende K het geleidelik toegeneem oor die seisoene ten spyte van die feit dat K ook 'n geleidelike opbou in die gronde getoon het. Hierdie neiging dui aan dat 'n groter behoefte geskep word deur 'n algemene verhoging van grondvrugbaarheid oor die jare. Hierdie neiging in K-reaksie beklemtoon die belangrikheid van gereelde vasstelling van veranderings oor 'n periode langer as een of twee seisoene.

Die uitskakeling van toksiese Al deur die toediening van landboukalk het 'n aansienlike verhoogde reaksie op toegediende voedingstowwe en dus opbrengs gehad. Dit het verder duidelik uit die resultate geblyk dat minstens drie seisoene nodig was vir maksimum effek en dat onderhoudstoedienings benodig word om verdere vrystelling van toksiese aluminium te voorkom.

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