THE GROWTH OF FLUE-CURED TOBACCO
IN
ACID SOILS.

by

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SUMMARY

The main effects of lime, aluminium, iron and manganese were studied in field and greenhouse grown tobacco; relations between soil and plant measurements were examined.

Ground limestone, ground mixed lime, ground dolomite and slaked lime at rates equivalent to 1,000 and 2,000 lb. $CaCO_3$/acre increased yield and quality of flue-cured tobacco both on Triassic and granite sands, whether applied early (February/March) or late (September); the highest rate and late application were often best. Yields increased with 4,000 and 6,000 lb. dolomite/acre applied late, but quality decreased when the pH was about 6.0.

Lime did not affect leaf maturity as reflected by nitrogen and reducing sugars concentration. Where leaf discolouration (slate) occurred, the best quality and least discoloured leaf had the lowest manganese concentration and was grown on limed soil. On a very acid and probably nitrogen deficient soil, lime, borax and nitrogen (nitrate only tested) reduced the discolouration and improved the quality, but potassium sulphate increased discolouration and decreased quality.

Calcium concentration in the leaf was increased by lime, particularly calcitic materials, and magnesium concentration was increased by dolomite. Lime also increased the filling value and petroleum ether extract, but decreased manganese, boron, chloride and sometimes potassium, and had no effect on phosphorus, nitrogen, aluminium, iron, crude fibre, nicotine, reducing sugars and equilibrium moisture. The inorganic composition of greenhouse plants was similar; generally gypsum increased calcium concentration more than calcium carbonate but it did not affect manganese concentration, which was decreased by calcium carbonate.

In the stem and roots of field grown plants (dolomite only tested), the concentration of magnesium was increased but the concentrations of calcium, potassium, aluminium and iron were

unaffected. Although the concentration of nitrogen was increased and that of phosphorus was decreased in the stem, these were unaffected in the roots. Aluminium and iron behaved differently to other nutrient ions, being more concentrated in the roots than aerial plant parts.

Boron and magnesium deficiencies were observed in a dry and wet year, respectively, suggesting that variable mineral deficiencies can affect responses to lime.

Initially soil pH was affected more by source of lime, but later mostly by rates. Slaked lime increased the soil pH more than did ground limestone, mixed lime or dolomite. In a glasshouse experiment, pH was more important than calcium supply and in the field, the largest yields were often associated with the highest pH.

In pot experiments, aluminium drastically reduced yields in nutrient solution but not in soils, whereas iron was more severe in soils; manganese had little effect on yield. Manganese was readily taken up and translocated to the tops, but aluminium and iron were mainly concentrated in the roots, as was found in field grown plants. Iron decreased manganese concentration in all plant parts and aluminium decreased calcium and manganese in nutrient solution only. Although aluminium and iron generally increased the concentration of phosphorus in the roots, they did not interfere with phosphorus transport in the plant.

Manganese caused the leaf to become chlorotic and when no iron was present the upper leaves became yellow, and developed brown and white lesions. However, in soil grown plants, sufficient iron was present in the soil solution to prevent break down of tissue. Yellowing of the upper leaves also occurred when plants were grown in nutrient solution with aluminium and no iron; when both were present, the plants were darker in colour. Although aluminium damaged roots in nutrient solution, high rates of iron severely damaged leaves of plants grown in soil.

Since the concentrations of aluminium, iron and manganese were decreased in the soil solution by liming, they were compared with plant growth and composition in 17 different soils, with and without lime. As was expected, lime increased soil pH. It also increased exchangeable calcium, but decreased exchangeable aluminium, iron and manganese; exchangeable magnesium and potassium and resin extractable phosphorus were not affected. As the Ratio Law does not hold for all Rhodesian soils, anion adsorption will be avoided if the soils are equilibrated with 0.0005M $CaCl_2$; the concentrations of the cations in solution were affected in the same way as exchangeable cations, but phosphorus was increased.

There was no relationship between yield of tobacco and its chemical composition. The correlations between soil solution data and plant composition were poor, except for manganese and phosphorus; the relation between Mn ppm. in plant vs $\sqrt{a_{Mn}/a_{Ca + Mg}}$ in solution, and P% vs pH_2PO_4 or $pH_2PO_4 + \frac{1}{2}pCa$, were both curvilinear. On the other hand, all measurements of exchangeable cations were poorly correlated with plant composition. Finally yield was poorly correlated with soil solution data, and pH was as satisfactory as any other measurement tested.

Manganese toxicity was observed on three soils, and a probable manganese deficiency on one. It was not possible to define a limit above which manganese toxicity occurred, but manganese deficiency developed at about 63 ppm. manganese.

Variations in pH and the availability of aluminium, iron and manganese occurred when soils were incubated at about field capacity, generally the main effects having developed within seven days. In all soils, there was an initial increase in soil pH and a maximum value was reached in one to four days, decreasing by variable amounts with longer periods of incubation. Although the concentration of aluminium was larger than that of iron, the relation between both ions and soil pH was curvilinear, their concentrations increasing with decreasing pH. Increased temperature of incubation increased pH with a resultant decrease in the concentration of aluminium, but in one soil it appreciably increased the availability of iron in the early periods of incubation. Autumn and spring ploughing did not affect subsequent pH or the concentration of aluminium and iron in the soil solution. Manganese concentration varied from soil to soil and was not related to soil pH. In most soils there was a decrease in manganese concentration with length of incubation and it decreased more rapidly the lower the initial concentration. Temperature effects were variable and moisture affected the behaviour of manganese more than temperature. These findings and the distribution of aluminium, iron and manganese in the plant helped to explain the poor correlations.

INTRODUCTION

In a recent classification of Rhodesian soils the importance of climate in soil forming processes was studied (1). The percentage base saturation, cation exchange capacity and soil pH were lowered with increasing rainfall, and where annual rainfall exceeded 40 in. weatherable mineral reserves were destroyed and highly porous, strongly leached soils were formed. Sideris and Krauss (2) reported similar results for Hawaiian soils. Under normal climatic conditions, rainfall, which contains dissolved carbon dioxide, is the most important factor in removing bases like calcium and magnesium from the soil, and acidification occurs. Eventually an equilibrium is set up in which the amount of bases removed by leaching is equal to those generated from both the weatherable mineral reserves in the soil and decomposition of organic matter, such as grass and leaf drop. When the land is opened for arable cropping, acidification occurs more rapidly; besides losses due to leaching, additional amounts of bases are removed by erosion. This is particularly aggravated by tobacco, which is grown on clean-cultivated ridges on light textured soils; on a land with a 5% slope, soil losses were about 16 tons/acre compared with nine tons for maize (3). Furthermore, as with all crops, bases are removed in the harvested material (4, 5). There is also the additional acidifying effect of certain nitrogenous fertilisers, particularly ammonium sulphate (6 - 9) and ammonium nitrate (10). Consequently, normal accepted farming practices cause soil acidification which can only be overcome by liming.

Truog (11) in his paper "Putting soil science to work" stated that liming of land was definitely practiced before the Christian Era; Roman authors mentioned liming; in Britain the land might have been limed before the Roman invasion since lime, as chalk or marl, is plentiful and by the 16th and 17th centuries it was accepted as routine practice. Truog also discussed the achievements of Edmund Ruffin who, in his "Essay on calcareous manures" published in 1821, concluded that "upland mineral soils in humid regions often need lime because they are acid". This is one of the earliest remarks relating liming to soil acidity. However, it was not until the turn of this century that more attention was given to studying the adverse effects of soil acidity on plant growth, a subject that has been intensively investigated, often with conflicting results.

Lime has been used as a soil conditioner for many centuries but unfortunately often only after serious decreases in crop yields have been observed. A most striking example of this was reported by Crowther and Basu (7) on the continuous cropping plots at Woburn Experimental Station. After 20 years, yields of barley and wheat failed, particularly where ammonium sulphate and chloride were applied. These infertile plots were acid to litmus. In 1897 certain plots were halved and limed, with beneficial effects. These results stressed the importance of liming, which Crowther and Basu considered had been ignored because of the success of artificial fertilisers on the Rothamsted heavy clay loam soils, which had been heavily limed by former generations of farmers. Potato yields were also reduced after 13 years of continuous cropping and on reducing the acidity with lime, yields were improved (12). If the crop is more tolerant of acidity, then the detrimental effects might only be observed when another crop is introduced into the rotation, as was found in a long term trial at Grasslands Research Station, Rhodesia. Here a Star grass pasture was heavily fertilised with ammonium sulphate, with and without lime, for a period of five years and the infertility of the soil was only noticed when a test crop of unfertilised maize was grown; the grass did not respond to lime but the maize did (9). These examples stress the importance of guarding against excessive soil acidity, and rectifying this before drastic decreases in yields become apparent.

Liming of acid soils will generally improve crop yields (13 - 20). Coleman, Kamprath and Weed (21) in their review on liming only very briefly mention tobacco and then with some diffidence. Garner (22) considered that the liming of tobacco soils was not good practice unless the pH fell below 5.0 - or about 4.3 when measured in 0.01M $CaCl_2$ (23). Darkis, Dixon, Wolf and Gross (24) showed that dolomite increased the yield of flue-cured tobacco but depressed quality; burnt lime was detrimental to tobacco and was not recommended (25); calcitic limestone gave no permanent beneficial effects, and when used continuously tended to reduce both yield and quality, although dolomite was beneficial (6). Posey (26) suggested that heavy dressings of lime should never be used and not more than 1,000 lb./acre of limestone or its equivalent should be applied before the crop is planted, and that if heavier applications were necessary to correct soil pH they should be made immediately after harvesting the tobacco. Lime delayed the maturity of flue-cured tobacco (24, 27) and reduced the fire-holding capacity of cigar leaf (28). More recently flue-cured tobacco yield and quality were improved using calcitic limestone and dolomite at rates up to 4,000 lb./acre (29), and also with ground limestone at 1,000 lb./acre (30). Clearly, responses of tobacco have not been consistent and vary with the source of the liming material.

Because responses to lime were often conflicting, certain aspects of previous work will be discussed. Darkis et al (24) reviewed six experiments extending over a period from 1928 to 1933. Dolomite was broadcast every third year at 2,000 lb./acre just before the tobacco was planted, beginning in 1920 and continuing through to 1929. The rotation was tobacco, oats followed in the same year by soybeans, which were turned in, and then rye; yields of flue-cured tobacco increased by variable amounts from 29 to 369 lb./acre.

Extensive leaf analysis was done but little emphasis was given to soil measurements. Moss et al (6) also established that dolomite was beneficial when broadcast; when drilled, dolomite was better than calcitic limestone, but this method applies lime as a fertiliser rather than as a soil conditioner and the response was attributed to magnesium on a soil probably deficient in it. Sometimes the first application of lime was beneficial but subsequent applications were detrimental, as found by Hutcheson and Berger (25), yet they concluded that lime was not beneficial to the growth of tobacco without considering any soil factors or even the possibility of minor element deficiencies occurring. Askew (31) induced boron deficiency with 2,000 lb./acre of ground limestone, which increased the soil pH from 6.25 to 7.10. But no deficiency symptoms were observed by Thomson et al (30) who increased the soil pH from 5.3 to 6.3 with four applications of 1,000 lb./acre every second year, although on an adjacent area which received a very large application of lime, boron deficiency did occur. Using 4,000 lb./acre of calcitic limestone and dolomite, Breland et al (29) obtained increased yields without inducing boron deficiency, when the soil pH was increased from 5.4 to 6.0. Thus, the lower the initial soil pH the more lime could be applied without producing boron deficiency. Since the intensity of infection of black root rot is governed by soil pH, only sufficient lime to bring the pH to about 5.6 should be applied where this disease is endemic (30, 32). Although there are limitations in determining soil pH with pure water (33), nevertheless it is easily measured and can be a useful tool in determining crop response to lime. However, the potential disease hazard and the lack of consistent responses undoubtedly restricted the use of lime on flue-cured tobacco.

In their critical evaluation of the cause of poor growth on acid soils, Fried and Peech (34), Schmehl, Peech and Bradfield (35) and Vlamis (36) generally agreed that it was not caused by a lack of calcium but rather by toxicities of aluminium, manganese and iron; only Vlamis considered pH itself a major factor. The relative importance of these ions depended on the crop and the soil. Furthermore, Schmehl et al (37) stressed the importance of the antagonistic effects of aluminium, hydrogen and manganese ions on the absorption of calcium, resulting in a low calcium concentration in the plant. In the light of these general findings it is interesting to consider the work done on tobacco.

The influence of acidity on the growth of Turkish tobacco (Xanthi variety) in water culture was studied by Steinberg (38). There was only a slight increase in yield when the pH was increased from about 4.6 to 7.1, and on increasing the calcium concentration from 25 to 200 ppm. at either pH value, the yield increased to a maximum at 150 ppm.; in both instances the yield response was not significant. The adverse effect of the hydrogen ion was overcome by increasing the rate of calcium, suggesting that calcium nutrition was the main deficiency on acid soils, as proposed by Albrecht (39) and Albrecht and Smith (40) However, the response of tobacco to gypsum as a soluble form of calcium has never been tested, although it was of little benefit to several other crops (34, 41-43), except peanuts, for which calcium is important in the formation of the fruit (44, 45).

Adding 1, 20 and 24 ppm. aluminium to nutrient solutions retarded growth of Turkish (46), Burley (47) and cigar tobaccos (48). Although Hiatt and Ragland (47) reported yellow mottling on the upper leaves, which was attributed to phosphorus deficiency, generally the plants were greener than the controls with no chlorosis or leaf abnormalities, but having poorly developed, thick, short roots, sometimes with lesions when the toxicity was very severe. Aluminium was mainly concentrated in the roots and the concentration in the tops was not proportional to the amount applied in solution. Aluminium toxicity was decreased by adding calcium (48), and applying aluminium decreased the uptake of manganese (47). Bortner (46) also examined soil leachates in which little or no aluminium was present;

aluminium was only present in unlimed soils. Eisenmenger (48) found that additions of aluminium sulphate (100 ppm. Al) to the soil did not restrict growth because phosphorus immobilised it by forming insoluble aluminium compounds.

On very acid soils in Kentucky and Connecticut, a characteristic mottling was observed on the tobacco. It was identified as manganese toxicity on Turkish tobacco by Bortner (46), on Burley tobacco by Hiatt and Ragland (47) and on cigar tobacco by Jacobson and Swanback (49). Recently similar symptoms were reported by Murthy and Patwardham (50) on flue-cured tobacco grown in nutrient solution. Jacobson and Swanback found that manganese concentrations in the soil and plant were positively related; lime decreased the manganese concentration in both soil extract and plant; phosphorus increased it in the plants. In plants with toxicity symptoms, most manganese was found in the middle leaves and least in the upper; roots contained more than stems and leaves more than roots. Bortner also found that lime decreased the manganese concentration in the tobacco and the soil leachate; phosphorus also decreased it, contrary to the findings of Jacobson and Swanback (49).

The response of Burley tobacco to iron has been studied by Hiatt and Ragland (47), who showed that the symptoms of manganese toxicity - chlorotic areas between veins, giving the leaf a mottled appearance - were not the same as iron deficiency - uniform yellowing of the whole leaf. They also reported that manganese concentration in the plant parts was decreased when the concentration of iron was increased in the substrate, although the concentration of iron was very slightly increased in the tops and much more so in the roots. Iron deficiency is a feature of calcareous soils (51) and has not been reported in field grown tobacco.

Iron toxicity has been frequently observed in rice, because the reducing conditions in paddy soils favour the formation of ferrous ions, the form in which plants take up iron (52 - 54). Although there seems to be no mention of iron toxicity in tobacco, high iron concentrations have been discussed in relation to "black" cigar tobacco and "grey" flue-cured tobacco. Black tobacco is dull, matt-surfaced low quality leaf that cures very dark brown with a blue or purple-grey hue, produced on excessively acid soils low in calcium and phosphorus (55). This leaf contained more iron and manganese than light leaf from the same farm. LeCompte (56) reduced the amount of black tobacco by applying lime and phosphorus; the quality of the leaf was poor if it contained more than 0.16% iron and 0.03% manganese but no definite range of values of the Fe:Mn ratio characterised a particular leaf grade. In the flue-cured district of Ontario grey tobacco was produced on numerous farms; in the field it had a bronze cast or distinct peppery appearance and the cured leaf had a dull, variegated grey colour (57). Lime decreased the amount of grey tobacco but applications of manganese and boron had no consistent effect. More detailed studies by Elliot and Finn (58) on grey tobacco, grown under field and greenhouse conditions, produced different results. The incidence of grey tobacco was again lowered by applications of calcium carbonate which increased the soil pH and decreased the uptake of iron, manganese and zinc. In the field grey tobacco was correlated positively with manganese concentration, Mn:Fe ratio, and negatively with total nitrogen concentration; in the greenhouse it was correlated positively with iron concentration only. Phosphorus applied without calcium increased the grey index in the field but decreased it in the greenhouse. These authors discussed the possibility of temperature and light intensity being responsible for the different manganese results. Lime tended to decrease the availability of soil phosphorus and exchangeable manganese.

Manganese and copper have been associated with a breakdown of flue-cured tobacco leaf tissue in New Zealand. Thomson and Askew (59) considered that this was due to the Mn:Cu ratio exceeding 28, and that sound leaves did not contain more than 130 ppm. manganese and not less than 6 ppm. copper. The damage was corrected by adding copper sulphate, which slightly increased the concentration of copper and decreased manganese and nitrogen concentrations in the leaf. However, it is possible that the same effect might have been obtained with lime, because healthy leaves were obtained on the least acid soil of pH 6.1.

Except for that on grey tobacco and the effect of Mn:Cu ratio, the work quoted here was on cigar, Turkish and Burley tobaccos, mostly in nutrient solution, and usually examined the effect of a single ion; when extended to the soil little emphasis was given to the relationship between soil and plant measurements. With field grown tobacco the effects of liming were variable, in some cases being beneficial but in others detrimental.

Although lime is effective on tropical soils that are very acid (33, 60), there appears to be some reluctance to use it. 80% of Rhodesian tobacco soils analysed by the Chemistry Branch of the Ministry of Agriculture need lime (61). This compares favourably with the figure of 85% in Wake County, N. Carolina (62), but in that State half the crop land is not properly limed (63). In Ireland (64) and England and Wales (65) lime is required on 60% and 34% of the soils, respectively.

The aim of this study is threefold; firstly to evaluate the effects of varying rates of different liming materials on the yield and quality of Rhodesian flue-cured tobacco; secondly to establish the effects and interactions of aluminium, iron and manganese on the growth of flue-cured tobacco and their distribution in the plant; thirdly to try and relate plant and soil measurements.

MATERIALS and METHODS

Field Studies.

Standard cultural and management practices were employed for seedling production, fertilisation, nematode and insect control, topping, suckering, reaping and curing (66).

Ground dolomite (67) was tested in all six experiments and slaked lime in the first four, on reverted land (experiments 1 to 4), second year land (experiment 5) and third year land (experiment 6); ground mixed lime (experiments 1 and 2) and ground limestone (experiments 3 and 4) were each tested twice. In experiments 1, 3 and 4 lime equivalent to 1,000 and 2,000 lb./acre of calcium carbonate was applied and in experiment 2 it was equivalent to 2,000 lb./acre of calcium carbonate; in experiments 5 and 6 rates of ground dolomite were 1,000, 2,000, 4000 lb., and 3,000 and 6,000 lb./acre, respectively.

Experiment 1. Triassic sand, 1961-62. The liming materials were applied on 15th March and 27th September. The basic fertiliser was 600 lb. of a 2:18:15 mixture/acre (12 lb.N, 108 lb. P_2O_5, 90 lb. K_2O, 2 lb. borate), and after three weeks the tobacco was side-dressed with 4 lb. N and 8 lb. K_2O/acre. Plant spacing was 3 ft. 6 in. between, and 2 ft. within rows.

Experiment 2. Lime and borax experiment. Triassic sand, 1962-63. Ground mixed lime and ground dolomite were applied on 7th March and 19th September; slaked lime was applied only in September. The fertiliser mixture contained 12 lb. N, 100 lb. P_2O_5, 90 lb. K_2O per acre, and 0, 2 or 8 lb. borax/acre; 8 lb. N + 16 lb. K_2O/acre was side-dressed three weeks after planting. The spacing was 3 ft. 6 in. by 2 ft.

Experiment 3. Granite sand, 1963-64. Liming materials were applied on 24th April and 16th September. The basic fertiliser was 600 lb. of a 4:18:15 mixture/acre (24 lb. N, 108 lb. P_2O_5, 90 lb.

K_2O, 2 lb. borate). Spacing was 3 ft. 9 in. by 2 ft.

Experiment 4. Granite sand, 1963-64. The liming materials were applied on 27th March and 4th September. The fertiliser was 600 lb. of a 4:18:15 mixture. Spacing was 4 ft. by 2 ft.

Experiment 5. Granite sand, 1965-66. Lime was applied on 23rd September. The basic fertiliser was 600 lb. of a 4:18:15 mixture/acre. Spacing was 3 ft. 9 in. by 1 ft. 8 in.

Experiment 6. Lime, boron and side-dressings of nitrogen and potassium experiment. Granite sand, 1965-66. The lime was applied on 17th September. The basic fertiliser mixture contained 24 lb. N, 108 lb. P_2O_5 and 90 lb. K_2O/acre and 0, 8 or 16 lb. borax/acre; on 19th November 10 lb. N, 28 lb. K_2O or 10 lb. N + 28 lb. K_2O/acre was side-dressed. Spacing was 4 ft. by 2 ft.

In experiments 1 to 4 lime was broadcast and disc-ploughed to a depth of about 11 in. in March; the soil was disc-harrowed a few months later and after the late application the whole experiment was again cross-ploughed. In experiments 5 and 6 the lime was broadcast and disc-ploughed; in experiment 5 it was only incorporated to a depth of about 6 in. because of the gravelly nature of the soil.

Experiments 1, 3 and 4 had the same design, three replications of a 3 x 2 x 2 lattice in blocks of six plots each plus a control; experiment 2 comprised selected treatments arranged in a semi-regular group divisible partially balanced incomplete block design in eight blocks of seven plots each; experiment 5, three randomised blocks of four plots each; experiment 6, two replications of a 3 x 3 x 2 x 2 factorial in six blocks of 12 plots each.

In all experiments leaf was weighed after curing in conventional barns. Each leaf was assigned to a named grade, to which a relative value was given, and the overall quality was expressed as a weighted mean of these values.

Slate was the only quality factor assessed separately (Appendix V). It was separated into groups having heavy, medium, slight and no discolouration, with relative values of 4, 3, 2 and 1, respectively. The overall slate index was expressed as the weighted mean of these values.

Four weeks after planting, leaf areas were measured on four plants per plot (experiment 1), commencing with the first reapable leaf and each subsequent third leaf. Area was calculated as length x width x 0.66 (68).

Only selected treatments of experiment 1 were analysed; leaf from the unlimed plots and plots limed at the high rate in March were analysed for filling value, equilibrium moisture (Appendix V), nitrogen, phosphorus, potassium, chloride, calcium, magnesium, aluminium, iron, manganese, boron, nicotine, reducing sugars, petroleum ether extract (resin), and crude fibre (see Appendix 1A). In experiment 5 the leaf, stem and roots were analysed for calcium, magnesium, potassium, phosphorus, nitrogen, aluminium, iron and manganese, and leaf filling value and equilibrium moisture were also measured; in experiment 6, leaf boron was also determined but aluminium, iron, filling value and equilibrium moisture were not.

Soil samples were taken through the season from experiments 1, 3, 4, 5 and 6 and their pH was determined in 0.01M $CaCl_2$. Composite soil samples were taken from each experimental site for analysis (see Appendix IV). Analytical methods for soils are listed in Appendix IB.

Greenhouse Studies.

Here the individual effects and interactions of aluminium, iron, manganese and calcium were studied in both nutrient solution and Kutsaga granite sand. The flue-cured tobacco variety Kutsaga 51 was grown in all these experiments. In experiments 1a and 2 the seeds were both germinated and pricked out in vermiculite, but in all the other experiments seedlings were grown in sand; they were watered at weekly intervals with half strength initial nutrient solution (see below). Uniform tobacco plants were selected for each experiment.

In the nutrient solution studies the pots were 2 litre plastic containers painted black; each lid had two holes of diameter 1 in. for the plants, and two holes $\frac{3}{8}$ in. diameter for an airline and an attached support for the plants. The initial nutrient solution contained 93 mg. P, 137 mg. K, 87 mg. N, 49 mg. Mg, 100 mg. Ca/litre plus Hoagland and Arnon (69) trace element solution containing 0.5 ppm. B, 0.5 ppm. Mn, 0.05 ppm. Zn, 0.02 ppm. Cu, 0.01 ppm. Mo and 0.5 ppm. Fe; in experiments 3 and 4 the concentration of Fe was increased to 2.5 ppm. (see Appendix II). This solution was renewed weekly. The pH of this and subsequent nutrient solutions was adjusted to between 4.0 and 4.5 using a dilute solution of either sulphuric acid or sodium carbonate (70, 71).

In the granite sand studies, the soil was fumigated with methyl bromide before weighing a 1,000 g. sample into bituminised earthenware pots. The same amounts of nutrients as in the nutrient studies were added weekly, and to prevent serious flooding of the soil the total volume of solution was kept at about 100 ml. The pH of these solutions was also adjusted to between 4.0 and 4.5. The plants were watered when necessary with demineralised water to saturate the soil at each application.

Experiment 1. The effect of aluminium and manganese.

(a) Nutrient solution. Two seedlings were planted in each pot. After 14 days' growth in the initial nutrient solution, which was renewed weekly, different amounts of aluminium and manganese were applied. In order to ensure that there was no reaction between aluminium and phosphate ions, two nutrient solutions were used and applied alternately (70, 71); one was identical to the initial nutrient solution and was applied for three days; the other had potassium sulphate instead of potassium dihydrogen phosphate, aluminium (0, 5.0, 12.5 or 31.25 ppm.) and manganese (0.5, 5.0, 12.5 or 31.25 ppm.), and was applied for four days. The roots and pots were thoroughly washed at each change of solution. The treatments were applied three times and the plants were reaped after a final application of the initial nutrient solution.

The plants were dried for four days in a forced-draught oven at 80° C., and then for 16 hours at 105° C. before weighing the roots and leaves plus stem. After grinding they were analysed for aluminium, manganese, phosphorus, calcium and iron (Appendix IA).

(b) Granite sand. Three days after transplanting a basic dressing of initial nutrients was added and the treatments were applied after 21 days. The same procedure and rates of applied nutrients were used as described under (a) except that a zero level of manganese replaced the 0.5 ppm. rate. Similarly, after three treatment periods the plants were reaped, dried and weighed. They were analysed for phosphorus, aluminium and manganese.

Experiment 2. The effect of aluminium and calcium.

This experiment was done in nutrient solution only. Here the initial solutions contained 50, 100 and 200 mg. Ca/litre, these rates being maintained throughout the experiment. Since the calcium was applied as nitrate, the total nitrogen in solution was adjusted to a uniform level using ammonium nitrate. The procedure was the same as described in Experiment 1 (a); two plants per pot were used and the aluminium treatments (0, 5.0, 12.5, 31.25 ppm.) were applied on the 17th day after transplanting. The plants were dried, weighed and analysed for calcium, phosphorus, aluminium and manganese.

Experiment 3. The effect of manganese and iron.

(a) Nutrient solution. Each pot contained one plant, which was grown for 14 days in the initial nutrient solution before manganese and iron at the rates 0, 5.0, 12.5, 31.25 ppm. were applied. Since the iron source was a chelated compound, precipitation of phosphate ions was avoided and the use of two alternating solutions was unnecessary. The treatment solutions were renewed weekly and applied for a period of 14 days.

(b) Granite sand. A basic dressing of initial nutrients was applied on the 7th and 14th day after transplanting, and the treatments commenced on the 21st day, using the same rates of iron and manganese, and procedure, as in Experiment 3(a).

The plants from each experiment were dried, weighed and analysed for manganese, iron and phosphorus.

Experiment 4. The effect of aluminium and iron.

(a) Nutrient solution. Each pot contained one plant which was grown in the initial nutrient solution for 14 days before treatments were applied. The same technique was used as in Experiment 1(a) and the rates of both aluminium and iron were 0, 5.0, 12.5, 31.25 ppm.

(b) Granite sand. A basic dressing of initial nutrients was applied on the 7th and 21st day after transplanting, and treatments commenced on the 27th day. The same technique was used as described in Experiment 1(b) and the rates of iron and aluminium were 0, 5.0, 12.5, 31.25 ppm.

The plants from each experiment were dried, weighed and analysed for aluminium, iron and phosphorus.

In all these experiments frequent observations were made on the growth of both aerial plant parts and roots, and on any abnormal discolourations on the leaves and roots.

The nutrient solution experiments 1, 3 and 4 had the same design, two replicates of selected treatments, in a completely randomised arrangement; experiment 2 comprised two replicates of all treatments in completely randomised arrangements.

The granite sand studies all had three randomised blocks of 16 pots each.

Soil Studies.

Experiment 1. Testing the Ratio Law.

Schofield and Taylor (72) showed that $a_H/\sqrt{a_{Ca + Mg}}$ or pH - ½p(Ca + Mg) was constant if the soil had a predominantly negative charge; with soils having many positive charges, chloride was adsorbed at relatively dilute concentrations, and functions such as pH - ½p(Ca + Mg) were not independent of the chloride concentration.

The effect of concentration on pH and ½p(Ca + Mg) in Rhodesian soils was tested by equilibrating six soils in different strength $CaCl_2$ solutions, ranging from 0.0001 to 0.01M.

25 g. of soil were equilibrated in 50 ml. of $CaCl_2$ for two hours at 21.2° C., then filtered through Whatman No. 42 papers, doubled for solutions less than 0.003M in which some deflocculation of the clay is possible (72). pH was measured by glass electrode before filtering; (Ca + Mg) in the filtrates was determined by titration with ethylene-diamine-tetra-acetic acid (Appendix IC).

The activity coefficients were calculated using the second approximation of the Debye-Hückel equation in the form

$$-\log f = \frac{A z^2 \sqrt{I}}{1 + B a \sqrt{I}}$$

where f is the activity coefficient of the ion having valency z and ionic strength I given by $\frac{1}{2}\Sigma m z^2$, m being the molar concentration of each ion; A and B are constants incorporating absolute temperature and the dielectric constant of the solvent which for water at 25°C are 0.507 and 3.282×10^7, respectively; a is the sum of the ionic radii of two oppositely charged ions having an approximate value between 4.0 and 4.8 Å (73). Schofield and Taylor (74) and Taylor (75) applied this equation as

$$-\log f = \frac{0.5 z^2 \sqrt{I}}{1 + 1.5 \sqrt{I}}$$

in their studies in soil solutions.

Experiment 2. The effect of available calcium content and/or soil pH on the growth of flue-cured tobacco.

In order to ensure that the amount of lime applied to the soil adequately increased the soil pH, the relationship between pH and added calcium carbonate in Triassic sands was determined by prior laboratory studies. 20 g. soil samples were treated with 0, 0.0025, 0.0050, 0.0100, 0.0200 g. A.R. calcium carbonate and 72 ml. 0.01M $CaCl_2$ were added. The mixture was placed on a mechanical shaker for three hours and then shaken intermittently for a further 19 hours. The pH of the suspension was measured with a glass electrode (Appendix IV : Soil studies).

Three soils, a Triassic sand and two granite sands, were studied and the rates of lime (calcium carbonate) used were 0, 0.1, 0.5 and 1.0 g./kg. soil. The air-dried soil was fumigated with methyl bromide, then shaken with the appropriate amount of lime in a large reagent bottle. The treated soil was transferred to a bituminised earthenware pot, whose drainage hole was covered with a piece of nylon mesh, upon which was placed a small piece of bituminised pot, carefully moistened with demineralised water (approximately 200 ml.) until slightly more than saturated. The pot was sealed with polythene sheeting covered by brown paper, and the soil was incubated for two weeks. It was then dried, crushed and sieved (2 mm.), and a composite soil sample was taken of each respective treatment. Where applicable, 10 g. gypsum/kg. soil was added and mixed by shaking just before cropping. This excess gypsum was added to maintain an adequate and constant calcium concentration in solution over all calcium treatments, although soil solution pH might be affected by adding gypsum the function pH - ½p(Ca + Mg) or $a_H/\sqrt{a_{Ca + Mg}}$ should be unaltered.

All pots received a weekly application of 96 mg. N, 80 mg. P, 101 mg. K, 95 mg. Mg, 16 mg. S and 0.29 mg. B per plant (Appendix III). Tobacco seedlings (cultivar Kutsaga 51) were grown until about 5 g. of dry matter had been produced, and harvested at soil level.

On one of the granite sands anomalous results were obtained possibly due to trace element deficiencies. The soil was limed as before and gypsum treatments were excluded; the trace element treatments were weekly applications of 0.29 mg. B only, and 0.29 mg. B, 0.5 mg. Mn, 0.05 mg. Zn, 0.02 mg. Cu, 0.01 mg. Mo, 0.5 mg. Fe/kg. soil. Except for boron, these rates are the same as the Hoagland and Arnon (69) trace element solution.

Demineralised water was applied at the first sign of wilting, but only in slight excess of saturation requirements.

The lime and gypsum experiments had three randomised blocks of eight pots each, but the lime and trace elements had only two randomised blocks.

The aerial parts of the plant were dried for four days in a forced-draught oven at 80°C. and then at 105°C. for 16 hours before weighing. They were analysed for calcium, magnesium, manganese, iron and aluminium (Appendix IA).

Depending on the initial treatment, 25 g. soil were equilibrated with either 50 ml. 0.01M $CaCl_2$ or 50 ml. 0.0148M $CaSO_4$ (i.e. a saturated solution of gypsum) for two hours at 21.2°C., then filtered through Whatman No. 42 paper. pH was measured in the suspension by glass electrode; (Ca + Mg) was determined in the filtrate with ethylene-diamine-tetra-acetic acid (Appendix IC), the activities being calculated using the second approximation of the Debye-Hückel equation.

Experiment 3. The effect of lime (calcium carbonate) on hydronium, aluminium, iron and manganese in soil solution.

A Triassic sand and two granite sands were studied. Here 100 g. soil was mixed with 0, 0.010, 0.050, 0.100 g. calcium carbonate, moistened with 10 ml. distilled water and incubated for two weeks at 21.2°C. The soil was air-dried and equilibrated with 200 ml. 0.01M $CaCl_2$. The pH of the suspension was measured; after filtering through Whatman No. 42 and discarding the first 10 ml. of filtrate to overcome the preferential adsorption of aluminium by the filter paper (Appendix IV : Soil studies), (Ca + Mg), Al, Fe and Mn were determined (Appendix IC) and activities calculated.

The activity of aluminium was calculated using the formula derived by Lindsay, Peech and Clark (76). In very dilute aqueous solutions below pH 5.5, aluminium ions undergo a simple first stage hydrolysis.

$$Al(H_2O)_6^{+++} + H_2O \rightleftharpoons AlOH(H_2O)_5^{++} + H_3O^+$$

Schofield and Taylor (77) determined the hydrolysis constant, K, for this reaction as 7.41×10^{-6} at 21.5°C. (pK value of 5.13).

From the concentration of aluminium and pH, the activity of aluminium in soil extracts is given by

$$(Al^{+++}) = \frac{[\text{Total Al}]}{1/f_{Al^{+++}} + K/(H^{+})f_{AlOH^{++}}}$$

where squared brackets and paranthesis represent concentration and activity, respectively, and f is the molar activity coefficient.

<u>Experiment 4.</u> The effect of hydronium, aluminium, iron and manganese activities on the growth of flue-cured tobacco.

In Experiment 2, soil pH affected growth more than calcium supply, possibly due to the effect of hydronium, aluminium, iron or manganese activities in solution (Experiment 3). Deficiencies of other nutrients may also have affected growth. These factors were all studied in this experiment.

17 Soils with widely differing pH values and soil textures were used (Appendix IV). Lime (0, 0.25 or 0.50 of $CaCO_3$/kg. soil) was thoroughly mixed with fumigated soil (Appendix IV), placed in a one pint waxed cream carton to prevent possible contamination. The carton had a ½ in. hole in its base, covered by nylon mesh, onto which was poured a ½ in. layer of well washed granite chips (larger than 2 mm.). After wetting the soil, the carton was sealed and placed in a larger waxed carton and the soil incubated for one month in a dark room. The soils were inspected regularly and watered, if necessary, to maintain moisture at approximately field capacity. For each soil treatment, an additional pot was added for analytical purposes. Uniform tobacco seedlings (cultivar Kutsaga 51) were transplanted into the containers. Since methyl bromide seriously retards nitrification (78), all plants received weekly 7 mg. N and the complete nutrient treatments an additional 20 mg. P, 25 mg. K, 10 mg. Ca, 3 mg. Mg, 4 mg. S, 0.05 mg. B, 0.2 mg. Cu, 0.2 mg. Zn, and 0.01 mg. Mo weekly (Appendix III). The design comprised three randomised blocks of 68 pots each.

When required, demineralised water was added in slight excess of saturation.

Tobacco was harvested when about 5 g. dry matter had been produced, and the plants were analysed for calcium, magnesium, potassium, phosphorus, aluminium, manganese and iron (Appendix IA).

After air-drying, the soils were measured for pH, using 1:2 suspensions in 0.0005M $CaCl_2$; Ca, Mg and K were determined in soil extracts using normal ammonium acetate of pH 7; Al, Mn and Fe were determined in soil extracts using ammonium acetate adjusted to the soil pH with either acetic acid or ammonium hydroxide; available P was determined by extraction with anion exchange resin (Appendix IB).

The soil solution measurements were done by equilibrating 100 g. soil with 200 ml. 0.0005M $CaCl_2$ for two hours at 21.2°C., then filtering through two Whatman No. 42 papers, discarding the first 20 ml. of filtrate. pH was measured by glass electrode before filtering; after filtering (Ca + Mg), Ca, K, P, Al, Fe and Mn were determined (Appendix 1C). Their activities were calculated as before but for phosphorus it was necessary to apply a correction as the range in soil pH is large. This correction, originally derived by Aslyng, was quoted by White and Beckett (79) as :-

$$-\log_{10}\text{conc.}H_2PO_4 = p(P) + p\left(\frac{H}{(K'' + H)}\right)$$

where (P) is the total concentration of phosphorus in the solution, $p\left(\frac{H}{(K'' + H)}\right)$ is a correction factor, relating the ratio H_2PO_4/P to pH, and K'' is the second dissociation constant of phosphoric acid. Therefore, the value of pH_2PO_4 is given by $-(\log_{10}\text{conc.}H_2PO_4 + \log_{10}f)$.

<u>Experiment 5.</u> The effect of incubating soil at about field capacity on soil pH and the availability of aluminium, iron and manganese.

11 Soils were studied. 100 g. air-dried soil was moistened with 10ml. water and incubated at 21.2°C. for 0, 1 hour, 1, 2, 3, 4, 7, 14 and 21 days (later only up to 7 days), then equilibrated with 200 ml. 0.01M $CaCl_2$ at 21.2°C. for two hours. pH was done on the suspension; after discarding the first 10 ml. Ca, Mg, Al, Fe and Mn were determined in the filtrate (Appendix IC).

RESULTS

Field Studies.

Yield.

In experiments 1, 2, 3, 5 and 6, liming materials at all rates and times of application improved yield of flue-cured leaf (Table 1), but in experiment 4, the yield was reduced by early application of ground limestone and ground dolomite. In all experiments the highest rates and late applications were usually most beneficial. The total leaf area per plant, measured only in experiment 1, was increased from 130 to about 147 dm^2/plant by liming but differences between sources and rates of lime were small (Table 2). The response to lime was less the higher the initial soil pH; in general, yield increments decreased from about 225 lb. at pH 4.2 to 50 lb./acre at pH 4.8. The only significant increases in yield were obtained by slaked lime on Triassic sands (experiment 2) and by dolomite on granite sands (experiment 5), being 438 and 160 lb./acre, respectively; both liming materials were applied late.

Table 2.

The effect of liming materials on leaf area (dm^2/plant).

Experiment	1. Triassic sand, 1961-62.			
Material	Time of application	Low	High	Mean
S.E.		(9.5)		(6.7)
No lime	-	-	-	130
Ground mixed lime	Early	138	155	146
	Late	155	159	157
Ground dolomite	Early	137	150	144
	Late	134	152	143
Slaked lime	Early	165	135	150
	Late	131	154	142
S.E.		(3.9)		
Mean (excluding control)	-	143	151	147

In experiment 5, the yields of stem and roots were increased by liming (Table 3). On the other hand, borax had little effect on yield (Tables 1 and 4), as did side-dressings of nitrogen, potassium and potassium plus nitrogen (Table 5).

Table 1.

Yield of flue-cured tobacco leaf (lb./acre).

Experiment		1. Triassic sand, 1961-62.			3. Granite sand, 1963-64.			4. Granite sand, 1963-64.		
Rainfall		15.84 in.			16.12 in.			19.79 in.		
Material	Time of application	Low	High	Mean	Low	High	Mean	Low	High	Mean
S.E.		(104.1)		(73.6)	(103.0)		(72.8)	(80.3)		(56.8)
No lime	-	-	-	1376	-	-	1988	-	-	2067
Ground limestone/	Early	1639	1556	1598	2242	2059	2150	1979	1973	1976
ground mixed lime	Late	1556	1786	1671	2225	2023	2124	2014	2252	2133
Ground dolomite	Early	1596	1656	1625	1971	2140	2055	2007	2059	2033
	Late	1556	1647	1602	2122	2043	2083	2103	2139	2121
Slaked lime	Early	1630	1534	1582	2176	1980	2078	2180	2155	2168
	Late	1474	1551	1513	2256	2110	2183	2110	2298	2204
S.E.		(42.5)			(42.1)			(32.8)		
Mean (excluding control)	-	1575	1622	1598	2165	2059	2094	2066	2146	2100

Experiment	2. Triassic sand, 1962-63							Granite sand, 1965-66. 5.	6.
Rainfall	33.81 in.							25.37 in.	26.09 in.
Borax lb./acre	No lime	Ground mixed lime Early	Late	Slaked lime Late	Ground dolomite Early	Late	Ground dolomite lb./acre		
S.E.				(101.5)				(35.8)	(28.2)
0	793	977	1174	1078	-	-	0	1439	1171
2	760	930	924	1198	949	1037	1,000	1592	-
8	817	1132	973	1009	-	-	2,000	1590	-
							3,000	-	1252
							4,000	1628	-
							6,000	-	1236

In all tables the figures in brackets are the standard errors of treatment means.

Table 3.

The effect of ground dolomite on yield of stem and roots.

(lb./acre, dry weight)

Experiment	5. Granite sand, 1965-66.	
Ground dolomite lb./acre	Stem	Roots
S.E.	(35.8)	(39.2)
0	559	501
1,000	621	539
2,000	633	587
4,000	599	590

Table 4.

The effect of lime and borax on yield of flue-cured tobacco leaf.

(lb./acre)

Experiment	6. Granite sand, 1965-66.			
	Borax lb./acre			Mean
Ground dolomite lb./acre	0	8	16	
S.E.		(52.3)		(28.2)
0	1251	1157	1104	1171
3,000	1273	1262	1220	1252
6,000	1155	1300	1252	1236
S.E.		(28.2)		
Mean	1226	1240	1192	1219

Table 5.

The effect of lime and side-dressings of nitrogen, potassium, and potassium plus nitrogen on yield. (lb./acre)

Experiment	6. Granite sand, 1965-66.				
Ground dolomite	Side-dressings				Mean
lb./acre	No N or K	10 lb. N per acre	28 lb. K_2O per acre	10 lb. N plus 28 lb. K_2O/acre	
S.E.		(56.5)			(28.2)
0	1130	1136	1192	1225	1171
3,000	1217	1308	1235	1246	1252
6,000	1193	1260	1225	1266	1236
S.E.		(32.6)			
Mean	1180	1234	1217	1246	1219

Quality.

Quality was evaluated in experiments 1, 2, 5 and 6; all sources of lime improved quality, except ground dolomite at 4,000 lb./acre in experiment 5 (Table 6). Likewise, 8 lb. borax/acre was beneficial, as was 16 lb. borax/acre at the highest rate of dolomite (Tables 6 and 7).

In experiments 5 and 6, faint peppery spots were observed on the ripening leaf in February, occurring more frequently on the unlimed treatments. These were still present on the cured leaf, which was distinctly grey in colour from the unlimed plots, but a clearer, brighter colour from the limed plots. Slate, which is defined as a greyish or greyish-brown leaf discolouration associated with a stiffer and less pliable texture, was closely associated with overall quality; the best quality leaf had least discolouration and also the lowest manganese concentration. The manganese concentration was negatively correlated with leaf quality and positively with leaf discolouration (slate), the percentage of plants with peppery spotted

Table 6.

Quality of flue-cured tobacco leaf.

Experiment	1. Triassic sand, 1961-62.			
Material	Time of application	Low	High	Mean
S.E.		(0.91)		(0.64)
No lime	-	-	-	17.4
Ground mixed lime	Early	20.7	20.8	20.8
	Late	19.7	20.6	20.2
Ground dolomite	Early	19.4	20.6	20.1
	Late	19.9	20.1	20.1
Slaked lime	Early	20.1	18.8	19.5
	Late	18.8	19.6	19.2
S.E.		(0.37)		
Mean (excluding control)	-	19.8	20.1	20.0

Experiment	2. Triassic sand, 1962-63.					
Borax lb./acre	No lime	Ground mixed lime Early	Ground mixed lime Late	Slaked lime Late	Ground dolomite Early	Ground dolomite Late
S.E.			(1.03)			
0	13.7	13.3	16.5	15.1	-	-
2	13.5	14.0	15.5	15.8	14.6	16.2
8	14.1	17.0	15.5	17.0	-	-

Granite sand, 1965-66.	5.		6.	
Ground dolomite lb./acre	Quality index	Slate index	Quality index	Slate index
	(0.55)	(0.062)	(0.63)	(0.076)
0	23.4	1.50	18.0	1.17
1,000	24.5	1.43	-	-
2,000	24.2	1.27	-	-
3,000	-	-	19.4	0.97
4,000	22.8	1.40	-	-
6,000	-	-	19.7	0.91

leaves and the percentage of cured leaf classified as nondescript (Table 8). Lime produced a better quality leaf and also appreciably lowered the manganese concentration.

Table 7.

The effect of lime and borax on quality of flue-cured tobacco leaf.

Experiment	6. Granite sand, 1965-66.			
	Borax lb./acre			Mean
Ground dolomite lb./acre	0	8	16	
S.E.		(1.16)		(0.63)
0	17.2	19.5	17.3	18.0
3,000	19.1	20.7	18.5	19.4
6,000	18.3	20.9	20.0	19.7
S.E.		(0.63)		
Mean	18.2	20.4	18.6	19.0

Table 8.

The effect of lime on grade index, slate index, percentage cured leaf classified as nondescript, percentage plants with spots and manganese concentration.

Experiment	5. Granite sand, 1965-66				
Dolomite lb./acre	Grade Index	ND %	Slate Index *	Plants with spots %	Mn ppm.
S.E.	(0.55)	(1.070)	(0.062)	(4.304)	(44.2)
0	23.4	6.63	1.50	18.63	566
1,000	24.5	4.47	1.43	10.29	446
2,000	24.2	5.20	1.27	8.82	439
4,000	22.8	5.87	1.40	12.75	497

* On a scale 1 - none and 4 - heavy.

Experiment 6 was designed to study the effects of lime, boron, and side-dressings of nitrogen, potassium and potassium plus nitrate on the quality of flue-cured tobacco. Dolomite improved quality and reduced leaf discolouration. This was associated with a significant increase in magnesium concentration, and a slight increase in calcium concentration, but significantly decreased manganese, boron and potassium; nitrogen and phosphorus were unaffected (Table 17, experiment 6). However, it should not be overlooked that the concentration of phosphorus was increased slightly by dolomite in the presence of potassium and decreased by 3,000 lb. dolomite in the absence of potassium (Appendix IV). Applied potassium only increased potassium concentration slightly; applied nitrogen and borax significantly increased their respective concentrations in the leaf, and except at 16 lb./acre borax, they significantly improved quality and reduced the amount of leaf discolouration (Table 9). Side-dressing of nitrogen and potassium had large effects on leaf quality and leaf discolouration, these being most pronounced in the presence of 3,000 lb./acre dolomite (Table 10). Potassium nitrate was much more effective than sodium nitrate alone in improving quality, but potassium sulphate alone produced the worst leaf. Side-dressing materials had little effect on calcium, magnesium, boron and phosphorus concentrations, but both sodium nitrate and potassium nitrate increased nitrogen concentration and the latter potassium in two instances only, and potassium sulphate increased potassium concentration but did not change the nitrogen concentration. Irrespective of the side-dressing, 3,000 lb./acre dolomite appreciably lowered manganese concentration, and at this rate of dolomite, potassium nitrate and sodium nitrate treated leaves contained slightly less manganese than leaves of no side-dressing and potassium sulphate treatments (Table 10). Borax and applied potassium had little effect on calcium, magnesium, nitrogen, phosphorus and manganese concentrations, but increased potassium and boron concentrations; potassium did not decrease the concentration of boron in the plant (Table 11).*

*In a more recent experiment, the same side-dressings only affected quality slightly, probably because of the dry November and December, and very wet January (Appendix IV: Field Studies, Experiment 7).

Table 9.

The effect of nitrogen, potassium and boron on leaf quality, leaf discolouration and the chemical composition of cured leaf lamina.

Experiment	6. Granite sand, 1965-66.								
Material	Grade index	Slate index	N %	K %	B ppm.	Ca %	Mg %	P %	Mn ppm.
Borax, lb./acre.									
S.E.	(0.063)	(0.076)	(0.020)	(0.029)	(0.81)	(0.042)	(0.020)	(0.004)	(20.6)
0	18.2	1.16	1.34	2.26	18.3	1.90	0.71	0.23	371
8	20.4	0.79	1.39	2.31	24.3	1.86	0.74	0.24	358
16	18.6	1.11	1.37	2.32	33.8	1.90	0.70	0.22	400
N side-dressing, lb./acre.									
S.E.	(0.51)	(0.062)	(0.016)	(0.024)	(0.66)	(.035)	(0.016)	(0.004)	(16.8)
0	17.4	1.25	1.31	2.28	25.9	1.87	0.72	0.23	390
10	20.7	0.79	1.42	2.31	25.0	1.91	0.72	0.23	363
K side-dressing, lb./acre.									
S.E.	(0.51)	(0.062)	(0.016)	(0.024)	(0.66)	(0.035)	(0.016)	(0.004)	(16.8)
0	19.5	0.98	1.38	2.28	25.2	1.89	0.72	0.24	386
28	18.6	1.06	1.35	2.32	25.6	1.89	0.72	0.23	367
Mean	19.0	1.02	1.37	2.30	25.4	1.89	0.72	0.23	376

All chemical results are expressed on a 100% dry matter basis.

Table 10.

The effect of lime and side-dressings of nitrogen, potassium and potassium plus nitrogen on leaf quality, leaf discolouration, and the chemical composition of cured leaf lamina.

Experiment		6. Granite sand, 1965-66.								
Side-dressing lb./acre	Ground dolomite lb./acre	Grade index	Slate index	N %	K %	B ppm.	Mn ppm.	Ca %	Mg %	P %
S.E.		(1.25)	(0.151)	(0.039)	(0.058)	(1.63)	(41.2)	(0.085)	(0.039)	(0.009)
No N or K	0	17.5	1.30	1.30	2.40	30.5	515	1.73	0.57	0.25
	3,000	18.8	1.25	1.32	2.28	23.3	388	1.95	0.74	0.22
	6,000	20.0	0.94	1.32	2.14	24.0	264	1.89	0.86	0.24
10 lb. N	0	18.3	0.94	1.46	2.41	26.3	596	1.91	0.54	0.24
	3,000	20.9	0.68	1.47	2.27	24.3	289	1.90	0.80	0.23
	6,000	21.4	0.74	1.42	2.16	22.8	266	1.93	0.82	0.23
28 lb. K_2O	0	15.9	1.52	1.34	2.50	26.3	54.8	1.82	0.62	0.22
	3,000	15.0	1.31	1.28	2.19	26.0	309	1.84	0.74	0.22
	6,000	17.1	1.20	1.33	2.20	25.0	315	1.98	0.77	0.24
10 lb. N plus 28 lb. K_2O	0	20.3	0.94	1.36	2.51	27.2	487	1.79	0.56	0.21
	3,000	23.1	0.65	1.41	2.25	24.8	268	1.89	0.77	0.22
	6,000	20.5	0.78	1.39	2.27	24.5	273	2.01	0.86	0.24

Table 11.

The effect of boron and potassium on the chemical composition of cured leaf lamina.

Experiment		6. Granite sand, 1965-66.						
Material	Ground dolomite	K%	B ppm.	Ca%	Mg%	P%	N%	Mn ppm.
S.E.		(0.070)	(2.00)	(0.104)	(0.048)	(0.011)	(0.048)	(50.4)
No Borax or K	0	2.27	20.7	1.82	0.56	0.26	1.33	483
	3,000	2.20	17.1	1.95	0.78	0.24	1.34	321
	6,000	2.12	16.5	1.97	0.83	0.24	1.43	285
8 lb. Borax no K	0	2.44	24.5	1.76	0.63	0.26	1.41	479
	3,000	2.37	24.4	1.91	0.72	0.22	1.41	359
	6,000	2.11	21.8	1.90	0.89	0.25	1.32	232
16 lb. Borax no K	0	2.50	40.1	1.88	0.46	0.22	1.40	704
	3,000	2.25	30.0	1.90	0.81	0.22	1.44	334
	6,000	2.22	31.9	1.87	0.80	0.21	1.37	277
No Borax 28 lb. K_2O	0	2.55	18.7	1.79	0.50	0.21	1.27	593
	3,000	2.22	19.3	1.85	0.79	0.23	1.31	258
	6,000	2.20	17.3	1.99	0.83	0.25	1.34	286
8 lb. Borax 28 lb. K_2O	0	2.53	27.0	1.78	0.66	0.23	1.41	518
	3,000	2.19	21.9	1.84	0.76	0.22	1.38	275
	6,000	2.23	26.1	1.99	0.81	0.24	1.39	282
16 lb. Borax 28 lb. K_2O	0	2.42	34.6	1.86	0.61	0.21	1.37	442
	3,000	2.25	35.0	1.92	0.71	0.22	1.34	331
	6,000	2.26	30.9	1.99	0.80	0.23	1.33	313

Soil pH.

In experiment 1, the pH of the soil sampled in September (Table 12) was increased more by ground dolomite and slaked lime than by ground mixed lime; between September and October there was a large increase with slaked lime, particularly on plots limed in March. This difference decreased steadily and from January was not statistically significant. From December onwards, plots receiving high rates had higher pH values than those limed at low rates, and the difference increased as the season progressed. Plots treated with slaked lime reached their highest pH in October, whereas ground mixed lime and ground dolomite had their largest effect in December and January, respectively. Up to December pH was affected only by source of lime, but later was affected only by the rates of lime applied. Similar results were obtained in experiments 3 and 4.[*]

At rates equivalent to 1,000 and 2,000 lb. $CaCO_3$/acre, slaked lime increased soil pH by 0.3 - 0.5 and 0.7 - 1.0 units, but ground limestone, dolomite and mixed lime increased pH by only 0.2 - 0.4 and 0.3 - 0.6 units, respectively. In experiment 6, 3,000 and 6,000 lb./acre ground dolomite increased the pH by 0.8 and 1.2 units respectively, but in experiment 5, 1,000, 2,000 and 4,000 lb./acre dolomite increased the pH by 0.48, 0.96 and 1.49 units (Table 13).

Table 13.

Soil pH.

Experiment	5. Granite sand, 1965-66.					6. Granite sand, 1965-66.			
Sampling date	22nd Nov.	17th Dec.	4th Feb.	22nd Mar.	22nd Apr.	25th Oct.	3rd Jan.	24th Mar.	5th May.
S.E.	(0.089)	(0.067)	(0.095)	(0.100)	(0.097)	(0.039)	(0.044)	(0.079)	(0.059)
Dolomite lb./acre									
0	4.62	4.48	4.46	4.54	4.54	4.31	4.37	4.64	4.66
1,000	5.00	4.92	4.98	5.06	4.94	-	-	-	-
2,000	5.29	5.38	5.42	5.51	5.50	-	-	-	-
3,000	-	-	-	-	-	4.65	5.13	5.24	5.44
4,000	5.77	5.75	5.87	6.14	5.91	-	-	-	-
6,000	-	-	-	-	-	4.92	5.53	5.54	5.88

[*] The effect of lime on flue-cured tobacco has been published in the Rhodesia, Zambia and Malawi Journal of Agricultural Research Vol. 5, 81 - 86, 1967 in which experiments 1, 2, 3 and 4 were discussed with respect to yield, quality and soil pH.

Table 12.

Soil pH.

Experiment			1. Triassic sand, 1961-62.				3. Granite sand, 1963-64.			4. Granite sand, 1963-64.		
Sampling date			27th Sept.	18th Oct.	1st Dec.	16th Feb.	8th Oct.	19th Dec.	9th Mar.	3rd. Oct.	7th Jan.	12th Mar.
Material	Time of application	Rate										
S.E.			(0.047)	(0.111)	(0.082)	(0.079)	(0.203)	(0.120)	(0.059)	(0.112)	(0.143)	(0.084)
No lime	-	-	4.09	4.16	4.30	4.26	4.74	4.66	4.61	4.78	4.86	4.66
S.E.			(0.067)	(0.157)	(0.116)	(0.112)	(0.287)	(0.169)	(0.084)	(0.159)	(0.202)	(0.119)
Ground limestone/ ground mixed lime	Early	Low	4.19	4.31	4.46	4.37	4.83	4.99	4.99	4.85	5.20	4.87
		High	4.18	4.41	4.62	4.57	5.10	5.34	5.21	4.87	5.20	4.95
	Late	Low	-	4.33	4.73	4.47	5.02	4.85	4.99	4.91	5.24	4.87
		High	-	4.35	4.61	4.63	4.69	5.25	5.22	5.04	5.64	5.38
Ground dolomite	Early	Low	4.30	4.42	4.42	4.43	5.04	4.79	4.89	4.91	5.29	4.82
		High	4.42	4.62	4.68	4.76	5.05	4.99	5.07	4.96	5.39	5.15
	Late	Low	-	4.43	4.44	4.50	4.78	4.97	4.85	4.91	5.64	4.91
		High	-	4.44	4.56	4.80	5.08	5.06	5.05	5.05	5.68	5.25
Slaked lime	Early	Low	4.30	4.84	4.61	4.63	5.17	5.15	5.04	4.81	5.04	4.96
		High	4.29	5.23	5.10	4.93	5.71	5.69	5.39	5.19	5.35	4.99
	Late	Low	-	4.47	4.47	4.53	5.76	5.50	5.11	5.29	5.52	5.13
		High	-	4.67	4.97	4.70	6.56	5.61	5.57	5.94	6.29	5.94
S.E.			(0.067)	(0.111)	(0.082)	(0.079)	(0.203)	(0.120)	(0.059)	(0.112)	(0.143)	(0.084)
Ground limestone/ ground mixed lime		Low	4.19	4.32	4.59	4.42	4.93	4.92	4.99	4.88	5.22	4.87
		High	4.18	4.38	4.62	4.60	4.89	5.30	5.21	4.96	5.42	5.17
Ground dolomite		Low	4.30	4.42	4.43	4.47	4.91	4.88	4.87	4.91	5.47	4.87
		High	4.42	4.53	4.62	4.78	5.06	5.03	5.06	5.01	5.54	5.20
Slaked lime		Low	4.30	4.66	4.54	4.58	5.47	5.33	5.08	5.05	5.28	5.05
		High	4.29	4.95	5.04	4.82	6.13	5.65	5.48	5.56	5.82	5.47

Table 14.

Soil nitrogen, ppm.

(Sampled October 18, before fumigation or fertilisation)

Experiment			1. Triassic sand, 1961-62.			
Material	Time of application	Rate	Initial		Incubated	
			NH_4	NO_3	NH_4	NO_3
None*	-	-	7.8	5.2	6.8	12.8
S.E.			(0.66)	(1.01)	(2.07)	(1.54)
Ground mixed lime	March	Low	8.1	5.8	6.3	15.0
		High	7.4	5.0	6.4	13.5
	Sept.	Low	8.4	3.3	6.7	13.8
		High	6.6	4.8	5.8	16.0
Dolomite	March	Low	8.4	5.9	11.8	15.9
		High	7.6	4.6	6.2	13.5
	Sept.	Low	8.9	3.6	6.9	16.1
		High	7.4	4.9	4.8	16.9
Slaked lime	March	Low	7.7	6.2	9.9	14.4
		High	8.5	5.8	8.3	13.8
	Sept.	Low	7.1	5.3	5.0	15.3
		High	7.5	4.8	6.4	14.7
S.E.			(0.47)	(0.72)	(1.47)	(1.09)
Ground mixed lime	March		7.8	5.4	6.3	14.3
	Sept.		7.5	4.1	6.3	14.9
Dolomite	March		8.0	5.3	9.0	14.7
	Sept.		8.2	4.3	5.8	16.5
Slaked lime	March		8.1	6.0	9.1	14.1
	Sept.		7.3	5.1	5.7	15.0
S.E.			(0.47)	(0.72)	(1.47)	(1.09)
Ground mixed lime		Low	8.3	4.6	6.5	14.4
		High	7.0	4.9	6.1	14.8
Dolomite		Low	8.7	4.8	9.3	16.0
		High	7.5	4.8	5.5	15.2
Slaked lime		Low	7.4	5.8	7.4	14.8
		High	8.0	5.3	7.3	14.3
S.E.			(0.33)	(0.51)	(1.04)	(0.77)
Ground mixed lime			7.6	4.8	6.3	14.6
Dolomite			8.1	4.8	7.4	15.6
Slaked lime			7.7	5.5	7.4	14.5

*Excluded from analysis.

Table 15.

The effect of liming materials on equilibrium moisture and filling value

Experiment	1. Triassic sand, 1961-62.			
Material	Reaping groups			Weighted mean
	1 - 3	4 - 6	7 - 9	
I. Equilibrium moisture, %.				
S.E.	(0.11)	(0.14)	(0.13)	(0.10)
None	13.8	14.2	14.0	14.1
S.E.	(0.16)	(0.19)	(0.18)	(0.14)
Ground mixed lime	13.3	14.3	14.2	14.1
Dolomite	13.5	14.4	14.4	14.2
Slaked lime	13.3	14.0	14.1	13.9
II. Filling value, cc./g.				
S.E.	(0.069)	(0.082)	(0.096)	(0.053)
None	2.54	2.33	2.49	2.42
S.E.	(0.098)	(0.116)	(0.135)	(0.074)
Ground mixed lime	2.97	2.40	2.54	2.55
Dolomite	3.00	2.53	2.47	2.61
Slaked lime	3.03	2.34	2.53	2.55

Experiment	5. Granite sand, 1965-66.			
Ground dolomite lb./acre	Reaping groups			Weighted mean
	1 - 3	4 - 6	7 -10	
I. Equilibrium moisture, %.				
S.E.	(0.12)	(0.20)	(0.08)	(0.08)
0	15.3	14.4	14.6	14.8
1,000	15.5	14.3	14.9	14.9
2,000	15.5	14.8	14.6	14.9
4,000	15.3	14.3	14.6	14.7
II. Filling value, cc./g.				
S.E.	(0.202)	(0.099)	(0.075)	(0.114)
0	2.89	3.18	3.96	3.38
1,000	3.28	3.25	3.65	4.43
2,000	3.37	3.23	3.95	3.58
4,000	3.57	3.42	3.80	3.64

Mineralisable nitrogen was increased by lime (Table 14) but there was little difference between sources and rates, which had a large effect on soil pH.

Chemical and physical analysis.

(a) Cured leaf lamina.

In experiments 1 and 5, lime had no effect on equilibrium moisture but increased the filling value (Table 15.) The only organic constituent which was increased by lime was the petroleum ether extract, but lime had no effect on crude fibre, nicotine and reducing sugars (Table 16).

Table 16.

The effect of lime on the organic constituent composition.

Experiment	1. Triassic sand, 1961-62.			
Material	Nicotine %	Reducing sugars %	Petroleum ether extract %	Crude fibre %
S.E.	(0.105)	(0.73)	(0.105)	(0.264)
None	1.80	18.3	5.79	7.65
S.E.	(0.149)	(1.03)	(0.149)	(0.373)
Ground mixed lime	1.82	17.8	5.74	7.95
Ground dolomite	1.61	17.2	6.27	7.72
Slaked lime	1.64	16.4	5.96	6.98

The effect of lime on the chemical composition of flue-cured tobacco was assessed in experiments 1, 5 and 6 (Table 17). Calcium concentration in the leaf was increased by lime, particularly calcitic materials, and magnesium concentration was increased by dolomite. Lime decreased manganese, boron, and chloride, and had no effect on phosphorus, nitrogen, aluminium and iron; potassium concentration was not affected below 2,000 lb. of lime but in excess of this rate it was decreased. Generally any effects were most marked in the early reapings and decreased progressively in the middle and upper reapings (Table 15, Table 18, Appendix IV : Experiments 1, 5 and 6).

(b) Stem and roots.

In the stem and roots (experiment 5) the concentration of calcium, potassium, aluminium and iron were unaffected; manganese was decreased and magnesium increased (Table 19). Although the concentration of nitrogen was increased and of phosphorus was decreased in the stem, these were unaffected in the roots.

Table 17.

The effect of liming materials on the chemical composition of flue-cured tobacco leaf lamina

Material	Ca %	Mg %	K %	P %	N %	B ppm.	Al ppm.	Fe ppm.	Mn ppm.	Cl %
Experiment 1. Triassic sand, 1961-62.										
S.E.	(0.034)	(0.020)	(0.059)	(0.012)	(0.017)	(0.79)	(37.0)	(19.0)	(36.8)	(0.043)
None	1.39	0.27	3.17	0.27	1.75	23.3	192	185	502	0.54
S.E.	(0.048)	(0.028)	(0.084)	(0.017)	(0.024)	(1.12)	(52.4)	(26.9)	(52.1)	(0.061)
Ground mixed lime	1.81	0.28	3.12	0.27	1.72	18.8	263	215	460	0.54
Ground dolomite	1.58	0.41	2.96	0.26	1.73	18.5	265	216	343	0.52
Slaked lime	1.83	0.32	3.13	0.24	1.69	18.7	252	213	370	0.47
Experiment 5. Granite sand, 1965-66.										
Ground dolomite										
lb./acre										
S.E.	(0.069)	(0.026)	(0.084)	(0.003)	(0.033)	-	(78.2)	(20.3)	(44.2)	-
0	1.75	0.99	2.98	0.29	1.61	-	911	413	566	-
1,000	1.88	0.98	3.10	0.27	1.61	-	907	404	446	-
2,000	1.99	1.10	2.94	0.27	1.68	-	953	405	439	-
4,000	1.99	1.17	2.89	0.28	1.72	-	1015	443	497	-
Experiment 6. Granite sand, 1965-66.										
Ground dolomite										
lb./acre										
S.E.	(0.042)	(0.020)	(0.029)	(0.004)	(0.020)	(0.81)	-	-	(20.6)	-
0	1.82	0.57	2.45	0.23	1.37	27.6	-	-	537	-
3,000	1.90	0.76	2.25	0.22	1.37	24.6	-	-	313	-
6,000	1.95	0.82	2.19	0.24	1.36	24.1	-	-	279	-

Table 18.

The distribution of plant nutrients in bottom, middle and upper reaping groups.

Experiment	1. Granite sand, 1961-62.			
	Reaping groups			Weighted mean
	Bottom	Middle	Upper	
I. Calcium, %.				
S.E.	(0.074)	(0.082)	(0.058)	(0.034)
None	1.84	1.21	1.29	1.39
S.E.	(0.104)	(0.115)	(0.083)	(0.048)
Ground mixed lime	3.08	1.54	1.50	1.81
Dolomite	2.25	1.30	1.47	1.58
Slaked lime	2.28	1.66	1.73	1.83
II. Magnesium, %.				
S.E.	(0.038)	(0.029)	(0.019)	(0.020)
None	0.34	0.21	0.28	0.27
S.E.	(0.054)	(0.041)	(0.027)	(0.028)
Ground mixed lime	0.45	0.20	0.26	0.28
Dolomite	0.68	0.31	0.35	0.41
Slaked lime	0.43	0.18	0.35	0.32
III. Manganese, ppm.				
S.E.	(87.4)	(40.5)	(31.8)	(36.8)
None	692	488	428	502
S.E.	(123.6)	(57.3)	(44.9)	(52.1)
Ground mixed lime	577	396	461	460
Dolomite	415	316	337	343
Slaked lime	462	308	370	370

Table 19.

The effect of lime on the chemical composition of stem and roots.

Experiment	5. Granite sand, 1965-66.							
Ground Dolomite lb./acre	Stem							
	Ca %	Mg %	K %	N %	P %	Fe ppm.	Mn ppm.	Al. ppm.
S.E.	(0.022)	(0.018)	(0.097)	(0.028)	(0.006)	(20.6)	(5.7)	(12.4)
0	0.40	0.25	2.56	0.63	0.18	188	82	193
1,000	0.45	0.24	2.69	0.63	0.18	212	69	233
2,000	0.39	0.31	2.54	0.66	0.17	183	67	183
3,000	0.42	0.32	2.59	0.65	0.16	209	73	201
	Roots							
S.E.	(0.021)	(0.008)	(0.049)	(0.016)	(0.010)	(97.6)	(6.3)	(258.3)
0	0.38	0.10	1.25	0.68	0.10	952	73	3041
1,000	0.48	0.12	1.25	0.73	0.10	1172	77	3423
2,000	0.38	0.12	1.21	0.69	0.11	1179	69	3500
3,000	0.36	0.13	1.24	0.69	0.10	1198	64	3598

Table 20.

Variation in chemical composition of leaf, stem and roots.

Element	Cured leaf lamina	Stem	Roots
Ca %	1.90	0.41	0.40
Mg %	1.06	0.28	0.12
N %	1.66	0.64	0.70
P %	0.28	0.17	0.10
K %	2.98	2.59	1.24
Mn ppm.	487	73	71
Al ppm.	946	202	3390
Fe ppm.	416	198	1125

Table 20 shows the variation in chemical composition of leaf, stem and roots, and the overall treatment means of experiment 5 are used to illustrate this. Aluminium and iron behave very differently from the other ions, being more concentrated in the roots, with least in the stem.

Greenhouse Studies.

Experiment 1. The effect of aluminium and manganese.

(a) Nutrient solution.

After the first application, aluminium retarded root development and caused the root tips to become brown, these effects increasing with aluminium concentration. After three applications at three day intervals, aluminium at 12.5 and 31.25 ppm. stunted the plants and caused the roots to become brown, stubby, stunted and jointed; this applied both in the presence and absence of manganese. After the final treatments new roots appeared above the old in the high aluminium treatment. Although aluminium had such drastic effects on the plant growth, there was no leaf chlorosis.

The effects of manganese were also noticeable after the first treatment; 31.25 ppm. caused a "spotted" chlorosis, which was often confined to the base of the leaf, and became less intense as the experiment progressed. The roots were not damaged by manganese.

Irrespective of the rate of manganese, 12.5 ppm. aluminium reduced the yields of leaves plus stem, and roots, and a further decrease was produced by 31.25 ppm. (Table 21). The concentration of aluminium in the leaves and stem (Table 22) was independent of the rate of manganese; increasing the rate of aluminium from 0 to 5 ppm. significantly increased aluminium concentration, but higher rates had no further effect. However, it increased progressively in the roots with increasing rates of aluminium in the solution. The concentration of phosphorus was increased in the roots at the high aluminium rates, but it was unaffected in the leaves and stem (Table 23).

Except for the increase in yield at 12.5 ppm. manganese in the absence of aluminium, manganese had little effect on yields (Table 21). It increased manganese concentration in all plant parts, whereas it was slightly decreased in the leaves and stem and greatly in the roots by aluminium (Table 24).

Table 21.

The effect of aluminium and manganese on the yield of tobacco grown in nutrient solution (g./plant).

	Leaves and stems				Roots				Whole plant			
Aluminium,	Manganese, ppm.				Manganese, ppm.				Manganese, ppm.			
ppm.	0.5	5.0	12.5	31.25	0.5	5.0	12.5	31.25	0.5	5.0	12.5	31.25
S.E.	(1.15)				(0.218)				(1.34)			
0	13.4	13.6	16.5	14.1	2.38	2.75	2.60	2.39	15.8	16.4	19.1	16.5
5.0	13.1	-	14.0	-	2.63	-	2.41	-	15.7	-	16.4	-
12.5	10.1	10.9	10.4	11.0	2.00	2.08	2.19	1.99	12.1	13.0	12.6	13.0
31.25	9.8	-	6.3	-	1.76	-	0.98	-	11.6	-	7.3	-

All results are expressed on a 100% dry matter basis.

Table 22.

The effect of aluminium and manganese on aluminium concentration and uptake in tobacco plants grown in nutrient solution.

	Leaves and stems				Roots				Whole plant			
Aluminium, ppm.	Manganese, ppm.				Manganese, ppm.				Manganese, ppm.			
	0.5	5.0	12.5	31.25	0.5	5.0	12.5	31.25	0.5	5.0	12.5	31.25
I. Aluminium, ppm.												
S.E.	(81.8)				(1293.1)				(183.0)			
0	371	404	359	426	598	833	850	455	405	480	427	431
5.0	651	-	682	-	4760	-	3580	-	1334	-	1107	-
12.5	563	713	670	622	13370	8500	9350	11800	2681	1952	2207	2325
31.25	680	-	840	-	17450	-	11350	-	3239	-	2277	-
II. Uptake, mg./plant.												
S.E.	(1.197)				(2.95)				(3.01)			
0	4.82	5.50	5.88	6.00	1.4	2.3	2.3	1.1	6.2	7.8	8.2	7.1
5.0	8.65	-	9.55	-	12.8	-	8.5	-	21.4	-	18.1	-
12.5	5.62	7.82	6.93	6.66	26.8	17.1	20.5	23.9	32.4	24.9	27.4	30.6
31.25	6.76	-	5.41	-	30.5	-	11.0	-	37.3	-	16.4	-

Table 23.

The effect of aluminium and manganese on the phosphorus concentration and uptake in tobacco plants grown in nutrient solution.

	Leaves and stems				Roots				Whole plant			
Aluminium,	Manganese, ppm.				Manganese, ppm.				Manganese, ppm.			
ppm.	0.5	5.0	12.5	31.25	0.5	5.0	12.5	31.25	0.5	5.0	12.5	31.25
I. Phosphorus, %.												
S.E.	(0.055)				(0.051)				(0.045)			
0	0.43	0.50	0.44	0.40	0.35	0.44	0.50	0.32	0.42	0.49	0.45	0.39
5.0	0.46	-	0.47	-	0.36	-	0.40	-	0.44	-	0.46	-
12.5	0.46	0.46	0.45	0.47	0.74	0.52	0.62	0.46	0.51	0.46	0.48	0.47
31.25	0.50	-	0.40	-	0.56	-	0.60	-	0.50	-	0.43	-
II. Uptake, mg./plant.												
S.E.	(8.30)				(1.17)				(8.90)			
0	56.5	67.3	73.8	57.1	8.4	12.2	12.9	7.8	64.9	79.6	86.7	64.9
5.0	60.1	-	65.6	-	9.6	-	9.7	-	69.7	-	75.2	-
12.5	48.1	49.4	46.2	52.0	14.4	10.7	13.5	9.3	62.6	60.1	59.7	61.3
31.25	48.6	-	25.0	-	9.8	-	5.9	-	58.4	-	30.9	-

Table 24.

The effect of aluminium and manganese on manganese concentration and uptake in tobacco plants grown in nutrient solution.

	Leaves and stems				Roots				Whole plant			
	Manganese, ppm.				Manganese, ppm.				Manganese, ppm.			
Aluminium, ppm.	0.5	5.0	12.5	31.25	0.5	5.0	12.5	31.25	0.5	5.0	12.5	31.25
I. Manganese, ppm.												
S.E.	(147.0)				(330.5)				(162.9)			
0	208	640	1015	2850	618	4200	6980	8480	269	1234	1819	3671
5.0	198	-	1285	-	590	-	4620	-	263	-	1774	-
12.5	150	540	1290	3050	605	3000	4060	7700	225	933	1778	3762
31.25	118	-	930	-	533	-	3940	-	181	-	1336	-
II. Uptake, mg./plant.												
S.E.	(1.03)				(0.90)				(1.50)			
0	2.6	8.7	16.8	40.1	1.5	11.5	17.9	20.3	4.1	20.2	34.7	60.4
5.0	2.7	-	18.0	-	1.6	-	11.1	-	4.3	-	29.1	-
12.5	1.6	5.9	13.2	33.1	1.2	6.4	8.9	15.2	2.8	12.3	22.1	48.3
31.25	1.2	-	5.8	-	0.9	-	3.9	-	2.1	-	9.7	-

The concentrations of calcium and iron in the leaves and stem were unaffected by aluminium and manganese. In the roots, calcium concentration was decreased by aluminium and manganese, and iron concentration was increased by aluminium (Tables 25 and 26).

(b) Granite sand.

Aluminium had little effect on yields of leaves, stem and roots (Table 27), although high aluminium did cause slight browning of root tips. Manganese toxicity was very pronounced at 12.5 and 31.25 ppm. levels, being manifested as yellow chlorotic areas; on the older leaves these were mainly confined to the base and extending upwards, but on younger leaves the chlorosis covered the whole leaf.

The yields of leaves, stem and roots (Table 27), and concentrations of aluminium (Table 28) and phosphorus (Table 29) were unaffected by aluminium and manganese treatments. The concentration of aluminium in the roots was appreciably higher than in the leaves and stem (Table 28).

Manganese concentration in all plant parts increased linearly with increasing rates of applied manganese (Table 30); there was also a small but consistent increase in manganese concentration of leaves and stem with increasing rates of aluminium. The concentration of manganese in the roots was only slightly more than in the leaves and stem.

Iron concentration was independent of manganese and aluminium treatments (Table 31).

Experiment 2. The effect of aluminium and calcium in nutrient solution.

There was a steady decrease in yield of all plant parts with increasing rates of aluminium, particularly at the 12.5 ppm. level (Table 32). The concentration of aluminium in the leaves and stem was considerably increased by aluminium at 5 ppm. followed by smaller increases at higher rates (Table 33). In the roots the concentration was much higher and increased linearly with increasing rates of

Table 25.

The effect of aluminium and manganese on calcium concentration and uptake in tobacco plants grown in nutrient solution.

Aluminium, ppm.	Leaves and stems				Roots				Whole plant			
	Manganese, ppm.				Manganese, ppm.				Manganese, ppm.			
	0.5	5.0	12.5	31.25	0.5	5.0	12.5	31.25	0.5	5.0	12.5	31.25
I. Calcium, %.												
S.E.		(0.235)				(0.345)				(0.188)		
0	2.18	2.53	2.61	2.19	3.20	2.59	2.41	2.42	2.34	2.53	2.58	2.22
5.0	2.47	-	2.36	-	2.09	-	1.91	-	2.40	-	2.29	-
12.5	2.45	2.73	2.55	2.80	2.34	1.85	1.59	1.67	2.43	2.59	2.38	2.62
31.25	2.25	-	2.26	-	1.40	-	1.37	-	2.12	-	2.14	-
II. Uptake, mg./plant.												
S.E.		(42.6)				(10.94)				(46.0)		
0	289	343	436	308	77.8	71.1	62.1	58.4	367	414	498	366
5.0	326	-	329	-	54.4	-	45.9	-	380	-	375	-
12.5	246	304	263	303	48.7	37.9	34.9	33.4	295	342	298	337
31.25	223	-	144	-	24.7	-	13.4	-	247	-	157	-

Table 26.

The effect of aluminium and manganese on iron concentration and uptake in tobacco plants grown in nutrient solution.

	Leaves and stems				Roots				Whole plant			
	Manganese, ppm.				Manganese, ppm.				Manganese, ppm.			
Aluminium, ppm.	0.5	5.0	12.5	31.25	0.5	5.0	12.5	31.25	0.5	5.0	12.5	31.25
I. Iron, ppm.												
S.E.	(46.2)				(134.1)				(40.1)			
0	275	244	241	296	965	845	1200	1060	378	346	371	407
5.0	327	-	300	-	860	-	1035	-	416	-	408	-
12.5	290	245	205	244	1184	1234	1234	1119	437	402	384	377
31.25	290	-	193	-	1459	-	1693	-	468	-	395	-
II. Uptake, mg./plant.												
S.E.	(0.574)				(0.202)				(0.572)			
0	3.74	3.32	3.95	4.17	2.21	2.32	3.10	2.54	5.96	5.64	7.05	6.71
5.0	4.19	-	4.20	-	2.28	-	2.48	-	6.48	-	6.68	-
12.5	2.96	2.63	2.12	2.66	2.31	2.48	2.70	2.21	5.27	5.11	4.82	4.87
31.25	2.94	-	1.21	-	2.56	-	1.66	-	5.51	-	2.86	-

Table 27.

The effect of aluminium and manganese on yield of tobacco plants grown in granite sands.

(g., dry material)

Aluminium,	Leaves and stems					Roots					Whole plant				
	Manganese, ppm.					Manganese, ppm.					Manganese, ppm.				
ppm.	0.0	5.0	12.5	31.25	Mean	0.0	5.0	12.5	31.25	Mean	0.0	5.0	12.5	31.25	Mean
S.E.		(0.174)			(0.087)		(0.052)			(0.026)		(0.191)			(.096)
0.0.	2.78	2.50	2.59	2.64	2.62	0.59	0.57	0.65	0.74	0.64	3.37	3.06	3.24	3.38	3.26
5.0	2.88	2.93	2.81	2.59	2.80	0.64	0.70	0.64	0.47	0.61	3.52	3.63	3.45	3.05	3.41
12.5	2.73	2.55	2.80	2.57	2.66	0.60	0.64	0.68	0.70	0.66	3.33	3.19	3.47	3.27	3.32
31.25	2.44	2.66	2.58	2.47	2.54	0.62	0.67	0.67	0.57	0.63	3.05	3.33	3.26	3.04	3.17
S.E.		(0.087)					(0.026)					(0.096)			
Mean	2.70	2.66	2.69	2.57	2.66	0.61	0.65	0.66	0.62	0.64	3.32	3.30	3.36	3.18	3.29

Table 28.

The effect of aluminium and manganese on aluminium concentration and uptake in tobacco plants grown in granite sand.

Aluminium ppm.	Leaves and stems					Roots					Whole plant				
	Manganese, ppm.					Manganese, ppm.					Manganese, ppm.				
	0.0	5.0	12.5	31.25	Mean	0.0	5.0	12.5	31.25	Mean	0.0	5.0	12.5	31.25	Mean
I. Aluminium, ppm.															
S.E.		(83.0)			(41.5)		(349.8)			(174.9)		(100.4)			(50.2)
0.0	191	243	232	269	234	1677	1179	944	2320	1530	451	423	373	699	487
5.0	275	465	196	429	341	1795	1267	1595	1231	1472	550	647	456	567	555
12.5	339	255	263	219	269	1888	1805	2216	1795	1926	623	561	647	551	595
31.25	260	297	292	318	292	1851	1160	1064	1021	1274	587	477	441	446	487
S.E.		(41.5)					(174.9)					(50.2)			
Mean	266	315	246	309	284	1803	1353	1455	1592	1550	552	527	479	566	531
II. Uptake, mg./plant.															
S.E.		(0.294)			(0.147)		(0.229)			(0.114)		(0.384)			(0.192)
0.0	0.52	0.61	0.61	0.71	0.61	0.99	0.71	0.61	1.63	0.98	1.51	1.31	1.22	2.34	1.60
5.0	0.80	1.54	0.55	1.16	1.01	1.15	0.90	1.04	0.59	0.92	1.95	2.44	1.59	1.75	1.93
12.5	0.94	0.66	0.75	0.57	0.73	1.18	1.16	1.49	1.24	1.27	2.12	1.82	2.23	1.80	1.99
31.25	0.62	0.78	0.75	0.78	0.73	1.14	0.78	0.66	0.56	0.78	1.76	1.56	1.42	1.33	1.52
S.E.		(0.147)					(0.114)					(0.192)			
Mean	0.72	0.90	0.66	0.80	0.77	1.12	0.89	0.95	1.00	0.99	1.84	1.78	1.62	1.81	1.76

Table 29.

The effect of aluminium and manganese on phosphorus concentration and uptake in tobacco plants grown in granite sands.

Aluminium, ppm.	Leaves and stems					Roots					Whole plant				
	Manganese, ppm.					Manganese, ppm.					Manganese, ppm.				
	0.0	5.0	12.5	31.25	Mean	0.0	5.0	12.5	31.25	Mean	0.0	5.0	12.5	31.25	Mean
I. Phosphorus, %.															
S.E.		(0.038)			(0.019)		(0.087)			(0.043)		(0.031)			(0.016)
0.0	0.78	0.82	0.80	0.77	0.79	0.83	0.78	0.85	0.71	0.79	0.78	0.81	0.81	0.76	0.79
5.0	0.81	0.82	0.78	0.82	0.81	0.93	0.61	0.73	0.65	0.73	0.84	0.77	0.77	0.79	0.79
12.5	0.77	0.78	0.77	0.84	0.79	0.59	0.81	0.71	0.73	0.71	0.74	0.79	0.76	0.81	0.78
31.25	0.76	0.84	0.78	0.67	0.76	0.68	0.97	0.74	0.78	0.79	0.74	0.86	0.76	0.69	0.76
S.E.		(0.019)					(0.043)					(0.016)			
Mean	0.78	0.82	0.78	0.77	0.79	0.76	0.79	0.76	0.72	0.76	0.78	0.81	0.78	0.76	0.78
II. Uptake, mg./plant.															
S.E.		(1.41)			(0.71)		(0.697)			(0.348)		(1.61)			(0.80)
0.0	21.5	20.6	20.6	20.4	20.8	4.87	4.29	5.55	5.22	4.98	26.4	24.9	26.1	25.6	25.8
5.0	23.4	23.6	21.8	21.2	22.5	5.99	4.25	4.75	2.90	4.47	29.4	27.8	26.5	24.1	27.0
12.5	21.1	20.0	21.5	21.5	21.0	3.65	5.27	4.79	5.10	4.70	24.8	25.2	26.3	26.6	25.7
31.25	18.2	22.3	19.9	16.5	19.2	4.30	6.53	5.03	4.40	5.06	22.6	28.9	24.9	20.9	24.3
S.E.		(0.71)					(0.348)					(0.80)			
Mean	21.1	21.6	20.9	19.9	20.9	4.70	5.09	5.03	4.40	4.81	25.8	26.7	26.0	24.3	25.7

Table 30.

The effect of aluminium and manganese on manganese concentration and uptake in tobacco plants grown in granite sand.

Aluminium, ppm.	Leaves and stems					Roots					Whole plant				
	Manganese, ppm.					Manganese, ppm.					Manganese, ppm.				
	0.0	5.0	12.5	31.25	Mean	0.0	5.0	12.5	31.25	Mean	0.0	5.0	12.5	31.25	Mean
I. Manganese, ppm.															
S.E.		(62.6)			(31.3)		(142.4)			(71.2)		(71.8)			(35.9)
0.0	151	326	563	1479	630	308	663	896	1633	875	178	388	630	1511	677
5.0	172	318	575	1609	669	341	625	855	2453	1069	202	375	629	1729	734
12.5	120	397	640	1741	725	257	708	905	1931	950	145	461	693	1780	770
31.25	196	435	766	1999	849	415	797	915	2144	1068	241	506	798	2022	892
S.E.		(31.3)					(71.2)					(35.9)			
Mean	160	369	636	1707	718	330	698	893	2040	990	192	432	688	1760	768
II. Uptake, mg./plant.															
S.E.		(0.182)			(0.091)		(0.069)			(0.034)		(0.220)			(0.110)
0.0	0.41	0.82	1.45	3.90	1.64	0.19	0.37	0.58	1.21	0.59	0.60	1.18	2.04	5.10	2.23
5.0	0.49	0.92	1.60	4.23	1.81	0.22	0.43	0.55	1.11	0.58	0.71	1.35	2.16	5.34	2.39
12.5	0.33	1.01	1.79	4.48	1.90	0.16	0.46	0.61	1.35	0.64	0.48	1.47	2.40	5.83	2.54
31.25	0.47	1.15	1.99	4.92	2.13	0.25	0.54	0.61	1.18	0.64	0.72	1.68	2.60	6.10	2.78
S.E.		(0.091)					(0.034)					(0.110)			
Mean	0.42	0.97	1.71	4.38	1.87	0.20	0.45	0.59	1.21	0.61	0.63	1.42	2.30	5.60	2.49

Table 31.

The effect of aluminium and manganese on iron concentration and uptake in tobacco plants grown in granite sands.

Aluminium, ppm.	Leaves and stems Manganese, ppm. 0.0	 5.0	 12.5	 31.25	 Mean
I. Iron, ppm.					
S.E.		(61.5)			(30.8)
0.0	222	253	189	345	252
5.0	295	366	202	307	293
12.5	333	302	260	232	282
31.25	201	335	302	266	276
S.E.		(30.8)			
Mean	263	314	238	288	276
II. Uptake, mg./plant.					
S.E.		(0.2072)			(0.1036)
0.0.	0.617	0.618	0.480	0.913	0.657
5.0	0.850	1.172	0.573	0.804	0.850
12.5	0.923	0.781	0.729	0.602	0.759
31.25	0.495	0.928	0.780	0.651	0.713
S.E.		(0.1036)			
Mean	0.721	0.875	0.640	0.742	0.745

Table 32.

The effect of aluminium and calcium on the yield of tobacco grown in nutrient solution (g./plant).

Aluminium, ppm.	Leaves + stems				Roots				Whole plant			
	Calcium, ppm.				Calcium, ppm.				Calcium, ppm.			
	50	100	200	Mean	50	100	200	Mean	50	100	200	Mean
S.E.		(0.590)		(0.340)		(0.101)		(0.058)		(0.675)		(0.390)
0	6.73	7.61	7.50	7.28	0.95	1.00	1.12	1.02	7.68	8.62	8.63	8.31
5	5.77	6.63	6.61	6.34	0.98	1.02	1.01	1.00	6.75	7.66	7.63	7.34
12.5	5.29	3.81	4.52	4.54	0.88	0.71	0.82	0.80	6.17	4.53	5.34	5.34
31.25	2.92	2.77	4.00	3.23	0.58	0.56	0.69	0.61	3.51	3.34	4.69	3.85
S.E.		(0.295)				(0.050)				(0.337)		
Mean	5.18	5.21	5.66	5.35	0.85	0.83	0.91	0.86	6.03	6.03	6.57	6.21

Table 33.

The effect of aluminium and calcium on aluminium concentration and uptake in tobacco plants grown in nutrient solution.

Aluminium, ppm.	Leaves and stems				Roots				Whole plant			
	Calcium, ppm.				Calcium, ppm.				Calcium, ppm.			
	50	100	200	Mean	50	100	200	Mean	50	100	200	Mean
I. Aluminium, ppm.												
S.E.		(72.8)		(42.0)		(1313.6)		(758.4)		(265.5)		(153.3)
0	557	488	511	518	2203	1277	1267	1582	772	579	610	654
5.0	732	814	890	812	7780	5720	5760	6420	1754	1470	1529	1585
12.5	907	968	784	886	9770	10640	11378	10596	2183	2491	2394	2356
31.25	1105	1040	1225	1123	12760	12990	14960	13570	3049	3063	3314	3142
S.E.		(36.4)				(656.8)				(132.8)		
Mean	825	827	852	835	8128	7657	8341	8042	1939	1901	1962	1934
II. Uptake, mg./plant.												
S.E.		(0.693)		(0.400)		(1.340)		(0.774)		(1.58)		(0.91)
0	3.95	3.60	3.71	3.75	1.93	1.25	1.38	1.52	5.9	4.8	5.1	5.3
5.0	4.27	5.40	5.88	5.18	7.74	5.95	5.75	6.48	12.0	11.4	11.6	11.7
12.5	4.75	3.70	3.54	4.00	8.62	7.58	9.23	8.48	13.4	11.3	12.8	12.5
31.25	3.22	2.88	4.89	3.66	7.56	7.33	10.32	8.41	10.8	10.2	15.2	12.1
S.E.		(0.347)				(0.670)				(0.79)		
Mean	4.05	3.90	4.51	4.15	6.46	5.53	6.67	6.22	10.5	9.4	11.2	10.4

aluminium; these effects were independent of the rate of calcium.

Added calcium had no visible effects on the roots and little effects on yields of leaves and stem, and roots (Table 32). The concentration of calcium in all plant parts increased with increasing rates of calcium; aluminium decreased it in the leaves and stem, and in the roots the decrease was linear with increasing rates of aluminium (Table 34).

There was a tendency for the manganese concentration to be slightly lower in the leaves and stem at the highest rate of aluminium (Table 35). The concentration of phosphorus in all plant parts varied erratically (Table 36).

Experiment 3. The effect of manganese and iron.

(a) Nutrient solution.

Two days after treatments had been applied, faint mottling appeared on the high manganese zero iron treatment, and after a further two days this mottling was very distinct, with numerous brown and white lesions; similar but less severe symptoms occurred on the other manganese treatments. At reaping, the upper leaves were very yellow with green bands along the veins, and with numerous whitish and brown lesions; the bottom leaves had developed numerous brown spots. Leaves of plants grown with neither iron nor manganese were lighter in colour than from other treatments and had a faint diffuse mottle. Where iron and high manganese were applied, chlorotic areas typical of manganese toxicity developed on the leaves after four days, becoming fainter as the experiment progressed.

Five ppm. iron increased yields but 31.25 decreased them (Table 37). Iron increased the concentration of iron mainly in the roots and had little effect on the tops (Table 38), but lowered the concentration of manganese in all parts (Table 39), and did not affect the concentration of phosphorus in these tobacco plants (Table 40).

Manganese had little effect on yields (Table 37) but linearly increased the concentration in all plant parts (Table 39). It also increased the concentration of iron in the roots (Table 38).

Table 34.

The effect of aluminium and calcium on calcium concentration and uptake in tobacco plants grown in nutrient solution.

	Leaves and stems				Roots				Whole plant			
	Calcium, ppm.				Calcium, ppm.				Calcium, ppm.			
Aluminium, ppm.	50	100	200	Mean	50	100	200	Mean	50	100	200	Mean
I. Calcium, %.												
S.E.		(0.130)		(0.075)		(0.110)		(0.063)		(0.114)		(0.066)
0	1.69	2.08	3.79	2.52	0.84	0.96	1.18	0.99	1.58	1.95	3.45	2.33
5.0	1.65	1.64	4.16	2.48	0.46	0.88	1.18	0.84	1.48	1.53	3.77	2.26
12.5	1.32	2.21	4.37	2.63	0.50	0.64	0.96	0.70	1.20	1.96	3.85	2.34
31.25	1.28	1.88	2.75	1.97	0.52	0.64	0.68	0.62	1.15	1.67	2.44	1.75
S.E.		(0.065)				(0.055)				(0.057)		
Mean	1.48	1.95	3.77	2.40	0.58	0.78	1.00	0.79	1.35	1.78	3.38	2.17
II. Uptake, mg./plant.												
S.E.		(19.78)		(11.42)		(1.331)		(0.768)		(20.06)		(11.58)
0	114.0	159.1	286.6	186.6	7.88	9.91	13.03	10.28	121.9	169.0	299.6	196.8
5.0	94.9	108.9	275.1	159.6	4.50	9.02	11.82	8.45	99.4	117.9	286.9	168.1
12.5	69.8	84.1	197.3	117.0	4.41	4.57	7.91	5.63	74.2	88.7	205.2	122.7
31.25	38.0	52.1	109.6	66.6	3.05	3.60	4.73	3.79	41.1	55.7	114.3	70.4
S.E.		(9.89)				(0.665)				(10.03)		
Mean	79.2	101.0	217.1	132.4	4.96	6.78	9.37	7.04	84.1	107.8	226.5	139.5

Table 35.

The effect of aluminium and calcium on manganese concentration and uptake in tobacco plants grown in nutrient solution.

Aluminium, ppm.	Leaves and stems Calcium, ppm. 50	100	200	Mean	Roots Calcium, ppm. 50	100	200	Mean	Whole plant Calcium, ppm. 50	100	200	Mean
I. Manganese, ppm.												
S.E.		(24.7)		(14.2)		(62.5)		(36.1)		(24.4)		(14.1)
0	184	140	130	151	808	776	832	805	262	214	222	233
5.0	134	150	122	135	718	780	670	723	218	233	195	215
12.5	132	152	126	137	840	816	690	782	234	257	213	234
31.25	116	124	126	122	734	764	708	735	218	232	213	221
S.E.		(12.3)				(31.3)				(12.2)		
Mean	142	142	126	136	775	784	725	761	233	234	211	226
II. Uptake, mg./plant.												
S.E.		(0.101)		(0.058)		(0.088)		(0.051)		(0.114)		(0.066)
0	1.16	1.04	0.98	1.06	0.76	0.79	0.94	0.83	1.91	1.83	1.91	1.89
5.0	0.77	0.98	0.80	0.85	0.69	0.79	0.69	0.72	1.47	1.77	1.49	1.58
12.5	0.70	0.58	0.57	0.62	0.74	0.58	0.57	0.63	1.44	1.16	1.14	1.25
31.25	0.34	0.34	0.50	0.40	0.43	0.43	0.49	0.45	0.77	0.78	0.99	0.85
S.E.		(0.051)				(0.044)				(0.057)		
Mean	0.74	0.74	0.71	0.73	0.65	0.65	0.67	0.66	1.40	1.39	1.38	1.39

Table 36.

The effect of aluminium and calcium on phosphorus concentration and uptake in tobacco plants grown in nutrient solution.

Aluminium	Leaves and stems				Roots				Whole plant			
	Calcium, ppm.				Calcium, ppm.				Calcium, ppm.			
ppm.	50	100	200	Mean	50	100	200	Mean	50	100	200	Mean
I. Phosphorus, %.												
S.E.		(0.059)		(0.034)		(0.047)		(0.027)		(0.050)		(0.029)
0	0.55	0.50	0.53	0.53	0.52	0.48	0.38	0.46	0.55	0.50	0.51	0.52
5.0	0.64	0.57	0.42	0.54	0.54	0.55	0.52	0.54	0.63	0.57	0.43	0.54
12.5	0.48	0.50	0.57	0.51	0.55	0.76	0.83	0.71	0.49	0.54	0.61	0.54
31.25	0.50	0.52	0.48	0.50	0.58	0.78	0.58	0.64	0.51	0.57	0.50	0.52
S.E.		(0.029)				(0.024)				(0.025)		
Mean	0.54	0.52	0.50	0.52	0.55	0.64	0.58	0.59	0.54	0.54	0.51	0.53
II. Uptake, mg./plant.												
S.E.		(4.58)		(2.64)		(0.671)		(0.388)		(4.75)		(2.74)
0	37.4	38.2	40.3	38.6	4.90	4.96	4.35	4.74	42.3	43.2	44.6	43.4
5.0	36.5	37.4	28.0	34.0	5.21	5.60	5.21	5.34	41.7	43.0	33.2	39.3
12.5	25.0	18.9	25.7	23.2	4.85	5.37	6.79	5.67	29.9	24.2	32.5	28.9
31.25	14.5	14.6	19.4	16.2	3.42	4.37	4.00	3.93	17.9	19.0	23.4	20.1
S.E.		(2.29)				(0.336)				(2.37)		
Mean	28.3	27.3	28.4	28.0	4.60	5.08	5.09	4.92	32.9	32.4	33.4	32.9

Table 37.

The effect of manganese and iron on the yield of tobacco grown in nutrient solution (g./plant).

	Leaves and stems				Roots				Whole plant			
	Manganese, ppm.				Manganese, ppm.				Manganese, ppm.			
Iron, ppm.	0	5.0	12.5	31.25	0	5.0	12.5	31.25	0	5.0	12.5	31.25
S.E.		(1.64)				(0.34)				(1.94)		
0	10.7	13.3	8.2	7.5	1.8	2.1	1.5	1.2	12.6	15.3	9.8	8.7
5.0	13.8	-	11.4	-	2.2	-	2.2	-	16.0	-	13.5	-
12.5	11.2	10.2	10.1	11.0	2.0	1.9	1.9	1.9	13.2	12.0	12.0	12.8
31.25	9.7	-	12.2	-	0.8	-	2.2	-	10.5	-	14.4	-

Table 38.

The effect of manganese and iron on iron concentration and uptake in tobacco plants grown in nutrient solution.

	Leaves and stems				Roots				Whole plant			
	Manganese, ppm.				Manganese, ppm.				Manganese, ppm.			
Iron, ppm.	0	5.0	12.5	31.25	0	5.0	12.5	31.25	0	5.0	12.5	31.25
I. Iron, ppm.												
S.E.		(24.6)				(513.7)				(117.8)		
0	181	283	243	227	745	922	1114	1403	264	371	375	388
5.0	213	-	262	-	1918	-	4872	-	452	-	994	-
12.5	339	249	290	286	2999	4745	6421	6975	728	961	1261	1264
31.25	267	-	309	-	5526	-	7955	-	680	-	1450	-
II. Uptake, mg./plant.												
S.E.		(0.442)				(2.632)				(3.014)		
0	1.91	3.76	1.99	1.70	1.40	1.97	1.66	1.67	3.31	5.80	3.65	3.37
5.0	2.91	-	2.97	-	4.25	-	10.36	-	7.16	-	13.33	-
12.5	3.80	2.50	2.99	3.10	5.78	9.53	12.40	13.70	9.58	12.02	15.39	16.80
31.25	2.54	-	3.78	-	4.50	-	17.19	-	7.05	-	20.97	-

Table 39.

The effect of manganese and iron on manganese concentration and uptake in tobacco grown in nutrient solution.

	Leaves and stems				Roots				Whole plant			
	Manganese, ppm.				Manganese, ppm.				Manganese, ppm.			
Iron, ppm.	0	5.0	12.5	31.25	0	5.0	12.5	31.25	0	5.0	12.5	31.25
I. Manganese, ppm.												
S.E.	(93.3)				(615.3)				(162.2)			
0	85	906	2330	5638	153	10114	10250	16335	95	2158	3560	7102
5.0	129	-	1137	-	374	-	3092	-	163	-	1448	-
12.5	95	584	954	2053	342	2056	3724	4970	130	818	1393	2500
31.25	86	-	932	-	500	-	2878	-	108	-	1222	-
II. Uptake, mg./plant.												
S.E.	(1.552)				(2.054)				(3.532)			
0	0.90	11.96	19.13	42.28	0.27	21.22	15.46	19.50	1.17	33.23	34.59	61.79
5.0	1.76	-	12.92	-	0.85	-	6.60	-	2.61	-	19.52	-
12.5	1.06	5.51	9.76	22.38	0.63	4.00	7.25	10.30	1.69	9.51	17.01	32.68
31.25	0.82	-	11.44	-	0.31	-	6.19	-	1.13	-	17.62	-

Table 40.

The effect of manganese and iron on phosphorus concentration and uptake in tobacco plants grown in nutrient solution.

	Leaves and stems				Roots				Whole plant			
	Manganese, ppm.				Manganese, ppm.				Manganese, ppm.			
Iron, ppm.	0	5.0	12.5	31.25	0	5.0	12.5	31.25	0	5.0	12.5	31.25
I. <u>Phosphorus, %.</u>												
S.E.	(0.046)				(0.109)				(0.049)			
0	0.66	0.72	0.78	0.70	0.90	1.01	1.10	1.04	0.69	0.76	0.83	0.75
5.0	0.65	-	0.59	-	0.93	-	1.12	-	0.69	-	0.67	-
12.5	0.64	0.64	0.60	0.62	0.92	1.02	1.29	1.21	0.68	0.70	0.71	0.70
31.25	0.56	-	0.56	-	0.96	-	1.22	-	0.58	-	0.66	-
II. <u>Uptake, mg./plant.</u>												
S.E.	(9.32)				(4.76)				(13.52)			
0	70.6	95.3	64.2	52.5	17.0	21.1	16.7	12.6	87.6	116.5	81.0	65.1
5.0	89.1	-	66.9	-	20.6	-	24.0	-	109.7	-	90.9	-
12.5	71.5	63.6	60.0	66.7	17.9	19.7	24.6	23.7	89.4	83.3	84.5	90.4
31.25	52.9	-	68.7	-	7.6	-	26.1	-	60.5	-	94.8	-

(b) Granite sand.

At the high rate of manganese, the leaves were often more chlorotic in the absence than in the presence of iron, but the chlorosis was less intense than symptoms observed in Experiment 1b. After four days, the highest rate of iron caused the plants to wilt, with greasy chlorotic leaf spots developing and eventually becoming black and necrotic; small black spots also appeared on the bottom leaves.

Applying manganese had no effect on the yield of any plant parts (Table 41), but linearly increased the concentration in all (Table 42). It also increased the iron (Table 43) and phosphorus concentrations in the roots (Table 44).

Iron reduced the yield at the highest rate (Table 41), increased the concentration in the leaves, stem and roots (Table 43), and reduced the manganese concentration in all plant parts (Table 42). It also decreased phosphorus in the roots at the highest rate (Table 44).

Experiment 4. The effect of aluminium and iron.

Ten days after the treatments were applied in solution culture, the upper rates of aluminium caused faint mottling of the leaves in the absence of iron but not with high rates of iron. At reaping the yellowing was very severe on the upper leaves, increasing with increasing rates of aluminium, whereas when high iron was also present the plants were dark green in colour. Rates of iron had no effect on the colour of the plants that received no aluminium. Aluminium retarded root growth.

In the soil plants no mottling was observed, but seven days after application all high rates of iron caused the leaf tissue to become dark green along the veins and brownish in the lamina. This became more pronounced with time until some of the plants died.

In the nutrient solution experiment aluminium decreased the yields of plant parts (Table 45) but had little effect on yield in the soil (Table 46). It increased the concentration of aluminium in the roots (Tables 47 and 48) and had no effect on the concentration of iron (Tables 49 and 50). The phosphorus concentration was increased

Table 41.

The effect of manganese and iron on the yield of tobacco grown in granite sand (g./plant).

	Leaves and stems					Roots					Whole plant				
	Manganese, ppm.					Manganese, ppm.					Manganese, ppm.				
Iron, ppm.	0	5.0	12.5	31.25	Mean	0	5.0	12.5	31.25	Mean	0	5.0	12.5	31.25	Mean
S.E.		(0.366)			(0.183)		(0.103)			(0.052)		(0.457)			(0.229)
0	3.05	2.84	2.47	2.55	2.73	0.75	0.72	0.62	0.68	0.69	3.80	3.56	3.08	3.21	3.42
5.0	1.58	2.73	2.90	2.28	2.38	0.42	0.75	0.83	0.53	0.63	2.00	3.48	3.73	2.82	3.01
12.5	2.73	2.14	2.23	1.73	2.21	0.67	0.45	0.47	0.45	0.51	3.40	2.59	2.70	2.18	2.72
31.25	1.43	1.40	1.55	1.35	1.43	0.38	0.37	0.37	0.32	0.36	1.82	1.77	1.92	1.67	1.79
S.E.		(0.183)					(0.052)					(0.229)			
Mean	2.20	2.28	2.29	1.98	2.19	0.55	0.57	0.57	0.50	0.55	2.75	2.85	2.86	2.47	2.73

Table 42.

The effect of manganese and iron on manganese concentration and uptake in tobacco plants grown in granite sand.

	Leaves and stems					Roots					Whole plant				
	Manganese, ppm.					Manganese, ppm.					Manganese, ppm.				
Iron, ppm.	0	5.0	12.5	31.25	Mean	0	5.0	12.5	31.25	Mean	0	5.0	12.5	31.25	Mean
I. Manganese, ppm.															
S.E.			(91.4)		(45.7)			(169.7)		(84.9)			(95.1)		(47.6)
0	291	595	1172	2192	1062	581	1087	1555	1899	1281	347	693	1243	2142	1106
5.0	372	502	929	2213	1004	572	700	859	1472	901	412	549	914	2071	986
12.5	275	537	1099	1840	938	335	529	917	1480	815	286	535	1070	1758	912
31.25	303	508	895	2104	953	465	489	589	1209	688	338	504	834	1935	903
S.E.			(45.7)					(84.9)					(47.6)		
Mean	310	535	1024	2087	989	488	701	980	1515	921	346	570	1016	1976	977
II. Uptake, mg./plant.															
S.E.			(0.646)		(0.323)			(0.192)		(0.096)			(0.791)		(0.395)
0	0.89	1.74	2.86	6.02	2.88	0.42	0.74	0.95	1.44	0.89	1.31	2.49	3.82	7.46	3.77
5.0	0.61	1.38	2.68	5.12	2.45	0.26	0.54	0.72	0.79	0.58	0.88	1.91	3.40	5.91	3.03
12.5	0.75	1.19	2.48	3.18	1.90	0.22	0.25	0.44	0.64	0.39	0.97	1.43	2.92	3.83	2.29
31.25	0.44	0.72	1.39	2.81	1.34	0.18	0.19	0.22	0.38	0.24	0.62	0.91	1.62	3.19	1.58
S.E.			(0.323)					(0.096)					(0.395)		
Mean	0.67	1.26	2.36	4.28	2.14	0.27	0.43	0.58	0.82	0.52	0.95	1.69	2.94	5.10	2.67

Table 43.

The effect of manganese and iron on iron concentration and uptake in tobacco plants grown in granite sand.

	Leaves and stems					Roots					Whole plant				
	Manganese, ppm.					Manganese, ppm.					Manganese, ppm.				
Iron, ppm.	0	5.0	12.5	31.25	Mean	0	5.0	12.5	31.25	Mean	0	5.0	12.5	31.25	Mean
I. Iron, ppm.															
S.E.		(100.8)			(50.4)			(303.6)		(151.8)			(109.0)		(54.5)
0	367	361	281	430	360	933	1084	911	984	978	479	512	407	495	473
5.0	400	496	341	403	410	1100	1542	1427	1500	1392	544	723	583	608	615
12.5	686	607	708	600	650	1529	1444	2736	2306	2004	851	754	1038	1019	915
31.25	1515	1445	1679	1438	1519	1824	1738	1965	2332	1965	1571	1506	1736	1624	1609
S.E.		(50.4)						(151.8)					(54.5)		
Mean	742	727	752	718	735	1346	1452	1760	1780	1585	861	874	941	937	903
II. Uptake, mg./plant.															
S.E.		(0.304)			(0.152)			(0.177)		(0.088)			(0.415)		(0.207)
0	1.05	1.07	0.68	0.98	0.95	0.71	0.80	0.56	0.94	0.75	1.76	1.87	1.24	2.14	1.75
5.0	0.66	1.29	0.99	0.93	0.97	0.48	1.18	1.21	0.80	0.92	1.14	2.47	2.20	1.72	1.88
12.5	1.86	1.34	1.56	1.07	1.46	1.00	0.67	1.16	1.17	1.00	2.86	2.02	2.71	2.41	2.50
31.25	2.16	2.12	2.64	1.95	2.22	0.67	0.70	0.72	0.75	0.71	2.83	2.82	3.36	2.70	2.93
S.E.		(0.152)						(0.088)					(0.207)		
Mean	1.44	1.45	1.47	1.23	1.40	0.71	0.84	0.91	0.91	0.84	2.15	2.29	2.38	2.24	2.27

Table 44.

The effect of manganese and iron on phosphorus concentration and uptake in tobacco plants grown in granite sand.

	Leaves and stems					Roots					Whole plant				
	Manganese, ppm.					Manganese, ppm.					Manganese, ppm.				
Iron, ppm.	0	5.0	12.5	31.25	Mean	0	5.0	12.5	31.25	Mean	0	5.0	12.5	31.25	Mean
I. Phosphorus, %.															
S.E.			(0.026)		(0.013)			(0.056)		(0.028)			(0.027)		(0.013)
0	0.73	0.75	0.75	0.71	0.74	0.67	0.68	0.70	0.67	0.68	0.72	0.73	0.74	0.70	0.72
5.0	0.71	0.73	0.75	0.74	0.73	0.53	0.73	0.71	0.70	0.67	0.67	0.73	0.74	0.73	0.72
12.5	0.74	0.79	0.71	0.78	0.75	0.67	0.54	0.65	0.64	0.62	0.72	0.74	0.69	0.75	0.73
31.25	0.73	0.65	0.68	0.72	0.69	0.37	0.36	0.35	0.46	0.38	0.65	0.59	0.62	0.67	0.63
S.E.			(0.013)					(0.028)					(0.013)		
Mean	0.73	0.73	0.72	0.74	0.73	0.56	0.58	0.60	0.62	0.59	0.69	0.70	0.70	0.71	0.70
II. Uptake mg./plant.															
S.E.			(2.83)		(1.41)			(0.84)		(0.42)			(3.56)		(1.78)
0	22.6	21.2	18.5	18.3	20.2	5.3	4.8	4.3	5.0	4.8	27.9	26.0	22.8	23.3	25.0
5.0	11.3	19.9	21.7	17.0	17.4	2.4	5.5	6.0	3.8	4.4	13.7	25.4	27.6	20.7	21.9
12.5	20.0	17.3	15.9	13.5	16.7	4.5	2.5	3.0	2.8	3.2	24.5	19.8	18.9	16.3	19.9
31.25	10.4	9.3	10.5	9.7	10.0	1.4	1.4	1.3	1.5	1.4	11.8	10.7	11.8	11.2	11.4
S.E.			(1.41)					(0.42)					(1.78)		
Mean	16.1	16.9	16.7	14.6	16.1	3.4	3.5	3.6	3.2	3.5	19.5	20.5	20.3	17.9	19.5

Table 45.

The effect of aluminium and iron on yield of tobacco grown in nutrient solution (g. D.M./plant).

	Leaves and stems				Roots				Whole plant			
	Aluminium, ppm.				Aluminium, ppm.				Aluminium, ppm.			
Iron, ppm.	0	5.0	12.5	31.25	0	5.0	12.5	31.25	0	5.0	12.5	31.25
S.E.	(2.441)				(0.554)				(2.919)			
0	23.10	19.71	14.73	6.57	3.60	3.10	2.70	1.30	26.70	22.81	17.42	7.87
5.0	23.90	-	17.87	-	3.72	-	3.50	-	27.63	-	21.37	-
12.5	27.41	19.90	16.23	13.68	4.32	3.60	2.70	2.25	31.74	23.50	18.93	15.93
31.25	25.66	-	12.26	-	3.60	-	2.50	-	29.26	-	14.76	-

Table 46.

The effect of aluminium and iron on yield of tobacco grown in granite sand (g. D.M./plant).

	Leaves and stems					Roots					Whole plant				
	Aluminium, ppm.					Aluminium, ppm.					Aluminium, ppm.				
Iron, ppm.	0	5.0	12.5	31.25	Mean	0	5.0	12.5	31.25	Mean	0	5.0	12.5	31.25	Mean
S.E.			(0.197)		(0.098)			(0.082)		(0.041)			(0.250)		(0.125)
0	2.08	2.38	2.43	1.93	2.21	0.41	0.47	0.58	0.39	0.46	2.49	2.84	3.01	2.32	2.67
5.0	2.57	2.14	2.55	2.20	2.36	0.39	0.29	0.41	0.37	0.37	2.97	2.43	2.96	2.57	2.73
12.5	2.19	2.36	2.35	2.17	2.27	0.19	0.37	0.34	0.40	0.33	2.38	2.73	2.69	2.57	2.59
31.25	1.17	1.42	1.54	1.46	1.40	0.15	0.26	0.12	0.19	0.18	1.32	1.68	1.66	1.65	1.58
S.E.			(0.098)					(0.041)					(0.125)		
Mean	2.00	2.07	2.22	1.94	2.06	0.29	0.35	0.36	0.34	0.33	2.29	2.42	2.58	2.28	2.39

Table 47.

The effect of aluminium and iron on aluminium concentration and uptake in tobacco plants grown in nutrient solution.

	Leaves and stems				Roots				Whole plant			
	Aluminium, ppm.				Aluminium, ppm.				Aluminium, ppm.			
Iron, ppm.	0	5.0	12.5	31.25	0	5.0	12.5	31.25	0	5.0	12.5	31.25
I. Aluminium, ppm.												
S.E.		(56.4)				(1230.2)				(241.1)		
0	180	217	353	408	1105	3086	6210	7181	304	598	1280	1524
5.0	248	-	296	-	657	-	10705	-	302	-	1964	-
12.5	146	153	202	257	1143	5124	12667	13524	284	906	1973	2125
31.25	337	-	193	-	1277	-	8266	-	505	-	1616	-
II. Uptake, mg./plant.												
S.E.		(1.166)				(2.739)				(3.238)		
0	4.36	4.28	5.40	2.79	4.65	9.36	16.34	9.34	9.01	13.64	21.74	12.13
5.0	6.06	-	5.06	-	2.48	-	36.55	-	8.53	-	41.62	-
12.5	3.99	2.88	3.29	3.53	5.10	17.76	33.73	30.32	9.09	20.64	37.02	33.85
31.25	8.52	-	2.26	-	4.68	-	20.00	-	14.59	-	22.26	-

Table 48.

The effect of aluminium and iron on aluminium concentration and uptake in tobacco plants grown in granite sands.

	Leaves and stems					Roots					Whole plant				
	Aluminium, ppm.					Aluminium, ppm.					Aluminium, ppm.				
Iron, ppm.	0	5.0	12.5	31.25	Mean	0	5.0	12.5	31.25	Mean	0	5.0	12.5	31.25	Mean
I. Aluminium, ppm.															
S.E.			(37.2)		(18.6)			(698.7)		(349.3)			(137.1)		(68.5)
0	110	147	111	216	146	2930	3470	4044	4509	3738	527	679	867	881	738
5.0	135	144	132	159	142	2484	2681	3584	3771	3130	465	446	608	687	551
12.5	198	186	142	221	187	3379	2730	3804	4551	3616	453	533	583	894	616
31.25	207	153	224	242	207	6314	4250	4643	6041	5312	816	762	583	1027	797
S.E.			(18.6)					(349.3)					(68.5)		
Mean	163	158	152	210	170	3777	3283	4019	4718	3949	565	605	660	872	676
II. Uptake, mg./plant.															
S.E.			(0.069)		(0.034)			(0.344)		(0.172)			(0.367)		(0.184)
0	0.22	0.35	0.27	0.39	0.31	1.15	1.56	2.33	1.83	1.72	1.37	1.92	2.60	2.23	2.03
5.0	0.35	0.31	0.34	0.35	0.34	1.09	0.82	1.47	1.45	1.21	1.44	1.13	1.81	1.80	1.54
12.5	0.43	0.43	0.34	0.48	0.42	0.66	1.00	1.29	1.84	1.20	1.10	1.42	1.63	2.31	1.62
31.25	0.23	0.22	0.33	0.36	0.28	0.80	1.13	0.56	1.29	0.95	1.03	1.35	1.02	1.65	1.26
S.E.			(0.034)					(0.172)					(0.184)		
Mean	0.31	0.33	0.32	0.39	0.34	0.93	1.13	1.42	1.60	1.27	1.23	1.46	1.77	2.00	1.61

Table 49.

The effect of aluminium and iron on iron concentration and uptake in tobacco plants grown in nutrient solution.

	Leaves and stems				Roots				Whole plant			
	Aluminium, ppm.				Aluminium, ppm.				Aluminium, ppm.			
Iron, ppm.	0	5.0	12.5	31.25	0	5.0	12.5	31.25	0	5.0	12.5	31.25
I. Iron, ppm.												
S.E.	(74.2)				(317.8)				(100.8)			
0	220	190	223	192	701	765	984	1179	284	266	341	356
5.0	318	-	402	-	1496	-	1538	-	476	-	585	-
12.5	213	319	270	273	928	1524	2105	2009	307	504	531	520
31.25	483	-	357	-	2010	-	2928	-	668	-	806	-
II. Uptake, mg./plant.												
S.E.	(1.574)				(1.093)				(2.251)			
0	4.89	3.74	3.35	1.27	2.73	2.30	2.70	1.61	7.63	6.04	6.05	2.88
5.0	7.73	-	6.88	-	5.69	-	5.24	-	13.42	-	12.11	-
12.5	5.83	6.21	4.38	3.76	3.89	5.74	5.61	4.53	9.72	11.95	9.98	8.29
31.25	12.45	-	4.18	-	7.08	-	7.16	-	19.53	-	11.34	-

Table 50.

The effect of aluminium and iron on iron concentration and uptake in tobacco plants grown in granite sands.

	Leaves and stems					Roots					Whole plant				
	Aluminium, ppm.					Aluminium, ppm.					Aluminium, ppm.				
Iron, ppm.	0	5.0	12.5	31.25	Mean	0	5.0	12.5	31.25	Mean	0	5.0	12.5	31.25	Mean
I. Iron, ppm.															
S.E.		(82.5)			(41.3)		(215.9)			(108.0)		(84.7)			(42.3)
0	203	195	233	261	233	1526	1322	1780	1690	1579	403	381	529	474	447
5.0	342	260	275	281	290	1520	1350	1893	1667	1608	518	387	501	483	472
12.5	596	425	384	363	442	1714	1883	2228	2095	1980	687	622	618	616	636
31.25	1068	1228	1200	665	1040	3560	2549	2831	2787	2932	1329	1413	1316	938	1249
S.E.		(41.3)					(108.0)					(42.3)			
Mean	553	527	523	393	499	2080	1776	2183	2060	2025	734	701	741	628	701
II. Uptake, mg./plant.															
S.E.		(0.173)			(0.086)		(0.166)			(0.083)		(0.245)			(0.122)
0	0.43	0.46	0.57	0.52	0.49	0.62	0.62	1.02	0.65	0.73	1.05	1.08	1.59	1.17	1.22
5.0	0.86	0.57	0.70	0.62	0.68	0.68	0.40	0.78	0.65	0.63	1.53	0.96	1.48	1.26	1.31
12.5	1.25	1.00	0.91	0.79	0.99	0.34	0.69	0.80	0.80	0.66	1.59	1.69	1.71	1.59	1.65
31.25	1.21	1.74	1.91	0.97	1.46	0.51	0.65	0.34	0.57	0.52	1.72	2.39	2.26	1.53	1.98
S.E.		(0.086)					(0.083)					(0.122)			
Mean	0.94	0.94	1.02	0.72	0.91	0.54	0.59	0.74	0.67	0.63	1.47	1.53	1.76	1.39	1.54

in the roots of the nutrient solution plants (cf. Tables 51 and 52).

Only the highest rate of iron decreased yields, but only in the soil experiment (cf. Tables 45 and 46). Iron increased the iron concentration in all parts of plants grown in the soil but only in the roots of the nutrient solution plants (cf. Tables 49 and 50). High rates of iron increased the aluminium concentration in roots of soil grown plants (cf. Tables 47 and 48), and the phosphorus concentration in roots in solution (cf. Tables 51 and 52).

Table 51.

The effect of aluminium and iron on phosphorus concentration and uptake in tobacco plants grown in nutrient solution.

	Leaves and stems				Roots				Whole plant			
	Aluminium, ppm.				Aluminium, ppm.				Aluminium, ppm.			
Iron, ppm.	0	5.0	12.5	31.25	0	5.0	12.5	31.25	0	5.0	12.5	31.25
I. Phosphorus, %.												
S.E.	(0.034)				(0.057)				(0.030)			
0	0.44	0.45	0.50	0.49	0.36	0.48	0.54	0.64	0.43	0.45	0.51	0.52
5.0	0.46	-	0.38	-	0.54	-	0.58	-	0.47	-	0.41	-
12.5	0.45	0.42	0.34	0.37	0.40	0.58	0.87	0.83	0.44	0.44	0.41	0.44
31.25	0.44	-	0.50	-	0.44	-	0.82	-	0.44	-	0.55	-
II. Uptake, mg./plant.												
S.E.	(12.68)				(2.43)				(14.52)			
0	102.0	88.7	74.5	31.7	13.0	14.6	14.5	8.3	115.0	103.3	89.0	40.0
5.0	111.7	-	66.9	-	19.3	-	19.3	-	131.0	-	86.2	-
12.5	123.2	83.1	54.3	50.7	17.1	21.1	23.4	18.7	140.3	104.3	77.7	69.3
31.25	114.2	-	62.8	-	16.1	-	20.7	-	130.2	-	83.5	-

Table 52.

The effect of aluminium and iron on phosphorus concentration and uptake in tobacco grown in granite sand.

	Leaves and stems					Roots					Whole plant				
	Aluminium, ppm.					Aluminium, ppm.					Aluminium, ppm.				
Iron, ppm.	0	5.0	12.5	31.25	Mean	0	5.0	12.5	31.25	Mean	0	5.0	12.5	31.25	Mean
I. Phosphorus, %.															
S.E.			(0.080)		(0.040)			(0.085)		(0.042)			(0.070)		(0.035)
0	0.73	0.75	0.76	1.03	0.82	0.69	0.72	0.68	0.78	0.72	0.72	0.74	0.75	1.00	0.80
5.0	0.73	0.80	0.72	0.69	0.74	0.62	0.70	0.67	0.67	0.66	0.71	0.79	0.71	0.69	0.73
12.5	0.71	0.72	0.72	0.72	0.72	0.64	0.63	0.69	0.71	0.67	0.71	0.71	0.72	0.73	0.72
31.25	0.84	0.78	0.75	0.56	0.73	0.78	0.55	0.60	0.65	0.64	0.84	0.75	0.74	0.57	0.72
S.E.			(0.040)					(0.042)					(0.035)		
Mean	0.75	0.76	0.76	0.75	0.75	0.68	0.65	0.66	0.70	0.67	0.74	0.75	0.73	0.74	0.74
II. Uptake, mg./plant.															
S.E.			(2.40)		(1.20)			(0.69)		(0.35)			(2.67)		(1.33)
0	15.8	17.7	18.5	20.8	18.2	2.9	3.3	4.0	3.2	3.3	18.7	20.9	22.5	24.0	21.5
5.0	18.9	17.3	18.2	15.1	17.4	2.4	2.0	2.8	2.7	2.5	21.3	19.3	21.0	17.8	19.8
12.5	15.3	17.0	16.9	15.6	16.2	1.3	2.3	2.6	3.1	2.3	16.6	19.3	19.4	18.7	18.5
31.25	9.7	11.0	11.5	8.4	10.2	1.2	1.5	0.7	1.2	1.1	11.0	12.5	12.2	9.5	11.3
S.E.			(1.20)					(0.35)					(1.33)		
Mean	14.9	15.7	16.3	15.0	15.5	2.0	2.3	2.5	2.5	2.3	16.9	18.0	18.8	17.5	17.8

Soil Studies.

Experiment 1. Testing the Ratio Law.

Six Rhodesian soils differing in soil pH, soil texture and parent material (Table 53) were equilibrated in different solutions containing varied concentrations of calcium. If the Ratio Law holds, then $a_H/\sqrt{a_{Ca + Mg}}$ or pH - $\frac{1}{2}$p(Ca + Mg) is constant, and plotting pH against $\frac{1}{2}$p(Ca + Mg) gives a straight line of slope 1.0. Figure 1 shows that:

Table 53.

Soil pH and mechanical analyses.

Soil	Locality	Parent material	pH (in 0.01M $CaCl_2$)	% clay ($<2\mu$)	% silt ($2-20\mu$)
1	Kutsaga	Biotite granite	4.82	5	5
2	Trelawney	Biotite granite + migmatites	5.49	12	10
3	Beatrice	Triassic sand	4.30	4	1
4	Norton	Phyllite schist	4.39	6	6
5	Kutsaga	Biotite granite (organic sponge)*	4.81	33	11
6	Inyanga	Dolerite/granite contact	3.88	22	9

* Organic matter removed by hydrogen peroxide: 9%.

1. The Ratio Law applied at concentrations up to 0.01M with soils 1 to 5 but not with 6. With this, serious deviations occurred above about 0.001M and the pH decreased progressively less steeply than $\frac{1}{2}$p(Ca + Mg) as the concentration increased.
2. The pH rises as $\frac{1}{2}$p(Ca + Mg) is increased (or as the concentration of calcium chloride is reduced).*

Experiment 2. The effect of available calcium content and/or soil pH on the growth of flue-cured tobacco.

The relationship between soil pH and the amount of $CaCO_3$ applied was linear for the Triassic sands, but on the granite sands soil pH increased much more with the first two rates tested than with the largest (Table 54). The increase in pH of the Triassic sands

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* These findings have been published in the Rhodesian Journal of Agricultural Research Vol. 2, 51-52, 1964 with Dr. R.C. Salmon as co-author titled "A Note on the measurement of soil pH in calcium chloride solutions".

Figure 1.

Relationships between pH and ½p(Ca + Mg) at different electrolyte concentrations.

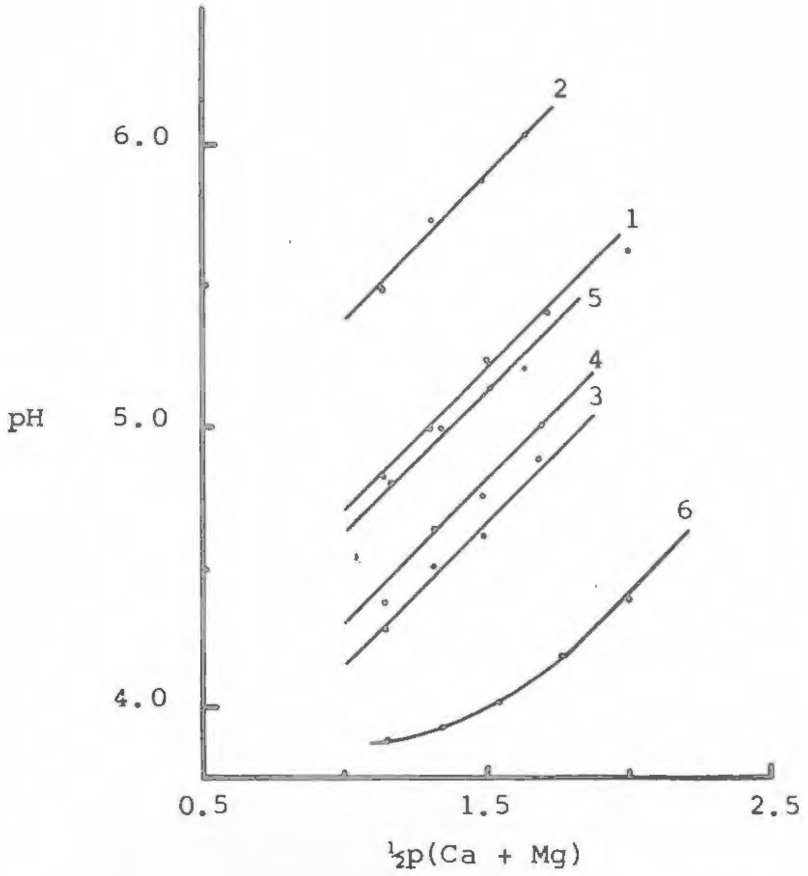


Table 54.

The effect of calcium carbonate and gypsum on soil pH and the functions pH - ½pCa and pH - ½p(Ca + Mg).

Experiment:	I. Triassic sand		II. Granite sand		III. Granite sand		IIIa. Granite sand	
	$CaSO_4.2H_2O$, g/kg. soil		$CaSO_4.2H_2O$, g/kg. soil		$CaSO_4.2H_2O$, g/kg. soil		Trace elements	
$CaCO_3$, g/kg. soil	0	10	0	10	0	10	Abs.	Pres.
I. pH								
0	4.89	4.82	4.86	4.94	5.12	5.19	5.32	5.30
0.1	5.05	5.04	5.22	5.29	5.48	5.45	5.52	5.50
0.5	5.62	5.61	6.06	6.07	6.15	6.14	6.19	6.13
1.0	6.35	6.46	6.73	6.82	6.97	6.93	6.85	6.95
II. -½ log f								
Mean	0.136	0.181	0.138	0.178	0.137	0.179	0.135	0.135
III. -½ log (Ca+Mg)								
0	1.01	0.899	1.00	0.919	1.01	0.915	1.02	1.02
0.1	1.00	0.899	1.00	0.919	1.01	0.913	1.02	1.02
0.5	1.00	0.899	1.00	0.917	1.00	0.910	1.01	1.01
1.0	1.00	0.895	0.99	0.907	1.00	0.906	1.00	1.00
IV. ½p(Ca+Mg)								
0	1.14	1.08	1.14	1.10	1.15	1.09	1.16	1.16
0.1	1.14	1.08	1.14	1.10	1.15	1.09	1.16	1.16
0.5	1.14	1.08	1.14	1.10	1.14	1.09	1.15	1.15
1.0	1.14	1.08	1.13	1.09	1.14	1.09	1.14	1.14
V. pH-½p(Ca+Mg)								
0	3.75	3.74	3.72	3.84	3.97	4.10	4.16	4.14
0.1	3.91	3.96	4.08	4.19	4.33	4.36	4.36	4.34
0.5	4.48	4.53	4.92	4.97	5.01	5.05	5.04	4.98
1.0	5.21	5.38	5.60	5.73	5.83	5.84	5.71	5.81
VI. pH-½pCa								
0	3.74	3.80	3.69	3.83	3.95	4.08	4.14	4.12
0.1	3.90	4.00	4.05	4.17	4.31	4.35	4.35	4.33
0.5	4.47	4.60	4.90	4.96	4.99	5.04	5.03	4.97
1.0	5.21	5.42	5.58	5.72	5.82	5.84	5.70	5.80

amounted to 0.75 for each 0.5 g. $CaCO_3$/kg. soil. On the granite sands adding 0.5 g. $CaCO_3$/kg. soil increased the pH by 1.0 unit; a further 0.5 g. $CaCO_3$ increased the pH by 0.75 units.

In these experiments sufficient gypsum was applied for the plants to grow in a saturated solution of gypsum, but soil pH was little different from that in 0.01M $CaCl_2$, and the functions pH - ½p(Ca + Mg) and pH - ½pCa were similar for both treatments (Table 54).

Calcium carbonate (lime) improved tobacco yields particularly on very acid Triassic and granite sands of Experiments I and II respectively, where the main effects were produced with the first and second increments of calcium carbonate (Table 55). In Experiment III, where the granite sand was less acid, calcium carbonate reduced yields. This might have been due to trace element deficiencies, but on testing this possibility in Experiment IIIa, where calcium carbonate increased yields as in Experiment II, trace elements had only a slight beneficial effect on yield. The effects of calcium carbonate were similar both in the absence and presence of gypsum. However, the overall effect of gypsum was to reduce tobacco yields (Table 55).

The calcium concentration of plants increased with increasing rates of calcium carbonate; in the presence of gypsum the results were erratic but generally the concentrations were larger than in the absence of gypsum (Table 56).

In both the presence and absence of gypsum, the manganese concentration decreased with increasing rates of calcium carbonate, but gypsum had no effect on manganese concentration in this series of experiments (Table 57). In Experiment IIIa, manganese concentration in the plants was decreased even though manganese was added in the trace element mixture.

The effect of treatments on magnesium (Table 58), aluminium (Table 59) and iron (Table 60) concentrations were very erratic.

<u>Experiment 3.</u> The effect of lime (calcium carbonate) on hydronium, aluminium, iron and manganese concentrations in soil solution.

Table 55.

The effect of calcium carbonate and gypsum on the yield of tobacco leaves and stem (g./plant).

Experiment:	I. Triassic sand			II. Granite sand			III. Granite sand			IIIa. Granite sand		
$CaCO_3$,	$CaSO_4 2H_2O$, g/kg.soil			$CaSO_4 2H_2O$, g/kg.soil			$CaSO_4 2H_2O$, g/kg.soil			Trace elements		
g/kg.soil	0	10	Mean	0	10	Mean	0	10	Mean	Abs.	Pres.	Mean
S.E.	(0.347)		(0.245)	(0.440)		(0.311)	(0.602)		(0.426)	(0.542)		(0.383)
0	2.40	1.21	1.80	4.53	4.05	4.29	4.04	3.28	3.66	4.73	4.89	4.81
0.1	3.15	1.89	2.52	4.17	5.05	4.61	3.68	3.07	3.37	4.63	4.96	4.80
0.5	3.17	3.42	3.30	6.44	5.43	5.93	2.75	2.12	2.44	5.25	5.99	5.62
1.0	3.39	3.28	3.34	5.85	4.58	5.21	2.84	2.17	2.51	5.12	5.38	5.25
S.E.	(0.174)			(0.220)			(0.301)			(0.271)		
Mean	3.03	2.45	2.74	5.25	4.78	5.01	3.33	2.66	2.99	4.93	5.30	5.12

Table 56.

The effect of calcium carbonate and gypsum on the calcium concentration and uptake in leaves and stem of tobacco plants.

Experiment:	I. Triassic sand			II. Granite sand			III. Granite sand			IIIa. Granite sand		
$CaCO_3$,	$CaSO_4 2H_2O$, g/kg. soil			$CaSO_4 2H_2O$, g/kg. soil			$CaSO_4 2H_2O$, g/kg. soil			Trace elements		
g/kg. soil	0	10	Mean	0	10	Mean	0	10	Mean	Abs.	Pres.	Mean
I. Calcium, %.												
S.E.	(0.106)		(0.075)	(0.099)		(0.070)	(0.156)		(0.110)	(0.049)		(0.0349)
0	0.37	0.69	0.53	0.33	0.44	0.38	0.64	1.84	1.24	0.65	0.75	0.70
0.1	0.37	0.80	0.59	0.46	0.45	0.46	0.70	1.15	0.93	0.87	1.00	0.94
0.5	0.60	0.76	0.68	0.57	0.61	0.60	0.99	1.30	1.14	1.14	1.09	1.12
1.0	0.64	0.89	0.76	0.38	0.53	0.46	1.56	1.91	1.73	1.22	1.11	1.16
S.E.	(0.059)			(0.050)			(0.078)			(0.025)		
Mean	0.49	0.79	0.64	0.44	0.51	0.47	0.97	1.55	1.26	0.97	0.99	0.98
II. Uptake, mg./plant.												
S.E.	(4.59)		(3.24)	(5.89)		(4.16)	(9.78)		(6.92)	(5.53)		(3.91)
0	8.6	8.4	8.5	13.8	19.1	16.5	27.6	62.2	44.9	30.9	36.7	33.8
0.1	12.2	15.2	13.7	19.1	22.4	20.8	26.4	35.6	31.0	40.0	49.5	44.8
0.5	19.6	26.0	22.8	37.0	33.0	35.0	28.1	27.6	27.8	60.0	65.2	62.6
1.0	23.3	30.3	26.8	22.4	24.9	23.7	47.1	41.0	44.0	62.5	59.6	61.0
S.E.	(2.29)			(2.94)			(4.89)			(2.77)		
Mean	15.9	20.0	18.0	23.1	24.9	24.0	32.3	41.6	36.9	48.4	52.8	50.6

Table 57.

The effect of calcium carbonate and gypsum on manganese concentration and uptake in leaves and stem of tobacco plants.

Experiment:	I. Triassic sand			II. Granite sand			III. Granite sand			IIIa. Granite sand		
$CaCO_3$, g/kg. soil	$CaSO_4 2H_2O$, g/kg. soil 0	10	Mean	$CaSO_4 2H_2O$, g/kg. soil 0	10	Mean	$CaSO_4 2H_2O$, g/kg. soil 0	10	Mean	Trace elements Abs.	Pres.	Mean
I. Manganese, ppm.												
S.E.	(31.9)		(22.6)	(31.8)		(22.5)	(50.0)		(35.4)	(23.7)		(16.8)
0	592	500	546	293	299	296	196	355	275	370	251	311
0.1	525	519	522	243	251	247	213	242	227	356	185	271
0.5	448	485	467	203	211	207	222	129	176	84	66	75
1.0	408	416	412	197	179	188	141	101	121	57	62	59
S.E.	(16.0)			(15.9)			(25.0)			(11.8)		
Mean	493	480	487	234	235	234	193	207	200	217	141	179
II. Uptake, mg./plant.												
S.E.	(0.169)		(0.120)	(0.218)		(0.154)	(0.173)		(0.122)	(0.091)		(0.065)
0	1.44	0.60	1.02	1.34	1.23	1.28	0.85	1.21	1.03	1.72	1.23	1.47
0.1	1.65	0.97	1.31	1.02	1.26	1.14	0.72	0.78	0.75	1.62	0.91	1.27
0.5	1.41	1.66	1.53	1.31	1.13	1.22	0.46	0.26	0.36	0.44	0.40	0.42
1.0	1.41	1.32	1.37	1.18	0.85	1.01	0.41	0.22	0.31	0.28	0.33	0.31
S.E.	(0.085)			(0.109)			(0.087)			(0.046)		
Mean	1.48	1.14	1.31	1.21	1.12	1.16	0.61	0.62	0.61	1.01	0.72	0.87

Table 58.

The effect of calcium carbonate and gypsum on the magnesium concentration and uptake in leaves and stem of tobacco plants.

Experiment:	I. Triassic sand			II. Granite sand			III. Granite sand			IIIa. Granite sand		
$CaCO_3$,	$CaSO_4 2H_2O$, g/kg.soil			$CaSO_4 2H_2O$, g.kg.soil			$CaSO_4 2H_2O$, g/kg.soil			Trace elements		
g/kg.soil	0	10	Mean	0	10	Mean	0	10	Mean	Abs.	Pres.	Mean
I. Magnesium, %.												
S.E.	(0.083)		(0.058)	(0.093)		(0.066)	(0.121)		(0.085)	(0.066)		(0.047)
0	2.36	2.10	2.23	2.02	1.99	2.01	1.31	1.58	1.44	1.45	1.63	1.54
0.1	2.24	2.27	2.25	1.72	2.01	1.87	1.63	1.17	1.40	1.70	1.54	1.62
0.5	2.10	2.47	2.29	1.88	1.83	1.86	1.94	1.37	1.66	1.62	1.41	1.51
1.0	2.34	2.07	2.20	1.89	1.90	1.89	1.95	1.61	1.78	1.56	1.56	1.56
S.E.	(0.041)			(0.046)			(0.060)			(0.033)		
Mean	2.26	2.23	2.24	1.88	1.94	1.91	1.71	1.44	1.57	1.58	1.53	1.56
II. Uptake, mg./plant.												
S.E.	(7.68)		(5.43)	(10.31)		(7.29)	(10.96)		(7.75)	(9.01)		(6.37)
0	57.3	24.9	41.1	93.4	80.2	86.8	56.5	53.1	54.8	68.3	79.4	73.8
0.1	70.2	42.9	56.5	71.9	101.7	86.8	59.0	37.3	48.2	78.1	76.7	77.4
0.5	66.7	84.6	75.6	121.1	99.0	110.0	51.1	29.5	40.3	85.2	84.4	84.8
1.0	79.4	66.7	73.1	110.5	87.5	99.0	54.9	34.9	44.9	80.4	83.9	82.2
S.E.	(3.84)			(5.16)			(5.48)			(4.51)		
Mean	68.4	54.8	61.6	99.2	92.1	95.6	55.4	38.7	47.0	78.0	81.1	79.5

Table 59.

The effect of calcium carbonate and gypsum on aluminium concentration and uptake in leaves and stem of tobacco plants.

Experiment:	I. Triassic sand			II. Granite sand			III. Granite sand			IIIa. Granite sand		
$CaCO_3$,	$CaSO_4 2H_2O$, g/kg.soil			$CaSO_4 2H_2O$, g/kg.soil			$CaSO_4 2H_2O$, g/kg.soil			Trace elements		
g/kg. soil	0	10	Mean	0	10	Mean	0	10	Mean	Abs.	Pres.	Mean
I. Aluminium, ppm.												
S.E.	(57.6)		(40.7)	(16.0)		(11.3)	(68.2)		(48.2)	(70.1)		(49.6)
0	217	580	399	221	233	227	421	445	433	441	504	473
0.1	247	333	290	243	203	223	487	445	466	437	582	510
0.5	228	230	229	239	255	247	575	517	546	370	402	386
1.0	233	223	228	211	237	224	508	557	533	331	444	388
S.E.	(28.8)			(8.0)			(34.1)			(35.1)		
Mean	231	341	286	229	232	230	497	491	494	395	483	439
II. Uptake, mg./plant.												
S.E.	(0.101)		(0.072)	(0.148)		(0.105)	(0.339)		(0.239)	(0.255)		(0.180)
0	0.53	0.70	0.61	1.01	0.93	0.97	1.75	1.35	1.55	2.01	2.42	2.22
0.1	0.75	0.56	0.66	1.02	1.03	1.02	1.77	1.34	1.56	1.99	2.86	2.42
0.5	0.73	0.79	0.76	1.54	1.38	1.46	1.47	1.16	1.31	1.95	2.40	2.17
1.0	0.79	0.73	0.76	1.24	1.09	1.16	1.45	1.23	1.34	1.69	2.39	2.04
S.E.	(0.051)			(0.074)			(0.169)			(0.127)		
Mean	0.70	0.69	0.70	1.20	1.11	1.15	1.61	1.27	1.44	1.91	2.52	2.21

Table 60.

The effect of calcium carbonate and gypsum on iron concentration and uptake in leaves and stem of tobacco plants.

Experiment:	I. Triassic sand			II. Granite sand			III. Granite sand			IIIa. Granite sand		
CaCO$_3$,	CaSO$_4$2H$_2$O, g/kg.soil			CaSO$_4$2H$_2$O, g/kg.soil			CaSO$_4$2H$_2$O, g/kg.soil			Trace elements		
g/kg.soil	0	10	Mean	0	10	Mean	0	10	Mean	Abs.	Pres.	Mean
I. Iron, ppm.												
S.E.	(108.6)		(76.8)	(122.6)		(86.7)	(31.6)		(22.3)	(29.1)		(20.6)
0	340	833	587	483	493	488	360	422	391	288	305	296
0.1	450	539	495	273	380	327	377	480	428	308	320	314
0.5	408	393	401	293	677	485	453	423	438	278	345	311
1.0	377	313	345	243	393	318	453	433	443	305	335	320
S.E.	(54.3)			(61.3)			(15.8)			(14.6)		
Mean	394	520	457	323	486	405	411	440	425	294	326	310
II. Uptake, mg./plant.												
S.E.	(0.264)		(0.187)	(0.669)		(0.473)	(0.304)		(0.215)	(0.126)		(0.089)
0	0.82	1.08	0.95	2.29	1.93	2.11	1.47	1.31	1.39	1.32	1.48	1.40
0.1	1.46	0.93	1.20	1.15	1.91	1.53	1.38	1.47	1.43	1.41	1.59	1.50
0.5	1.27	1.35	1.31	1.89	3.88	2.88	1.24	0.93	1.08	1.46	2.07	1.76
1.0	1.27	1.05	1.16	1.40	1.65	1.53	1.31	0.95	1.13	1.54	1.81	1.67
S.E.	(0.132)			(0.334)			(0.152)			(0.063)		
Mean	1.21	1.10	1.15	1.68	2.34	2.01	1.35	1.17	1.26	1.43	1.73	1.58

As expected, adding lime increased soil pH. In the soil solution the concentration of calcium was increased but the concentrations of aluminium, iron, manganese, potassium and sometimes magnesium were decreased with each increment of lime (Table 61). It therefore follows that their activity ratios were decreased with each application of lime (Table 62). Generally soil pH affected the concentrations of aluminium, iron and manganese more than calcium, magnesium and potassium.

The relationship between applied lime and soil pH was linear for Triassic sands and curvilinear for granite sands (Table 62). The values of the functions $pH - \frac{1}{2}pCa$ and $pH - \frac{1}{2}p(Ca + Mg)$ are almost the same (Table 62), and increase with increasing rates of lime, as did the values of the function $pH - \frac{1}{3}\,pAl$ (Table 62).

<u>Experiment 4.</u> The effect of hydronium, aluminium, iron and manganese on the growth of flue-cured tobacco.

Seventeen days after planting, distinct mottling resembling manganese toxicity appeared on all calcium carbonate treatments on soils 1, 5 and 17. By the 27th day this mottling had become fainter where nutrient had been applied but where no nutrients had been applied brown lesions, confined often to the tips and edges of the leaves, had developed. Finally after 36 days when the plants were harvested, yellow mottling and black lesions had developed on treatments receiving no calcium carbonate or nutrients. In many cases mottling disappeared on the no calcium carbonate treatments which received nutrients.

After 23 days, faint mottling was seen on all treatments of soil 15, being more pronounced on the limed soil, and persisted throughout the experiment.

Although lime (calcium carbonate) had no effect on yield, it significantly increased calcium, decreased manganese and did not affect phosphorus and iron concentrations; there was a tendency for the potassium, magnesium and aluminium concentrations to be slightly

Table 61.

The effect of lime on the composition of the soil solution.

Lime (per 100 g. soil)	pH	Ca millimole/l.	Mg millimole/l.	K millimole/l.	Al micromole/l.	Fe micromole/l.	Mn micromole/l.
Granite sand.							
0	4.640	8.153	0.760	0.2251	22.25	13.23	58.58
0.01	4.910	8.207	0.706	0.2200	11.75	8.45	54.71
0.05	6.052	8.216	0.652	0.2072	2.48	2.27	33.90
0.10	6.920	8.587	0.544	0.1995	2.08	2.17	15.49
Triassic sand.							
0	4.430	8.533	0.380	0.4264	35.00	20.59	83.76
0.01	4.752	8.642	0.326	0.4169	14.42	11.82	76.02
0.05	5.959	8.802	0.380	0.3939	4.12	3.26	40.67
0.10	7.180	9.185	0.326	0.3911	2.08	2.17	8.72
Granite sand.							
0	4.890	8.642	0.380	0.3274	14.42	1.74	33.41
0.01	5.395	8.696	0.380	0.3121	3.49	2.27	15.98
0.05	7.040	8.913	0.490	0.2993	0.63	1.20	3.88
0.10	7.410	8.968	0.380	0.2890	0.41	1.09	2.42

Table 62.

The effect of lime on chemical potentials and activity ratios.

Lime (per 100 g. soil)	pH	pH - $\frac{1}{2}$pCa	pH - $\frac{1}{2}$p(Ca + Mg)	pH - $\frac{1}{3}$pAl	$a_K/\sqrt{a_{Ca+Mg}}$ (mole/l.)$^{\frac{1}{2}}$	$\sqrt[3]{a_{Al}}/\sqrt{a_{Ca+Mg}}$ (mole/l.)$^{-1/6}$	$\sqrt{a_{Fe}/a_{Ca+Mg}}$ mole/l.	$\sqrt{a_{Mn}/a_{Ca+Mg}}$ mole/l.
Granite sand.								
0	4.640	3.47	3.48	2.87	0.002777	0.2440	0.03852	0.08107
0.01	4.910	3.74	3.75	3.03	0.002714	0.1903	0.03079	0.07834
0.05	6.052	4.88	4.89	3.76	0.002558	0.07249	0.01596	0.06166
0.10	6.920	5.76	5.77	4.34	0.002433	0.03701	0.01541	0.04118
Triassic sand.								
0	4.430	3.26	3.27	2.73	0.005265	0.2885	0.04807	0.09694
0.01	4.750	3.59	3.60	2.91	0.005131	0.2078	0.03630	0.09207
0.05	5.959	4.80	4.81	3.76	0.004790	0.08941	0.01883	0.06654
0.10	7.180	6.03	6.04	4.51	0.004675	0.02986	0.01511	0.03028
Granite sand.								
0	4.890	3.73	3.73	3.04	0.004020	0.2078	0.01389	0.06085
0.01	5.395	4.23	4.24	3.29	0.003821	0.1111	0.01581	0.04196
0.05	7.040	5.88	5.89	4.24	0.003600	0.02242	0.01130	0.02031
0.10	7.410	6.25	6.26	4.43	0.003485	0.01474	0.01080	0.01609

decreased (Table 63).

As expected, added nutrients improved yield. They significantly decreased calcium, magnesium, aluminium and manganese, and increased potassium and phosphorus concentrations; iron concentration was unaffected (Table 63).

Lime increased exchangeable calcium, decreased exchangeable aluminium, iron and manganese and did not affect exchangeable magnesium and potassium and resin extractable phsophorus (Table 64). The concentration of the ions in the soil solution increased as their amounts in the exchangeable form increased (Table 64). except phosphorus which increased.

Table 64.

The effect of lime on exchangeable ions and their concentration in soil solution.

Element	Chemical analysis of soil.		Chemical analysis of soil solution.	
	Unlimed	Limed	Unlimed	Limed
pH	5.71	5.99	5.71	5.99
	me./100 g.		10^{-6} mol./litre.	
Ca	2.08	2.39	357.7	471.2
Mg	1.01	0.98	260.8	235.9
K	0.24	0.23	318.5	319.4
	ppm.			
P	4.7	5.0	0.89	1.89
Al	39.9	18.0	3.725	1.577
Mn	65.9	53.6	4.537	2.818
Fe	12.4	5.7	3.839	2.561

There was no relationship between the growth of tobacco and its chemical composition, although when no calcium carbonate or nutrients were added tobacco yields tended to increase with decreasing concentration of aluminium and iron in the plant, but when either calcium carbonate or nutrients were added this was not apparent. When soil solution data was compared with plant

Table 63.

The effect of lime on yield and chemical composition of flue-cured tobacco.

Treatments		Yield	Ca	Mg	K	P	Al	Mn	Fe
$CaCO_3$	Nutrients	g./plant	%	%	%	%	ppm.	ppm.	ppm.
S.E.		(0.0645)	(0.051)	(0.0134)	(0.063)	(0.0091)	(29.5)	(102.7)	(22.1)
Abs.	Abs.	0.994	1.90	0.548	2.44	0.106	911	1594	435
Pres.	Abs.	1.019	2.27	0.524	2.31	0.106	871	858	450
Abs.	Pres.	1.318	1.21	0.445	3.67	0.473	789	1094	411
Pres.	Pres.	1.268	1.25	0.418	3.63	0.456	784	564	421
S.E.		(0.0456)	(0.036)	(0.0095)	(0.045)	(0.0065)	(20.9)	(72.6)	(15.6)
Abs.	Mean	1.156	1.55	0.497	3.05	0.289	850	1344	423
Pres.	Mean	1.143	1.76	0.471	2.97	0.281	827	711	436
S.E.		(0.0456)	(0.036)	(0.0095)	(0.045)	(0.0065)	(20.9)	(72.6)	(15.6)
Mean	Abs.	1.006	2.08	0.536	2.37	0.106	891	1226	443
Mean	Pres.	1.293	1.23	0.432	3.65	0.464	786	826	416
Mean		1.150	1.65	0.484	3.01	0.285	839	1027	429

Table 65.

Regressions of phosphorus and manganese concentrations in the plant on their respective soil solution measurement.

Treatment		Linear	Quadratic
I.	P% in plant on pH_2PO_4.		
	Unlimed and limed soils, no nutrients.	- 0.4682 ± 0.09512***	0.03246 ± 0.007355***
II.	P% in plant on $pH_2PO_4 + \frac{1}{2}pCa$.		
	Unlimed and limed soils, no nutrients.	- 0.5224 ± 0.10977***	0.02901 ± 0.006699***
III.	Mn ppm. in plant $\sqrt{a_{Mn}/a_{Ca + Mg}}$		
	Unlimed, no nutrients.	- 64120 ± 14836.2***	603131 ± 73166.2***
	Unlimed, nutrients.	- 17551 ± 10833.6	239208 ± 53427.0***
	Limed, no nutrients.	26572 ± 2535.3***	-------
	Limed, nutrients.	15507 ± 1372.8***	-------
	All treatments.	29080 ± 9011.0**	347188 ± 47387.2***

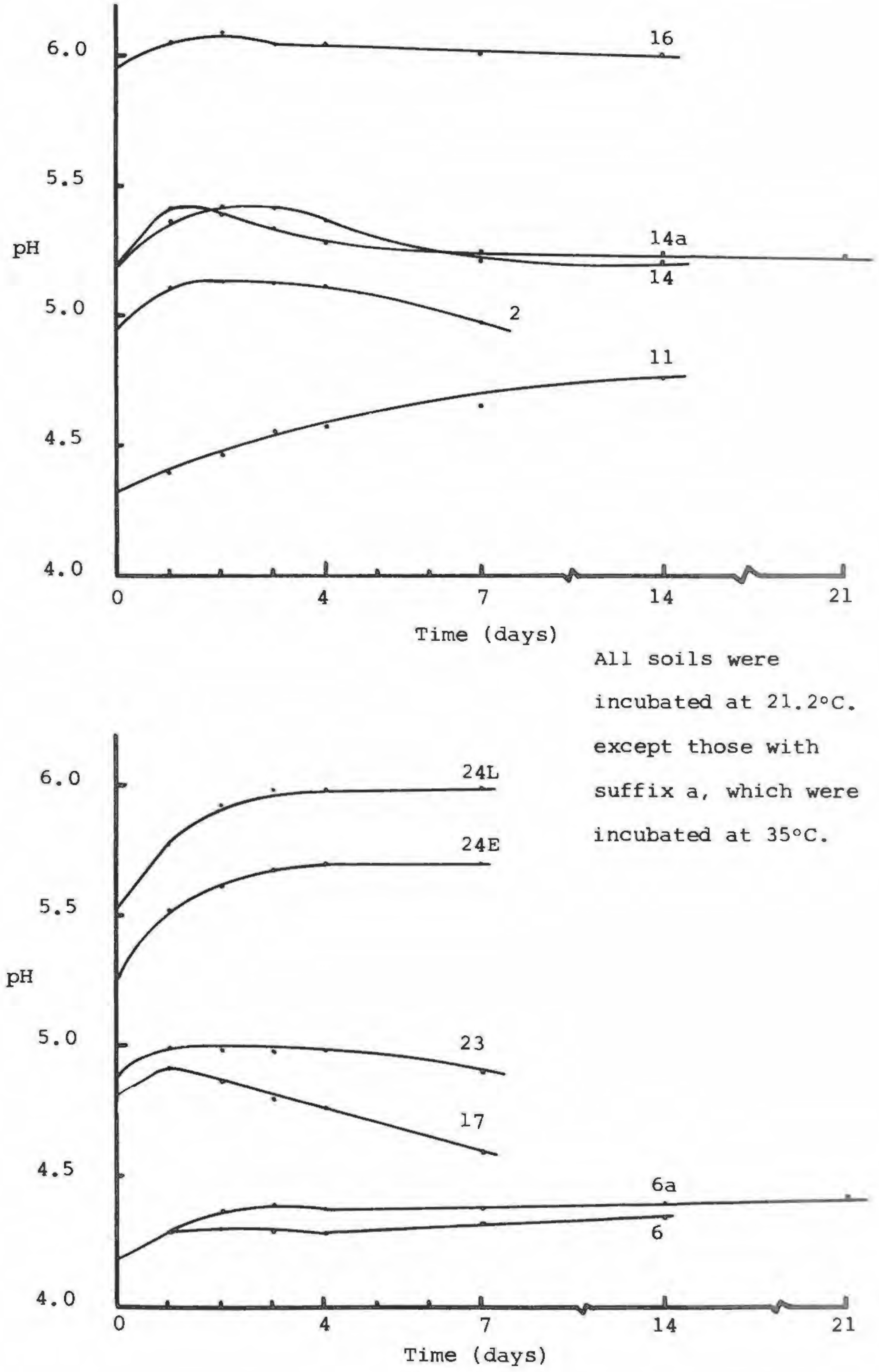
composition the correlations were poor except for phosphorus and manganese. The relationship between percentage phosphorus in the plant and pH_2PO_4 or $pH_2PO_4 + \frac{1}{2}pCa$ (phosphate potential) in solution was curvilinear, as was Mn ppm. in the plant vs $\sqrt{a_{Mn}/a_{Ca + Mg}}$ in solution; their regression coefficients with their standard errors are in Table 65. Finally yield was also poorly correlated with solution data and pH alone was as effective as $pH - \frac{1}{2}p(Ca + Mg)$, $pH - \frac{1}{2}pCa$, $pH - \frac{1}{2}pFe$, $pH - \frac{1}{2}pMn$, $pH - \frac{1}{3}\ pAl$ and $pH - p(\sqrt{a_{Ca + Mg}} + \sqrt{a_{Mn}} + a_K + \sqrt{a_{Fe}} + \sqrt[3]{a_{Al}})$. For each of the 17 soils, their yield and chemical composition of tobacco, and soil and soil solution measurements will be found in Appendix IV; Soil Studies, Experiment 4.

Experiment 5. The effect of incubating soil at about field capacity on soil pH and availability of aluminium, iron and manganese.

In figure 2 variations in soil pH are illustrated. On all soils there was initial increase in soil pH, generally even after one hour incubation, and a maximum value was obtained after one day for soils 2, 14, 17 and 23. Soils 2 and 23 maintained a constant pH up to the fourth day, and then their pH decreased to almost the initial value, but on soils 14 and 17 pH decreased to a value which was similar to the initial pH of the former and lower than the initial pH of the latter. However, soils 6, 11 and 16 behaved differently. The pH of soil 16 attained a maximum value after two days and then gradually decreased to a constant value midway between the maximum and initial pH; soil 6 reached a maximum value after four days which remained constant thereafter; the pH of soil 11 increased progressively. When the temperature of incubation was increased from 21.2 to 35^{o}C., after seven days the pH increased by about 0.05 unit for soils 6 and 14. Only one comparison was done on early (autumn) and late (spring) ploughed soils, designated 24E and 24L respectively; the pH changes were the same and a constant value (about 0.5 unit higher than the initial pH) was reached after four days.

Figure 2.

Variation in soil pH with time of incubation.



All soils were incubated at 21.2°C. except those with suffix a, which were incubated at 35°C.

A curvilinear relation existed between the concentration of aluminium in the soil solution and the soil pH (figure 3); when the pH was greater than 4.8 very small quantities of aluminium were found in the soil solution. For all soils the concentration of aluminium increased with decrease in pH; at very low concentrations (less than 0.2 ppm.) there was more variation in results but this did not affect the overall pattern. On incubating soil 6, the effect of temperature is very striking and the aluminium concentration was decreased as the pH increased (figure 4). Soils 24E and 24L behaved similarly; the concentration of aluminium in the soil solution decreased to a very small amount.

Iron concentration increased with decreasing pH (figure 5). In most instances the concentration of iron was very low (less than 0.1 ppm.) and the highest (about 0.8 ppm.) were associated with the more acidic soils Nos. 6 and 11. The effect of temperature was very marked on soil 6 but not on soil 14 (figure 6); here the concentration of iron increased from 0.38 to 3.14 ppm. in two days and then decreased to 0.11 ppm. on the 14th day, approximately the same value as the iron concentration at the lower temperature.

The manganese concentration varied from soil to soil, ranging from 2 to 12 ppm. in different air-dried soils; these concentrations were not related to initial air-dried pH. This is clearly illustrated by soils 2, 17 and 23 whose pH were 4.94, 4.82 and 4.90, and manganese concentrations 11.88, 5.44 and 2.00 ppm. respectively. A characteristic feature here was the decrease in manganese with time of incubation; for soils 2, 14, 16, 17 and 23 a maximum value was reached in either one or two days and then the concentration fell off rapidly to a much lower value, but for soils 24E and 24L manganese concentration decreased immediately (figure 7). Manganese decreased more rapidly the lower its initial concentration. Soil 11 maintained a fairly uniform level of manganese, but soil 6 reached a maximum value after two days and this level was maintained thereafter. Temperature slightly increased and decreased the availability of manganese in soils 6 and 14, respectively.

Figure 3.

The relationship between soil pH and available aluminium.

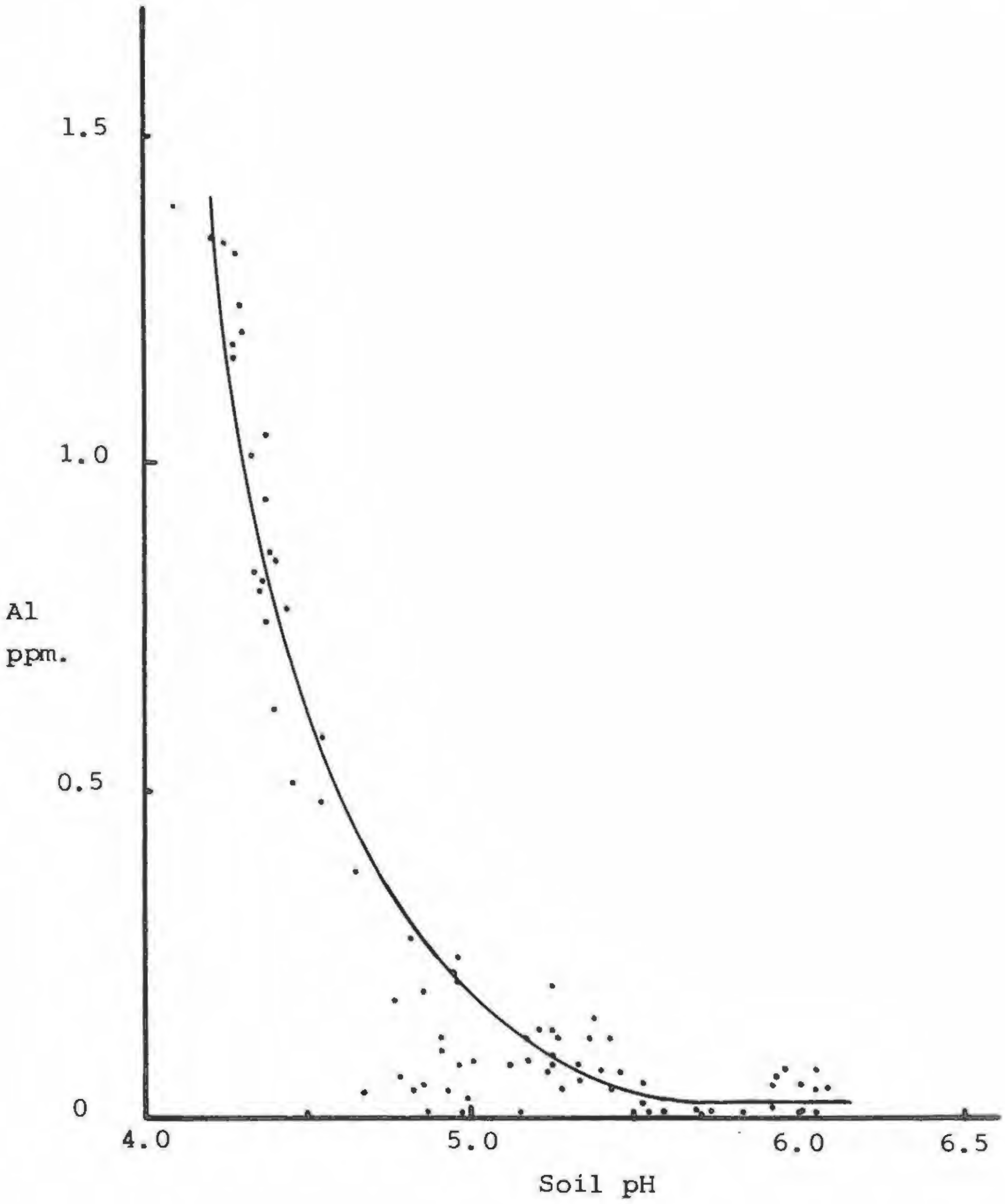
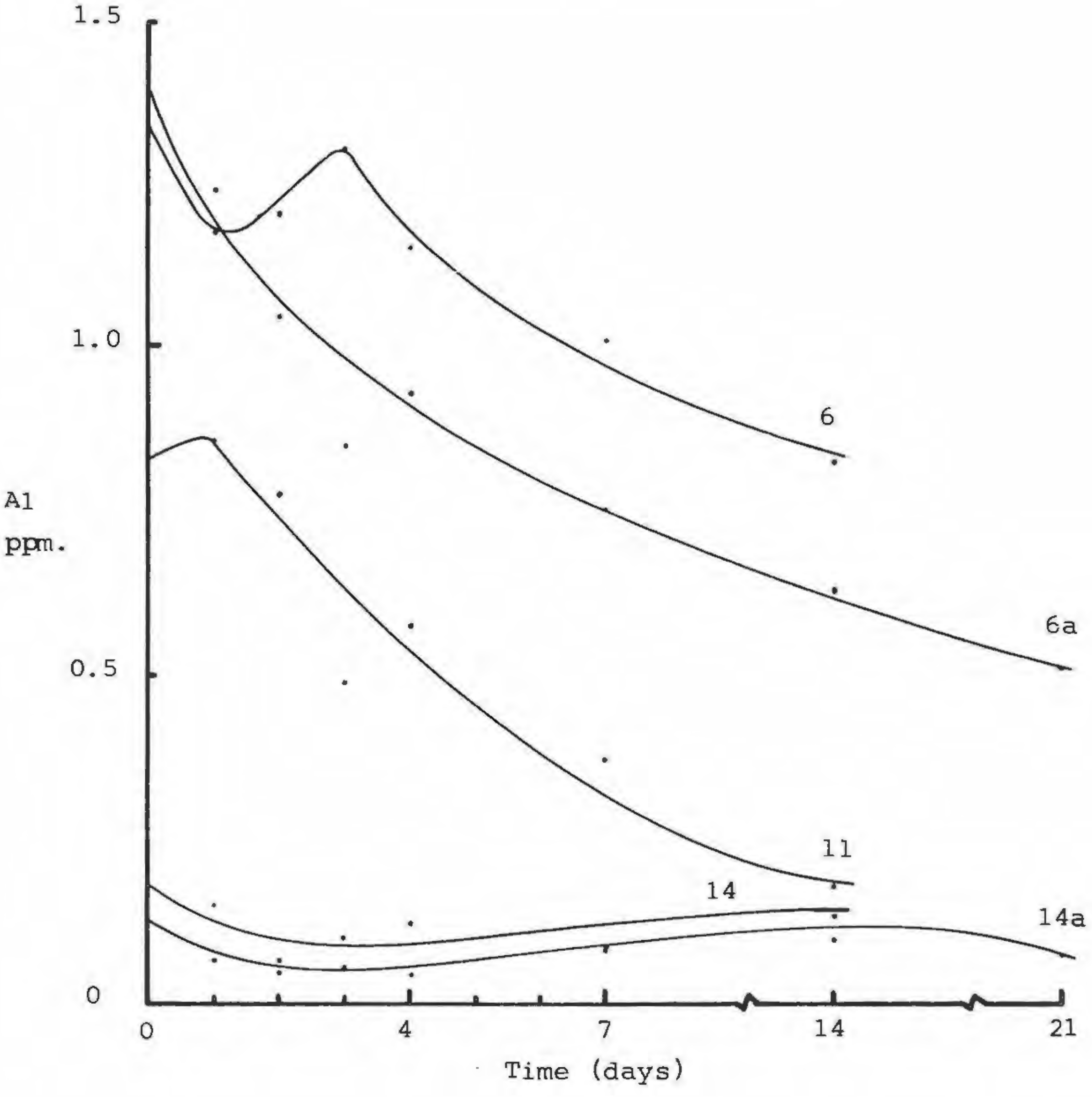


Figure 4.

The variation of available aluminium with time and temperature of incubation.



All soils were incubated at 21.2°C. except those with suffix a, which were incubated at 35°C.

Figure 5.

The relationship between soil pH and available iron.

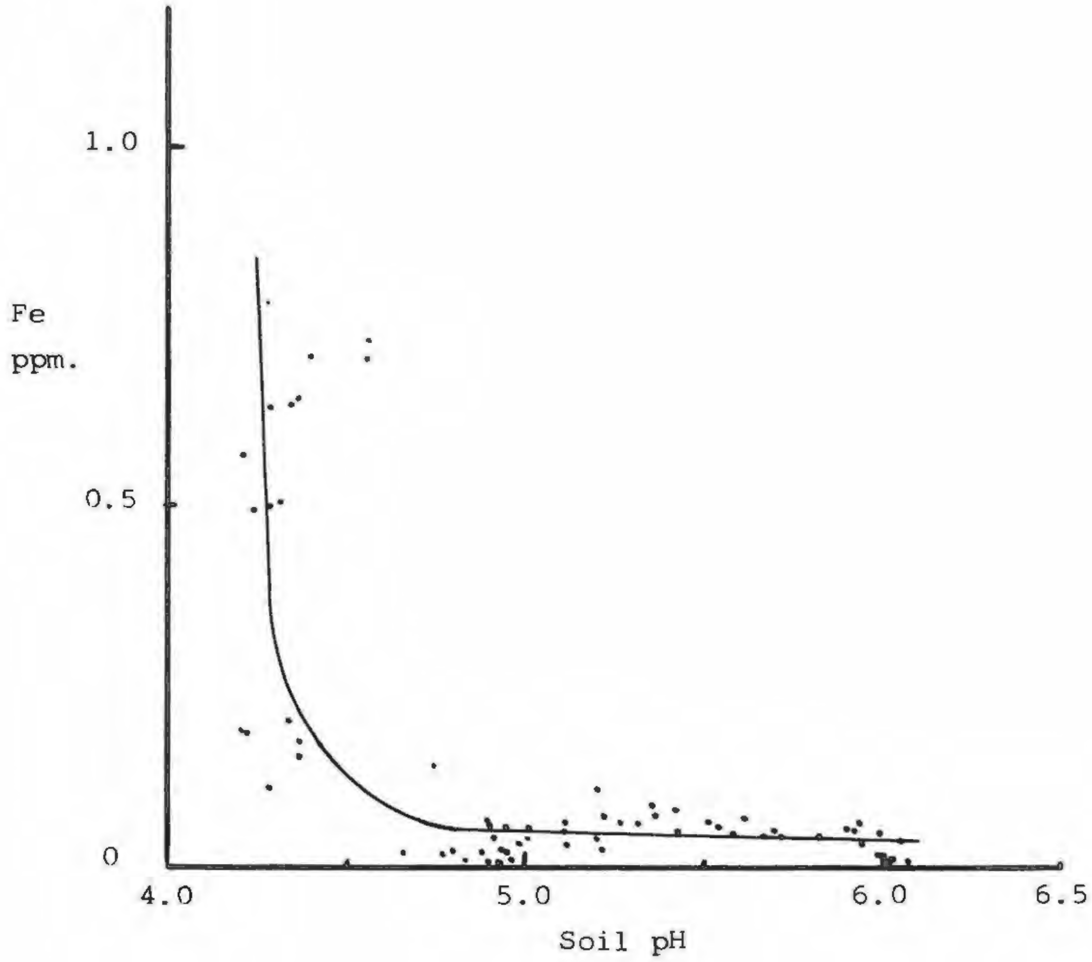
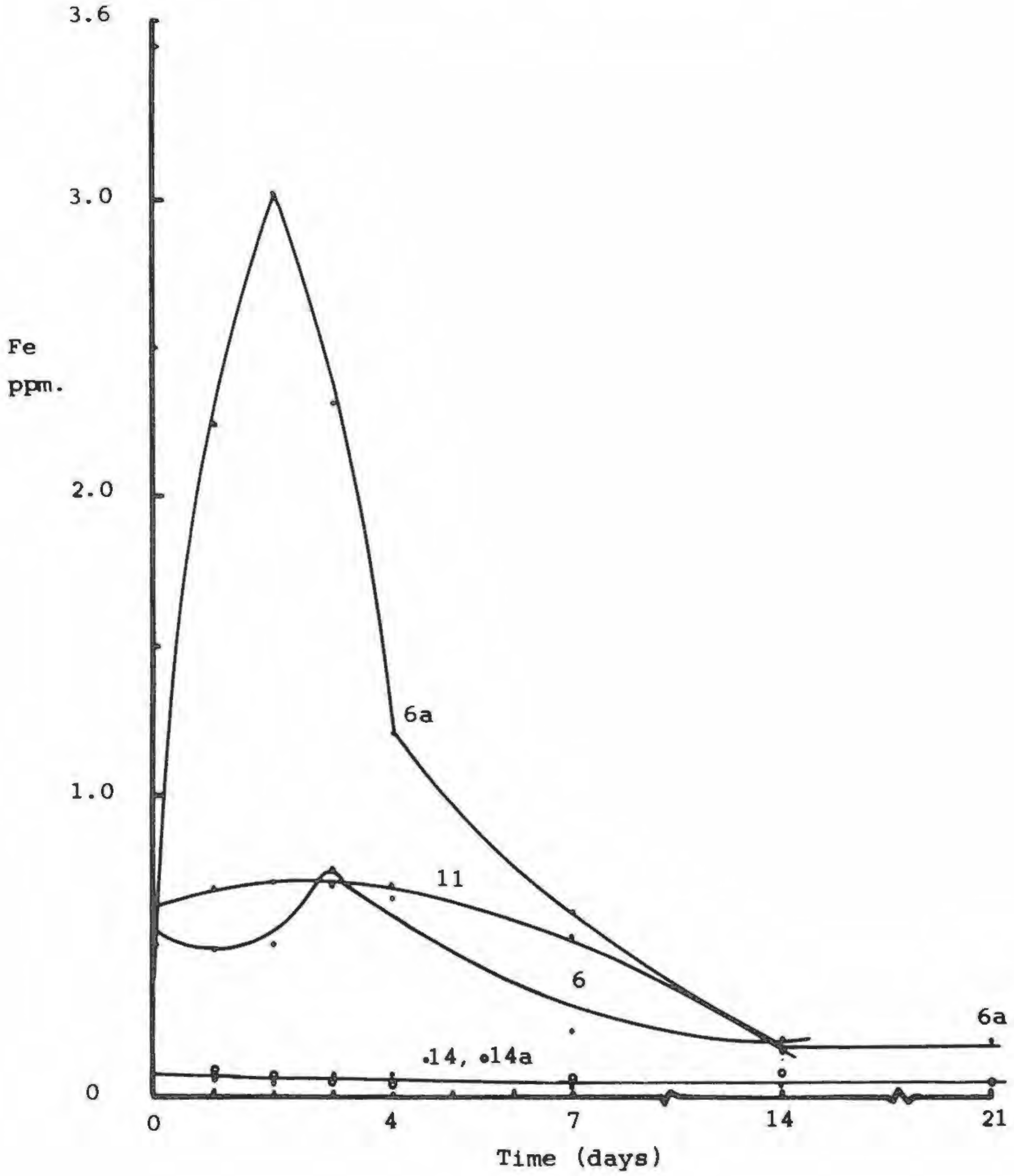


Figure 6.

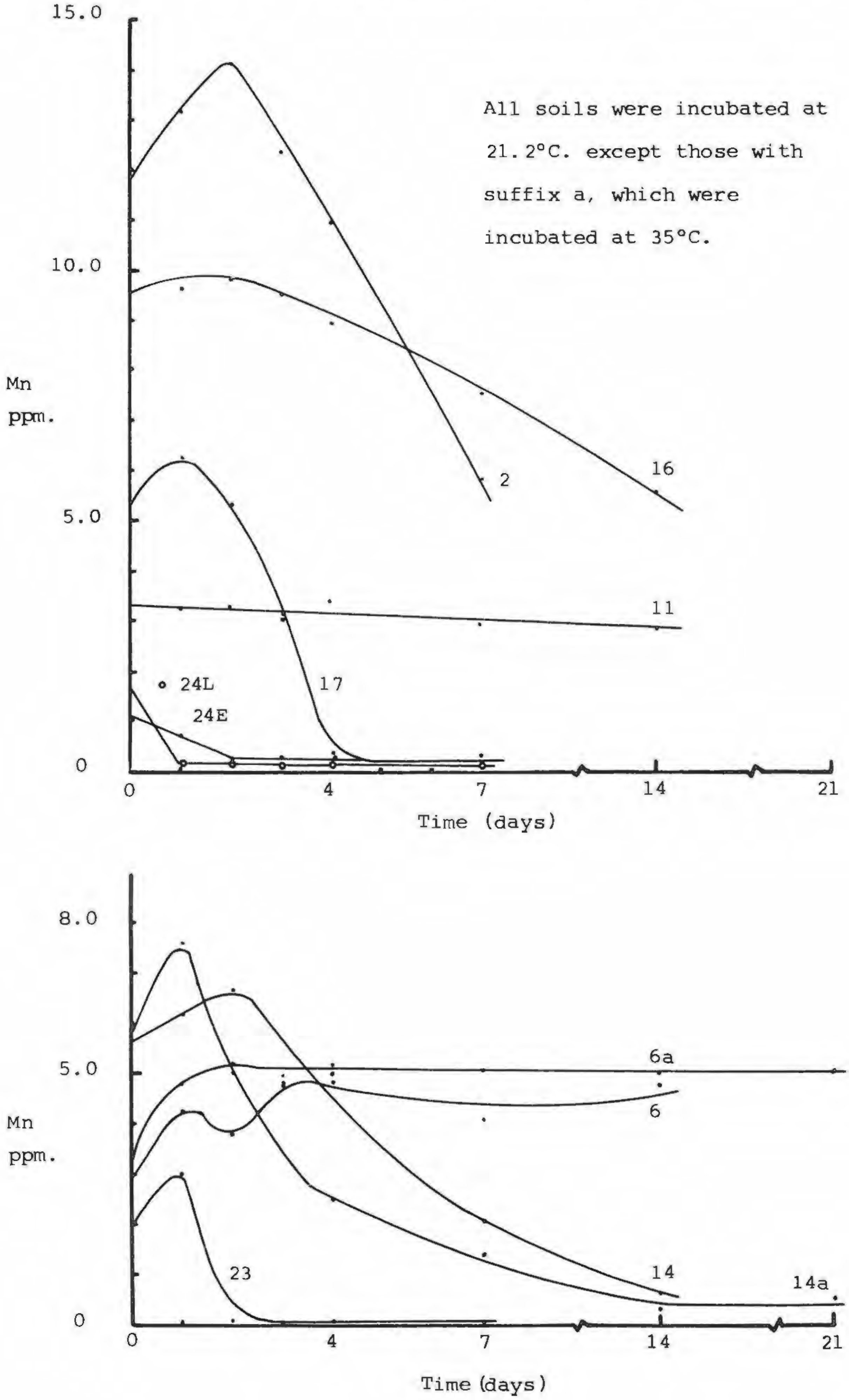
The variation of available iron with time and temperature of incubation.



All soils were incubated at 21.2°C. except those with suffix a, which were incubated at 35°C.

Figure 7.

The variation of available manganese with time and temperature of incubation.



DISCUSSION

Field Studies.

Yield.

The agronomic studies clearly illustrated the beneficial effects of lime on the yield of flue-cured tobacco in contrast to earlier American results. The effect of source (ground limestone, ground mixed lime, ground dolomite and slaked lime) and times of application (autumn or spring) were small, indicating a fundamental need for lime on acid soils. The largest yields were often associated with the highest pH (or the heaviest rate of applied lime). Generally, the beneficial effects of dolomite agreed with those cited earlier (6, 24), but the detrimental effects found by others with slaked lime (25) and ground calcitic limestone (6) were not observed. Although Posey (26), Askew (31), and, where black root rot is a problem, Swanback and Anderson (32) and Thomson _et al_ (30) recommended that lime should not be applied in excess of 1,000 lb./acre, here dressings far in excess of 1,000 lb./acre gave good results - as was also found by Breland _et al_ (29, 80).

In all these experiments lime did not increase the incidence of disease. Where mineral deficiencies were observed, weather was the main contributory factor. In experiment 1, tobacco growth was severely interrupted by a five weeks' dry spell. When growth was resumed some plants showed dead apices, characteristic of boron deficiency, despite the borax (2 lb./acre) in the fertiliser. Boron deficiency can be induced by lime (30, 31) but only slaked lime, applied early at the rate equivalent to 2,000 lb. calcium carbonate/acre, increased the number of affected plants. In experiments 2 and 6 rates of borax were varied. In these wetter seasons, no boron deficiency was observed, as anticipated in snap beans by Purvis and Hanna (81) and tomato by Hobbs and Bertramson (82). Instead, magnesium deficiency occurred in experiment 2 on all treatments except ground dolomite, and was also observed on an unlimed plot on a sandier portion of experiment 3. Since these soils are acid sands with little exchangeable magnesium, magnesium deficiency would be likely under heavy rainfall (6, 83).

These observations suggest that responses to lime on acid soils could be seriously affected by a variety of mineral deficiencies under different conditions.

In experiment 5, the yields of stem and roots were increased by liming, and this is consistent with results for other crops - alfalfa (84), crimson clover (85). The side-dressing of limed and unlimed plots with nitrogen, potassium, nitrogen plus potassium, had little effect on yield of cured leaf, even though it was applied four days after a very wet spell in which 4.77 in. rain fell in six days (experiment 6).

Quality.

Tobacco quality is difficult to assess since there are no absolute criteria and all evaluations are based on subjective assessments, the most important of which are feel, smell and visual characteristics.

Generally quality is assessed by dividing the tobacco into named grades to which relative values have been given, based either on current prices (America) or on a nominal value related to average prices over a number of years (Rhodesia), and the overall quality is expressed either as a weighted mean of these values or as dollars/ acre. In agronomic experiments the overall quality is of value in interpreting the results, but sometimes individual quality components such as body, texture, clarity of colour, slate (all of which are difficult to define precisely - Appendix V: Glossary of tobacco terms) and certain chemical properties must be assessed separately.

All sources of lime improved quality except ground dolomite at 4,000 lb./acre in experiment 5. It seemed that to produce a good quality tobacco, the soil pH should be maintained above 5.0 but not higher than 6.0, at which value yield was still increased, but quality decreased.

Darkis et al (24) studied the effect of dolomite on leaf quality in great detail and concluded that it produced a poor quality, bright-coloured leaf which contained more nitrogen and less reducing sugars than from the unlimed treatments, possibly because it had been reaped immaturely. This increase in the nitrogen concentration was due to the dolomite increasing nitrogen availability in the soil. In experiment 1, although liming increased the mineral nitrogen in the soil, both the reducing sugars and nitrogen concentrations in the leaves were unaffected, suggesting that leaf maturity was not affected. This was also reported by Moss et al (6), Breland et al (29) and Thomson et al (30); the former found the highest gross return per acre was obtained from dolomite, which probably offset a lack of magnesium in the soil.

Although the source of lime had no marked effect on the overall quality and maturity in the present experiments, all liming materials showed a marked reduction in the boron and manganese concentrations in the leaf. Hutcheson and Woltz (86) reported a marked improvement in tobacco quality after applying borax which also increased the boron concentration; boron deficiency occurred when the concentration in leaves (about 4 in. long and 2 in wide), near the terminal bud was less than 15 ppm. The boron concentration can be less than this in the bottom leaves without deficiency symptoms appearing, although critical levels have not been established. In experiment 1 boron deficiency was induced by a dry spell; in wetter seasons it was not observed even when three tons of dolomite were applied, although the concentration of boron was reduced by lime. Generally 8 lb. borax/acre was only slightly beneficial, as was 16 lb. borax/acre at the highest rate of dolomite.

In experiments 5 and 6, lime produced a better quality tobacco by decreasing the amount of slatey leaf. Leaves which are slatey become peppered with faint grey spots. These were more frequent from unlimed treatments than limed treatments and persisted in the cured leaf, conferring on it an overall "grey" discolouration. In the present work, the amount of "grey" discolouration is positively correlated with manganese concentration, percentage plants with peppery spots and percentage cured leaf classified as nondescript. Lime also appreciably lowered the manganese concentration in the leaf; this feature is well established and increases in soil pH, brought about by liming, will promote oxidation of manganese to a less available form (87). Elliot and Finn (58) also showed that the incidence of "grey" tobacco in Canada was reduced by liming and that this discolouration was associated with high manganese and iron concentration in the leaf. In Rhodesia it was true for manganese but not for iron.

In a recent survey of slatey tobacco in Rhodesia, Wiltshire (88) considered it was due to nutrient starvation, particularly with respect to nitrogen and potassium, which might have been leached in the early stages of growth of the plant. On these very infertile acid sands, heavy dressings of lime could upset the availability of soil potassium (89) and boron (30, 31), and if nitrification was increased (33, 46) leaching may have offset this effect(90). To test this in experiment 6, as well as liming to decrease the manganese availability and the addition of borax to maintain an adequate supply of boron, some plots were side-dressed with nitrogen (as sodium nitrate), potassium (as potassium sulphate) and nitrogen plus potassium (as potassium nitrate), four days after a very wet spell. Quality was greatly improved by potassium nitrate and 8 lb. borax, but it deteriorated with potassium sulphate; sodium nitrate and lime was less effective than potassium nitrate in improving quality. Leaf quality was improved as leaf discolouration was decreased and deteriorated when leaf discolouration increased. Side-dressings of nitrogen and potassium had large effects on quality, these being most pronounced in the presence of 3,000 lb./acre dolomite. However, the improvement in quality by dolomite was associated with an increase in magnesium and calcium concentrations, a decrease in boron, potassium and manganese; there was no effect on nitrogen and phosphorus concentrations. The better quality leaf was produced by potassium nitrate and sodium nitrate side-dressings; both materials increased the nitrogen concentration and the former potassium in two instances only. The worst quality leaf was produced by potassium sulphate, which increased the potassium concentration, but did not change the nitrogen concentration. Borax also improved quality by increasing the boron concentration (cf. 86) and it did not affect the concentrations of other nutrient ions. 3,000 lb./acre dolomite appreciably lowered the manganese concentration and at this rate of dolomite, potassium nitrate and sodium nitrate treated leaves contained slightly less manganese than leaves of no side-dressing or potassium sulphate. Side-dressings had little effect on the calcium, magnesium, boron and phosphorus concentrations but these compounds can influence the uptake of manganese, as shown on oats (91), sugar cane and pineapples (92), and snap beans and corn (93). Therefore on this soil, nitrogen, boron and manganese were probably the more important quality components. It can be concluded that slatey tobacco on acid and probably nitrogen deficient soil can be ameliorated by applying lime, borax and nitrogen (only nitrate tested here), but potassium, as potassium sulphate, aggravated this undesirable feature, probably because of excess sulphate (94); high manganese concentration in the leaf was a contributory factor in the discolouration ("greying") of flue-cured tobacco. Except for potassium, these results confirmed the findings of Wiltshire (88).

Soil pH.

Initially the soil pH was affected by sources of lime, probably due to the poor rainfall at the beginning of the seasons and the relative fineness of the materials (67), but later was affected only by rates of lime applied. Slaked lime reacted faster than the other liming materials; ground dolomite was generally more effective than calcitic limestones. Also, 4,000 lb. dolomite/acre (experiment 5) produced a greater pH rise than 6,000 lb. (experiment 6), probably because the lime was incorporated to a depth of 6 and 11 in., respectively, and the resultant dilution of the liming material would explain the different effects on pH, as suggested by Schoemaker (95). The neutralisation curve of a soil is similar to the neutralisation curve of a weak acid and the relationship between pH and applied lime is not linear, as was also shown by Russell (33) and Naftel (8, 96). If a soil is free from sodium salts, the maximum pH it can attain is 8.5, and this will depend on the partial pressure of carbon dioxide in the air for the system $CaCO_3$-H_2O-CO_2. Once this value is reached, further applications of lime will have no major effect, although fluctuations will occur since the partial pressure of carbon dioxide varies in the soil air and the reduction in pH is approximately proportional to the logarithm of the partial pressure of carbon dioxide (33).

Beacher and Merkle (97), Beacher, Longenecker and Merkle (98) and Hoyert and Axley (99) also found that slaked lime, because of its fineness and greater solubility, reacts faster than dolomite, ground limestone and mixed lime, and consequently is more efficient in raising soil pH. Although calcitic limestone is potentially more effective than dolomite because of its greater solubility (14, 20, 97, 98), in practice it was less efficient, probably because of the smaller percentage of finer particles (67). For high rates of ground mixed lime and dolomite, the pH rise was slightly higher than figures quoted for a sand by Breland et al (29), and a sandy loam by Hoyert and Axley (99) and Brown, Munsell, Holt and King (100). These discrepancies can be expected between soils, because of varying exchange capacities and buffering powers; highly buffered soils containing a high percentage of clay or organic matter will require larger quantities of lime to neutralise them than very sandy and less well-buffered soils. pH is also related to the percentage base saturation (43, 99) and the lower the soil pH the smaller the percentage base saturation, but this relationship is only applicable to soils which have similar clay or organic matter fractions; at a given percentage base saturation the pH of 1:1 lattice clay (kaolinite clay) is higher than 2:1 lattice clay (illite and bentonite) and a peaty soil (101, 102), probably because the hydrogen ion is held with varying strengths.

Chemical and physical analysis.

(a) Cured leaf lamina.

In experiments 1 and 5, lime had no effect on equilibrium moisture but increased the filling value, being more pronounced in the bottom reaping group. Filling value is an important commercial measurement that reflects the number of cigarettes that can be made from a given weight of leaf. The only organic constituent which was increased by lime was the petroleum ether extract, but lime had no effect on crude fibre, nicotine and reducing sugars. Although Thomson et al (30) also found that ground limestone had no effect on reducing sugars, Darkis et al (24) reported that dolomite decreased reducing sugars, petroleum ether extract and nicotine concentrations. These tobacco constituents were determined to evaluate leaf quality, discussed on page 106.

It is interesting to compare the effects of lime on the chemical composition of Rhodesian flue-cured tobacco with those found elsewhere:

(i) Calcium concentration was increased by lime, particularly calcitic materials, as was magnesium by ground dolomite. Similar findings were reported by Darkis et al (24), Breland et al (29) and Thomson et al (30). All values were higher than the deficiency levels of 1.0% and 0.20% for calcium and magnesium, respectively, as quoted by McMurtrey (83) and Garner, McMurtrey and Bowling (103).

(ii) Manganese concentration was decreased by lime, as found by Bortner (46), Jacobson and Swanback (49) and Elliot and Finn (58).

(iii) Boron concentration was also reduced, but not to such an extent as to induce boron deficiency, as reported by Askew (31).

(iv) Chloride concentration was decreased, as found by Darkis et al (24), but in the present work it was affected mainly by slaked lime, which gave the highest pH rise. This might be expected as the chloride concentration of tobacco leaves is inversely proportional to soil pH (104).

(v) Calcitic limestone had no effect on magnesium concentration, as was also found by Thomson et al (30), though Askew (31) found a decrease.

(vi) Phosphorus concentration was unaffected in experiment 1, as found by Thomson et al (30), but decreased with dolomite in experiment 5; both these findings are contrary to those of Darkis et al (24), who showed an increase.

(vii) Potassium concentration was decreased at rates in excess of 2,000 lb./acre, as was also found by Darkis et al (24) and Askew (31);

it was unaffected at lower rates, as found by Thomson et al (30).

(viii) Nitrogen concentration was unaffected by lime, as also reported by Thomson et al (30) and Breland et al (80), although Darkis et al (24) reported an increase.

(ix) Aluminium and iron concentrations were unaffected, as reported by Darkis et al (24), although Elliot and Finn (58) found that iron was decreased in the lower reapings only.

Perhaps certain of these conflicting results might be attributed to climatic factors, past fertiliser dressings and cropping history and the inherent fertility of the soil. Generally any effects were most marked in the early reapings and decreased progressively in the middle and upper reapings.

(b) Stem and roots.

In the stem and roots (experiment 5) the concentration of calcium, potassium, aluminium and iron were unaffected; manganese was decreased and magnesium increased. Although the concentration of nitrogen was increased and of phosphorus was decreased in the stem, these were unaffected in the roots.

Generally the nutrient ions are concentrated in the leaf, with least in the roots. However, aluminium and iron behaved very differently, being more concentrated in the roots; this behaviour of aluminium and iron is well known for other crops and has been observed by Hiatt and Ragland (47) on Burley tobacco. Also, the uptake of nutrient ions was greater where plants had received lime, manganese being the exception.

In this work, yield and quality of flue-cured tobacco was improved by lime irrespective of time of application or source, and the manganese concentration was decreased. The availability of aluminium, iron and manganese is decreased in the soil solution by lime (34 - 36), but the effects of this were observed in the plant only for manganese and not for aluminium and iron. As aluminium, iron and manganese have been considered important factors in the growth of plants on acid soils (34, 35, 37) it was considered necessary to investigate more fully how their behaviour and interactions affected the growth and composition of flue-cured tobacco plants. This detailed study, discussed in the next section, explains many effects of aluminium, iron and manganese.

Greenhouse Studies.

Aluminium and manganese.

(a) Nutrient solution.

Aluminium caused the roots to become brown, stubby, stunted and jointed; and no chlorosis occurred on the leaves. Similar results were found by Bortner (46) on Turkish tobacco, and Eisenmenger (48) on an unnamed variety of cigar tobacco, as well as on sunflower (105), cotton (106), and grain crops (70, 107, 108). However, chlorosis and tip die-back were seen on spinach and barley by Rees and Sidrak (109), and yellowing of the flag leaf on Burley tobacco by Hiatt and Ragland (47), which the latter considered due to phosphorus deficiency, although their technique of applying aluminium should have avoided this.

Manganese at 31.25 ppm. caused a "spotted" chlorosis, which was often confined to the base of the leaf, and became less intense as the experiment progressed, as also found by Smiley, Atkinson and Massie (110) on Burley tobacco and Jacobson and Swanback (49) on cigar tobacco. When manganese toxicity was not very severe, similar chlorosis was reported on Burley (47), Turkish (46), cigar (49) and flue-cured (50) tobaccos. Although Burley tobacco roots were shortened and blackened at the tips in the presence of 100 and 200 ppm. manganese (47), the roots of flue-cured tobacco in present experiment were not damaged, as in agreement with results of Bortner (46) with 55 ppm. manganese on Turkish tobacco, and Rios and Pearson (106) with 180 ppm. manganese on cotton. These findings confirmed Romney and Toth's (111) observations on soybeans, buckwheat, sunflower and tomatoes that manganese injury is confined mainly to the leaves of the plant. The chlorosis, which did not persist, occurred both with and without aluminium. In this experiment the maximum rate of aluminium in the substrate was only 31.25 ppm. and aluminium only slightly reduced the manganese concentration, but Hiatt and Ragland (47) and Rees and Sidrak (109) found that 50 to 100 ppm. aluminium reduced both the amount of chlorosis and the concentration of manganese, showing that the chlorosis was due to manganese only.

Aluminium decreased yields of all plant parts and did not stimulate growth between 3 to 13 ppm. as observed by McLean and Gilbert (107) on grain, vegetable and fodder crops. Hiatt and Ragland (47) and Eisenmenger (48) also obtained a decrease in yield at 20 - 24 ppm. aluminium, and 2 ppm. affected the growth of Turkish tobacco (46). It is possible that aluminium affected Bortner's Turkish tobacco because the solution cultures were not aerated but only changed daily; his techniques were otherwise the same and the solution pHs were adjusted to 4.5. McLean and Gilbert (71, 107) reported that different aluminium salts behaved similarly but that crops varied in their sensitivity to aluminium, so perhaps Turkish tobacco is more sensitive than other tobaccos.

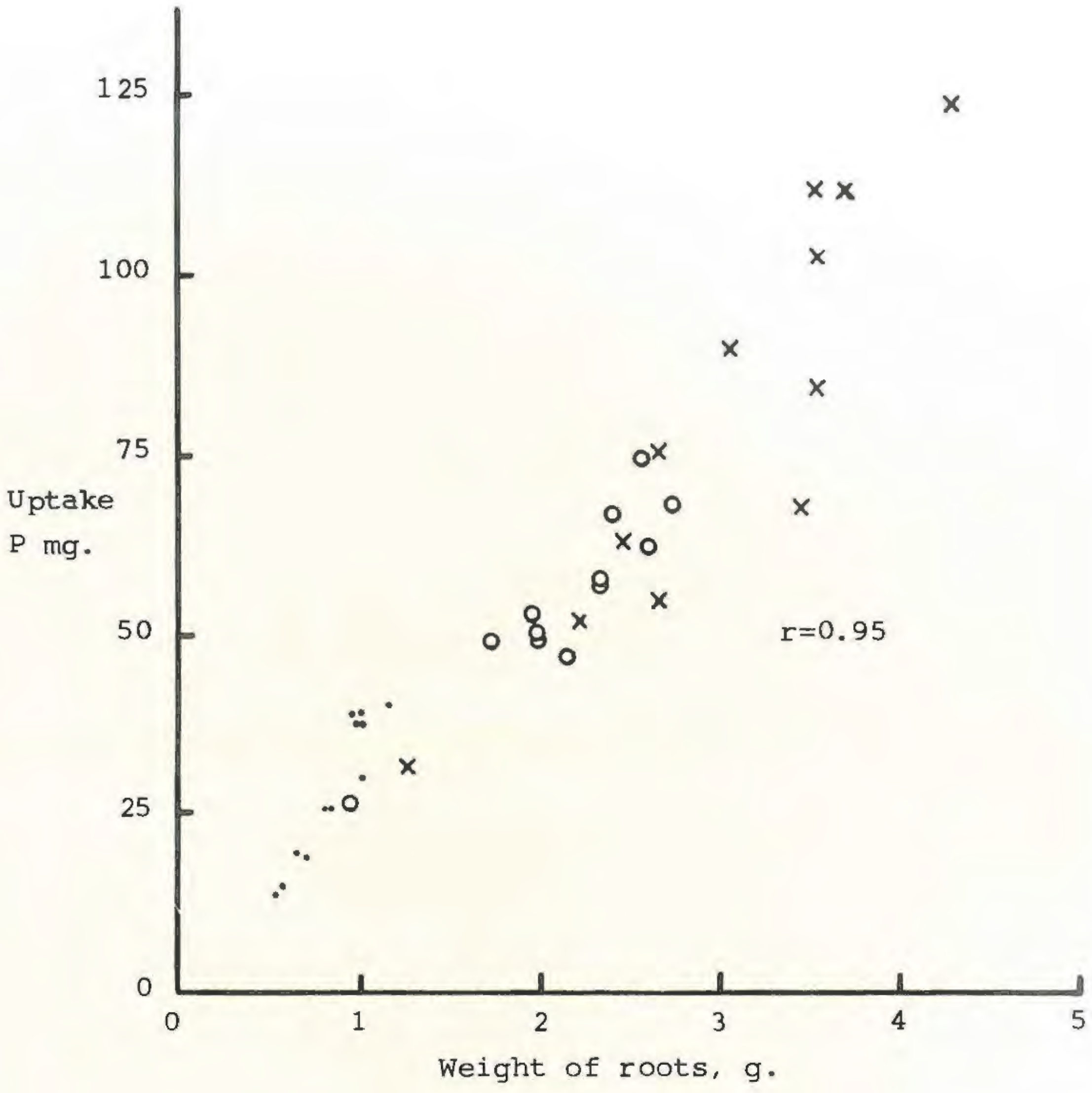
The concentration of aluminium in the tops was not affected by rates of aluminium, whereas it increased progressively in the roots with increasing rates of aluminium in the solution. Uptake of aluminium by the roots was very large, but very little was translocated into the leaves and stem; these results were similar to those of numerous workers on Burley (47) and cigar (48) tobaccos, fodder (35) and grain (109, 112) crops, sunflower (105) and spinach (109). Examination of root sections of vegetables (71) and barley (113, 114) showed that aluminium was distributed throughout the cortical region and concentrated along the outer wall of the endodermis, but that there was only a small quantity in the vascular system. The aluminium in the untreated plants was probably extracted from the vermiculite in which the seedlings were originally grown, as found by Hiatt and Ragland (47).

Although the concentration of phosphorus was increased in tobacco roots at the high aluminium rates, it was not immobilised there, because the concentrations in the leaves and stem were unaffected. There is much conflicting evidence about the behaviour of aluminium and phosphorus in plants. Recently Clarkson (144) reported that the radioactivity of P^{32} in barley shoots and roots was decreased and increased, respectively, when the plant was treated with aluminium; at first sight these results could be interpreted as a reduction in phosphorus transport, but the same amount of phosphorus per unit weight of root was transported for the control and aluminium treated plants, and the difference in concentrations resulted from different shoot:root ratios. Clarkson therefore concluded that there was no evidence that aluminium enhanced phosphorus uptake as reported on rye grass by Randall and Vose (115) or that the superficial reaction between aluminium and phosphorus interfered with phosphorus transport as suggested on barley by Wright (116) and Wright and Donahue (113), and on legumes by McLeod and Jackson (117). In the nutrient solution experiments 1, 2 and 4 there was a linear relationship between phosphorus uptake in the leaves and stem, and the root dry weight (Figure 8: r = 0.95), which supported Clarkson's findings.

Except for the increase in yield at 12.5 ppm. manganese in the absence of aluminium, manganese had little effect on yields, but both these and Bortner's (46) rates were lower than those of Hiatt and Ragland (47), who obtained yield reductions at 80 ppm. manganese. This was surprising, in view of the toxic effects observed by Jacobson and Swanback (49) in solution and sand cultures containing either 1 or 80 ppm. manganese. The toxic symptoms of the solution culture plants might have been accentuated by lack of oxygen and other nutritional problems because the solution was not aerated or changed during the growth period (65 days) and the volume was maintained constant with distilled water. These experimental conditions are very severe since normally solutions are well aerated, changed frequently and maintained to constant volume with nutrient solution. Like Hiatt and Ragland (47), Bortner (46) and Rios and Pearson (106) found, increasing the rate of manganese increased its concentration in all plant parts and, as Romney and Toth (111) and Rios and Pearson (106) also showed, manganese was readily translocated into the leaves and stem. Aluminium decreased manganese slightly in the leaves and stem and greatly in the roots, which is consistent with the results of other workers (47, 109, 112); in practice, however, even if aluminium ameliorated manganese toxicity symptoms, its own adverse effects would outweigh any possible benefits.

Figure 8.

The relationship between phosphorus uptake in the leaves and stem, and root dry weight of plant grown in nutrient solution.



o Experiment 1. The effect of aluminium and manganese.

• Experiment 2. The effect of aluminium and calcium.

× Experiment 4. The effect of aluminium and iron.

(b) Granite sand.

There was no marked effect of aluminium in reducing yields of leaves, stem and roots, as observed in the previous experiment, although high aluminium did cause slight browning of root tips. Manganese toxicity was very pronounced at 12.5 and 31.25 ppm. levels and it persisted, contrary to nutrient solution observations. The lack of effect on yield, despite severe manganese toxicity symptoms is not unusual, having also been reported by Fried and Peech (34) and Schmehl et al (35) on grain crops and alfalfa, respectively, and by Bortner (46) on Turkish tobacco.

The yields of leaves, stem and roots, and concentrations of aluminium and phosphorus, were unaffected by aluminium and manganese treatments. In the nutrient solution experiment the roots and pots were thoroughly washed at each change in solution. This could not be done in the soil, and the constant presence of phosphorus probably ameliorated the adverse effect of aluminium by precipitating it as aluminium phosphate (70, 71, 107,118 - 120). However, Schmehl et al (35) reported that aluminium sulphate drastically reduced yields of alfalfa and produced the lowest pH of all treatments, possibly because aluminium was not completely immobilised by the low rate of phosphorus applied. The concentration of aluminium in the roots was appreciably higher than in the leaves and stem.

Plants grew more slowly, produced smaller yields and contained lower concentrations of nutrient ions in soil than in nutrient solutions. This might have been because the solution had forced aeration which continually agitated the solution and maintained an ample supply of oxygen, or because the nutrient ions were all readily available in solution. Manganese had similar effects in both media, but aluminium did not because aluminium and phosphate were applied separately in the nutrient solution experiment, whereas they were both present in the soil. However, this does not preclude aluminium toxicity occurring in soils, and it was reported on black peppers (121), maize and cowpeas (119) and sugar cane (122). The symptoms are generally stunted growth and dark coralline roots (often dead), and in addition to this de Waard and Sutton (121) reported necrotic spots with a surrounding yellow halo (unfortunately manganese concentration was not measured).

Aluminium and calcium.

Aluminium affected root development as discussed earlier. There was a steady decrease in yield of all plant parts with increasing rates of aluminium, particularly at the 12.5 ppm. level. Although Eisenmenger(48) reported that in cigar tobacco, calcium reduced the toxic effects by aluminium, it had no effect here, as also found on cotton by Rios and Pearson (106) and on grain crops by Pierre (123). The concentration of aluminium was independent of the rate of calcium and in the roots it increased linearly with increasing rates of aluminium.

Added calcium had no visible effects on the roots and little effect on yields of leaf and stem, and roots. Wallace, Frolich and Lunt (124) grew normal tobacco plants at 2 and 5 ppm. Ca in a solution culture containing 1/50 Hoagland's concentrations, provided the levels of copper, iron, manganese, zinc and magnesium were balanced, although Rice and Pearson (106) found that cotton plant roots were discoloured and poorly branched at 5 ppm., whereas at 200 ppm. they were white and well branched. Steinberg (38) and Arnon and Johnson (125) obtained better responses to calcium, using Turkish tobacco, and tomato and lettuce, respectively, than found here.

The concentration of calcium in all plant parts increased with increasing rates of calcium; aluminium decreased it in the leaves and stem, and in the roots the decrease was linear with increasing rates of aluminium. Paterson (112), Hortenstine and Fiskell (105) and Rees and Sidrak (109) also reported that aluminium decreased calcium concentration, but McLeod and Jackson (117) found that calcium concentration was increased in the roots although decreased in the tops. Schmehl et al (37) in their study on acid soils found that aluminium depressed the uptake of calcium more than did hydrogen and manganese; they concluded that the low calcium concentration usually observed in plants grown on acid soils may be due to the antagonistic effect of aluminium, manganese and hydrogen ions on the absorption of calcium, as well as to the restricted root growth, rather than to the low calcium supply in the soil.

The concentration of phosphorus in all parts varied erratically but the relationship between phosphorus uptake in the aerial parts and the root dry weight was linear (Figure 8: r = 0.95), which indicated that the amount of phosphorus transported was the same per unit weight of roots whether plants were treated with aluminium or not.

Manganese and iron.

(a) Nutrient solution.

The upper leaves of tobacco plants of manganese zero iron treatments became very yellow with green bands along the veins and numerous brown and white lesions. Brown and Holmes (126) also illustrated the necessity of a continuous supply of available iron for the growth of soybeans, wheat and corn, for if it were suddenly withheld the mobility of iron in the plant ceased and the new growth was chlorotic. Leaves of plants grown with neither iron nor manganese were lighter in colour than from other treatments and had a faint diffuse mottle, resembling iron deficiency as described by McMurtrey (127). Manganese toxicity was observed on plants treated with high manganese and iron, and the symptoms became fainter as the experiment progressed, as discussed earlier.

Here additions of iron overcame the intense yellowing and breakdown of leaf tissue. These severe symptoms of manganese toxicity were described by Bortner (46), Jacobson and Swanback (49), Murthy and Patwardham (50), and Hiatt and Ragland (47) for tobacco grown in solutions containing 0.2 to 1.5 ppm. iron as compared with 2.5 ppm. in pretreatment solution and 5 ppm. the lowest rate used here; the latter authors also reduced the extent of chlorosis by adding iron. Therefore, symptoms of manganese toxicity may vary, depending on the concentration of iron in the substrate. These results confirm the interrelation between iron and manganese. The ratio of iron to manganese in the nutrient solution has been considered to be very important in its effect on plant growth. Somers and Shive (128) and Pearse (129) who grew soybeans, and strawberries and Cape gooseberries, considered that the most desirable Fe:Mn ratio was 2, with higher ratios reducing iron toxicity (= manganese deficiency) and lower rates giving manganese toxicity (= iron deficiency). Here the faint diffuse mottling and overall yellowing of the leaf, in the absence of both iron and manganese was very different from the distinct spotted mottle of the chlorosis due to manganese toxicity, as was also found on Burley tobacco by Hiatt and Ragland (47). Not all workers agree with the critical range of this ratio. Sideris and Young (130) showed that for pineapples Fe:Mn ratios of 0.1 and 1.0 produced equally good results if the manganese concentration was not excessively high, whilst Morris and Pierre (131) found no evidence to support Somers and Shive since severe symptoms of manganese toxicity were produced on lespedeza by increasing the manganese concentration, yet the Fe:Mn ratio was maintained constant. In the present work yields of tobacco were unaffected by Fe:Mn ratios varied from 0.4 to 2.5. It is probable that different plants need different iron-manganese ratios.

Five ppm. iron increased yields but 31.25 ppm. decreased them; Hiatt and Ragland (47) also found yield reduced by 20 ppm. of iron as sodium ferric diethylene-triamine-penta-acetic acid (NaFe-DTPA). This might be a true effect of iron, but chelating agents (e.g. ethylene-diamine-tetra-acetic acid), which can stimulate growth at low concentrations (132), may be toxic to plants at higher concentrations (133).

Iron increased the concentration of iron mainly in the roots and like aluminium, it was not readily translocated. These results are consistent with the findings of Riekels and Lingle (134) on tomatoes, Sideris (135) and Sideris and Young (130, 136) on pineapples, Somers and Shive (128) on soybeans and Rediske and Biddulph (137) on bush beans. Riekels and Lingle (134) found that iron translocation increased as the root temperature increased, but decreased as the iron concentration of the plant increased. In the present work, the pre-treatment culture solution contained 2.5 ppm. iron, as compared with 0.06 to 0.6 ppm. used by Riekels and Lingle; this and high greenhouse temperatures in summer may have ensured the early translocation of iron and an adequate concentration in the plant, resulting in practically no further translocation when the treatments were applied later.

Iron did not affect the concentration of phosphorus in these tobacco plants, whereas in pineapples (where iron phosphate was precipitated in the exodermal tissues) phosphorus translocation can be greatly reduced (136). This difference might be attributed to the source of iron or to pH. Sideris and Young used ferrous sulphate instead of Fe-DTPA, a chelated compound. High pH values caused a greater deposition of insoluble iron on the roots and a low pH resulted in less (138). Iron also lowered the concentration of manganese in all plant parts as reported previously by numerous authors on tobacco (47) and other crops (87, 128 - 131, 139). This is important if tobacco were grown on manganese-rich soils with adequate pH, on which lime could not be used to reduce manganese availability, applications of iron sulphate could overcome the adverse effect of manganese. This is being done successfully with pineapples, on which healthy leaf colour is restored by spraying with ferrous sulphate (130).

Manganese was readily taken up and translocated into the leaves and stem. As found by Sideris (135), Riekels and Lingle (134) and Sideris and Young (130), manganese increased the concentration of iron in the roots. Here manganese did not influence the translocation of iron, in agreement with the findings of Sideris and Young but not of several other workers (87, 134, 135). However, although Sideris and Young reported that manganese had no effect on the uptake of phosphorus, it was increased here in the roots. It is possible that all variations in the behaviour of iron and in its relation to manganese could be explained by variations in the sources of iron and their initial rates, solution pH and temperature.

The marked yellowing and necrotic spots which developed when manganese was applied in the absence of iron were not attributed to iron deficiency, since the iron concentration was unaffected. It was suggested earlier that the pretreatment rate of iron was sufficient to ensure adequate concentration in the plant, resulting in practically no further translocation when the treatments were applied later. Consequently manganese had little effect on the uptake and translocation of iron, in fact the iron concentration tended to be higher in the most severely affected plants. Iron chlorotic leaves often have been reported to contain more iron than non-chlorotic leaves (140 - 142), possibly due to inefficient washing (143 - 146) but not to contamination from the grinding mill (145). However, when iron was added these symptoms vanished and typical spotted chlorosis of manganese toxicity appeared; this occurred despite a considerable decrease in the manganese concentration. This illustrated the interdependence of manganese and iron stressed by Somers and Shive (128) who considered that an excess of manganese in the plant will lead to oxidation of ferrous iron to ferric which is physiologically inactive.

(b) Granite sand.

Manganese toxicity symptoms were observed at the high rate of manganese and they were often more chlorotic in the absence of iron. The highest rate of iron caused the plants to wilt, with greasy chlorotic leaf spots developing and eventually becoming black and necrotic; small black spots also appeared on the bottom leaves. Although these plants did not die, their growth was severely impaired, an effect attributed to the chelating agent, diethylene-triamine-penta-acetic acid (DTPA). Chelating agents are toxic to plant growth, since the entire chelate is absorbed (147), but their effects varied on different soils (148, 149).

Although soil plants grew more slowly and contained lower concentrations of nutrient ions than plants grown in nutrient solution, manganese and iron in both media had similar effects on plant composition, but the most severe leaf discolouration and necrosis was caused by manganese in the nutrient solution and by iron in the granite sand. The increase in iron concentration in the leaves and stem was more marked than that observed in the solution culture experiment. Since iron restricted the uptake of manganese, sufficient iron was probably present in the soil solution to ameliorate the adverse effects of manganese on leaf discolouration. Iron had more effect in granite sand probably because nutrients could not be washed out, as was done when nutrient solutions were changed.

The peppery spots observed in the field as the tobacco was ripening were not observed in the greenhouse, where the smaller plants were either rich green in colour or distinctly chlorotic, nor did they resemble the small black spots observed on the tobacco when effects of manganese and iron were compared. These peppery spots were associated with excess manganese, but the small black spots might be due to complex physiological processes occurring in a dying plant rather than to iron toxicity.

Aluminium and iron.

In nutrient solution, aluminium caused mottling of the leaves in the absence of iron but not with high rates of iron, which made the plants dark green. In the soil plants no mottling was observed, probably because sufficient iron was present in the soil, but all high rates of iron caused severe damage to leaf tissue and killed some plants. This may have been caused by the accumulation of the chelating agent. High aluminium caused slight browning of the root tips in soil but severely retarded root growth in nutrient solution.

Aluminium reduced yield in the nutrient solution; most of it remained in the roots, where its concentration was increased. Phosphorus was not immobilised in the roots of the nutrient solution plants (Figure 8) and the yellowing colouration was not due to phosphorus deficiency as suggested by Hiatt and Ragland (47). Nor could it be attributed to iron deficiency unless aluminium inactivated the iron within the plant, as suggested by Rees and Sidrak (109) who offered no explanation of this mechanism.

Iron decreased the yield in the soil experiment. In both media iron accumulated in the roots and, like aluminium, was not as readily translocated into the leaves and stem as was manganese. The concentration of phosphorus in the roots was increased by iron in the nutrient experiment, but it was not immobilised there as reported by Sideris and Young (136), nor was its uptake enhanced by the diethylene-triamine-penta-acetic acid complex, as observed for ethylene-diamine-tetra-acetic acid by Rees and Sidrak (109).

Aluminium and to a lesser extent iron, accumulated in the roots, and their translocation into aerial parts was not influenced by their rate of application. Manganese behaved completely differently and was readily taken up and translocated. However, plant measurements are only one aspect and the aim of the next section is to relate soil measurements to plant behaviour.

Soil Studies.

Soil solution studies received new impetus with the publication of the "Ratio Law" by Schofield (150), which stated that "When cations in solution are in equilibrium with a larger number of exchangeable ions, a change in the concentration of the solution will not disturb the equilibrium if the concentration of all monovalent ions are changed in one ration, those of all divalent ions in the square of that ratio, and those of all trivalent ions in the cube of that ratio".

$$\text{i.e.}\quad \frac{\left[M_1\right]^{1/z_1}}{\left[M_2\right]^{1/z_2}} \qquad \text{or more strictly} \quad \frac{\left(a_{M_1}\right)^{1/z_1}}{\left(a_{M_2}\right)^{1/z_2}} = \text{constant}$$

Where M_1 and M_2 are cations of activity a_{M_1} and a_{M_2}, and valency z_1 and z_2 in equilibrium with absorbed cations. As discussed by Schofield and Taylor (72) and numerous other workers (79, 151 - 157), this will only apply with soils having few positive charges and in relatively dilute solutions, when soluble anions are not adsorbed by the soil.

It is virtually impossible for a displacing agent used in the laboratory to produce a soil solution identical to that in contact with the plant roots. However, Schofield and Taylor (74) considered that in a non-saline soil, where the chief exchangeable cations are calcium and magnesium, these ions will predominate in the equilibrium solution and the concentration of the other ions present will be controlled by the total divalent ion concentration. Under these conditions the soil will be least disturbed if it is shaken with a dilute solution of calcium or calcium plus magnesium chloride; the concentration will not remain completely unchanged since small quantities of other ions - chiefly potassium - will be released to the solution by exchange, and the total concentration may be slightly increased by salts contained in the soil itself. The exact composition of the final solution can only be found by analysis after it has been shaken up with the soil. This gives an estimate of the relative availability or intensity levels of cations in the soil, measured by the activity ratio e.g. $a_H/\sqrt{a_{Ca + Mg}}$, $a_K/\sqrt{a_{Ca + Mg}}$.

These activity ratios are independent of the soil moisture status and normal variations in salt concentration (74), but depend on both the content of available ion and the strength with which it is held (158).

The Ratio Law.

Six Rhodesian soils were selected and since the composition of the equilibrium solution depends to some extent on temperature (153, 159), the soils were equilibrated in a constant temperature room at 21.2°C.

The Ratio Law holds for five of the soils tested, but on the sixth, serious deviations occurred above about 0.001M calcium chloride and the pH decreased progressively less steeply than $\frac{1}{2}p(Ca + Mg)$ as the concentration increased. Soil 6 was a highly weathered top soil from Inyanga (average rainfall 44.7 in.) in which positively charged iron oxides are likely to occur. Schofield (150) and Schofield and Taylor (72) obtained similar results with a red clay loam from Natal which was known to have a large proportion of positive charges developed on the iron oxide present.

The pH rises as $\frac{1}{2}p(Ca + Mg)$ is increased (or as the concentration of calcium chloride is reduced). Because the thickness of the Gouy diffuse doube layer decreases with increasing valency and concentration of electrolyte in solution (160), the more concentrated the solution the thinner the diffuse double layer and consequently less restriction in the movement of the hydrogen ions from the clay surface into solution. At the same concentration a divalent ion will form a thinner layer than a monovalent ion, resulting in a lower pH value. This explains the decrease of about 0.7 units in soil pH when soils are equilibrated in 0.01M $CaCl_2$ instead of water (23).

If all pHs were determined with 0.01M $CaCl_2$, then soil 6 would have a measured value of 3.88 but the value comparable with those of the other soils (if pH - $\frac{1}{2}p(Ca + Mg)$ was not affected by concentration) would be about 3.5. It is important that the pH measurements are characteristic of the soil and not of the method used (74), so although the use of 0.01M $CaCl_2$ is well established in many laboratories, with soils likely to have many positive charges a more dilute solution is desirable.

Lime and gypsum.

The first applications of these principles to the growth of flue-cured tobacco was to evaluate whether soil pH was more important than calcium supply. In these experiments, sufficient gypsum was added to maintain a constant calcium concentration in solution over all calcium carbonate treatments, i.e. the plants grew in a saturated solution of gypsum. Under these conditions, soil pH was little different from that in 0.01M $CaCl_2$ and the functions pH - ½pCa and pH - ½p(Ca + Mg) were similar for both treatments.

The relationship between soil pH and the amount of $CaCO_3$ applied was linear for the Triassic sands, but on the granite sands soil pH increased much more with the first two rates tested than with the largest, probably because of the higher buffering capacity of granite sands. This feature has been discussed on page 108 in the field studies section.

Lime improved yield on the more acid soils (pH about 4.8), but on less acid soil (pH about 5.2) conflicting results were obtained which could not be attributed to trace element deficiencies. Where added gypsum maintained a constant calcium concentration in solution, calcium supply did not limit growth and pH was the main variable. The effects of calcium carbonate were similar both in the absence and presence of gypsum indicating the importance of pH rather than calcium supply. However, the overall effect of gypsum was to reduce tobacco yields, possibly due to a higher salt concentration. Where lime and gypsum have been compared by others, plant growth or yield was generally superior with lime (34, 35, 42, 43), but peanuts were a notable exception since gypsum, as a soluble form of calcium, is important in the formation of the fruit which absorbs the calcium directly from the soil (44, 45).

The calcium concentration was increased by lime and gypsum, being larger for the gypsum treatments. This was found by Fried and Peech (34), Schmehl et al (35) and Reed and Brady (44).

In both the presence and absence of gypsum, the manganese concentration decreased with increasing rates of calcium carbonate; this effect has been discussed in the field studies on pages 106 and 110. Gypsum had no effect on the manganese concentration in this series of experiments, although Fried and Peech (34) and Schmehl et al (35) reported an increase, as a direct result of the gypsum lowering the soil pH, which was not observed here. Manganese concentration in the plant was decreased when manganese was added in the trace element mixture; this was attributed to iron, which can decrease the uptake of manganese (see page 120).

The effects of treatments on magnesium, aluminium and iron concentration were very erratic. Schmehl et al (35) also found that aluminium and iron concentration in the plant varied little with treatments, and Fried and Peech (34) in one instance only obtained a slight decrease in aluminium concentration with little effect on iron concentration.

These experiments produced similar results to Fried and Peech (34) and Schmehl et al (35) who demonstrated the adverse effects of aluminium, iron and manganese on plant growth; applied aluminium sulphate drastically affected growth and lowered the soil pH appreciably, but only variations in manganese concentration were detected by plant analysis. Schmehl et al (35) diluted the soil with sand and the beneficial effect of this on growth, which was more marked at the lowest soil pH of 4.75, was attributed to a decrease in the amounts of aluminium and manganese in the soil solution, particularly as the toxic effects of manganese were less marked; likewise the amounts of calcium were reduced but did not appear to affect growth. Thus they concluded that poor growth on acid soils was not due to a lack of calcium but to more complex interactions involving the toxicities of aluminium, iron and manganese. Schmehl et al (37) showed further that the low calcium concentration in plants usually observed on acid soils may be due to the antagonistic effects of aluminium, manganese and hydrogen ions on the absorption of calcium, as well as to the restricted root growth, rather than to the low calcium supply of the soil. This antagonism has already been discussed on pages 114 and 117.

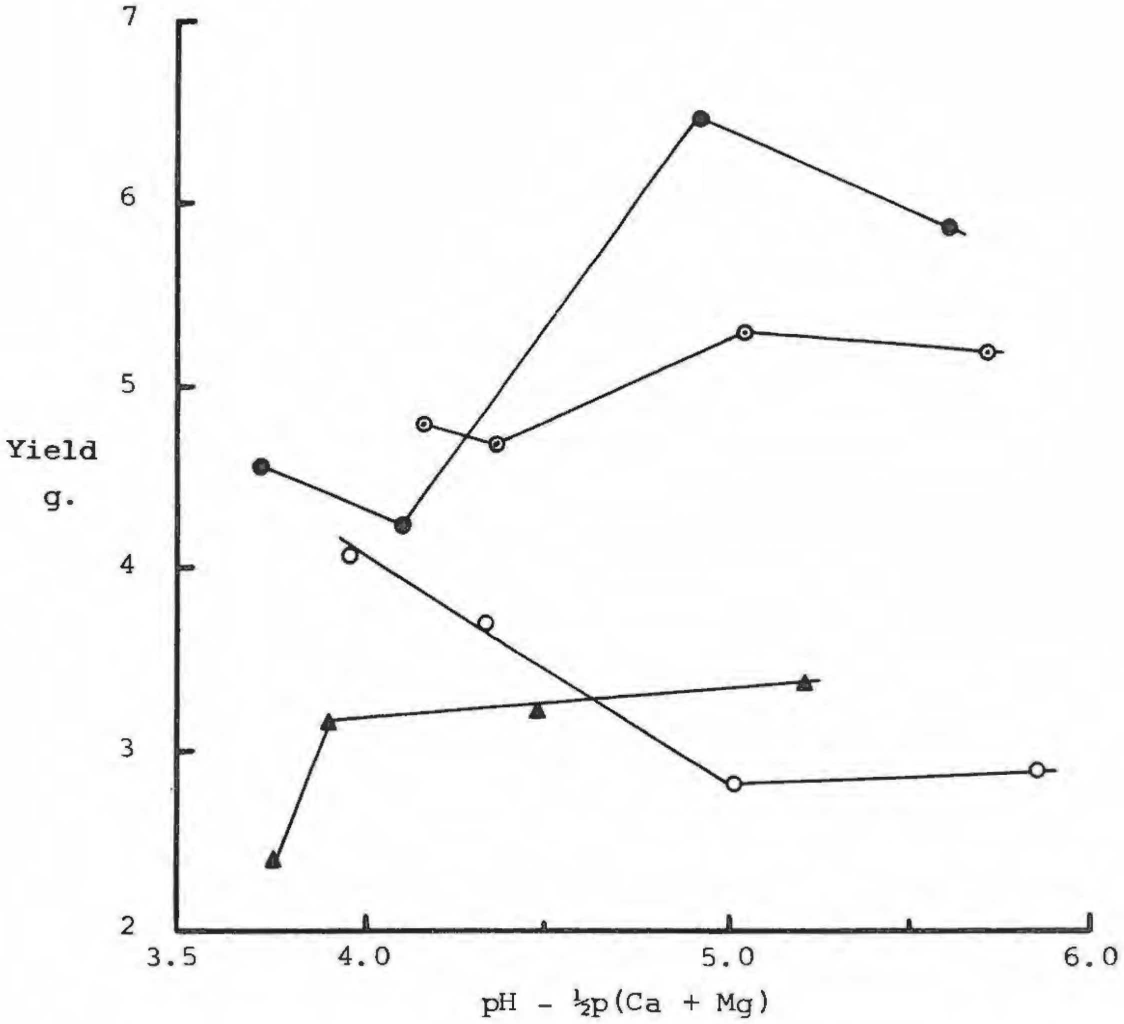
The chemical composition of field and greenhouse grown plants was altered similarly by lime. However, it was established that in flue-cured tobacco, manganese is very mobile and readily translocated into the leaves, whilst aluminium and iron were concentrated in the roots and very little translocated. This would explain why variations in the amount of manganese in the soil but not of aluminium and iron, could be detected by plant analysis, and possibly also accounts for the results of Fried and Peech (34) and Schmehl <u>et al</u> (35).

In figure 9, the yield of tobacco is plotted against $pH - \frac{1}{2}p(Ca + Mg)$, given by pH - 1.14 in 0.01M $CaCl_2$ (74). As the Ratio Law holds for these soils, then any change in soil pH which might have been brough about by adding gypsum, will not influence the ratio $a_H / \sqrt{a_{Ca + Mg}}$; this therefore gives a more reliable basis for comparison. Excluding the anomalous results on the less acid soil which cannot be explained, the relationships between $pH - \frac{1}{2}p(Ca + Mg)$ and calcium concentration and uptake, and manganese concentration and uptake are generally curvilinear; with increasing $pH - \frac{1}{2}p(Ca + Mg)$, calcium increased and manganese decreased. Although these experiments were grown at different times and comparisons between yields are not justified, responses in yield were compared with $pH - \frac{1}{2}p(Ca + Mg)$. However, there seems to be no definite range of either pH or $pH - \frac{1}{2}p(Ca + Mg)$ which was most suitable for the optimum growth of flue-cured tobacco.

pH affected plant growth more than calcium supply and this might be due to hydronium, aluminium, iron and manganese activities in solution.

Figure 9.

The effect of pH - ½p(Ca + Mg) on yield of tobacco.



▲ Experiment I. Triassic sand - lime treatments.

● Experiment II. Granite sand - lime treatments.

○ Experiment III. Granite sand - lime treatments.

⊙ Experiment IIIa. Granite sand - lime treatments without trace elements.

Lime and the soil solution.

As expected, adding lime increased soil pH. In the soil solution the concentration of calcium was increased but the concentration of aluminium, iron, manganese, potassium and sometimes magnesium were decreased with each increment of lime. Similar results were obtained by Vlamis (36), Fried and Peech (34) and Schmehl et al (35) in a displaced soil solution using distilled water. It therefore follows that the activity ratios of $a_K/\sqrt{a_{Ca + Mg}}$, $\sqrt{a_{Mn}/a_{Ca + Mg}}$, $\sqrt{a_{Fe}/a_{Ca + Mg}}$ and $\sqrt[3]{a_{Al}}/\sqrt{a_{Ca + Mg}}$ were decreased with each application of lime. Beckett (159) and Tinker (161) also showed that lime decreased the ratio $a_K/\sqrt{a_{Ca + Mg}}$.

The relationship between applied lime and soil pH was linear for Triassic sands and curvilinear for granite sands; this is in agreement with earlier findings. As the molarity of $CaCl_2$ was less than 0.01, the constant value of $\frac{1}{2}p(Ca + Mg)$ was 1.16 and not 1.14 (74). Consequently when pH - $\frac{1}{2}p(Ca + Mg)$ was plotted against applied lime the graph was similar in form to those mentioned above and to those described by Turner and Nichol (162), since applied lime increased the base saturation of the soil. These authors concluded that if pH - $\frac{1}{2}$pCa had a value greater than 2 there cannot be an appreciable amount of exchangeable iron present; if greater than 3.8 exchangeable aluminium must be essentially absent. These findings were based on soils saturated with a mixture of aluminium and iron varying from 20 - 100% iron and 30 - 100% aluminium, and the initial pH - $\frac{1}{2}$pCa varied from about 0.05 - 1.5 before titrating with calcium hydroxide. These were very extreme soil conditions but the results illustrated the relation between exchangeable aluminium and iron, and pH - $\frac{1}{2}$pCa, as well as showing that aluminium is more exchangeable than iron. In the present work the concentration of aluminium and iron increased with decreasing soil pH; this was slightly more pronounced for aluminium than iron (suggesting that the former was more exchangeable) and it occurred when the value of pH - $\frac{1}{2}$pCa was about 3.8. This effect was not as pronounced as indicated by Turner and Nichol (162), because aluminium and iron saturation was probably much less and pH - $\frac{1}{2}$pCa values larger. It is interesting to speculate on the findings of Magistad (70), who established that the amount of aluminium in the soil solution at various reactions was nearly identical to the solubility curve of aluminium sulphate in water at various pH values, and when the reaction of the soil was less than pH 4.7 amounts in excess of 3 ppm. of aluminium could exist. If Magistad's soil had a pH value of 4.7 in 0.01M $CaCl_2$, then the lime potential would be 3.56, given by pH - 1.14, at which exchangeable aluminium would also be expected by Turner and Nichol (162).

These soils were relatively infertile sands with a negligible salt concentration and the functions pH - $\frac{1}{2}$pCa and pH - $\frac{1}{2}$p(Ca + Mg) had almost the same value. This can be expected as Turner and Nichol (163) found that both pH - $\frac{1}{2}$pCa and pH - $\frac{1}{2}$pMg were sensitive to salt concentration when this involved changes in the ratio of calcium and magnesium, whereas pH - $\frac{1}{2}$p(Ca + Mg) was not, and in the absence of salts these functions had the same value. Since pH - $\frac{1}{2}$p(Ca + Mg) is independent of salt concentration it is a more reliable measure of the lime status of the soil than pH alone.

Lindsay, Peech and Clark (76) showed that for a given soil the value pH - $\frac{1}{3}$pAl was remarkably constant as the concentration of calcium chloride in the extracting solution was increased from 0.001 to 0.01M; this value was a characteristic of a given soil regardless of whether it was measured in 0.01M $CaCl_2$ or in the expressed soil solution. At similar pH values the results for Rhodesian soils were comparable to those of Lindsay et al and pH - $\frac{1}{3}$pAl increased with increasing pH although the aluminium concentration decreased sharply.

Chemical potentials and activity ratios of ions in soil solution have been studied in relation to potassium (153, 157, 159, 161, 164, 165), phosphorus (79, 157, 166), calcium and magnesium (158, 162, 163), and aluminium (72, 76). It has been suggested that these properties control the availability of ions to the plant, because the chemical potential of an ion in the soil determines the potential of that ion on the plant root exchange sites (161).

Correlations between plant and soil solution measurements have been reported for potassium by Woodruff (154), Barrow et al (167, 168), Arnold (151) and Tinker (164), phosphorus by Salmon (166) and magnesium by Salmon (169). Although such activity ratios are fundamental properties of a specific soil, their application to plant growth and chemical composition is not simple. Nevertheless the beneficial effects of pH on the growth of flue-cured tobacco might be due to the lowering of the activities of aluminium, iron and manganese in the soil solution, and these effects will be discussed next.

Relationships between plant and soil measurements.

All soils were fumigated with methyl bromide which retards nitrification (78). Since nitrate-nitrogen is important for the growth of flue-cured tobacco (170, 171) all treatments received weekly calcium nitrate, which also avoided the acidifying effects of ammonium salts.

Toxicity symptoms occurred on plants grown in soils 1, 5 and 17. These symptoms were the same as those for manganese observed in the greenhouse experiments and were consistent with those described in the effects of manganese and iron, and aluminium and manganese on the growth of flue-cured tobacco (pages 112 and 118).It is difficult to define a limit above which manganese toxicity occurs. In these experiments toxicity symptoms developed at 3497 ppm. in the plant, but in nutrient and soil experiments of the greenhouse studies plants were affected at contents above 2,000 and 600 ppm., respectively; these values were generally lower than figures quoted by Jacobson and Swanback (49) of 5,250 and 11,670 ppm. in two different seasons, and Hiatt and Ragland (47) of 3,000 ppm., yet Lohnis (172) did not report toxicity symptoms at 2,936 ppm. manganese. Bacon, Leighty and Bullock (173) also reported large variations in the manganese concentration in American tobaccos. It is possible that experimental techniques and environmental conditions contributed to the variations. Furthermore, less manganese toxicity was observed when the nutrients were applied; this will be discussed later.

Faint mottling was seen on all treatments of soil 15, being more pronounced on the limed soil. Manganese deficient tobacco grown in solution culture contained 22 ppm.; one of the lowest recorded amounts in American field tobacco was about 85 ppm. (173), which is more than the 63 ppm. found here, so this mottling strongly suggested manganese deficiency.

Lime (calcium carbonate) had no effect on the yield. It significantly increased calcium, decreased manganese and did not affect phosphorus and iron concentrations; there was a tendency for the potassium, magnesium and aluminium concentrations to be slightly decreased. Except for yield, these results are similar to those from field tobacco.

As expected, added nutrients improved the yield. They significantly decreased calcium, magnesium, aluminium and manganese, and increased potassium and phosphorus concentrations; iron concentration was unaffected. These decreased concentrations were attributed to the increase in yield, although manganese could have been affected by antagonistic effects of magnesium (174) and copper (59, 87, 175) - iron was not included in the nutrient solution. This decrease in manganese concentration presumably explains the decrease in manganese toxicity observed when nutrients were applied. In the case of the other ions, the variations could be attributed to their rate of absorption or ionic competition at the root sites, since potassium (176) and phosphorus (177) are very readily absorbed.

In order to overcome any deviations from the Ratio Law the soils were equilibrated with 0.0005M $CaCl_2$. Exchangeable calcium, magnesium and potassium were determined in the leachate of N ammonium acetate at pH 7, whereas aluminium, iron and manganese were measured in the leachate of ammonium acetate adjusted to the soil pH (done in 0.0005M $CaCl_2$) using acetic acid and/or ammonium hydroxide. Chenery (178) initially suggested that aluminium should be determined in ammonium acetate adjusted to the soil pH. This seems logical since pH affects the availability of aluminium (35, 36, 70, 179), iron (2, 180, 181), and manganese (34, 182 - 185).

The effect of lime on the exchangeable components of the soil and comparisons with other workers will be listed here.

(i) Soil pH and calcium, as expected, were increased.

(ii) Magnesium was unaffected as found by Moschler et al (186), although Askew (31) reported a decrease.

(iii) Potassium was unaffected; Lynd and Turk (187), Thomson et al (30), Moschler et al (186) obtained similar results but Powell and Hutcheson (188) and Naftel (96) reported that it was decreased.

(iv) Resin extractable soil phosphorus was unaffected. This was reported by Lynd and Turk (187), and Rai et al (17) but generally has been increased (18, 96, 189, 190).

(v) Aluminium was decreased, as found by numerous other workers (70, 98, 178, 191).

(vi) Iron was decreased, as found by numerous other workers (2, 137, 142, 180, 181, 192, 193).

(vii) Manganese was decreased, as found by numerous other workers (14, 87, 98, 187, 194 - 196).

Soil exchangeable cations are determined in solutions more concentrated than the field soil solution. Although these measurements indicate the content of "available" ions they do not reflect the strength with which the ions are held, as do activity ratios in equilibrium solution (see page 125). As was expected, the concentration of the ions in the soil solution increased as their amounts in the exchangeable form increased. The rate at which the exchange proceeds between ions adsorbed at or near the surface of plant root and exchanger, depends on the ease of diffusion through the medium and the concentration of the ions in the various phases of the nutritional environment of the roots (197). Thus the ionic composition of the solution phase is important and since activity ratios change with different proportions of ions in the soil solution, it was next attempted to relate these ratios to plant growth and nutrient uptake.

There was no relationship between the growth of tobacco and its chemical composition. However, there was a tendency for tobacco yields to increase with decreasing concentration of aluminium and iron in the plant but only in the absence of calcium carbonate and nutrients. Here the phosphate in the nutrient solution immobilised the aluminium (see page 116) and iron (198, 199), and calcium carbonate reduced their availability (see page 129).

When soil solution data were compared with plant composition e.g. Fe ppm. in plant vs $\sqrt{a_{Fe}/a_{Ca + Mg}}$ in solution, Al ppm. vs $\sqrt[3]{a_{Al}}/\sqrt{a_{Ca + Mg}}$, the correlations were poor except for phosphorus and manganese. Here the relationship between percentage phosphorus and pH_2PO_4 or $pH_2PO_4 + \frac{1}{2}pCa$ (phosphate potential) was curvilinear, but this only occurred in the absence of applied nutrients including phosphorus; Salmon (166) obtained similar results using rye grass. A similar relation existed between Mn ppm. vs. $\sqrt{a_{Mn}/a_{Ca + Mg}}$. On the other hand, all measurements of exchangeable cations were poorly correlated with plant composition. Finally yield was also poorly correlated with solution data and pH alone was as effective as $pH - \frac{1}{2}p(Ca + Mg)$, $pH - \frac{1}{2}pCa$, $pH - \frac{1}{2}pFe$, $pH - \frac{1}{3}pAl$, $pH - \frac{1}{2}pMn$, $pH - p(\sqrt{a_{Ca + Mg}} + a_K + \sqrt{a_{Mn}} + \sqrt{a_{Fe}} + \sqrt[3]{a_{Al}})$ - the latter potential was based on a "unified activity ratio", successfully used by Tinker (164) to predict oil palm responses to potassium fertilisation on very acid soils, but without any arbitrary constants. This substantiates an earlier finding where the importance of soil pH on growth was established.

Generally the correlations were very disappointing, although there is uncertainty with aluminium and iron since they were concentrated in the roots and their availability was affected by added nutrients. However, manganese was readily translocated, and a better correlation might have been expected.

Availability of aluminium, iron and manganese.

Both Arnold (151) and Salmon (165) showed that it was difficult to predict the availability of potassium and the latter author attributed this to variable fixation and release during cropping. In the greenhouse uniform watering is difficult, particularly when soils of different textures and amounts are used and it is possible that this might affect the exchange reactions. Variations in pH and the availability of aluminium, iron and manganese did occur when soils were incubated at about field capacity, generally the main effects having developed within seven days.

In all soils, the pH always increased at first, reaching a maximum in from one to four days, and sometimes continuing to increase up to 14 days (0.4 units higher) or later decreasing by variable amounts. Salmon (200) also showed that soil pH altered with periods of wetness. When the temperature of incubation was increased from 21.2 to 35°C., after seven days, the pH had increased by about 0.05 units. Early (autumn) and late (spring) ploughed soils behaved similarly and a constant value (about 0.5 higher than the initial pH) was reached after four days. These results illustrate the variation in soil pH with periods of wetness and temperature, and different soils derived from the same parent material behaved differently.

A curvilinear relation existed between the concentration of aluminium in the soil solution and soil pH, and the form of the graph was similar to that reported by Magistad (70). When the pH was greater than 4.8 very small quantities of aluminium were found in the soil solution. This also agrees with Magistad (70) and the more recent findings of Turner and Nichol (162). The effect of temperature was very striking on one soil and the concentration decreased as the pH increased. Autumn and spring ploughing affected similarly the concentration of aluminium which decreased to a very small value as the pH increased with incubation.

Like aluminium, iron concentration increased with decreasing soil pH, as found by numerous workers (2, 137, 180). The concentration of iron in solution was smaller than aluminium, suggesting iron was less exchangeable. The effect of temperature was very marked on one soil where the concentration of iron increased from about 0.1 to 3.1 ppm. in two days and then decreased gradually to 0.1 ppm. on the 14th day, this being the same value at the low temperature.

Manganese concentration varied from soil to soil and the concentration was not related to the initial air-dried soil pH. Also soil of similar pH contained very different concentrations of manganese. This was expected as the concentration of manganese in the soil solution is related to the exchangeable manganese which is known to vary appreciably between soils of similar pH (131, 195, 201). Generally, the concentration of manganese in the soil solution decreased with time of incubation; the concentration reached a maximum value in either one or two days, and then fell off rapidly to a much smaller value, occurring faster the lower the initial concentration. However, sometimes the manganese concentration maintained a fairly uniform level, or it reached a maximum and maintained this level thereafter. The manganese behaved the same in autumn and spring ploughed soils, and the temperature effects were variable. These decreases in manganese concentration cannot be attributed to soil pH but are more likely due to microbial oxidation (202, 203). This feature has been demonstrated practically by Sherman and Fujimoto (196), who showed that mulch was as effective as lime in lowering the availability of manganese, because the soil moisture was higher and the soil temperature lower. In the present work, temperature effects were only small and the moisture effect was the more important.

These fluctuations must have contributed to the poor manganese correlations, as uniform watering of potted plants is difficult and unavoidable variations in wetness will influence the availability of aluminium, iron and manganese, as well as pH. Furthermore, temperature variations and applied nutrients also affect their availability. Soil solutions contain little aluminium and iron, and since these ions accumulate in the roots, slight variations of their concentrations in the soil solution will be difficult to detect in the leaves and stem. Although manganese is readily taken up and translocated, only poor correlations can be expected with such large variations in the manganese concentration in the solution of a given soil.

CONCLUSIONS

Ground limestone, mixed lime, dolomite and slaked lime increased the yield of flue-cured tobacco on Triassic and granite sands because they increased soil pH, mineralisation of soil nitrogen and amount of available calcium and magnesium, and did not induce any recognisable minor element deficiencies. The effect of sources and times of application were small. Generally, the highest rates were best because pH changes were greatest. Although there was no definite range of either pH or pH - $\frac{1}{2}$p(Ca + Mg) that was most suitable for the optimum growth of flue-cured tobacco, field responses were less when initial soil pH was high; the main responses occurred when the initial pH was less than 5.0.

Mineral deficiency symptoms of boron and magnesium occurred in a dry and wet season, respectively; these observations suggest that lime responses on an acid soil could be seriously affected by various mineral deficiencies under different conditions.

Lime improved the quality of the leaf by lowering the manganese concentration and thus reducing the amount of slatey discolouration; it did not affect the maturity of the leaf as measured by concentrations of nitrogen and reducing sugars. Liming, particularly with calcitic materials increased calcium concentration. Similarly magnesium concentration was increased by dolomite. Other leaf features that were improved by liming were filling value and petroleum ether extract. There was less manganese, boron, chloride and sometimes potassium, whereas phosphorus, nitrogen, aluminium, iron, crude fibre, nicotine, reducing sugars and equilibrium moisture concentrations were unaffected. It seemed that to produce a good quality tobacco, the soil pH must be maintained above 5.0 but not higher than 6.0 at which value the yield still increased but the quality deteriorated.

In pot experiments the effects of aluminium, iron and manganese on flue-cured tobacco were similar to those described on other tobacco varieties and crops. Excess manganese caused leaf chlorosis, and additional brown and white lesions developed on plants grown in nutrient solution containing no iron. When iron was present in nutrient and soil solution, leaf tissue did not break down. Therefore, symptoms of manganese toxicity will vary depending on the concentration of iron in solution. Although aluminium damaged roots in nutrient solution, high rates of iron, aggravated by DTPA, drastically damaged leaves of plants grown in soil.

Increasing aluminium decreased yield of tobacco in nutrient solution, regardless of calcium, manganese or iron treatments but had no effect when applied to the soil probably because it was precipitated as the phsophate. Iron had no effect in nutrient solution but adversely affected growth when applied to the soil, probably because its chelating agent (DTPA) was able to accumulate here. Manganese had little effect on yield whether applied in solution or to the soil.

The concentrations and uptake of aluminium, iron and manganese were larger from nutrient solution than from soil, probably because the nutrient ions were more readily available in solution or because of the forced aeration that continually agitated them and maintained an ample supply of oxygen. However, their distribution in the plant was similar in both media. Manganese was readily taken up and translocated to the aerial parts but aluminium and iron were more concentrated in the roots and little was translocated. Therefore, foliar analysis could be used for measuring the availability of manganese, but would be much less reliable for aluminium and iron.

Aluminium decreased the concentration of calcium and manganese in all parts of plants grown in nutrient solution. In practice, even if aluminium will decrease manganese uptake, its own adverse effect would outweigh any possible benefits. Iron decreased manganese concentration in all plant parts; this suggests that if tobacco was grown in a manganese-rich soil of pH between 5.0 and 6.0, on which heavy applications of lime could not be used to decrease manganese uptake, applications of iron salts might overcome the adverse effect of manganese. Although aluminium and iron generally increased the concentration of phosphorus in the roots, they did not interfere with phosphorus transport in the plant.

It was impossible to define a limit above which manganese toxicity occurs, particularly as these symptoms have been observed here and by others from 600 to 11,670 ppm. manganese in dry material, probably because experimental techniques and environmental conditions were different. Manganese deficiency occurred at about 63 ppm. manganese.

A highly weathered topsoil from Inyanga did not obey the Ratio Law probably because of the presence of positively charged iron oxides. This limitation should be recognised in the routine determination of soil pH using 0.01M $CaCl_2$, since it would have a relatively higher value than normal soils. Under these conditions, pH is no longer characteristic of the soil but of the method used. In this laboratory 0.0005M $CaCl_2$ is now used when critical comparisons of soil pH are made.

Although lime decreased the availability of aluminium, iron and manganese, poor relationships were obtained between plant and soil measurements because variations in soil pH and availability of aluminium, iron and manganese occurred when a soil was moistened. Temperature variations and added nutrients also affected their availability. Furthermore, the concentration of aluminium and iron in the soil solution is small and since these ions accumulated in the roots, slight variations in concentration would be difficult to detect in leaves and stem. But manganese is readily translocated and only poor correlations can be expected if its concentration in the solution of a given soil varies unpredicably.

The success of liming cannot be attributed to one soil factor but rather to the cumulative effect of numerous factors which are initiated when soil pH is increased. When lime is incorporated thoroughly with the soil, it improves the soil environment for plant growth. Under these conditions, the availability of aluminium, iron and manganese is decreased, and phosphorus availability and soil nitrification are increased; also calcium and magnesium availability is increased, but the extent to which this is achieved depends on the source of lime. Unfortunately, analysis of tobacco leaf does not always reflect these changes. These anomalies between soil and plant measurements, particularly with respect to aluminium, iron and manganese, were successfully explained by critically determining their behaviour in the soil and plant. Unless due consideration is given to climate, past fertiliser dressings and cropping history, distribution of elements in the plant and inherent fertility of the soil, interpretations of results will vary and this has often lead to disagreement in studies on soil acidity.

Since normal accepted farming practices tend to cause soil acidification, it is essential for the soil to be judiciously limed in order to maintain a high level of productivity.

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Abbreviations as per "World list of scientific periodicals", Butterworth and Co. (Publishers) Ltd., London, 1963, 4th ed.

APPENDIX I

ANALYTICAL METHODS.

(A) Plant analysis.

- (i) Nicotine and nornicotine: Cundiff and Markunas (204).
- (ii) Petroleum ether extract: By Soxhlet extraction with petroleum ether, boiling point range 40-60°C.
- (iii) Chlorine: Nelson (205).
- (iv) Reducing sugars and sucrose: Somogyi (206).
- (v) Total nitrogen: By kjeldahl digestion method (207).
- (vi) Crude fibre: Method developed by the Imperial Tobacco Company, Bristol - personal communication.
- (vii) The tobacco was digested with nitric, sulphuric and perchloric acids (208), and subsequently analysed for
  - (a) Calcium: Diehl *et al* (209), using calcein indicator.
  - (b) Magnesium: Biedermann and Schwartzenbach (210), using erichrome black T indicator.
  - (c) Potassium: Eel flame photometer (207).
  - (d) Phosphorus: Kuttner and Lichtenstein (211).
  - (e) Iron: o-Phenanthroline method (212).
  - (f) Manganese: Potassium periodate oxidation (213).
  - (g) Aluminium: Aluminon method (Chenery, 178), but modified by adjusting pH to 3.5 and developing the colour by boiling gently for 5 minutes; absorbance was read after the colour had developed for at least six hours. These modifications were adapted from the method of Yuan and Fiskell (214).
- (viii) Boron: Davidson and Steyn (215), using curcumin reagent.
- (ix) Filling value and equilibrium moisture: Method developed by the Imperial Tobacco Company, Bristol - personal communication.

(B) Soil analysis.

(i) Mechanical analysis: Bouyoucos (216).

(ii) pH in 0.01M $CaCl_2$: Schofield and Taylor (74).

(iii) Exchangeable calcium, magnesium and potassium.

I. The soil was leached with neutral normal ammonium acetate and leachate analysed for calcium (209), magnesium (210) and potassium by Eel flame photometer (Chemistry Branch, Ministry of Agriculture, Rhodesia Government - personal communication).

II. Soil studies, Experiment 4. Soils were not leached for exchangeable determinations. Instead, 10g. soil and 50 ml. neutral normal ammonium acetate were shaken intermittently for 1 hour and filtered through Whatman No. 42 paper (152). The filtrate was analysed as in I above.

(iv) Exchangeable aluminium, iron and manganese.

Soil studies, Experiment 4. The exchangeable bases were extracted as in (iii) II above, using normal ammonium acetate which was adjusted to the soil pH with either acetic acid or ammonium hydroxide. An aliquot of this filtrate was placed in a beaker and evaporated to dryness on a sand bath; if a scum formed, water was added and taken to dryness again. This water treatment was repeated until no scum formed. 4 ml. 1:1 HNO_3 was added with care and evaporated to dryness, this was repeated with another 4 ml. HNO_3. If organic matter persists, 2.5 ml. 1:1 100 vol. H_2O_2 and 4 ml. 1:1 HNO_3 were added and evaporated to dryness. 10 ml. 1:50 HNO_3 was added, warmed and the resultant solution transferred to a volumetric flask. This solution was analysed for iron (212), manganese (213) and aluminium (178, 214).

(v) Exchange capacity: Thompson (217).

(vi) Available phosphorus: I. Alkali extraction. (218).

II. Resin extraction (219).

(vii) Total nitrogen: Piper (208).

(viii) Carbon: Walkley and Black (220).

(ix) Mineral nitrogen: Saunder et al (221).

(C) Soil solution analysis.

The soils were equilibrated in either 0.01M or 0.0005M $CaCl_2$ or 0.0148M $CaSO_4$ by shaking intermittently for 2 hours at 21.2°C. The soil : solution ratio was 1:2. The pH of the suspension was measured using a glass electrode; after filtering through Whatman No. 42 paper (two filter papers were used for very dilute solutions - Schofield and Taylor, 72) and discarding the first 10 ml., the filtrate was analysed for

(i) Calcium: I. Dielh et al (209).

II. Flame photometer using lanthanum at 2,000 ppm. in 0.1N HCl (222). This method was used only when soils were equilibrated with 0.0005M $CaCl_2$ in Soil studies, Experiment 4.

(ii) Calcium and magnesium (210).

(iii) Potassium: Eel flame photometer.

(iv) Phosphorus: Reduction of phosphomolybdic acid with stannous chloride.

(v) Aluminium: Aluminium method (76, 178) with modifications from the method of Yuan and Fiskell (214).

(vi) Iron: o-Phenanthroline method (212).

(vii) Manganese: Since chloride ions interfere in the determination of manganese, they were removed by boiling with 40 ml. conc. HNO_3 in a kjeldahl flask until the final volume was about 10 ml. The solution was transferred to a 100 ml. conical flask and the periodate method was applied (213).

All colorimetric readings were done on either a Beckman D.U. Spectrophotometer or Bausch and Lomb Spectronic 20 Colorimeter or Eel Colorimeter. Calcium and potassium were done on an Eel Flame Photometer using their respective filters. Initially pH was done by Beckman pH Meter but more recently by Beckman Expandermatic pH Meter.

The analytical methods listed in section (A) and (B) are the Current Methods of Chemical Analysis used by the Tobacco Research Board of Rhodesia.

APPENDIX II

COMPOSITION OF NUTRIENT SOLUTIONS USED IN GREENHOUSE STUDIES.

a) Initial nutrient solution used in Experiments 1, 3 and 4.

Chemical	Molarity of solution required	Weight of chemical g./l.
KH_2PO_4	0.003	0.4083
NH_4NO_3	0.0006	0.0480
$MgSO_4, 7H_2O$	0.002	0.4930
KCl	0.0005	0.0373
$Ca(NO_3)_2, 4H_2O$	0.0025	0.5892

Trace element solution (Hoagland and Arnon, 69)

Solution	Chemical	Weight of chemical g./l.
A	H_3BO_3	2.86
	$MnCl_2, 4H_2O$	1.81
	$ZnSO_4, 7H_2O$	0.22
	$CuSO_4, 5H_2O$	0.08
	H_2MoO_4	0.02
B	$C_6H_5O_7Fe$ (Ferric citrate) (scales)	2.1968

All chemicals of trace element solution A were dissolved together in the same volumetric flask; trace element solution B was made up separately and was kept in a dark bottle in a refrigerator. One millilitre of each solution in a litre of nutrient solution gave the required concentrations.

In Experiment 3 and 4, the concentration of iron was increased from 0.5 to 2.5 ppm. and a chelated iron compound replaced the citrate scales

Solution	Chemical	Weight of chemical g./l.
C	Sequestrene 330 Fe (Fe-DTPA : 10% Fe)	50

A half millilitre of C per litre of nutrient solution was used.

b) Initial nutrient solutions in Experiment 2.

Chemical	Molarity of solution required	Weight of chemical g./l.
KH_2PO_4	0.003	0.4083
NH_4NO_3	0.0006	0.0480
$MgSO_4, 7H_2O$	0.002	0.4930
KCl	0.0005	0.0373
$Ca(NO_3)_2, 4H_2O$	1. 50 ppm. Ca 0.00125	0.2946
	2. 100 ppm. Ca 0.0025	0.5892
	3. 200 ppm. Ca 0.0050	1.1784
NH_4NO_3	1. 0.0037	0.2995
Adjusting solution	2. 0.0025	0.1996
	3. -	-

Trace element solutions A and B were used.

c) Alternating nutrient solution used in Experiments 1, 2 and 4.

This solution is similar to the initial solution (a) except that potassium sulphate replaces potassium dihydrogen orthophosphate when the treatments are applied.

Chemical	Molarity of solution required	Weight of chemical g./l.
K_2SO_4	0.0015	0.2614

Treatment solutions.

Expt.	Chemicals	Stock solution g./l.	Rates				
1.	$Al_2(SO_4)_3,16H_2O$	58.4362	Al ppm.	0	5	12.5	31.25
			ml. stock*	0	1	2.5	6.25
	$MnCl_2,4H_2O$	18.10	Mn ppm.	0.5	5	12.5	31.25
			ml. stock*	0	1	2.5	6.25
Manganese was not omitted from the trace element mixture.							
2.	$Al_2(SO_4)_3,16H_2O$	58.4362	Al ppm.	0	5	12.5	31.25
			ml. stock*	0	1	2.5	6.25
4.	$Al_2(SO_4)_3,16H_2O$	58.4362	Al ppm.	0	5	12.5	31.25
			ml. stock*	0	1	2.5	6.25
	Fe-DTPA	50.00	Fe ppm.	0	5	12.5	31.25
			ml. stock*	0	1	2.5	6.25
Iron was omitted in the trace element solution.							

d) Treatment solutions used in Experiment 3.

Chemical	Stock solution g./l.	Rates				
Fe-DTPA	50.00	Fe ppm.	0	5	12.5	31.25
		ml. stock*	0	1	2.5	6.25
$MnCl_2,4H_2O$	18.10	Mn ppm.	0	5	12.5	31.25
		ml. stock*	0	1	2.5	6.25

Iron and manganese were omitted in the trace element solution; the other nutrients were the same as described in (a).

In the granite sand experiments, the same techniques and amounts of nutrients were added. In order to prevent flooding, the total volume was kept at about 100 ml., and the pH of all solutions

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* ml. stock solution in a litre of nutrient solution.

was adjusted to between 4.0 to 4.5, using a dilute solution of either sulphuric acid or sodium carbonate.

These nutrient solutions were made up from stock solutions in which a given volume of stock is required to the weight of chemical required. This technique considerably simplified and hastened up the making of solutions.

APPENDIX III

COMPOSITION OF NUTRIENT SOLUTIONS USED IN SOIL STUDIES.

a) Experiment 2.

Solution	Chemical	Weight of chemical g./l.	Volume of solution required. ml.
X	$Mg(NO_3)_2,6H_2O$	87.50	10
	$MgSO_4$, $7H_2O$	12.50	
	H_3BO_3	0.165	
Y	KH_2PO_4	35.0	10

Weekly applications of 10 ml. X and Y.

b) Experiment 2. Trace element effects: Experiment IIIa.

Solution	Chemical	Weight of chemical g./l.	Volume of solution required. ml.
A1	$MnCl_2,4H_2O$	1.81	1
	$ZnSO_4$, $7H_2O$	0.22	
	$CuSO_4,5H_2O$	0.08	
	H_2MoO_4	0.02	
B	Ferric citrate	2.1968	1

Solution A1 is identical to the trace element solution of Hoagland and Arnon, except that boric acid has been omitted.

The standard nutrient solution was the same as in (a) above and was applied at the same rates; the complete trace element solution contained an additional 1 ml. of A1 and B.

c) Experiment 4.

Solution	Chemical	Weight of chemical g./l.	Volume of solution required. ml.
R	$Ca(NO_3)_2,4H_2O$	5.9028	10
S	KH_2PO_4	8.7022	10
T	$MgSO_4,7H_2O$	3.0410	10
U	H_3BO_3	0.0286	10
	$CuSO_4,5H_2O$	0.0786	
	$ZnSO_4,7H_2O$	0.0880	
	H_2MoO_4	0.0017	

Equivalent amounts of S, T and U were mixed together and applied; 10 ml. R was applied separately.

APPENDIX IV

GENERAL INFORMATION AND ANALYTICAL RESULTS NOT INCLUDED IN MAIN TEXT.

Field Studies.

Experiment 1. Triassic sand, 1961-62.

(a) Cultural details.

Early application of liming material
  applied and disced in: March 15
Offset disced: August
Late application of liming material
  applied and disced in: September 27
Fertiliser, ridged
  and fumigated: October 18
Planted: November 10
Refills: November 17
Cultivated: November 29
Top dressed: December 1
Topped: January 12, 17, 19, 25; February 2, 13
Suckered: February 1, 15; March 3
Reaped: January 23; February 2, 6, 14, 21, 27;
  March 6, 16, 23, 27.

(b) Chemical and physical analysis of composite soil samples.

All results expressed in terms of air-dried sample passed through a 2 mm. sieve.

Horizon	0-7"	7"-14"	14"-21"
Mechanical analysis			
% Clay	4.4	5.0	5.5
% Silt	1.3	1.1	0.6
% Sand	94.3	93.9	93.9
Texture	Sand	Sand	Sand
pH (0.01M $CaCl_2$)	4.10	4.10	4.07
Exchangeable cations, me./100g.			
Calcium	0.35	0.11	0.26
Magnesium	0.14	0.08	0.07
Potassium	0.10	0.07	0.08
Exchange capacity, me./100g.	1.78	1.24	1.21
Alkali available phosphorus, ppm. P.	23	21	20
Mineral nitrogen, ppm. NO_3 + NH_4.			
Initial	13	6	5
Incubated	20	10	7
Total nitrogen, ppm.	275	159	128
% Carbon	0.242	0.081	0.075
C:N ratio	8.8	5.1	5.9

(c) Chemical analysis of cured leaf lamina.

All materials applied in March at the high rate of application.

Material	Reaping groups 1-3	4-6	7-10	Weighted mean
I. Calcium, % D.M.				
S.E.	(0.074)	(0.082)	(0.058)	(0.034)
None	1.84	1.21	1.29	1.39
S.E.	(0.104)	(0.115)	(0.083)	(0.048)
Ground mixed lime	3.08	1.54	1.50	1.81
Dolomite	2.25	1.30	1.47	1.58
Slaked lime	2.28	1.66	1.73	1.83
Mean	2.26	1.38	1.46	1.60
II. Magnesium, % D.M.				
S.E.	(0.038)	(0.029)	(0.019)	(0.020)
None	0.34	0.21	0.28	0.27
S.E.	(0.054)	(0.041)	(0.027)	(0.028)
Ground mixed lime	0.45	0.20	0.26	0.28
Dolomite	0.68	0.31	0.35	0.41
Slaked lime	0.43	0.18	0.35	0.32
Mean	0.45	0.22	0.31	0.31
III. Chloride, % D.M.				
S.E.	(0.058)	(0.037)	(0.084)	(0.043)
None	0.66	0.35	0.64	0.54
S.E.	(0.082)	(0.052)	(0.118)	(0.061)
Ground mixed lime	0.69	0.31	0.64	0.54
Dolomite	0.56	0.25	0.73	0.52
Slaked lime	0.46	0.29	0.60	0.47
Mean	0.61	0.31	0.65	0.52
IV. Nitrogen, % D.M.				
S.E.	(0.081)	(0.031)	(0.033)	(0.017)
None	1.77	1.58	1.89	1.75
S.E.	(0.115)	(0.044)	(0.046)	(0.024)
Ground mixed lime	2.04	1.49	1.80	1.72
Dolomite	1.88	1.59	1.78	1.73
Slaked lime	1.79	1.49	1.83	1.69
Mean	1.85	1.55	1.84	1.73

	Reaping groups			Weighted
Material	1-3	4-6	7-10	mean
V. Phosphorus, % D.M.				
S.E.	(0.019)	(0.026)	(0.024)	(0.012)
None	0.23	0.28	0.30	0.27
S.E.	(0.028)	(0.037)	(0.033)	(0.017)
Ground mixed lime	0.22	0.33	0.27	0.27
Dolomite	0.18	0.25	0.31	0.26
Slaked lime	0.20	0.22	0.30	0.24
Mean	0.21	0.27	0.29	0.26
VI. Potassium, % D.M.				
S.E.	(0.156)	(0.084)	(0.084)	(0.059)
None	3.67	3.56	2.57	3.17
S.E.	(0.220)	(0.119)	(0.119)	(0.084)
Ground mixed lime	3.74	3.54	2.55	3.12
Dolomite	3.40	3.37	2.40	2.96
Slaked lime	3.29	3.44	2.78	3.13
Mean	3.55	3.49	2.57	3.11
VII. Manganese, ppm. D.M.				
S.E.	(87.4)	(40.5)	(31.8)	(36.8)
None	692	488	428	502
S.E.	(123.6)	(57.3)	(44.9)	(52.1)
Ground mixed lime	577	396	461	460
Dolomite	415	316	337	343
Slaked lime	462	308	370	370
Mean	568	399	404	435
VIII. Aluminium, ppm. D.M.				
S.E.	(35.7)	(76.4)	(29.0)	(37.0)
None	252	167	189	192
S.E.	(50.4)	(108.0)	(41.0)	(52.4)
Ground mixed lime	321	270	217	263
Dolomite	290	318	214	265
Slaked lime	264	379	144	252
Mean	276	260	191	233
IX. Iron, ppm. D.M.				
S.E.	(21.5)	(36.8)	(27.6)	(19.0)
None	166	160	217	185
S.E.	(30.3)	(52.1)	(39.1)	(26.9)
Ground mixed lime	225	172	235	215
Dolomite	267	205	202	216
Slaked lime	185	249	200	213
Mean	202	189	214	203

	Reaping groups			Weighted
Material	1-3	4-6	7-10	mean
X. Boron, ppm. D.M.				
S.E.	(1.74)	(0.70)	(1.74)	(0.79)
None	14.2	21.8	30.5	23.3
S.E.	(2.46)	(0.99)	(2.47)	(1.12)
Ground mixed lime	9.4	18.9	24.0	18.8
Dolomite	9.5	17.8	23.7	18.5
Slaked lime	11.9	19.2	23.2	18.7
Mean	11.8	19.9	26.4	20.5
XI. Nicotine, % D.M.				
S.E.	(0.151)	(0.070)	(0.151)	(0.105)
None	1.26	1.30	2.58	1.80
S.E.	(0.214)	(0.099)	(0.213)	(0.149)
Ground mixed lime	1.20	1.34	2.42	1.82
Dolomite	1.40	1.33	1.94	1.61
Slaked lime	1.09	1.37	2.22	1.64
Mean	1.24	1.33	2.35	1.74
XII. Reducing sugars, % D.M.				
S.E.	(0.96)	(1.39)	(1.07)	(0.73)
None	14.4	21.9	17.2	18.3
S.E.	(1.36)	(1.96)	(1.52)	(1.03)
Ground mixed lime	12.3	25.1	14.9	17.8
Dolomite	14.0	21.8	15.2	17.2
Slaked lime	13.1	20.0	15.4	16.4
Mean	13.6	22.1	16.0	17.6
XIII. Resin, % D.M.				
S.E.	(0.193)	(0.301)	(0.225)	(0.105)
None	8.67	4.82	4.92	5.79
S.E.	(0.273)	(0.426)	(0.319)	(0.149)
Ground mixed lime	9.17	5.12	4.61	5.74
Dolomite	9.76	6.34	4.49	6.27
Slaked lime	9.25	5.35	4.72	5.96
Mean	9.10	5.29	4.73	5.91
XIV. Crude fibre, % D.M.				
S.E.	(0.443)	(0.268)	(0.417)	(0.264)
None	8.43	8.24	6.70	7.65
S.E.	(0.626)	(0.379)	(0.589)	(0.373)
Ground mixed lime	8.50	8.34	7.37	7.95
Dolomite	7.88	8.18	7.27	7.72
Slaked lime	8.14	7.42	6.24	6.98
Mean	8.28	8.08	6.85	7.59

Experiment 2. Lime and borax experiment. Triassic sand, 1962-63.

(a) Cultural details.

Ploughed:	March 7
Disced:	April
Harrowed:	October 13
Fertilized:	October 19
Ridged:	October 19
Fumigated:	October 19
Planted:	November 19
Reridged:	December 19
Suckered:	January 27, February 18, March 6.

(b) Chemical and physical analysis of composite soil samples.

All results expressed in terms of the air-dried sample passed through a 2 mm. sieve.

Mechanical analysis	
% Clay	2.5
% Silt	1.3
% Sand	96.2
Texture	Sand
pH	4.30
Exchangeable cations, me./100g.	
Calcium	0.52
Magnesium	0.32
Potassium	0.25
Exchange capacity, me./100g.	2.80
Base saturation	39%
Alkali available P, ppm.	17
Mineral nitrogen, ppm. $NO_3 + NH_4$	
Initial	10
Incubated	12
Total nitrogen, ppm.	420
% Carbon	0.341
C:N ratio	8.1

Experiments 3 and 4. Granite sand, 1963-64.

(a) Cultural details.

Experiment	3	4
Lime applied and ploughed:	(1) April 24 (2) September 16	(1) March 22 (2) September 4
Ridged and fertilized:	October 8	October 3
Fumigated:	October 8	October 14
Planted:	October 26	November 6
Reridged:	November 12 December 10	November 22 December 16
Cultivated:	November 13 December 11	November 14, 20 December 17
Topped:	December 24	January 3
Suckered:	December 30 January 13, 27 February 8	January 14, 22, 29 February 4, 14
Reaped:	January 2, 13, 20, 30; February 8, 19, 29; March 10	January 14, 22, 29; February 4, 11, 21, 29; March 9, 17, 29; April 5

(b) Chemical and physical analysis of composite soil sample.

All results expressed in terms of the air-dried sample passed through a 2 mm. sieve.

Experiment	3	4
Mechanical analysis		
% Clay	3.6	7.6
% Silt	5.5	4.6
% Sand	90.9	87.8
Texture	Sand	Sand
pH (0.01M $CaCl_2$)	4.80	4.58
Exchangeable cations, me./100g.		
Calcium	0.97	0.55
Magnesium	0.19	0.12
Potassium	0.10	0.13
Exchange capacity, me./100g.	2.22	1.85
Resin available P_2O_5, ppm.	9	11
Mineral nitrogen ppm. NO_3 + NH_4		
Initial	16	11
Incubated	25	18
Total nitrogen, ppm.	370	260
% Carbon	0.449	0.279
C:N ratio	12.1	10.7

Experiment 5. Granite sand, 1965-66.

(a) Cultural details.

Ploughed: May 1965
Disced: September 24
Lime applied: September 23
Fertilized, ridged and fumigated: October 14
Planted: November 13
Refilled: Nil
Cultivated: November 23, December 7, 17
Reridged: December 4, 13
Topped: January 10, 22, February 1
Suckered: January 31 - weekly thereafter.
Reaped: January 31; February 10, 18, 22, 28;
March 7, 14, 19, 26.

(b) Chemical and physical analysis of composite soil sample.

All results expressed in terms of air-dried sample passed through a 2 mm. sieve.

Mechanical analysis	
% Clay	7.0
% Silt	6.3
% Sand	86.8
Texture	Sand
pH (0.01M $CaCl_2$)	4.65
Exchangeable cations, me./100g.	
Calcium	1.04
Magnesium	0.73
Potassium	0.20
Exchange capacity, me./100g.	3.73
Total nitrogen, ppm.	370
Mineral nitrogen, ppm. $NO_3 + NH_4$	
Initial	18.5
Incubated	26.0
Resin available P_2O_5, ppm.	22.5
% Carbon	0.507
C:N ratio	13.7

(c) Chemical analysis of cured leaf lamina, stem and roots.

Dolomite tons/acre	Reaping groups - Leaves 1-3	4-6	7-9	Mean	Stems	Roots	Whole plant	Uptake Leaves lb/acre	Uptake Whole plant g/plant
I. Calcium, % D.M.									
S.E.	(0.089)	(0.115)	(0.105)	(0.069)	(0.022)	(0.021)	(0.042)	(1.40)	(0.074)
0	1.77	1.56	1.96	1.75	0.40	0.38	1.10	24.2	1.58
½	1.77	1.73	2.06	1.88	0.45	0.48	1.20	29.9	1.91
1	2.01	1.72	2.18	1.99	0.39	0.38	1.20	31.7	1.95
2	2.14	1.64	2.12	1.99	0.42	0.36	1.23	32.4	1.98
Mean	1.92	1.66	2.08	1.90	0.41	0.40	1.18	29.8	1.86
II. Magnesium, % D.M.									
S.E.	(0.081)	(0.050)	(0.038)	(0.026)	(0.018)	(0.008)	(0.018)	(0.58)	(0.041)
0	1.11	0.91	0.98	0.99	0.25	0.10	0.60	14.4	0.88
½	1.07	0.96	0.95	0.98	0.24	0.12	0.60	15.7	0.96
1	1.26	1.03	1.05	1.10	0.31	0.12	0.67	17.6	1.09
2	1.44	1.09	1.08	1.17	0.32	0.13	0.72	19.1	1.17
Mean	1.22	1.00	1.02	1.06	0.28	0.12	0.65	16.7	1.02
III. Potassium, % D.M.									
S.E.	(0.146)	(0.136)	(0.048)	(0.084)	(0.097)	(0.049)	(0.053)	(1.57)	(0.147)
0	2.94	3.10	2.90	2.98	2.56	1.25	2.48	42.9	3.58
½	3.37	3.06	2.97	3.10	2.69	1.25	2.58	49.4	4.10
1	3.11	3.07	2.73	2.94	2.54	1.21	2.43	46.7	3.94
2	3.29	2.86	2.70	2.89	2.59	1.24	2.43	47.0	3.93
Mean	3.18	3.02	2.82	2.98	2.59	1.24	2.48	46.5	3.89

(c) Chemical analysis continued.

Dolomite tons/acre	Reaping groups - Leaves.				Stems	Roots	Whole plant	Uptake	
	1-3	4-6	7-9	Mean				Leaves lb/acre	Whole plant g/plant
IV. Nitrogen, % DM.									
S.E.	(0.045)	(0.072)	(0.054)	(0.033)	(0.028)	(0.016)	(0.019)	(0.72)	(0.069)
0	1.68	1.56	1.62	1.61	0.63	0.68	1.15	23.2	1.66
½	1.66	1.58	1.60	1.61	0.63	0.73	1.16	25.6	1.85
1	1.71	1.67	1.67	1.68	0.66	0.69	1.19	26.7	1.93
2	1.84	1.62	1.71	1.72	0.65	0.69	1.22	28.0	1.98
Mean	1.72	1.61	1.65	1.66	0.64	0.70	1.18	25.9	1.85
V. Phosphorus, % D.M.									
S.E.	(0.011)	(0.012)	(0.013)	(0.003)	(0.006)	(0.010)	(0.004)	(0.08)	(0.011)
0	0.21	0.26	0.38	0.29	0.18	0.10	0.22	4.2	0.32
½	0.23	0.22	0.31	0.27	0.18	0.10	0.20	4.2	0.32
1	0.20	0.22	0.35	0.27	0.17	0.11	0.21	4.3	0.33
2	0.19	0.24	0.35	0.28	0.16	0.10	0.21	4.5	0.33
Mean	0.21	0.24	0.35	0.28	0.17	0.10	0.21	4.3	0.33
VI. Iron, ppm. D.M.									
S.E.	(46.4)	(70.9)	(32.1)	(20.3)	(20.6)	(97.6)	(23.7)	(0.030)	(5.14)
0	528	527	257	413	188	952	477	0.59	69.2
½	507	513	274	404	212	1172	525	0.64	83.1
1	592	462	251	405	183	1179	528	0.64	85.5
2	658	513	284	443	209	1198	567	0.72	92.5
Mean	572	504	266	416	198	1125	524	0.65	82.6

(c) Chemical analysis continued.

Dolomite tons/acre	Reaping groups - Leaves 1-3	4-6	7-9	Mean	Stems	Roots	Whole plant	Uptake Leaves lb/acre	Whole plant mg/plant
VII. Manganese, ppm. D.M.									
S.E.	(53.9)	(63.2)	(54.9)	(44.2)	(5.7)	(6.3)	(20.4)	(0.057)	(3.43)
0	546	484	650	566	82	73	332	0.81	47.4
½	406	441	471	446	69	77	267	0.71	42.4
1	425	439	456	439	67	69	256	0.70	41.5
2	459	444	548	497	73	64	292	0.81	47.7
Mean	459	452	531	487	73	71	287	0.76	44.7
VIII. Aluminium, ppm. D.M.									
S.E.	(143.6)	(140.7)	(46.2)	(78.2)	(12.4)	(258.3)	(51.2)	(0.118)	(10.0)
0	1692	1015	243	911	193	3041	1213	1.30	175
½	1494	1214	349	907	233	3423	1290	1.44	204
1	1764	1219	273	953	183	3500	1351	1.51	219
2	2057	1253	320	1015	201	3598	1435	1.66	234
Mean	1752	1175	296	946	202	3390	1322	1.48	208

Experiment 6. Lime, boron and side-dressings of nitrogen and potassium. Granite sand, 1965-66.

(a) Cultural details.

Ploughed: April
Disced: May
Lime applied: September 17
Fertilised, ridged and fumigated: October 11
Planted: October 25
Refilled: November 2, 11
Side-dressed: November 19
Cultivated: November 19, December 4
Reridged: December 31
Topped: January 3
Suckered: January 13, 24, 31; February 7, 14
Reaped: January 5, 17, 24, 29; February 7, 19, 26; March 7, 21.

(b) Chemical analysis of composite soil sample.

All results expressed in terms of air-dried sample passed through a 2 mm. sieve.

Texture	Sand
pH (0.01M $CaCl_2$)	4.5
Exchangeable cations, me./100g.	
Calcium	1.0
Magnesium	0.4
Potassium	0.17
Total nitrogen, ppm.	190
Mineral nitrogen, ppm.	NO_3+NH_4
Initial	13
Incubated	29
Resin available P_2P_5 ppm.	26

Analysis done by Chemistry Branch, Ministry of Agriculture.

(c) Soil pH.

Material	Borax lb./acre			N side-dressings lb./acre		K_2O side-dressings lb./acre		
	0	8	16	0	10	0	28	Mean
I. October 25								
Dolomite, tons/acre								
S.E.	(0.068)			(0.055)		(0.055)		(0.039)
0	4.32	4.36	4.26	4.32	4.30	4.26	4.36	4.31
1.5	4.69	4.65	4.63	4.64	4.66	4.66	4.65	4.65
3.0	4.97	4.84	4.96	4.93	4.91	4.93	4.92	4.92
Borax, lb./acre								
S.E.				(0.055)		(0.055)		(0.039)
0	-	-	-	4.71	4.60	4.63	4.69	4.66
8	-	-	-	4.55	4.68	4.63	4.60	4.61
16	-	-	-	4.63	4.59	4.60	4.63	4.61
N side-dressing, lb./acre								
S.E.						(0.045)		(0.032)
0	-	-	-	-	-	4.64	4.62	4.63
10	-	-	-	-	-	4.60	4.66	4.63
S.E.	(0.039)			(0.032)		(0.032)		
Mean	4.66	4.61	4.61	4.63	4.63	4.62	4.64	4.63
II. January 3								
Dolomite, tons/acre								
S.E.	(0.076)			(0.062)		(0.062)		(0.044)
0	4.41	4.41	4.29	4.38	4.37	4.32	4.43	4.37
1.5	5.20	5.16	5.03	5.13	5.12	5.13	5.13	5.13
3.0	5.66	5.47	5.45	5.50	5.55	5.53	5.53	5.53
Borax, lb./acre								
S.E.				(0.062)		(0.062)		(0.044)
0	-	-	-	5.12	5.06	5.10	5.08	5.09
8	-	-	-	4.97	5.06	5.00	5.02	5.01
16	-	-	-	4.92	4.92	4.87	4.98	4.92
N side-dressing, lb./acre								
S.E.						(0.051)		(0.036)
0	-	-	-	-	-	5.00	5.01	5.00
10	-	-	-	-	-	4.98	5.05	5.02
S.E.	(0.044)			(0.036)		(0.036)		
Mean	5.09	5.01	4.92	5.00	5.02	4.99	5.03	5.01

Soil pH (contd.)

Material	Borax lb./acre			N side-dressings lb./acre		K_2O side-dressings lb./acre		
	0	8	16	0	10	0	28	Mean
III. March 24								
Dolomite, tons/acre								
S.E.		(0.137)		(0.112)		(0.112)		(0.079)
0	4.59	4.77	4.56	4.66	4.61	4.57	4.71	4.64
1.5	5.34	5.26	5.13	5.28	5.21	5.28	5.21	5.24
3.0	5.72	5.43	5.46	5.51	5.56	5.51	5.56	5.54
Borax, lb./acre								
S.E.				(0.112)		(0.112)		(0.079)
0	-	-	-	5.29	5.14	5.25	5.19	5.22
8	-	-	-	5.07	5.24	5.14	5.16	5.15
16	-	-	-	5.10	5.00	4.97	5.13	5.05
N side-dressing, lb./acre								
S.E.						(0.092)		(0.065)
0	-	-	-	-	-	5.13	5.17	5.15
10	-	-	-	-	-	5.11	5.15	5.13
S.E.		(0.079)		(0.065)		(0.065)		
Mean	5.22	5.15	5.05	5.15	5.13	5.12	5.16	5.14
IV. May 5								
Dolomite, tons/acre								
S.E.		(0.102)		(0.084)		(0.084)		(0.059)
0	4.67	4.70	4.63	4.66	4.67	4.63	4.70	4.66
1.5	5.47	5.45	5.40	5.42	5.46	5.42	5.46	5.44
3.0	5.98	5.83	5.83	5.89	5.87	5.85	5.91	5.88
Borax, lb./acre								
S.E.				(0.084)		(0.084)		(0.059)
0	-	-	-	5.46	5.29	5.37	5.38	5.37
8	-	-	-	5.22	5.43	5.34	5.31	5.33
16	-	-	-	5.30	5.27	5.20	5.37	5.29
N side-dressing, lb./acre								
S.E.						(0.068)		(0.048)
0	-	-	-	-	-	5.32	5.33	5.33
10	-	-	-	-	-	5.28	5.38	5.33
S.E.		(0.059)		(0.048)		(0.048)		
Mean	5.37	5.33	5.29	5.33	5.33	5.30	5.36	5.33

(d) Yield, grade and discolouration index.

Material	Borax lb./acre			N side-dressings lb./acre		K_2O side-dressings lb./acre		
	0	8	16	0	10	0	28	Mean
I. Yield, lb./acre								
Dolomite, tons/acre								
S.E.		(52.3)		(39.9)		(39.9)		(28.2)
0	1251	1157	1104	1161	1180	1133	1209	1171
1.5	1273	1262	1220	1226	1277	1263	1241	1252
3.0	1155	1300	1252	1209	1263	1227	1246	1236
Borax, lb./acre								
S.E.				(39.9)		(39.9)		(28.2)
0	-	-	-	1194	1258	1202	1250	1226
8	-	-	-	1236	1244	1219	1260	1240
16	-	-	-	1166	1218	1200	1185	1192
N side-dressing, lb./acre								
S.E.						(32.6)		(23.1)
0	-	-	-	-	-	1180	1217	1199
10	-	-	-	-	-	1234	1246	1240
S.E.		(28.2)		(23.1)		(23.1)		
Mean	1226	1240	1192	1199	1240	1207	1232	1219
II. Grade index								
Dolomite, tons/acre								
S.E.		(1.16)		(0.89)		(0.89)		(0.63)
0	17.2	19.5	17.3	16.7	19.3	17.9	18.1	18.0
1.5	19.1	20.7	18.5	16.9	22.0	19.8	19.0	19.4
3.0	18.3	20.9	20.0	18.5	21.0	20.7	18.8	19.7
Borax, lb./acre								
S.E.				(0.89)		(0.89)		(0.63)
0	-	-	-	17.2	19.2	18.7	17.7	18.2
8	-	-	-	19.1	21.6	20.9	19.8	20.4
16	-	-	-	15.8	21.4	18.8	18.4	18.6
N side-dressing, lb./acre								
S.E.						(0.72)		(0.51)
0	-	-	-	-	-	18.7	16.0	17.4
10	-	-	-	-	-	20.2	21.3	20.7
S.E.		(0.63)		(0.51)		(0.51)		
Mean	18.2	20.4	18.6	17.4	20.7	19.5	18.6	19.0

Material	Borax lb./acre			N side-dressings lb./acre		K_2O side-dressings lb./acre		
	0	8	16	0	10	0	28	Mean
III. Discolouration index								
Dolomite, tons/acre								
S.E.	(0.140)			(0.107)		(0.107)		(0.076)
0	1.39	0.85	1.29	1.41	0.94	1.12	1.23	1.17
1.5	1.09	0.69	1.14	1.28	0.67	0.97	0.98	0.97
3.0	1.00	0.84	0.90	1.07	0.76	0.84	0.99	0.91
Borax, lb./acre								
S.E.				(0.107)		(0.107)		(0.076)
0	-	-	-	1.36	0.96	1.11	1.21	1.16
8	-	-	-	1.03	0.55	0.73	0.86	0.79
16	-	-	-	1.36	0.85	1.08	1.13	1.11
N side-dressing, lb./acre								
S.E.						(0.087)		(0.062)
0	-	-	-	-	-	1.16	1.34	1.25
10	-	-	-	-	-	0.79	0.79	0.79
S.E.	(0.076)			(0.062)		(0.062)		
Mean	1.16	0.79	1.11	1.25	0.79	0.98	1.06	1.02

(e) Chemical analysis of cured leaf lamina.

I. Calcium, % D.M.

Material	Borax lb./acre			N side-dressings lb./acre		K_2O side-dressings lb./acre		
	0	8	16	0	10	0	28	Mean
Reaping 1-3								
Dolomite, tons/acre								
S.E.	(0.121)			(0.093)		(0.093)		(0.065)
0	2.71	2.75	2.97	2.73	2.89	2.87	2.75	2.81
1.5	2.78	2.77	2.93	2.83	2.83	2.84	2.81	2.83
3.0	2.87	2.77	2.85	2.75	2.90	2.74	2.91	2.83
Borax, lb./acre								
S.E.				(0.093)		(0.093)		(0.065)
0	-	-	-	2.63	2.94	2.78	2.79	2.78
8	-	-	-	2.74	2.78	2.70	2.83	2.76
16	-	-	-	2.94	2.89	2.97	2.86	2.92
N side-dressing, lb./acre								
S.E.						(0.076)		(0.053)
0	-	-	-	-	-	2.76	2.78	2.77
10	-	-	-	-	-	2.88	2.86	2.87
S.E.	(0.065)			(0.053)		(0.053)		
Mean	2.78	2.76	2.92	2.77	2.87	2.82	2.82	2.82
Reaping 4-6								
Dolomite, tons/acre								
S.E.	(0.095)			(0.073)		(0.073)		(0.051)
0	1.59	1.56	1.59	1.54	1.61	1.58	1.58	1.58
1.5	1.59	1.58	1.60	1.56	1.62	1.62	1.56	1.59
3.0	1.65	1.60	1.58	1.58	1.64	1.54	1.67	1.61
Borax, lb./acre								
S.E.				(0.073)		(0.073)		(0.051)
0	-	-	-	1.54	1.67	1.61	1.60	1.61
8	-	-	-	1.56	1.60	1.56	1.61	1.58
16	-	-	-	1.58	1.60	1.57	1.61	1.59
N side-dressing, lb./acre								
S.E.						(0.059)		(0.042)
0	-	-	-	-	-	1.55	1.58	1.56
10	-	-	-	-	-	1.61	1.64	1.62
S.E.	(0.051)			(0.042)		(0.042)		
Mean	1.61	1.58	1.59	1.56	1.62	1.58	1.61	1.59

Calcium, % D.M. (contd.)

Material	Borax lb./acre			N side-dressings lb./acre		K_2O side-dressings lb./acre		
	0	8	16	0	10	0	28	Mean
Reaping 7-9								
Dolomite, tons/acre								
S.E.		(0.079)		(0.061)		(0.061)		(0.043)
0	1.61	1.51	1.63	1.58	1.59	1.62	1.55	1.58
1.5	1.78	1.71	1.73	1.76	1.72	1.76	1.72	1.74
3.0	1.81	1.79	1.74	1.79	1.77	1.77	1.79	1.78
Borax, lb./acre								
S.E.				(0.061)		(0.061)		(0.043)
0	-	-	-	1.67	1.80	1.77	1.70	1.73
8	-	-	-	1.73	1.62	1.69	1.66	1.67
16	-	-	-	1.73	1.67	1.69	1.71	1.70
N side-dressing, lb./acre								
S.E.						(0.050)		(0.035)
0	-	-	-	-	-	1.71	1.71	1.71
10	-	-	-	-	-	1.72	1.67	1.69
S.E.		(0.043)		(0.035)		(0.035)		
Mean	1.73	1.67	1.70	1.71	1.69	1.71	1.69	1.70
Weighted mean								
Dolomite, tons/acre								
S.E.		(0.079)		(0.060)		(0.060)		(0.042)
0	1.81	1.77	1.87	1.78	1.85	1.82	1.81	1.82
1.5	1.90	1.88	1.91	1.89	1.90	1.92	1.87	1 90
3.0	1.98	1.94	1.93	1.94	1.97	1.91	1.99	1.95
Borax, lb./acre								
S.E.				(0.060)		(0.060)		(0.042)
0	-	-	-	1.82	1.97	1.92	1.88	1.90
8	-	-	-	1.88	1.85	1.86	1.87	1.86
16	-	-	-	1.91	1.90	1.88	1.92	1.90
N side-dressing, lb./acre								
S.E.						(0.049)		(0.035)
0	-	-	-	-	-	1.86	1.88	1.87
10	-	-	-	-	-	1.91	1.90	1.91
S.E.		(0.042)		(0.035)		(0.035)		
Mean	1.90	1.86	1.90	1.87	1.91	1.89	1.89	1.89

II. Magnesium, % D.M.

Material	Borax lb./acre			N side-dressings lb./acre		K_2O side-dressings lb./acre		
	0	8	16	0	10	0	28	Mean
Reaping 1-3								
Dolomite, tons/acre								
S.E.	(0.0682)			(0.0521)		(0.0521)		(0.0368)
0	0.847	1.005	0.886	0.921	0.904	0.873	0.952	0.912
1.5	1.275	1.162	1.307	1.203	1.292	1.272	1.223	1.248
3.0	1.317	1.367	1.275	1.288	1.352	1.316	1.324	1.320
Borax, lb./acre								
S.E.				(0.0521)		(0.0521)		(0.0368)
0	-	-	-	1.125	1.167	1.144	1.148	1.146
8	-	-	-	1.162	1.194	1.157	1.198	1.178
16	-	-	-	1.126	1.187	1.160	1.152	1.156
N side-dressing, lb./acre								
S.E.						(0.0425)		(0.0301)
0	-	-	-	-	-	1.139	1.136	1.137
10	-	-	-	-	-	1.168	1.197	1.183
S.E.	(0.0368)			(0.0301)		(0.0301)		
Mean	1.146	1.178	1.156	1.137	1.183	1.154	1.166	1.160
Reaping 4-6								
Dolomite, tons/acre								
S.E.	(0.0377)			(0.0288)		(0.0288)		(0.0204)
0	0.434	0.560	0.449	0.518	0.444	0.460	0.503	0.481
1.5	0.669	0.622	0.630	0.618	0.663	0.653	0.628	0.640
3.0	0.704	0.696	0.682	0.678	0.709	0.698	0.690	0.694
Borax, lb./acre								
S.E.				(0.0288)		(0.0288)		(0.0204)
0	-	-	-	0.603	0.603	0.603	0.603	0.603
8	-	-	-	0.634	0.618	0.607	0.645	0.626
16	-	-	-	0.578	0.596	0.601	0.573	0.587
N side-dressing, lb./acre								
S.E.						(0.0235)		(0.0166)
0	-	-	-	-	-	0.608	0.602	0.605
10	-	-	-	-	-	0.599	0.612	0.605
S.E.	(0.0204)			(0.0166)		(0.0166)		
Mean	0.603	0.626	0.587	0.605	0.605	0.603	0.607	0.605

Magnesium, % D.M. (contd.)

Material	Borax lb./acre			N side-dressings lb./acre		K_2O side-dressings lb./acre		
	0	8	16	0	10	0	28	Mean
<u>Reaping 7-9</u>								
Dolomite, tons/acre								
S.E.	(0.0323)			(0.0247)		(0.0247)		(0.0174)
0	0.467	0.537	0.453	0.508	0.463	0.486	0.486	0.486
1.5	0.667	0.637	0.622	0.629	0.655	0.648	0.636	0.642
3.0	0.664	0.707	0.634	0.667	0.670	0.689	0.648	0.668
Borax, lb./acre								
S.E.				(0.0247)		(0.0247)		(0.0174)
0	-	-	-	0.608	0.591	0.616	0.583	0.600
8	-	-	-	0.639	0.615	0.641	0.613	0.627
16	-	-	-	0.557	0.583	0.567	0.573	0.570
N side-dressing, lb./acre								
S.E.						(0.0201)		(0.0142)
0	-	-	-	-	-	0.618	0.585	0.601
10	-	-	-	-	-	0.598	0.594	0.596
S.E.	(0.0174)			(0.0142)		(0.0142)		
Mean	0.600	0.627	0.570	0.601	0.596	0.608	0.590	0.599
<u>Weighted mean</u>								
Dolomite, tons/acre								
S.E.	(0.0361)			(0.0275)		(0.0275)		(0.0195)
0	0.530	0.646	0.537	0.594	0.547	0.553	0.588	0.571
1.5	0.785	0.737	0.758	0.739	0.782	0.769	0.752	0.760
3.0	0.826	0.849	0.795	0.811	0.836	0.836	0.811	0.823
Borax, lb./acre								
S.E.				(0.0275)		(0.0275)		(0.0195)
0	-	-	-	0.720	0.707	0.722	0.706	0.714
8	-	-	-	0.745	0.743	0.747	0.742	0.744
16	-	-	-	0.679	0.714	0.690	0.703	0.697
N side-dressing, lb./acre								
S.E.						(0.0225)		(0.0159)
0	-	-	-	-	-	0.722	0.707	0.715
10	-	-	-	-	-	0.717	0.727	0.722
S.E.	(0.0195)			(0.0159)		(0.0159)		
Mean	0.714	0.744	0.697	0.715	0.722	0.719	0.717	0.718

III. Potassium, % D.M.

Material	Borax lb./acre			N side-dressings lb./acre		K_2O side dressings lb./acre		
	0	8	16	0	10	0	28	Mean
Reaping 1-3								
Dolomite, tons/acre								
S.E.	(0.099)			(0.076)		(0.076)		(0.054)
0	3.11	3.17	3.15	3.21	3.09	3.08	3.21	3.15
1.5	2.73	2.86	2.90	2.85	2.80	2.78	2.88	2.83
3.0	2.70	2.76	2.83	2.71	2.81	2.66	2.86	2.76
Borax, lb./acre								
S.E.				(0.076)		(0.076)		(0.054)
0	-	-	-	2.88	2.81	2.68	3.00	2.84
8	-	-	-	2.89	2.97	2.86	3.01	2.93
16	-	-	-	3.00	2.92	2.98	2.94	2.96
N side-dressing, lb./acre								
S.E.						(0.062)		(0.044)
0	-	-	-	-	-	2.90	2.95	2.92
10	-	-	-	-	-	2.78	3.02	2.90
S.E.	(0.054)			(0.044)		(0.044)		
Mean	2.84	2.93	2.96	2.92	2.90	2.84	2.98	2.91
Reaping 4-6								
Dolomite, tons/acre								
S.E.	(0.065)			(0.050)		(0.050)		(0.035)
0	2.27	2.29	2.30	2.29	2.28	2.23	2.34	2.28
1.5	2.05	2.11	2.04	2.08	2.05	2.08	2.05	2.07
3.0	2.01	1.97	2.08	2.01	2.03	1.99	2.05	2.02
Borax, lb./acre								
S.E.				(0.050)		(0.050)		(0.035)
0	-	-	-	2.13	2.09	2.04	2.18	2.11
8	-	-	-	2.07	2.17	2.11	2.13	2.12
16	-	-	-	2.18	2.10	2.15	2.13	2.14
N side-dressing, lb./acre								
S.E.						(0.041)		(0.029)
0	-	-	-	-	-	2.12	2.13	2.13
10	-	-	-	-	-	2.08	2.16	2.12
S.E.	(0.035)			(0.029)		(0.029)		
Mean	2.11	2.12	2.14	2.13	2.12	2.10	2.15	2.12

Potassium, % D.M. (contd.)

Material	Borax lb./acre			N side-dressings lb./acre		K_2O side-dressings lb./acre		
	0	8	16	0	10	0	28	Mean
Reaping 7-9								
Dolomite, tons/acre								
S.E.	(0.047)			(0.036)		(0.036)		(0.026)
0	2.23	2.31	2.31	2.26	2.31	2.27	2.30	2.29
1.5	2.09	2.14	2.13	2.07	2.16	2.18	2.06	2.12
3.0	2.00	2.01	2.06	2.00	2.05	2.00	2.05	2.03
Borax, lb./acre								
S.E.				(0.036)		(0.036)		(0.026)
0	-	-	-	2.07	2.15	2.09	2.13	2.11
8	-	-	-	2.10	2.21	2.17	2.14	2.16
16	-	-	-	2.16	2.17	2.19	2.14	2.17
N side-dressing, lb./acre								
S.E.						(0.030)		(0.021)
0	-	-	-	-	-	2.11	2.11	2.11
10	-	-	-	-	-	2.19	2.16	2.17
S.E.	(0.026)			(0.021)		(0.021)		
Mean	2.11	2.16	2.17	2.11	2.17	2.15	2.14	2.14
Weighted mean								
Dolomite, tons/acre								
S.E.	(0.053)			(0.041)		(0.041)		(0.029)
0	2.41	2.48	2.46	2.45	2.46	2.40	2.50	2.45
1.5	2.21	2.28	2.25	2.23	2.26	2.27	2.22	2.25
3.0	2.16	2.17	2.24	2.17	2.21	2.15	2.23	2.19
Borax, lb./acre								
S.E.				(0.041)		(0.041)		(0.029)
0	-	-	-	2.26	2.26	2.20	2.33	2.26
8	-	-	-	2.26	2.36	2.31	2.32	2.31
16	-	-	-	2.33	2.31	2.33	2.31	2.32
N side-dressing, lb./acre								
S.E.						(0.033)		(0.024)
0	-	-	-	-	-	2.27	2.30	2.28
10	-	-	-	-	-	2.28	2.34	2.31
S.E.	(0.029)			(0.024)		(0.024)		
Mean	2.26	2.31	2.32	2.28	2.31	2.28	2.32	2.30

IV. Nitrogen, % D.M.

Material	Borax lb./acre			N side-dressings lb./acre		K_2O side-dressings lb./acre		
	0	8	16	0	10	0	28	Mean
Reaping 1-3								
Dolomite, tons/acre								
S.E.	(0.049)			(0.038)		(0.038)		(0.027)
0	1.55	1.57	1.64	1.54	1.64	1.61	1.56	1.59
1.5	1.49	1.56	1.60	1.48	1.62	1.58	1.53	1.55
3.0	1.64	1.56	1.61	1.52	1.69	1.64	1.56	1.60
Borax, lb./acre								
S.E.				(0.038)		(0.038)		(0.027)
0	-	-	-	1.46	1.65	1.59	1.53	1.56
8	-	-	-	1.49	1.64	1.57	1.56	1.57
16	-	-	-	1.58	1.65	1.67	1.56	1.62
N side-dressing, lb./acre								
S.E.						(0.031)		(0.022)
0	-	-	-	-	-	1.53	1.50	1.51
10	-	-	-	-	-	1.69	1.60	1.65
S.E.	(0.027)			(0.022)		(0.022)		
Mean	1.56	1.57	1.62	1.51	1.65	1.61	1.55	1.58
Reaping 4-6								
Dolomite, tons/acre								
S.E.	(0.045)			(0.035)		(0.035)		(0.024)
0	1.14	1.26	1.19	1.15	1.24	1.23	1.16	1.20
1.5	1.16	1.23	1.22	1.14	1.27	1.25	1.16	1.20
3.0	1.20	1.16	1.14	1.14	1.19	1.16	1.17	1.17
Borax, lb./acre								
S.E.				(0.035)		(0.035)		(0.024)
0	-	-	-	1.13	1.21	1.22	1.12	1.17
8	-	-	-	1.17	1.27	1.21	1.23	1.22
16	-	-	-	1.14	1.23	1.22	1.14	1.18
N side-dressing, lb./acre								
S.E.						(0.028)		(0.020)
0	-	-	-	-	-	1.16	1.13	1.14
10	-	-	-	-	-	1.27	1.20	1.24
S.E.	(0.024)			(0.020)		(0.020)		
Mean	1.17	1.22	1.18	1.14	1.24	1.22	1.16	1.19

Nitrogen, % D.M. (contd.)

Material	Borax lb./acre			N side-dressings lb./acre		K_2O side-dressings lb./acre		
	0	8	16	0	10	0	28	Mean
Reaping 7-9								
Dolomite, tons/acre								
S.E.	(0.042)			(0.032)		(0.032)		(0.023)
0	1.33	1.44	1.44	1.36	1.45	1.40	1.40	1.40
1.5	1.39	1.43	1.41	1.34	1.48	1.41	1.41	1.41
3.0	1.38	1.40	1.37	1.37	1.40	1.38	1.39	1.39
Borax, lb./acre								
S.E.				(0.032)		(0.032)		(0.023)
0	-	-	-	1.30	1.43	1.37	1.36	1.37
8	-	-	-	1.41	1.44	1.41	1.44	1.42
16	-	-	-	1.36	1.46	1.42	1.40	1.41
N side-dressing, lb./acre								
S.E.						(0.026)		(0.019)
0	-	-	-	-	-	1.34	1.37	1.36
10	-	-	-	-	-	1.46	1.43	1.44
S.E.	(0.023)			(0.019)		(0.019)		
Mean	1.37	1.42	1.41	1.36	1.44	1.40	1.40	1.40
Weighted mean								
Dolomite, tons/acre								
S.E.	(0.036)			(0.028)		(0.028)		(0.020)
0	1.30	1.41	1.39	1.32	1.41	1.38	1.35	1.37
1.5	1.33	1.39	1.39	1.30	1.44	1.39	1.34	1.37
3.0	1.38	1.36	1.35	1.33	1.40	1.37	1.36	1.36
Borax, lb./acre								
S.E.				(0.028)		(0.028)		(0.020)
0	-	-	-	1.27	1.40	1.37	1.31	1.34
8	-	-	-	1.34	1.43	1.38	1.39	1.39
16	-	-	-	1.32	1.42	1.40	1.35	1.37
N side-dressing, lb./acre								
S.E.						(0.023)		(0.016)
0	-	-	-	-	-	1.31	1.31	1.31
10	-	-	-	-	-	1.45	1.39	1.42
S.E.	(0.020)			(0.016)		(0.016)		
Mean	1.34	1.39	1.37	1.31	1.42	1.38	1.35	1.37

V. Phosphorus, % D.M.

Material	Borax lb./acre			N side-dressings lb./acre		K$_2$O side-dressings lb./acre		
	0	8	16	0	10	0	28	Mean
Reaping 1-3								
Dolomite, tons/acre								
S.E.	(0.0131)			(0.0100)		(0.0100)		(0.0071)
0	0.238	0.205	0.207	0.233	0.200	0.231	0.203	0.217
1.5	0.204	0.208	0.199	0.213	0.194	0.205	0.203	0.204
3.0	0.226	0.226	0.172	0.209	0.207	0.196	0.220	0.208
Borax, lb./acre								
S.E.				(0.0100)		(0.0100)		(0.0071)
0	-	-	-	0.233	0.213	0.230	0.216	0.223
8	-	-	-	0.221	0.205	0.218	0.208	0.213
16	-	-	-	0.202	0.183	0.183	0.202	0.193
N side-dressing, lb./acre								
S.E.						(0.0082)		(0.0058)
0	-	-	-	-	-	0.221	0.217	0.219
10	-	-	-	-	-	0.201	0.200	0.200
S.E.	(0.0071)			(0.0058)		(0.0058)		
Mean	0.223	0.213	0.193	0.219	0.200	0.211	0.208	0.209
Reaping 4-6								
Dolomite, tons/acre								
S.E.	(0.0074)			(0.0057)		(0.0057)		(0.0040)
0	0.206	0.215	0.192	0.211	0.198	0.213	0.195	0.204
1.5	0.196	0.199	0.196	0.199	0.195	0.197	0.198	0.197
3.0	0.212	0.212	0.191	0.211	0.199	0.204	0.206	0.205
Borax, lb./acre								
S.E.				(0.0057)		(0.0057)		(0.0040)
0	-	-	-	0.214	0.195	0.210	0.199	0.205
8	-	-	-	0.209	0.208	0.210	0.208	0.209
16	-	-	-	0.198	0.188	0.194	0.192	0.193
N side-dressing, lb./acre								
S.E.						(0.0046)		(0.0033)
0	-	-	-	-	-	0.208	0.206	0.207
10	-	-	-	-	-	0.202	0.193	0.197
S.E.	(0.0040)			(0.0033)		(0.0033)		
Mean	0.205	0.209	0.193	0.207	0.197	0.205	0.199	0.202

Phosphorus, % D.M. (contd.)

Material	Borax lb./acre			N side-dressings lb./acre		K_2O side-dressings lb./acre		
	0	8	16	0	10	0	28	Mean
<u>Reaping 7-9</u>								
Dolomite, tons/acre								
S.E.		(0.0114)		(0.0087)		(0.0087)		(0.0061)
0	0.265	0.277	0.247	0.261	0.265	0.282	0.244	0.263
1.5	0.271	0.245	0.243	0.249	0.257	0.252	0.253	0.253
3.0	0.273	0.288	0.259	0.273	0.273	0.276	0.271	0.273
Borax, lb./acre								
S.E.				(0.0087)		(0.0087)		(0.0061)
0	-	-	-	0.269	0.270	0.280	0.259	0.270
8	-	-	-	0.268	0.272	0.283	0.257	0.270
16	-	-	-	0.246	0.253	0.247	0.252	0.250
N side-dressing, lb./acre								
S.E.						(0.0071)		(0.0050)
0	-	-	-	-	-	0.271	0.252	0.261
10	-	-	-	-	-	0.269	0.261	0.265
S.E.		(0.0061)		(0.0050)		(0.0050)		
Mean	0.270	0.270	0.250	0.261	0.265	0.270	0.256	0.263
<u>Weighted mean</u>								
Dolomite, tons/acre								
S.E.		(0.0079)		(0.0061)		(0.0061)		(0.0043)
0	0.235	0.244	0.218	0.236	0.228	0.247	0.217	0.232
1.5	0.230	0.221	0.219	0.223	0.223	0.224	0.222	0.223
3.0	0.241	0.248	0.219	0.237	0.234	0.233	0.238	0.236
Borax, lb./acre								
S.E.				(0.0061)		(0.0061)		(0.0043)
0	-	-	-	0.239	0.232	0.243	0.227	0.235
8	-	-	-	0.238	0.237	0.245	0.230	0.237
16	-	-	-	0.219	0.217	0.217	0.220	0.218
N side-dressing, lb./acre								
S.E.						(0.0050)		(0.0035)
0	-	-	-	-	-	0.237	0.228	0.232
10	-	-	-	-	-	0.233	0.224	0.229
S.E.		(0.0043)		(0.0035)		(0.0035)		
Mean	0.235	0.237	0.218	0.232	0.229	0.235	0.226	0.230

VI. Boron, ppm. D.M.

Material	Borax lb./acre			N side-dressings lb./acre		K_2O side-dressings lb./acre		
	0	8	16	0	10	0	28	Mean
Reaping 1-3								
Dolomite, tons/acre								
S.E.		(2.25)		(1.72)		(1.72)		(1.21)
0	17.7	26.6	46.7	30.6	30.1	32.3	28.4	30.3
1.5	17.4	24.2	35.6	24.4	27.0	24.9	26.5	25.7
3.0	17.4	24.6	40.3	25.4	29.5	28.4	26.5	27.5
Borax, lb./acre								
S.E.				(1.72)		(1.72)		(1.21)
0	-	-	-	17.6	17.4	17.1	17.9	17.5
8	-	-	-	24.7	25.6	24.5	25.8	25.1
16	-	-	-	38.2	43.6	44.0	37.8	40.9
N side-dressing, lb./acre								
S.E.						(1.40)		(0.99)
0	-	-	-	-	-	27.8	25.8	26.8
10	-	-	-	-	-	29.3	28.4	28.9
S.E.		(1.21)		(0.99)		(0.99)		
Mean	17.5	25.1	40.9	26.8	28.9	28.5	27.1	27.8
Reaping 4-6								
Dolomite, tons/acre								
S.E.		(1.58)		(1.21)		(1.21)		(0.85)
0	15.1	22.0	34.0	23.9	23.5	24.6	22.8	23.7
1.5	14.1	18.9	28.8	20.4	20.8	20.8	20.3	20.6
3.0	15.6	20.0	28.2	22.4	20.2	20.3	22.3	21.3
Borax, lb./acre								
S.E.				(1.21)		(1.21)		(0.85)
0	-	-	-	16.9	13.0	14.3	15.6	15.0
8	-	-	-	20.1	20.5	20.3	20.3	20.3
16	-	-	-	29.8	30.9	31.1	29.6	30.3
N side-dressing, lb./acre								
S.E.						(0.98)		(0.70)
0	-	-	-	-	-	21.9	22.6	22.3
10	-	-	-	-	-	21.8	21.1	21.5
S.E.		(0.85)		(0.70)		(0.70)		
Mean	15.0	20.3	30.3	22.3	21.5	21.9	21.8	21.9

Boron, ppm. D.M. (contd.)

Material	Borax lb./acre			N side-dressings lb./acre		K_2O side-dressings lb./acre		
	0	8	16	0	10	0	28	Mean
Reaping 7-9								
Dolomite, tons/acre								
S.E		(2.39)		(1.83)		(1.83)		(1.29)
0	24.1	28.6	36.8	31.8	27.8	30.8	28.8	29.8
1.5	22.3	26.1	33.9	28.2	26.7	25.8	29.1	27.4
3.0	18.0	26.6	29.6	25.7	23.8	23.7	25.8	24.7
Borax, lb./acre								
S.E.				(1.83)		(1.83)		(1.29)
0	-	-	-	23.0	19.9	21.6	21.3	21.5
8	-	-	-	28.1	26.1	25.8	28.4	27.1
16	-	-	-	34.6	32.3	32.9	33.9	33.4
N side-dressing, lb./acre								
S.E.						(1.49)		(1.05)
0	-	-	-	-	-	28.8	28.3	28.6
10	-	-	-	-	-	24.7	27.5	26.1
S.E.		(1.29)		(1.05)		(1.05)		
Mean	21.5	27.1	33.4	28.6	26.1	26.8	27.9	27.3
Weighted mean								
Dolomite, tons/acre								
S.E.		(1.51)		(1.15)		(1.15)		(0.81)
0	19.7	25.8	37.3	28.4	26.8	28.4	26.8	27.6
1.5	18.2	23.2	32.5	24.7	24.6	23.8	25.4	24.6
3.0	16.9	23.9	31.4	24.5	23.7	23.4	24.8	24.1
Borax, lb./acre								
S.E.				(1.15)		(1.15)		(0.81)
0	-	-	-	19.5	17.0	18.1	18.4	18.3
8	-	-	-	24.7	23.9	23.6	25.0	24.3
16	-	-	-	33.4	34.1	34.0	33.5	33.8
N side-dressing, lb./acre								
S.E.						(0.94)		(0.66)
0	-	-	-	-	-	25.9	25.8	25.9
10	-	-	-	-	-	24.5	25.5	25.0
S.E.		(0.81)		(0.66)		(0.66)		
Mean	18.3	24.3	33.8	25.9	25.0	25.2	25.6	25.4

VII. Manganese, ppm. D.M.

Material	Borax lb./acre			N side-dressings lb./acre		K_2O side-dressings lb./acre		
	0	8	16	0	10	0	28	Mean
Reaping 1-3								
Dolomite, tons/acre								
S.E.		(70.2)		(53.6)		(53.6)		(37.9)
0	872	782	949	880	855	924	811	868
1.5	387	415	473	482	368	435	414	425
3.0	353	352	408	381	361	353	389	371
Borax, lb./acre								
S.E.				(53.6)		(53.6)		(37.9)
0	-	-	-	539	536	515	560	537
8	-	-	-	582	451	515	518	516
16	-	-	-	622	597	683	537	610
N side-dressing, lb./acre								
S.E.						(43.8)		(30.9)
0	-	-	-	-	-	572	591	581
10	-	-	-	-	-	570	486	528
S.E.		(37.9)		(30.9)		(30.9)		
Mean	537	516	610	581	528	571	538	554
Reaping 4-6								
Dolomite, tons/acre								
S.E.		(42.7)		(32.6)		(32.6)		(23.1)
0	479	440	510	484	469	490	462	476
1.5	254	292	282	303	249	306	246	276
3.0	255	224	260	263	230	232	261	246
Borax, lb./acre								
S.E.				(32.6)		(32.6)		(23.1)
0	-	-	-	332	326	326	333	329
8	-	-	-	352	286	301	337	319
16	-	-	-	366	335	401	300	351
N side-dressing, lb./acre								
S.E.						(26.6)		(18.8)
0	-	-	-	-	-	353	347	350
10	-	-	-	-	-	333	299	316
S.E.		(23.1)		(18.8)		(18.8)		
Mean	329	319	351	350	316	343	323	333

Manganese, ppm. D.M. (contd.)

Material	Borax lb./acre			N side-dressings lb./acre		K_2O side-dressings lb./acre		
	0	8	16	0	10	0	28	Mean
Reaping 7-9								
Dolomite, tons/acre								
S.E.		(30.9)		(23.6)		(23.6)		(16.7)
0	451	412	475	433	459	465	427	446
1.5	278	287	309	324	258	317	266	291
3.0	276	240	265	267	254	244	276	260
Borax, lb./acre								
S.E.				(23.6)		(23.6)		(16.7)
0	-	-	-	325	345	330	340	335
8	-	-	-	352	274	322	304	313
16	-	-	-	348	352	374	326	350
N side-dressing, lb./acre								
S.E.						(19.3)		(13.6)
0	-	-	-	-	-	345	338	341
10	-	-	-	-	-	339	308	324
S.E.		(16.7)		(13.6)		(13.6)		
Mean	335	313	350	341	324	342	323	332
Weighted mean								
Dolomite, tons/acre								
S.E.		(38.1)		(29.1)		(29.1)		(20.6)
0	538	499	573	532	542	556	518	537
1.5	290	317	333	348	278	338	288	313
3.0	286	257	295	289	269	265	294	279
Borax, lb./acre								
S.E.				(29.1)		(29.1)		(20.6)
0	-	-	-	369	373	363	379	371
8	-	-	-	397	318	357	358	358
16	-	-	-	403	398	439	362	400
N side-dressing, lb./acre								
S.E.						(23.8)		(16.8)
0	-	-	-	-	-	389	391	390
10	-	-	-	-	-	384	343	363
S.E.		(20.6)		(16.8)		(16.8)		
Mean	371	358	400	390	363	386	367	376

(f) The effect of lime, boron and side-dressing of potassium, and lime and side-dressings of nitrogen and potassium on yield, grade and discolouration index.

Dolomite, tons/acre	Borax + K_2O, lb./acre						N + K_2O, lb./acre			
	0+0	8+0	16+0	0+28	8+28	16+28	0+0	10+0	0+28	10+28
I. Yield, lb./acre.										
S.E.			(69.2)					(56.5)		
0	1238	1152	1008	1263	1162	1201	1130	1136	1192	1225
1.5	1209	1288	1291	1336	1236	1150	1217	1308	1235	1246
3.0	1160	1219	1301	1151	1382	1203	1193	1260	1225	1266
II. Grade Index.										
S.E.			(1.54)					(1.25)		
0	17.3	20.9	15.5	17.0	18.1	19.0	17.5	18.3	15.9	20.3
1.5	19.6	20.4	19.5	18.6	21.1	17.4	18.8	20.9	15.0	23.1
3.0	19.2	21.5	21.3	17.4	20.3	18.8	20.0	21.4	17.1	20.5
III. Discolouration.										
S.E.			(0.186)					(0.151)		
0	1.42	0.58	1.36	1.36	1.12	1.21	1.30	0.94	1.52	0.94
1.5	1.05	0.80	1.06	1.13	0.59	1.22	1.25	0.68	1.31	0.65
3.0	0.87	0.82	0.83	1.13	0.86	0.97	0.94	0.74	1.20	0.78

(g) The effect of lime, boron and side-dressing of potassium, and lime and side-dressings of nitrogen and potassium on the chemical composition of cured leaf lamina.

I. Calcium, % D.M.

Dolomite, tons/acre	Borax + K_2O, lb./acre						N + K_2O, lb./acre			
	0+0	8+0	16+0	0+28	8+28	16+28	0+0	10+0	0+28	10+28
i. Reaping 1-3.										
S.E.	(0.160)						(0.131)			
0	2.72	2.79	3.12	2.70	2.71	2.83	2.70	3.05	2.76	2.73
1.5	2.83	2.68	3.01	2.73	2.87	2.84	2.91	2.77	2.74	2.88
3.0	2.79	2.64	2.79	2.94	2.90	2.90	2.66	2.83	2.85	2.97
ii. Reaping 4-6.										
S.E.	(0.126)						(0.103)			
0	1.59	1.57	1.57	1.59	1.55	1.60	1.46	1.69	1.63	1.54
1.5	1.66	1.55	1.65	1.51	1.62	1.55	1.60	1.63	1.52	1.60
3.0	1.59	1.55	1.49	1.70	1.65	1.67	1.58	1.50	1.58	1.77
iii. Reaping 7-9.										
S.E.	(0.105)						(0.086)			
0	1.67	1.52	1.65	1.54	1.51	1.61	1.59	1.64	1.56	1.55
1.5	1.82	1.77	1.69	1.74	1.65	1.76	1.79	1.73	1.73	1.71
3.0	1.82	1.77	1.72	1.80	1.82	1.76	1.74	1.80	1.85	1.74
iv. Weighted mean.										
S.E.	(0.104)						(0.085)			
0	1.82	1.76	1.88	1.79	1.78	1.86	1.73	1.91	1.82	1.79
1.5	1.95	1.91	1.90	1.85	1.84	1.92	1.95	1.90	1.84	1.89
3.0	1.97	1.90	1.87	1.99	1.99	1.99	1.89	1.93	1.98	2.01

II. Magnesium, % D.M.

Dolomite, tons/acre	Borax + K_2O, lb./acre						N + K_2O, lb./acre			
	0+0	8+0	16+0	0+28	8+28	16+28	0+0	10+0	0+28	10+28
i. Reaping 1-3.										
S.E.			(0.0902)					(0.0736)		
0	0.885	0.981	0.754	0.808	1.028	1.019	0.872	0.875	0.970	0.933
1.5	1.241	1.120	1.456	1.309	1.203	1.158	1.213	1.332	1.193	1.253
3.0	1.306	1.371	1.270	1.328	1.364	1.280	1.333	1.298	1.243	1.405
ii. Reaping 4-6.										
S.E.			(0.0499)					(0.0407)		
0	0.457	0.519	0.404	0.412	0.601	0.494	0.487	0.433	0.550	0.455
1.5	0.667	0.597	0.694	0.672	0.647	0.566	0.615	0.690	0.622	0.635
3.0	0.684	0.704	0.704	0.724	0.687	0.659	0.722	0.673	0.635	0.745
iii. Reaping 7-9.										
S.E.			(0.0428)					(0.0349)		
0	0.501	0.558	0.398	0.434	0.516	0.508	0.503	0.468	0.513	0.458
1.5	0.676	0.606	0.663	0.658	0.669	0.581	0.640	0.657	0.618	0.653
3.0	0.671	0.758	0.639	0.658	0.656	0.629	0.710	0.668	0.623	0.672
iv. Weighted mean.										
S.E.			(0.0477)					(0.0389)		
0	0.562	0.633	0.464	0.497	0.658	0.609	0.568	0.538	0.620	0.557
1.5	0.777	0.720	0.811	0.794	0.755	0.706	0.743	0.795	0.735	0.768
3.0	0.826	0.887	0.795	0.826	0.812	0.795	0.855	0.817	0.767	0.855

III. Potassium, % D.M.

Dolomite, tons/acre	Borax + K_2O, lb./acre						N + K_2O, lb./acre			
	0+0	8+0	16+0	0+28	8+28	16+28	0+0	10+0	0+28	10+28
i. Reaping 1-3.										
S.E.			(0.132)					(0.107)		
0	2.84	3.08	3.32	3.38	3.27	2.99	3.22	2.93	3.19	3.24
1.5	2.64	2.88	2.82	2.81	2.84	2.97	2.83	2.73	2.87	2.88
3.0	2.57	2.61	2.80	2.82	2.91	2.85	2.65	2.67	2.78	2.94
ii. Reaping 4-6.										
S.E.			(0.086)					(0.070)		
0	2.15	2.24	2.29	2.38	2.34	2.30	2.26	2.19	2.31	2.37
1.5	2.02	2.18	2.05	2.09	2.05	2.03	2.11	2.05	2.06	2.05
3.0	1.94	1.92	2.10	2.08	2.01	2.05	1.99	1.99	2.03	2.07
iii. Reaping 7-9.										
S.E.			(0.062)					(0.051)		
0	2.14	2.32	2.36	2.32	2.31	2.27	2.21	2.34	2.31	2.28
1.5	2.12	2.23	2.19	2.06	2.05	2.06	2.15	2.22	2.00	2.11
3.0	2.00	1.96	2.02	2.01	2.07	2.09	1.98	2.01	2.02	2.09
iv. Weighted mean.										
S.E.			(0.070)					(0.058)		
0	2.27	2.44	2.50	2.55	2.53	2.42	2.40	2.41	2.50	2.51
1.5	2.20	2.37	2.25	2.22	2.19	2.25	2.28	2.27	2.19	2.25
3.0	2.12	2.11	2.22	2.20	2.23	2.26	2.14	2.16	2.20	2.26

IV. Nitrogen, % D.M.

Dolomite, tons/acre	Borax + K_2O, lb./acre						N + K_2O, lb./acre			
	0+0	8+0	16+0	0+28	8+28	16+28	0+0	10+0	0+28	10+28
i. Reaping 1-3.										
S.E.			(0.065)					(0.053)		
0	1.51	1.61	1.72	1.59	1.54	1.56	1.55	1.68	1.53	1.60
1.5	1.49	1.59	1.65	1.48	1.54	1.55	1.51	1.64	1.45	1.61
3.0	1.77	1.52	1.64	1.51	1.60	1.57	1.51	1.77	1.52	1.60
ii. Reaping 4-6.										
S.E.			(0.060)					(0.049)		
0	1.22	1.27	1.22	1.06	1.26	1.16	1.16	1.30	1.14	1.19
1.5	1.22	1.23	1.31	1.10	1.23	1.13	1.17	1.33	1.10	1.21
3.0	1.22	1.12	1.15	1.18	1.20	1.14	1.15	1.17	1.14	1.21
iii. Reaping 7-9.										
S.E.			(0.056)					(0.046)		
0	1.36	1.43	1.42	1.30	1.45	1.46	1.32	1.48	1.40	1.41
1.5	1.37	1.43	1.44	1.41	1.44	1.38	1.34	1.49	1.35	1.47
3.0	1.39	1.36	1.39	1.37	1.44	1.36	1.37	1.40	1.37	1.41
iv. Weighted mean.										
S.E.			(0.048)					(0.039)		
0	1.33	1.41	1.40	1.27	1.41	1.37	1.30	1.46	1.34	1.36
1.5	1.34	1.41	1.44	1.31	1.38	1.34	1.32	1.47	1.28	1.41
3.0	1.43	1.32	1.37	1.34	1.39	1.33	1.32	1.42	1.33	1.39

V. <u>Phosphorus, % D.M.</u>

Dolomite, tons/acre	Borax + K_2O, lb./acre						N + K_2O, lb./acre			
	0+0	8+0	16+0	0+28	8+28	16+28	0+0	10+0	0+28	10+28
i. Reaping 1-3.										
S.E.	(0.0173)						(0.0141)			
0	0.267	0.211	0.214	0.209	0.199	0.199	0.255	0.207	0.212	0.193
1.5	0.207	0.219	0.189	0.202	0.197	0.209	0.208	0.202	0.218	0.187
3.0	0.216	0.224	0.147	0.236	0.227	0.197	0.198	0.193	0.220	0.220
ii. Reaping 4-6.										
S.E.	(0.0098)						(0.0080)			
0	0.228	0.218	0.194	0.183	0.211	0.191	0.215	0.212	0.207	0.183
1.5	0.196	0.196	0.198	0.196	0.203	0.193	0.195	0.198	0.203	0.192
3.0	0.206	0.216	0.191	0.218	0.209	0.191	0.213	0.195	0.208	0.203
iii. Reaping 7-9.										
S.E.	(0.0150)						(0.0123)			
0	0.291	0.305	0.248	0.239	0.248	0.246	0.285	0.278	0.237	0.252
1.5	0.273	0.246	0.238	0.268	0.244	0.248	0.248	0.257	0.250	0.257
3.0	0.275	0.298	0.254	0.270	0.278	0.264	0.278	0.273	0.268	0.273
iv. Weighted mean.										
S.E.	(0.0105)						(0.0086)			
0	0.259	0.261	0.223	0.211	0.226	0.213	0.252	0.243	0.220	0.213
1.5	0.235	0.221	0.216	0.225	0.221	0.221	0.222	0.227	0.225	0.220
3.0	0.236	0.253	0.211	0.246	0.243	0.226	0.237	0.230	0.238	0.238

VI. Boron, ppm. D.M.

Dolomite, tons/acre	Borax + K_2O, lb./acre						N + K_2O, lb./acre			
	0+0	8+0	16+0	0+28	8+28	16+28	0+0	10+0	0+28	10+28
i. Reaping 1-3.										
S.E.			(2.97)						(2.42)	
0	17.4	25.9	53.4	17.9	27.2	40.1	33.7	30.8	27.5	29.3
1.5	17.4	22.9	34.4	17.4	25.4	36.7	22.7	27.2	26.2	26.8
3.0	16.4	24.6	44.2	18.4	24.6	36.4	27.0	29.8	23.8	29.2
ii. Reaping 4-6.										
S.E.			(2.09)						(1.71)	
0	15.0	22.9	35.9	15.2	21.1	32.1	25.3	23.8	22.5	23.2
1.5	13.9	19.2	29.4	14.4	18.5	28.1	19.5	22.2	21.3	19.3
3.0	14.1	18.6	28.0	17.1	21.4	28.5	21.0	19.5	23.8	20.8
iii. Reaping 7-9.										
S.E.			(3.16)						(2.58)	
0	26.7	26.1	39.7	21.4	31.1	34.0	35.2	26.5	28.5	29.2
1.5	19.7	28.4	29.1	25.0	23.7	38.6	26.2	25.3	30.2	28.0
3.0	18.4	22.7	29.9	17.6	30.5	29.2	25.2	22.2	26.2	25.3
iv. Weighted mean.										
S.E.			(2.00)						(1.63)	
0	20.7	24.5	40.1	18.7	27.0	34.6	30.5	26.3	26.3	27.2
1.5	17.1	24.4	30.0	19.3	21.9	35.0	23.3	24.3	26.0	24.8
3.0	16.5	21.8	31.9	17.3	26.1	30.9	24.0	22.8	25.0	24.5

VII. Manganese, ppm. D.M.

Dolomite, tons/acre	Borax + K_2O, lb./acre						N + K_2O, lb./acre			
	0+0	8+0	16+0	0+28	8+28	16+28	0+0	10+0	0+28	10+28
i. Reaping 1-3.										
S.E.			(92.8)					(75.8)		
0	781	791	1199	963	772	698	854	994	906	716
1.5	399	439	468	375	391	477	520	351	444	385
3.0	365	314	380	341	391	435	341	365	421	357
ii. Reaping 4-6.										
S.E.			(56.5)					(46.1)		
0	432	396	643	525	484	377	471	510	496	428
1.5	291	317	311	217	268	253	350	262	257	235
3.0	256	190	250	255	257	270	238	226	288	234
iii. Reaping 7-9.										
S.E.			(40.9)					(33.4)		
0	412	410	573	490	414	376	435	495	431	423
1.5	313	336	301	243	237	317	355	279	294	238
3.0	265	221	247	286	259	284	244	245	289	263
iv. Weighted mean.										
S.E.			(50.4)					(41.2)		
0	483	479	704	593	518	442	515	596	548	487
1.5	321	359	334	258	275	331	388	289	309	268
3.0	285	232	277	286	282	313	264	266	315	273

Experiment 7. Lime and side-dressing of nitrogen and potassium. Granite sand, 1966 - 67.

Dolomite was applied at the rate of 2,000 lb./acre. The two basic fertiliser mixtures contained 18 or 36 lb. N, 108 lb. P_2O_5, 90 lb. K_2O and 4 lb. borate/acre; on 3rd January 18 lb. N (as $NaNO_3$), 45 lb. K_2O (as K_2SO_4) or 18 lb. N + 45 lb. K_2O/acre (as $NaNO_3$ and K_2SO_4) was side-dressed. Spacing was 4 ft. by 2 ft.

The experiment comprised a balanced 2 x 3 x 3 lattice in 12 blocks of 6 plots each.

(a) Cultural details.

Ploughed: January
Disced: January
Lime applied: September 22
Fertilised, ridged and fumigated: October 2
Planted: November 11
Refilled: November 16
Cultivated: December 2
Reridged: December 13
Side-dressed: January 3
Topped: January 9
Suckered: January 19; February 1, 13, 24
Reaped: January 23, 30; February 8, 15, 23; March 1, 9, 16, 23
Soil sampled for pH: May 5

(b) Chemical analysis of composite soil samples.

All results expressed in terms of air-dried sample passed through a 2 mm. sieve.

Block	I & II	III & IV
Texture	Sand	Sand
pH (0.01M $CaCl_2$)	4.8	4.6
Exchangeable cations, me./100g.		
Calcium	0.65	0.50
Magnesium	0.75	0.80
Potassium	0.08	0.11
Total nitrogen, ppm.	210	200
Mineral nitrogen, ppm. NO_3 + NH_4		
Initial	10	12
Incubated	27	27
Resin available P_2O_5, ppm.	26	23

Analysis done by Chemistry Branch, Ministry of Agriculture.

(c) Yield, grade and discolouration index.

Material	N, lb./acre			K_2O, lb./acre			
	18	36	18+18	90	135	90+45	Mean
I. Yield, lb./acre.							
Dolomite, lb./acre							
S.E.		(37.8)			(37.8)		(21.8)
0	1852	1901	1798	1812	1836	1903	1850
2,000	1854	1845	1879	1846	1812	1919	1859
Nitrogen, lb./acre.							
S.E.					(46.3)		(26.7)
18	-	-	-	1838	1804	1917	1853
36	-	-	-	1873	1833	1911	1873
18 + 18	-	-	-	1776	1835	1904	1838
S.E.		(26.7)			(26.7)		
Mean	1853	1873	1838	1829	1824	1911	1855
II. Grade index.							
Dolomite, lb./acre							
S.E.		(0.53)			(0.53)		(0.31)
0	19.0	19.8	19.2	19.3	20.0	18.7	19.3
2,000	19.9	19.5	20.2	19.5	20.6	19.5	19.9
Nitrogen, lb./acre							
S.E.					(0.65)		(0.38)
18	-	-	-	19.2	20.5	18.6	19.5
36	-	-	-	19.4	19.6	19.9	19.6
18 + 18	-	-	-	19.6	20.7	18.8	19.7
S.E.		(0.38)			(0.38)		
Mean	19.5	19.6	19.7	19.4	20.3	19.1	19.6
III. Discolouration index.							
Dolomite, lb./acre							
S.E.		(1.69)			(1.69)		(0.98)
0	59.7	55.9	57.6	55.7	59.5	58.0	57.7
2,000	58.8	55.1	52.0	55.0	54.2	56.7	55.3
Nitrogen, lb./acre							
S.E.					(2.07)		(1.20)
18	-	-	-	57.6	57.9	62.2	59.2
36	-	-	-	55.3	56.9	54.2	55.5
18 + 18	-	-	-	53.1	55.8	55.5	54.8
S.E.		(1.20)			(1.20)		
Mean	59.2	55.5	54.8	55.3	56.9	57.3	56.5

(d) Soil pH.

Material	N, lb./acre			K_2O, lb./acre			
	18	36	18+18	90	135	90+45	Mean
Dolomite, lb./acre							
S.E.		(0.076)			(0.076)		(0.044)
0	4.47	4.59	4.59	4.53	4.51	4.61	4.55
2,000	5.61	5.62	5.81	5.67	5.75	5.02	5.68
Nitrogen, lb./acre							
S.E.					(0.093)		(0.054)
18	-	-	-	5.06	5.05	5.00	5.04
36	-	-	-	5.00	5.17	5.14	5.10
18+18	-	-	-	5.23	5.18	5.20	5.20
S.E.		(0.054)			(0.054)		
Mean	5.04	5.10	5.20	5.10	5.13	5.11	5.11

Greenhouse studies.

Experiment 1 (b). The effect of aluminium and manganese on tobacco grown in granite sand.

Chemical and physical analysis of granite sand.

All results expressed in terms of air-dried sample passed through a 2 mm. sieve.

Mechanical analysis	
% Clay	5.4
% Silt	4.4
% Sand	90.2
Texture	Sand
pH (0.01M $CaCl_2$)	5.42
Exchangeable cations, me./100g.	
Calcium	0.88
Magnesium	0.15
Potassium	0.10
Exchange capacity, me./100g.	1.50
Total nitrogen, ppm.	300
Mineral nitrogen, ppm. NO_3 + NH_4.	
Initial	17
Incubated	28
Resin available P_2O_5, ppm.	9
% Carbon	0.282
C:N ratio	9.4

Experiment 3(b). The effect of manganese and iron on tobacco grown in granite sand.

Chemical and physical analysis of granite sand.

All results expressed in terms of air-dried sample passed through a 2 mm. sieve.

Mechanical analysis	
% Clay	3.4
% Silt	4.2
% Sand	92.4
Texture	Sand
pH (0.01M $CaCl_2$)	4.76
Exchangeable cations, me./100g.	
Calcium	0.32
Magnesium	0.22
Potassium	0.07
Exchange capacity, me./100g.	1.54
Total nitrogen, ppm.	390
Mineral nitrogen, ppm. NO_3 + NH_4.	
Initial	16.0
Incubated	29.0
Resin available P_2O_5, ppm.	5.5
% Carbon	0.413
C:N ratio	10.6

Experiment 4(b). The effect of aluminium and iron on tobacco grown in granite sand.

Chemical and physical analysis of granite sand.

All results expressed in terms of air-dried sample passed through a 2 mm. sieve.

Mechanical analysis	
% Clay	4
% Silt	5
% Sand	91
Texture	Sand
pH (0.01M $CaCl_2$)	5.0*
Exchangeable cations, me./100g.	
Calcium	0.9*
Magnesium	0.6*
Potassium	0.22*
Exchange capacity, me./100g.	1.06
Total nitrogen, ppm.	290*
Mineral nitrogen, ppm. NO_3 + NH_4	
Initial	17*
Incubated	29*
Resin available P_2O_5, ppm.	23*
% Carbon	0.44
C:N ratio	15.2

* Analysis done by Chemistry Branch, Ministry of Agriculture.

Soil studies.

Experiment 1. Testing the Ratio Law.

Changes in soil pH with ½p(Ca + Mg) at different electrolyte concentrations.

Soil	pH	[Ca + Mg] millimols/l.	[Cl] millimols/l.	-½logf	-½log(Ca+Mg)	½p(Ca+Mg)
1	4.82	9.89	10.01	0.14	1.00	1.14
	5.00	3.63	3.67	0.09	1.22	1.31
	5.24	1.29	1.36	0.06	1.44	1.50
	5.40	0.43	0.51	0.04	1.68	1.72
	5.62	0.11	0.19	0.02	1.98	2.00
2	5.49	10.04	9.96	0.14	1.00	1.14
	5.73	3.60	3.67	0.09	1.22	1.31
	5.87	1.48	1.34	0.06	1.42	1.48
	6.04	0.62	0.52	0.04	1.60	1.64
3	4.30	10.08	9.96	0.14	1.00	1.14
	4.51	3.64	3.67	0.09	1.22	1.31
	4.62	1.40	1.34	0.06	1.43	1.49
	4.88	0.53	0.52	0.04	1.64	1.68
4	4.39	10.14	9.96	0.14	1.00	1.14
	4.63	3.55	3.67	0.09	1.22	1.31
	4.75	1.36	1.34	0.06	1.43	1.49
	5.00	0.49	0.52	0.04	1.65	1.69
5	4.81	9.42	9.96	0.14	1.01	1.15
	4.99	3.30	3.67	0.09	1.24	1.33
	5.13	1.21	1.34	0.06	1.46	1.52
	5.20	0.67	0.52	0.04	1.59	1.63
6	3.88	8.92	10.01	0.13	1.02	1.15
	3.92	3.11	3.67	0.09	1.25	1.34
	4.02	1.05	1.36	0.05	1.49	1.54
	4.19	0.33	0.51	0.03	1.74	1.77
	4.38	0.11	0.19	0.02	1.98	2.00

Experiment 2. The effect of available calcium content and/or soil pH on the growth of flue-cured tobacco.

The relationship between soil pH and added calcium carbonate.

$CaCO_3$ g./kg. soil	pH
0	4.22
0.125	4.61
0.250	5.13
0.500	5.62
1.000	6.10

Experiment 3. The effect of lime on hydronium, aluminium, iron and manganese concentrations in soil solution.

The effect of Whatman No. 42 filter paper on concentrations of aluminium, iron and manganese in soil solution.

50 g. Triassic sand were equilibrated with 100 ml. 0.01M $CaCl_2$ for two hours at 21.2°C. Successive 10 ml. aliquots were taken and the results are the mean of two determinations.

Aliquot 10 ml.	Aluminium mg.	Iron mg.	Manganese mg.
1st	14.05	4.41	35.84
2nd	17.25	3.86	35.32
3rd	17.43	4.14	34.81
4th	17.69	4.41	33.77
5th	16.73	4.07	36.36

Aluminium was more readily adsorbed than iron or manganese. Consequently, about the first 10 ml. of filtrate was discarded and the rest collected for analysis.

Experiment 4. The effect of hydronium, aluminium, iron and manganese activities on the growth of flue-cured tobacco.

(a) Soil information and mechanical analysis.

Soil	Parent material and locality	% Clay	% Silt	% Total Sands	Soil Texture
1	Dolomite, Angwa South	8.8	8.4	82.8	Loamy sand
2	Micaceous schists, Broken Hill	9.1	4.9	86.0	Sand
3	" " , Karoi	11.9	10.8	77.3	Sandy loam
4	Triassic sand, Beatrice	3.0	2.2	94.8	Sand
5	Arkose, Angwa South	5.0	8.3	86.7	Sand
6	Biotite granite and migmatites, Trelawney	12.0	9.0	79.0	Sandy loam
7	" " , Norton	7.9	7.4	84.7	Loamy sand
8	" " , Kutsaga	3.9	5.9	90.2	Sand
9	" " , Kutsaga vlei margin	3.4	5.9	90.7	Sand
10	" " , Mayo	6.1	7.2	86.7	Sand
11	Dolerite/granite, Inyanga	23.9	13.4	62.7	Sandy clay loam
12	Phyllites, Angwa North	16.1	18.7	65.2	Sandy loam
13	Paragneis, Sipolilo	15.1	13.2	71.7	Sandy loam
14	Tatagura, Henderson	24.3	29.0	46.7	Clay loam
15	Shamva grits, Glendale	25.7	16.4	57.9	Sandy clay loam
16	Slate, Angwa South	21.5	24.4	54.1	Sandy clay loam
17	Granite/dolerite, Headlands	20.7	8.2	71.1	Sandy clay loam

(b) Weight of soil and lime per pot.

Soil	Weight of soil, g/pot	Weight of $CaCO_3$, g/pot
1	600	0.1500
2	650	0.1625
3	600	0.1500
4	700	0.1750
5	650	0.1625
6	600	0.1500
7	700	0.1750
8	750	0.1875
9	700	0.1750
10	700	0.1750
11	500	0.2500
12	600	0.3000
13	500	0.2500
14	500	0.2500
15	600	0.3000
16	500	0.2500
17	600	0.3000

(c) Chemical analysis of soils.

Soil	pH	Ca, me./ 100g. soil	Mg, me./ 100g. soil	K, me./ 100g. soil	P_2O_5 ppm.	Al ppm.	Mn ppm.	Fe ppm.
Unlimed								
1	5.47	2.03	0.65	0.22	11.1	25.3	62.2	3.0
2	5.84	1.61	0.54	0.20	22.5	13.0	78.4	1.5
3	6.34	2.40	1.09	0.30	37.7	6.8	96.2	3.5
4	5.17	1.09	0.11	0.17	5.6	57.0	11.9	49.2
5	5.71	1.82	0.27	0.17	17.3	13.0	33.0	2.5
6	6.49	3.07	2.07	0.27	8.4	4.3	149.2	1.8
7	4.95	1.20	0.65	0.09	2.6	57.0	9.7	53.8
8	5.45	0.99	0.11	0.08	8.9	25.6	15.1	6.0
9	4.82	0.21	0.11	0.14	1.2	76.8	1.1	42.5
10	6.14	1.67	0.52	0.17	9.7	10.6	38.9	4.4
11	4.90	0.94	0.60	0.22	6.2	235.9	140.5	18.1
12	6.03	1.46	1.20	0.23	3.7	8.6	132.4	2.8
13	7.07	6.82	1.90	0.45	12.4	5.0	29.2	1.8
14	5.92	3.49	2.23	0.38	8.4	11.3	103.8	4.5
15	6.31	3.49	2.39	0.35	6.8	5.1	113.5	1.3
16	5.50	2.40	2.07	0.26	7.5	26.3	50.3	4.0
17	5.04	0.68	0.65	0.34	11.3	96.1	55.1	10.3
Mean	5.71	2.08	1.01	0.24	10.7	39.9	65.9	12.4
Limed								
1	5.99	2.19	0.71	0.25	17.6	10.3	57.8	1.5
2	6.30	1.72	0.49	0.20	27.5	5.8	54.1	1.8
3	6.68	2.60	1.09	0.31	39.4	4.6	98.4	1.8
4	5.68	1.30	0.11	0.18	4.5	21.9	11.4	16.6
5	6.16	2.08	0.22	0.17	18.6	5.5	27.0	2.0
6	6.49	3.23	2.01	0.28	8.3	3.6	87.6	0.8
7	5.36	1.25	0.60	0.08	4.0	29.9	9.2	24.6
8	6.09	1.09	0.16	0.11	5.1	8.6	11.4	1.0
9	5.45	0.42	0.05	0.11	1.2	33.2	0.5	18.6
10	6.50	2.12	0.50	0.16	11.3	9.1	35.1	6.2
11	5.29	1.61	0.54	0.20	5.2	114.9	136.8	8.0
12	6.67	1.87	1.14	0.23	4.1	3.9	107.0	1.0
13	7.40	6.98	1.90	0.43	9.7	7.5	16.2	3.0
14	6.26	3.70	2.34	0.38	8.7	2.7	82.2	1.5
15	6.66	3.91	2.23	0.34	8.7	4.1	91.9	2.3
16	5.75	3.23	2.18	0.22	8.8	13.0	43.2	3.5
17	5.71	1.25	0.38	0.28	10.3	27.2	41.1	2.5
Mean	6.14	2.39	0.98	0.23	11.4	18.0	53.6	5.7

(d) Chemical analysis of soil solutions.

Concentration in equilibrium solution of 1:2 suspension of soil in 0.0004990 M $CaCl_2$.

Soil	pH	Ca, 10^{-4} mol/l.	Mg, 10^{-4} mol/l.	K, 10^{-4} mol/l.	P, 10^{-6} mol/l.	Al, 10^{-6} mol/l.	Mn, 10^{-6} mol/l.	Fe, 10^{-6} mol/l.
Unlimed								
1	5.47	5.177	4.081	3.287	2.30	6.081	4.606	7.575
2	5.84	2.807	2.769	3.197	0.31	1.594	6.153	4.065
3	6.34	2.869	2.707	3.926	1.23	3.930	3.550	7.521
4	5.17	3.244	1.238	3.121	0.06	12.050	1.966	7.575
5	5.71	4.678	1.634	3.184	7.82	3.671	3.149	4.889
6	6.49	2.932	3.316	2.796	0.09	1.112	4.369	0.663
7	4.95	2.745	1.863	0.530	0.03	4.857	0.819	2.185
8	5.45	3.805	0.845	1.425	0.74	4.561	1.912	2.471
9	4.82	1.435	0.669	3.077	0.15	7.156	0.146	3.223
10	6.14	3.805	1.245	1.680	0.40	3.003	2.913	5.641
11	4.90	2.682	3.630	2.770	0.37	3.634	20.936	1.343
12	6.03	2.557	3.965	2.686	0.03	0.148	11.706	2.024
13	7.07	7.298	2.023	5.998	0.43	0.037	0.546	2.364
14	5.92	4.242	3.417	4.412	0.28	1.112	3.058	4.065
15	6.31	4.616	4.621	3.747	0.03	0.890	3.368	0.591
16	5.50	4.054	4.783	2.251	0.77	6.971	1.147	8.274
17	5.04	1.871	1.537	6.062	0.03	2.521	6.790	0.788
Mean	5.71	3.577	2.608	3.185	0.89	3.725	4.537	3.839
Limed								
1	5.99	6.050	3.250	4.156	4.87	0.742	4.424	3.474
2	6.30	3.493	2.083	3.333	4.13	0.037	2.276	1.719
3	6.68	3.743	2.779	4.169	4.42	2.966	3.696	7.253
4	5.68	4.304	0.346	3.044	0.77	6.674	1.238	5.892
5	6.16	6.050	1.125	3.338	10.86	2.002	1.693	5.426
6	6.49	3.244	3.783	2.698	0.03	0.037	2.640	0.501
7	5.36	2.807	1.801	0.435	0.09	0.408	0.419	0.645
8	6.09	5.177	1.219	1.957	2.68	0.890	1.238	2.418
9	5.45	1.934	0.380	2.801	0.35	5.747	0.146	2.095
10	6.50	4.990	1.743	1.944	1.50	0.037	2.185	0.107
11	5.29	4.054	2.258	2.668	0.09	1.669	13.745	1.236
12	6.67	4.179	2.407	2.668	0.03	0.037	5.735	2.633
13	7.40	10.292	2.101	6.139	0.29	0.037	0.510	2.006
14	6.26	5.427	3.199	4.706	0.09	0.037	1.784	1.827
15	6.66	5.676	5.096	3.358	0.29	0.037	2.603	0.591
16	5.75	5.489	5.031	1.867	1.36	5.080	1.056	5.552
17	5.71	3.119	1.510	5.018	0.29	0.371	2.512	0.161
Mean	6.14	4.712	2.359	3.194	1.89	1.577	2.818	2.561

(e) The effect of lime and applied nutrients on tobacco yields (g. D.M./plant).

Soil	No Ca or nutrients	$CaCO_3$	Nutrients	$CaCO_3$ and nutrients	$CaCO_3$		Nutrients		Mean
					Abs.	Pres.	Abs.	Pres.	
S.E.		(0.2661)			(0.1882)		(0.1882)		(0.1331)
1	1.233	1.330	1.003	1.220	1.118	1.275	1.282	1.112	1.197
2	0.573	1.420	0.443	1.183	0.508	1.302	0.997	0.813	0.905
3	2.500	1.707	2.093	1.380	2.297	1.543	2.103	1.737	1.920
4	0.413	0.633	0.853	0.840	0.633	0.737	0.523	0.847	0.685
5	0.723	0.683	0.817	0.510	0.770	0.597	0.703	0.663	0.683
6	0.823	0.960	2.103	1.853	1.463	1.407	0.892	1.978	1.435
7	0.560	0.527	0.753	0.437	0.657	0.482	0.543	0.595	0.569
8	0.740	0.500	0.810	0.660	0.775	0.580	0.620	0.735	0.678
9	0.680	0.513	1.403	0.947	1.042	0.730	0.597	1.175	0.886
10	0.883	0.733	0.690	1.530	0.787	1.132	0.808	1.110	0.959
11	0.627	0.900	1.040	0.713	0.833	0.807	0.763	0.877	0.820
12	0.500	0.793	0.660	0.787	0.580	0.790	0.647	0.723	0.685
13	1.413	1.170	2.640	2.260	2.027	1.715	1.292	2.450	1.871
14	0.833	0.957	0.917	0.497	0.875	0.727	0.895	0.707	0.801
15	1.453	1.080	2.213	2.547	1.833	1.813	1.267	2.380	1.823
16	0.820	1.163	1.197	1.760	1.008	1.462	0.992	1.478	1.235
17	2.120	2.247	2.770	2.433	2.445	2.340	2.183	2.602	2.393
S.E.		(0.0645)			(0.0456)		(0.0456)		
Mean	0.994	1.019	1.318	1.268	1.156	1.143	1.006	1.293	1.150

(f) The effect of lime and applied nutrients on calcium concentration (%).

Soil	No Ca or nutrients	$CaCO_3$	Nutrients	$CaCO_3$ and nutrients	$CaCO_3$		Nutrients		Mean
					Abs.	Pres.	Abs.	Pres.	
S.E.		(0.210)			(0.148)		(0.148)		(0.105)
1	1.44	1.73	1.29	1.07	1.36	1.40	1.59	1.18	1.38
2	1.38	1.79	0.78	1.16	1.08	1.48	1.59	0.97	1.28
3	1.39	1.72	1.19	1.28	1.29	1.50	1.55	1.23	1.39
4	2.70	2.88	1.13	1.18	1.91	2.03	2.79	1.15	1.97
5	2.13	2.07	1.57	1.41	1.85	1.74	2.10	1.49	1.79
6	1.84	2.55	0.97	1.33	1.41	1.94	2.20	1.15	1.67
7	1.85	1.95	1.10	1.09	1.47	1.52	1.90	1.09	1.49
8	2.01	2.42	1.24	1.26	1.62	1.84	2.21	1.25	1.73
9	1.97	2.13	0.83	0.99	1.40	1.56	2.05	0.91	1.48
10	2.01	2.00	1.34	0.80	1.68	1.40	2.00	1.07	1.54
11	2.53	2.94	1.41	2.04	1.97	2.49	2.73	1.72	2.23
12	1.57	2.67	1.58	1.35	1.57	2.01	2.12	1.46	1.79
13	2.86	2.62	1.35	1.57	2.10	2.10	2.74	1.46	2.10
14	1.37	2.11	1.12	1.25	1.24	1.68	1.74	1.18	1.46
15	2.24	2.41	1.52	1.22	1.88	1.81	2.32	1.37	1.85
16	1.47	1.89	1.23	1.09	1.35	1.49	1.68	1.16	1.42
17	1.47	2.68	0.86	1.15	1.17	1.92	2.08	1.01	1.54
S.E.		(0.051)			(0.036)		(0.036)		
Mean	1.90	2.27	1.21	1.25	1.55	1.76	2.08	1.23	1.65

(g) The effect of lime and applied nutrients on magnesium concentration (%).

Soil	No Ca or nutrients	$CaCO_3$	Nutrients	$CaCO_3$ and nutrients	$CaCO_3$		Nutrients		Mean
					Abs.	Pres.	Abs.	Pres.	
S.E.		(0.0554)			(0.0392)		(0.0392)		(0.0277)
1	0.490	0.483	0.510	0.423	0.500	0.453	0.487	0.467	0.477
2	0.410	0.343	0.323	0.370	0.367	0.357	0.377	0.347	0.362
3	0.413	0.493	0.460	0.417	0.437	0.455	0.453	0.438	0.446
4	0.407	0.403	0.400	0.350	0.403	0.377	0.405	0.375	0.390
5	0.363	0.313	0.403	0.333	0.383	0.323	0.338	0.368	0.353
6	0.697	0.933	0.477	0.497	0.587	0.715	0.815	0.487	0.651
7	0.503	0.502	0.420	0.370	0.462	0.436	0.502	0.395	0.449
8	0.300	0.312	0.357	0.297	0.328	0.304	0.306	0.327	0.316
9	0.173	0.207	0.280	0.277	0.227	0.242	0.190	0.278	0.234
10	0.417	0.413	0.432	0.353	0.424	0.383	0.415	0.393	0.404
11	0.707	0.393	0.553	0.480	0.630	0.437	0.550	0.517	0.533
12	0.930	0.800	0.737	0.570	0.833	0.685	0.865	0.653	0.759
13	0.691	0.550	0.360	0.410	0.525	0.480	0.620	0.385	0.503
14	0.633	0.723	0.527	0.580	0.580	0.652	0.678	0.553	0.616
15	0.910	0.760	0.360	0.477	0.635	0.618	0.835	0.418	0.627
16	0.897	0.977	0.686	0.660	0.791	0.818	0.937	0.673	0.805
17	0.380	0.303	0.287	0.250	0.333	0.277	0.342	0.268	0.305
S.E.		(0.0134)			(0.0095)		(0.0095)		
Mean	0.548	0.524	0.445	0.418	0.497	0.471	0.536	0.432	0.484

(h) The effect of lime and applied nutrients on potassium concentration (%).

Soil	No $CaCO_3$ or nutrients	$CaCO_3$	Nutrients	$CaCO_3$ and nutrients	$CaCO_3$		Nutrients		Mean
					Abs.	Pres.	Abs.	Pres.	
S.E.		(0.260)			(0.184)		(0.184)		(0.130)
1	2.18	2.23	3.50	3.33	2.84	2.78	2.21	3.42	2.81
2	3.00	2.32	3.22	3.65	3.11	2.99	2.66	3.43	3.05
3	2.59	3.11	3.48	3.40	3.03	3.26	2.85	3.44	3.14
4	2.92	2.34	4.63	4.25	3.78	3.30	2.63	4.44	3.54
5	2.45	2.41	4.01	3.19	3.23	2.80	2.43	3.60	3.01
6	2.93	2.54	3.85	3.88	3.39	3.21	2.74	3.87	3.30
7	1.17	1.08	3.07	2.86	2.12	1.97	1.13	2.96	2.05
8	1.38	1.66	3.84	3.53	2.61	2.60	1.52	3.69	2.60
9	1.77	1.96	3.83	4.12	2.80	3.04	1.86	3.97	2.92
10	1.47	1.87	3.77	3.09	2.62	2.48	1.67	3.43	2.55
11	3.27	2.67	4.93	5.09	4.10	3.88	2.97	5.01	3.99
12	2.39	2.24	2.95	3.78	2.67	3.01	2.32	3.37	2.84
13	3.50	2.95	3.92	3.78	3.71	3.36	3.22	3.85	3.54
14	3.08	2.72	3.15	3.22	3.12	2.97	2.90	3.19	3.04
15	2.45	3.16	3.60	3.79	3.03	3.47	2.81	3.69	3.25
16	2.08	1.79	2.64	3.22	2.36	2.51	1.94	2.93	2.43
17	2.81	2.26	3.99	3.58	3.40	2.92	2.54	3.79	3.16
S.E.		(0.063)			(0.045)		(0.045)		
Mean	2.44	2.31	3.67	3.63	3.05	2.97	2.37	3.65	3.01

(i) The effect of lime and applied nutrients on phosphorus concentration (%).

Soil	No $CaCO_3$ or nutrients	$CaCO_3$	Nutrients	$CaCO_3$ and nutrients	$CaCO_3$		Nutrients		Mean
					Abs.	Pres.	Abs.	Pres.	
S.E.		(0.0376)			(0.0266)		(0.0266)		(0.0188)
1	0.183	0.196	0.518	0.495	0.350	0.345	0.190	0.506	0.348
2	0.119	0.109	0.348	0.470	0.233	0.289	0.114	0.409	0.261
3	0.169	0.193	0.433	0.412	0.301	0.302	0.181	0.422	0.301
4	0.101	0.093	0.640	0.527	0.371	0.310	0.097	0.583	0.340
5	0.218	0.220	0.615	0.474	0.416	0.347	0.219	0.544	0.381
6	0.065	0.054	0.491	0.475	0.278	0.264	0.059	0.483	0.271
7	0.079	0.087	0.534	0.493	0.306	0.290	0.083	0.514	0.298
8	0.128	0.136	0.637	0.561	0.383	0.349	0.132	0.599	0.366
9	0.044	0.085	0.614	0.709	0.329	0.397	0.064	0.661	0.363
10	0.085	0.085	0.637	0.536	0.361	0.310	0.085	0.586	0.336
11	0.098	0.070	0.444	0.577	0.271	0.323	0.084	0.510	0.297
12	0.113	0.056	0.251	0.252	0.182	0.154	0.084	0.251	0.168
13	0.083	0.087	0.445	0.430	0.264	0.258	0.085	0.438	0.261
14	0.066	0.080	0.349	0.290	0.207	0.185	0.073	0.319	0.196
15	0.069	0.081	0.392	0.397	0.230	0.239	0.075	0.394	0.235
16	0.095	0.075	0.365	0.371	0.230	0.223	0.085	0.368	0.226
17	0.082	0.097	0.326	0.278	0.204	0.187	0.089	0.302	0.196
S.E.		(0.0091)			(0.0065)		(0.0065)		
Mean	0.106	0.106	0.473	0.456	0.289	0.281	0.106	0.464	0.285

(j) The effect of lime and applied nutrients on aluminium concentration (ppm.).

Soil	No $CaCO_3$ or nutrients	$CaCO_3$	Nutrients	$CaCO_3$ and nutrients	$CaCO_3$		Nutrients		Mean
					Abs.	Pres.	Abs.	Pres.	
S.E.		(121.6)			(86.0)		(86.0)		(60.8)
1	514	830	762	707	638	768	672	734	703
2	961	738	617	649	789	693	850	633	741
3	631	774	677	820	654	797	703	748	726
4	1134	793	811	807	973	800	964	809	886
5	1068	960	780	743	924	852	1014	762	888
6	793	839	777	701	785	770	816	739	777
7	1120	750	723	863	921	806	935	793	864
8	796	823	838	723	817	773	810	780	795
9	883	1042	811	990	847	1016	962	900	931
10	773	965	630	685	702	825	869	657	763
11	1409	932	905	892	1157	912	1170	899	1035
12	1285	945	820	757	1052	851	1115	788	952
13	787	953	850	799	818	876	870	824	847
14	705	740	853	1066	779	903	723	960	841
15	811	1045	759	709	785	877	928	734	831
16	936	911	697	723	817	817	924	710	817
17	886	761	1103	687	995	724	824	895	859
S.E.		(29.5)			(20.9)		(20.9)		
Mean	911	871	789	784	850	827	891	786	839

(k) The effect of lime and applied nutrients on manganese concentration (ppm.).

Soil	No $CaCO_3$ or nutrients	$CaCO_3$	Nutrients	$CaCO_3$ and nutrients	$CaCO_3$		Nutrients		Mean
					Abs.	Pres.	Abs.	Pres.	
S.E.		(423.4)			(299.4)		(299.4)		(211.7)
1	896	418	950	315	923	367	657	633	645
2	1127	686	891	610	1009	648	906	750	828
3	926	1330	1159	973	1043	1152	1128	1066	1097
4	810	640	518	372	664	506	725	445	585
5	851	475	905	462	878	469	663	683	673
6	345	1175	375	545	360	860	760	460	610
7	295	246	212	209	254	227	270	211	240
8	433	590	415	357	424	473	511	386	449
9	55	73	67	55	61	64	64	61	62
10	803	339	712	291	757	315	571	502	536
11	11093	3506	5633	2049	8363	2778	7300	3841	5571
12	3994	2023	3298	1272	3646	1647	3009	2285	2647
13	292	226	140	239	216	233	259	190	224
14	423	350	545	501	484	426	387	523	455
15	969	926	434	400	702	663	948	417	682
16	293	289	509	117	401	203	291	313	302
17	3497	1286	1842	817	2669	1052	2391	1330	1861
S.E.		(102.7)			(72.6)		(72.6)		
Mean	1594	858	1094	564	1344	711	1226	829	1027

(1) The effect of lime and applied nutrients on iron concentration (ppm.).

Soil	No $CaCO_3$ or nutrients	$CaCO_3$	Nutrients	$CaCO_3$ and nutrients	$CaCO_3$		Nutrients		Mean
					Abs.	Pres.	Abs.	Pres.	
S.E.		(91.1)			(64.4)		(64.4)		(45.5)
1	394	484	589	389	491	437	439	489	464
2	340	381	314	288	327	335	360	301	331
3	269	395	335	403	302	399	332	369	350
4	750	296	548	550	649	423	523	549	536
5	407	546	425	315	416	431	476	370	423
6	479	381	337	419	408	400	430	378	404
7	492	517	535	444	514	481	505	490	497
8	513	756	542	414	527	585	634	478	556
9	450	584	417	484	434	534	517	450	484
10	397	342	250	376	324	359	369	313	341
11	574	416	440	590	507	503	495	515	505
12	614	404	441	481	528	442	509	461	485
13	416	467	377	383	397	425	442	380	411
14	291	419	477	688	384	553	355	583	469
15	393	428	390	312	391	370	410	351	381
16	340	555	321	379	331	467	447	350	399
17	278	284	245	242	261	263	281	243	262
S.E.		(22.1)			(15.6)		(15.6)		
Mean	435	450	411	421	423	436	443	416	429

(m) Activity ratios.

Soil	$\sqrt{\frac{a_{Ca}}{a_{Ca + Mg}}}$, mol/l.	$\sqrt{\frac{a_{Mg}}{a_{Ca + Mg}}}$, mol/l.	$\frac{a_K}{\sqrt{a_{Ca + Mg}}}$, $(mol/l.)^{\frac{1}{2}}$	$\sqrt{\frac{a_{Mn}}{a_{Ca + Mg}}}$, mol/l.	$\sqrt{\frac{a_{Fe}}{a_{Ca + Mg}}}$, mol/l.	$\frac{\sqrt[3]{a_{Al}}}{\sqrt{a_{Ca + Mg}}}$, $(mol/l.)^{-1/6}$
Unlimed						
1	0.7479	0.6640	0.01136	0.07052	0.09048	0.3834
2	0.7098	0.7047	0.01411	0.1050	0.08540	0.2530
3	0.7172	0.6969	0.01732	0.07971	0.1161	0.2415
4	0.8508	0.5259	0.01533	0.06622	0.1292	0.7975
5	0.6741	0.5089	0.01324	0.07065	0.08801	0.3413
6	0.6851	0.7284	0.01169	0.08362	0.03257	0.1343
7	0.7901	0.6358	0.002570	0.04217	0.06884	0.6308
8	0.9043	0.4262	0.006878	0.06410	0.07291	0.4958
9	0.8267	0.5643	0.02189	0.02631	0.1238	1.1077
10	0.8677	0.4964	0.007794	0.07590	0.1056	0.2675
11	0.6520	0.7588	0.01152	0.1821	0.04614	0.4967
12	0.6258	0.7798	0.01100	0.1339	0.05571	0.2012
13	0.8848	0.5307	0.02063	0.02420	0.05035	0.0230
14	0.7443	0.6679	0.01670	0.06316	0.07284	0.1819
15	0.7068	0.7072	0.01296	0.06039	0.02529	0.1175
16	0.6773	0.7355	0.007928	0.03602	0.09672	0.4039
17	0.7408	0.6713	0.03393	0.1410	0.04806	0.5719
Limed						
1	0.8064	0.5910	0.01433	0.06896	0.06110	0.1378
2	0.7916	0.6114	0.01471	0.06391	0.05555	0.0525
3	0.7578	0.6531	0.01705	0.07527	0.1055	0.1584
4	0.9617	0.2728	0.01468	0.05217	0.1125	0.4932
5	0.9183	0.3961	0.01305	0.04858	0.08698	0.1939
6	0.6795	0.7338	0.01066	0.06128	0.02671	0.0408
7	0.7805	0.6252	0.002110	0.03015	0.03741	0.2335
8	0.8991	0.4361	0.008090	0.04396	0.06146	0.1644
9	0.9141	0.1281	0.01901	0.02509	0.09514	0.7579
10	0.8613	0.5089	0.007843	0.05694	0.01263	0.0414
11	0.8016	0.5983	0.01110	0.1474	0.04427	0.3302
12	0.7966	0.6043	0.01088	0.09329	0.06333	0.0369
13	0.9116	0.4118	0.01843	0.02028	0.04022	0.0156
14	0.7931	0.6093	0.01681	0.04548	0.04601	0.0436
15	0.7259	0.6878	0.01079	0.04915	0.02342	0.0292
16	0.7225	0.6915	0.006073	0.03169	0.07263	0.2881
17	0.8209	0.5706	0.02422	0.07361	0.01866	0.1852

(n) Chemical potential components.

Soil	pH	$\frac{1}{2}$pCa	$\frac{1}{2}$pMg	$\frac{1}{2}$p(Ca + Mg)	pK	$\frac{1}{2}$pMn	$\frac{1}{2}$pFe	$\frac{1}{3}$pAl	pH_2PO_4
Unlimed									
1	5.47	1.69	1.74	1.56	3.51	2.71	2.61	1.98	5.67
2	5.84	1.81	1.82	1.66	3.52	2.64	2.73	2.26	6.55
3	6.34	1.81	1.82	1.66	3.42	2.76	2.60	2.28	5.99
4	5.17	1.78	1.99	1.71	3.52	2.89	2.60	1.81	7.24
5	5.71	1.70	1.93	1.64	3.52	2.79	2.70	2.11	5.14
6	6.49	1.81	1.78	1.64	3.57	2.72	3.12	2.51	7.15
7	4.95	1.82	1.90	1.70	4.29	3.08	2.87	1.90	7.54
8	5.45	1.75	2.07	1.70	3.86	2.90	2.84	2.01	6.16
9	4.82	1.95	2.12	1.87	3.53	3.45	2.78	1.82	6.84
10	6.14	1.75	1.99	1.69	3.79	2.81	2.66	2.26	6.46
11	4.90	1.83	1.76	1.64	3.58	2.38	2.98	1.94	6.45
12	6.03	1.84	1.74	1.63	3.59	2.51	2.89	2.33	7.57
13	7.07	1.61	1.89	1.56	3.25	3.18	2.86	3.20	6.65
14	5.92	1.73	1.78	1.60	3.38	2.80	2.74	2.34	6.59
15	6.31	1.71	1.71	1.56	3.45	2.78	3.16	2.49	7.60
16	5.50	1.74	1.70	1.57	3.67	3.01	2.59	1.96	6.14
17	5.04	1.90	1.94	1.77	3.24	2.62	3.08	2.01	7.54
Limed									
1	5.99	1.65	1.79	1.56	3.40	2.72	2.77	2.42	5.36
2	6.30	1.77	1.88	1.66	3.49	2.85	2.92	2.94	5.46
3	6.68	1.75	1.82	1.63	3.40	2.76	2.61	2.43	5.48
4	5.68	1.72	2.27	1.70	3.54	2.99	2.65	2.01	6.14
5	6.16	1.65	2.02	1.61	3.50	2.93	2.67	2.33	5.02
6	6.49	1.79	1.75	1.62	3.59	2.83	3.19	3.01	7.62
7	5.36	1.81	1.91	1.70	4.38	3.22	3.13	2.34	7.08
8	6.09	1.68	2.00	1.64	3.73	2.99	2.85	2.42	5.62
9	5.45	1.89	2.24	1.85	3.57	3.45	2.87	1.97	6.49
10	6.50	1.69	1.92	1.63	3.73	2.87	3.52	3.01	5.92
11	5.29	1.74	1.86	1.64	3.59	2.47	2.99	2.12	7.07
12	6.67	1.73	1.90	1.63	3.59	2.66	2.83	3.06	7.65
13	7.40	1.54	1.89	1.50	3.24	3.20	2.90	3.31	7.05
14	6.26	1.68	1.79	1.58	3.35	2.92	2.91	2.94	7.12
15	6.66	1.67	1.69	1.53	3.50	2.84	3.16	3.07	6.67
16	5.75	1.68	1.70	1.54	3.75	3.04	2.68	2.08	5.90
17	5.71	1.79	1.95	1.70	3.32	2.84	3.43	2.44	6.57

Experiment 5. The effect of incubating soil at about field capacity on soil pH, and availability of aluminium, iron and manganese.

(a) Soil information and mechanical analysis.

Soil	Parent material and locality	% Clay	% Silt	% Sand	Soil Texture
2	Biotite granite, Umvukwes South	6.3	7.5	86.2	Sand
6	Triassic sand, Beatrice	3.0	2.2	94.8	Sand
11	Biotite granite, Norton	7.9	7.4	84.7	Loamy sand
14	" " , Kutsaga	3.9	5.9	90.2	Sand
16	" " , Mayo	6.1	7.2	86.7	Sand
17	" " , Inyazura South	(not analysed)			Sand
23	" " , Karoi North	6.0	6.8	87.2	Sand
24E	" " , Macheke	4.8	7.0	88.2	Sand
24L	" " , "	4.8	8.0	87.2	Sand

Soils 6, 11, 14 and 16 are the same as soils 4, 7, 8 and 10 of Experiment 4.

(b) Soil pH

Time	Soil 2	6	11	14	16	17	23	24E	24L	6a	14a
0	4.935	4.200	4.341	5.200	5.926	4.821	4.900	5.265	5.513	4.190	5.185
1 hr.	4.952	4.237	4.350	5.219	5.914	4.840	4.898	5.310	5.580	4.220	5.196
1 day	5.110	4.285	4.388	5.370	6.041	4.921	4.990	5.530	5.822	4.285	5.420
2 days	5.156	4.304	4.459	5.415	6.071	4.870	4.955	5.610	5.920	4.372	5.380
3 days	5.165	4.281	4.555	5.419	6.040	4.809	4.955	5.667	5.980	4.405	5.330
4 days	5.142	4.280	4.559	5.360	6.040	4.769	4.960	5.720	5.980	4.370	5.270
7 days	4.962	4.332	4.640	5.217	5.990	4.660	4.900	5.690	5.990	4.371	5.240
14 days	-	4.373	4.751	5.203	5.941	-	-	-	-	4.390	5.238
21 days	-	-	-	-	-	-	-	-	-	4.450	5.242

All soils incubated at 21.2°C. except those with suffix a, which were incubated at 35°C.

(c) Composition of soil solution.

	Soil										
Time	2	6	11	14	16	17	23	24E	24L	6a	14a
I. Aluminium, ppm.											
0	0.22	1.35	0.83	0.12	0.06	0.19	0.11	0.12	0.02	1.39	0.14
1 hr.	0.25	1.35	0.81	0.21	0.05	0.05	0.12	0.08	0.01	1.46	0.14
1 day	0.08	1.18	0.87	0.15	0.05	0.04	0.09	0.01	0.01	1.24	0.07
2 days	0.13	1.20	0.78	0.04	0.05	0.01	0.01	0.01	0.01	1.04	0.07
3 days	0.08	1.32	0.49	0.11	0.01	0.04	0.08	0.01	0.01	0.85	0.06
4 days	0.01	1.16	0.58	0.12	0.07	0.06	0.01	0.01	0.01	0.94	0.04
7 days	0.21	1.01	0.38	0.07	0.05	0.05	0.03	0.01	0.01	0.76	0.08
14 days	-	0.82	0.18	0.13	0.07	-	-	-	-	0.62	0.14
21 days	-	-	-	-	-	-	-	-	-	0.51	0.07
II. Iron, ppm.											
0	0.03	0.57	0.64	0.11	0.05	0.01	0.05	0.06	0.06	0.38	0.07
1 hr.	0.05	0.49	0.65	0.07	0.05	0.01	0.05	0.06	0.05	0.38	0.10
1 day	0.05	0.50	0.71	0.07	0.03	0.01	0.05	0.05	0.04	2.26	0.09
2 days	0.03	0.51	0.74	0.05	0.01	0.02	0.05	0.06	0.06	3.14	0.07
3 days	0.06	0.79	0.71	0.08	0.01	0.02	0.04	0.05	0.05	2.26	0.06
4 days	0.05	0.64	0.73	0.08	0.01	0.02	0.04	0.04	0.05	1.22	0.04
7 days	0.01	0.21	0.52	0.02	0.02	0.02	0.01	0.05	0.18	0.61	0.06
14 days	-	0.18	0.14	0.04	0.03	-	-	-	-	0.11	0.08
21 days	-	-	-	-	-	-	-	-	-	0.19	0.02

Composition of soil solution (contd.)

	Soil										
Time	2	6	11	14	16	17	23	24E	24L	6a	14a
III. Manganese, ppm.											
0	11.88	2.96	3.29	5.64	9.70	5.44	2.00	1.09	1.61	3.13	5.80
1 hr.	11.25	3.93	2.80	4.78	9.51	6.81	2.12	1.15	1.58	3.53	5.67
1 day	13.13	4.30	3.23	6.18	9.70	6.25	3.06	0.76	0.06	4.87	7.60
2 days	14.81	3.71	3.23	6.67	9.82	5.31	0.06	0.14	0.06	5.20	4.93
3 days	12.38	4.78	2.99	4.78	9.57	3.06	0.06	0.22	0.06	4.93	3.13
4 days	10.94	4.84	3.42	5.11	8.96	0.31	0.06	0.33	0.03	5.00	2.40
7 days	5.88	4.03	2.93	2.10	7.50	0.06	0.06	0.22	0.03	5.07	1.40
14 days	-	4.78	2.87	0.59	5.55	-	-	-	-	5.00	0.27
21 days	-	-	-	-	-	-	-	-	-	4.93	0.47
IV. Calcium, 10^{-3} mol/1.											
0	9.435	8.686	8.741	8.658	8.436	8.381	7.742	8.432	7.755	8.880	8.797
1 hr.	9.463	8.714	8.741	8.603	8.492	8.408	7.798	8.380	7.808	8.880	8.825
1 day	9.407	8.658	8.741	8.603	8.519	8.408	7.798	8.354	7.781	8.880	8.797
2 days	9.435	8.686	8.769	8.603	8.519	8.408	8.159	8.328	7.755	8.825	8.769
3 days	9.324	8.658	8.686	8.575	8.519	8.436	7.770	8.328	7.703	8.797	8.797
4 days	9.435	8.714	8.630	8.547	8.519	8.436	7.715	8.328	7.703	8.797	8.797
7 days	9.768	8.658	8.658	8.603	8.492	8.519	7.826	8.328	7.703	8.825	8.769
14 days	-	8.658	8.686	8.603	8.519	-	-	-	-	8.852	8.769
21 days	-	-	-	-	-	-	-	-	-	8.852	8.769

Composition of soil solution (contd.)

Time	Soil 2	6	11	14	16	17	23	24E	24L	6a	14a
V. Magnesium, 10^{-4} mol/l.											
0	8.05	4.44	6.94	3.61	8.05	6.93	14.99	4.95	8.07	4.16	4.72
1 hr.	9.16	4.44	7.22	3.88	7.49	6.94	18.59	5.47	7.80	4.16	4.72
1 day	9.44	5.00	6.94	3.88	7.22	6.94	19.15	5.47	8.07	4.72	4.16
2 days	9.44	4.72	6.94	3.05	6.94	6.94	15.54	5.99	8.33	4.16	4.44
3 days	9.44	5.27	7.22	3.33	6.94	6.66	13.88	5.99	9.11	4.16	4.16
4 days	8.05	4.71	7.49	3.61	7.22	7.22	14.70	5.99	9.11	5.00	4.16
7 days	8.60	5.83	6.94	3.33	7.22	6.66	14.43	5.99	9.37	5.00	4.16
14 days	-	5.55	6.66	3.60	7.49	-	-	-	-	4.72	3.61
21 days	-	-	-	-	-	-	-	-	-	4.16	3.33

APPENDIX V

GLOSSARY OF TOBACCO TERMS

BODY ------ The grading system of the Rhodesia Tobacco Marketing Board (223) defines body as the thickness and density of cured leaf, or weight per unit of surface.

COLOUR ------ Cured tobacco leaf can vary in colour from pure yellow to orange, brown and even darker shades. In some cases leaves are distinctly mottled. Uniformity in shade and depth of colour over the leaf surface is an important factor in determining the grade of a leaf within a type. Lustre or brilliance is also important, as leaves of either light or dark colours may present a high lustre or dull lifeless appearance (22).

The Rhodesian classification (223) defines colour as a subdivision of a group of closely related grades based on relative colour shades and brilliances common to the group, and on certain elements of quality, such as body and maturity, which are closely related to colour.

EQUILIBRIUM MOISTURE ------ The percentage moisture in tobacco rag which has been equilibrated for 72 hours at 60 $\pm$ 2% relative humidity and 21.1 $\pm$ 0.5^{o}C. (224).

FILLING VALUE ------ The residual volume, expressed as cc./gram, of equilibrated tobacco rag under pressure of 1.225 lb. f. in. squared for 10 minutes (224).

MATURITY ------ Mature leaves are thin to medium in body, fairly soft to slightly rough, fairly oily to fairly low in oil, ripe and open-grained, with a natural to mellow colour (223).

SLATEY ------ Leaf which is very close-grained and immature, having a very smooth flat surface and being distinctly grey in colour (223).

TEXTURE ------ Frequently used to indicate apparent density of structure i.e. the arrangements of leaf cells with intercellular air spaces. "Close-grained" or "close-textured" leaf has a denser structure of leaf tissue than "open-grained" leaf (22).

TOBACCO RAG ------ After removal of the midrib, lamina is cut to cigarette rag on a power driven sample cutter (224).