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By

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I. INTRODUCTION

The FIFAMANOR development project in the plateau around Antsirabe, Madagascar was established as a cooperative project between the Madagascar Ministry of Agriculture and the Norwegian Agency for International Development in 1972. One of the objectives of the project was to increase the wheat production. The cultivation of wheat on valley floor soils, or on volcanic soils under irrigation in the dry, cool season, has been reasonably successful. On the other hand growing wheat on the upland ferralitic soils during the rainy season has met with many difficulties. The problem of plant diseases was gradually solved in the 1970's, but yields continued to be rather low. The response to fertilizers and lime was variable and often small (NJØS & RYAN 1980).

It is well known that the upland soils are generally acid, leached, with a strong microstructure, but very poor with regard to soil fertility. The cation exchange capacity is quite low and the aluminium saturation high. Phosphates may be strongly fixed to the soil materials which are rich in iron and aluminium. This is a common problem in upland soils of wet tropical regions. (SANCHEZ & SALINAS 1981).

BOYER (1982) states that there may be limitations in the profile of ferralitic soils, such as the presence of dense and thick stonelines, seasonal waterlogged horizons near the surface, and in some cases compactness of sub-horizons. The factors determining soil structure are organic material and calcium in the upper layers of the soil, iron in lower layers, clay content, and action of plant roots. Generally, the ferralitic soils have low available water capacity, high or rather high permeability and easy drainage. Heavy rains cause leaching and cultivation leads to a decrease in permeability. The decay of the natural vegetation supplies newly cultivated soil with a certain amount of nutrients. The mineralization of the soil's organic nitrogen is accelerated sharply after cultivation, causing a 40% decrease in the soil's organic matter during the first two years of cultivation. The resulting mineral nitrogen increases to a maximum at the beginning of each rainy season, the nitrate flush, which is very sensitive to leaching. Exchangeable aluminium is found on the absorbing complex when the pH of water falls below 5.0–5.2 and increases exponentially in relation to a decrease in soil pH. Large amounts of exhangeable aluminium may be found deep within the soil and form a chemical barrier to plant roots, which is difficult to change by liming.

In tropical regions it is quite common that soils in low to medium precipitation areas are reasonably fertile, while soils in areas where rain is plentiful may be leached, acid and very poor. DUDAL (1977) has summarized the properties of ferralsols according to the FAO-UNESCO classification of 1974. The ferralsols (oxisols, USDA, 1974, Appendix 1) are strongly weathered, consisting mainly of kaolinite, quartz, hydrated oxides of iron and aluminium, with a very low cation exchange capacity. The nitrogen is easily leached by rain, if the surface is not covered by vegetation, and a strong fixation of phosphorus is common. The soil is low in the exchangeable bases Ca, Mg, and K, with an insufficient supply of molybdenum and high in exchangeable aluminium when the soil pH drops below 5.2. An excess of aluminium and manganese may produce toxic effects. The physical conditions of these soils are often good, except for the relatively low available moisture capacity. SANCHEZ (1977) pointed out that under tropical conditions in America the low available water capacity and the aluminium toxicity which hamper root development of cultivated plants often result in physiological drought. The phrase «wilting in the rain» might be used to describe these conditions.

Concerning fertilizers, BOYER (1972) considers soluble phosphates as the most preferable form for the ferralsols. VAN WAMBEKE (1972) found that phosphates with low solubility were inferior to superphosphate in the soils of the Congo. In the ferralsols there is a close correlation between phosphorus fixing potential and clay content.

COBRA NETTO et al. (1977) demonstrated a strong negative correlation between yield of wheat and free aluminium in the soil. An increase in free aluminium from 0.56 to 1.44 meq/100 cm^3 soil and a corresponding decrease in pH from 5.2 to 4.9 reduced yields from 531 to 88 g per pot of the SONORA wheat variety. MARTINI et al. (1977) cultivated wheat varieties from countries such as Brazil, Argentina, Zimbabwe, India, Mexico and Australia on ferralsols high in aluminium. For wheat varieties adapted to acid soils, and with some aluminium tolerance, possibly also with tolerance to manganese, the effect of liming was rather small. Other varieties reacted to liming with increased yields, among these were some Brazilian varieties. GARGANTINI (1974) showed with pot trials in Brazil that liming of dark red «Latosol» increased the pH from 5.2 to 6.5 and resulted in yield increases for maize and wheat. The calculation for lime requirement is based on the assumption that 1 meq Al/100 g soil corresponds to 1650 kg $CaCO_3$ per hectare (KAMPRATH 1970). This amount would eliminate aluminium toxicity in most soils. It is necessary to grind the lime sufficiently fine and add some magnesium.

The application of lime on the surface of ferralsols, which have deep, acid subsoils, would have little effect and the deep placement of lime to increase root development might be necessary. RITCHEY et al. (1980) showed significant movement of Ca to depths of 25, 75 and 180 cm in a laboratory experiment with an ferralsols after mixing $CaCl_2$ and $CaSO_4$ with the top 15 cm soil and leaching with 1200 mm of water. It may be of interest at this point to mention the results of GOEDERT et al. (1982) who found in field experiments in Brazil a rapid increase in rooting depth after simultaneous application of lime and superphosphate which provided the mobile anion for the vertical movement of calcium ions. After 5–6 years the rooting depth of wheat approached one metre.

ALSTON (1976) found greater root development when a combination of nitrogen and phosphorus were placed at 25 cm depth than at 5 cm depth. MUZILLI et al. (1976) found little effect of nitrogen, no effect of potassium, but a substantial effect of phosphorus on root development. The best combination of fertilizer used at Parana in Brazil was 75 kg N, 170 kg P_2O_5 and 40 kg K_2O per hectare. WINKLER (1976) obtained the highest wheat yields with 30–50 kg N per hectare at Sta. Catarina in Brazil, but he warned that the economic optimum often corresponded to half the application that rendered the highest yields. While response of these soils to phosphorus seems to be rather stable, the response to nitrogen is not very clear and in most it is probably due to limiting factors not yet clarified.

It is well known that cultivation of wheat is beset with difficulties in the humid and sub-humid tropics. Wheat is a crop developed for growth in temperature climates. KOPETZ (1960) stated that wheat normally does not thrive in tropical regions, where the temperature and humidity are high. These conditions are also found in the rain forest or woodland savannahs during the rainy season. He maintained that certain wheat varieties need a period with cold weather in order to produce high yields.

The effect of different night temperatures have been reported. High night temperature was found to be as optimal for the growth of a Canadian wheat variety as low night temperature (FRIEND 1966). This is in agreement with the results from experiments using a variety from the Mexican breeding progamme. However, Norwegian varieties clearly have the best seed setting at low temperature (KOLDERUP 1975).

In Zimbabwe wheat is usually produced as an irrigated winter crop at both high and low altitudes. However, in general the yields are considerably higher at high altitudes, where the temperature is lower and the winter season longer (CACKETT & WALL 1971). Low temperature seems to be an important factor in tiller production by barley and wheat (CANNELL 1969, RAWSON 1971). LUPTON & KIRKBY (1968) and KOLDERUP (1979) have pointed out that the number of spikelets per ear in cereal crops may be enhanced by increasing the length of the growth period of the panicle by decreasing the temperature. Maximal grain setting was found at low temperature from anthesis and onwards (WARDLAW 1970).

Sterility and poor filling of grains have been regularly observed in wheat fields during the rainy season. Usually a rise in the day temperature tends to shorten the kernel-filling period, since the higher temperature enhances the initial growth rate of the grains and hastens the senescence of the wheat plant. As a result the final grain yield decreases (THORNE 1973, SOFIELD et al. 1974, SPIERTZ 1974, FORD & THORNE 1975, MEREDITH & JENKINS 1976, SPIERTZ 1977).

With reference to results from the plateau of Madagascar it is of some interest to note that VELLY et al. (1972) found the response of wheat to nitrogen fertilizers during the dry, cold season with irrigation was higher than during the hot, rainy season. The response of wheat yield to phosphorus fertilizers was much clearer, and sometimes positive for doses up to 400 kg P_2O_5 per hectare. Soils high in organic matter require applications of dolomites (2 tons/ha) to supply magnesium. When the soil pH was 4.0–4.5, wheat yields were low without dolomite. BJOR (1975) demonstrated that wheat yields increased with increasing pH of the soils, but the general yield level was low, demonstrating that factors other than soil acidity were limiting the yields. In several places boron was indispensable. Other experiments in the Antsirabe region described by RINGLUND (1973) did not give conclusive results with regard to the effect of boron. On the contrary, the micronutrient compound, Nutramine, which contains Mn, Cu, Zn and Fe in addition to B, showed more promising results than B alone.

Although wheat yields during the wet season were usually low, RANDRIANARISON (1975) obtained 7–8 tons/ha of wheat under irrigation and heavy fertilization during the dry, cold season. BJOR (1980) obtained reasonable levels of wheat yield during the dry season with 20 trials in the region of Antsirabe by applying 500 kg/ha of a fertilizer containing 16% N, 16% P, and 16% K, 500 kg/ha of Thomas phosphate, and 2 tons/ha of dolomite. None of the treatment effects were significant. After subdivision it was found that the treatments effects were significant on the dark valley floor soils, but not on the upland, ferralitic soils. Recent experiments (RAKOTONDRAMANANA & LARSON 1982) have shown that Brazilian wheat varieties produce higher yields than the common varieties used up to now, e.g. Romany. Mexican-Brazilian crosses also produce rather high yields.

The first objective of the factorial phytotron experiment described in this report was to investigate the effects of and the interactions between night temperature, lime, phosphorus and nitrogen fertilizers and wheat yields produced on soils from Antsirabe, Madagascar. The second objective was to investigate possible causes for poor wheat performance grown on ferralitic soils during the rainy season.

II. MATERIALS AND METHODS

A. Site Description

The soil samples were collected at Mimosa, 15 km north-east of Antsirabe and at Betafo, 15 km west of Antsirabe. Mimosa is situated at an altitude of 1500 m above sea level, and Betafo at about 1200 m. The latitude is roughly 20° S. The climate is characterized by a cool, dry season from May to September and a warm, wet season from October to April. The rainfall is somewhat less during January, but not reduced enough to divide the rainy season into two seasons. At Mimosa the annual precipitation was 1478 mm for the years 1973–75 (Ringlund 1975), with only 15 per cent during the period May to September. The rains normally start sometime from the beginning of September to the end of November. The end of the rainy season varies from the end of March to the middle of May. The mean annual temperature for the rainy season 1973–75 was 18.5°C at Mimosa. The July temperature was 14.6°C while the Januar temperature was 21.0°C. The daily maximum temperature ranged from approximately 30°C in October to approximately 22.5°C in July. The daily minimum temperature ranged from approximately 12.5°C in December–February to 3°C in July (Fig. 1). At an altitued of 1400 to 1600 m the normal number of frost days are 1–10 days per year (Raunet 1980) from 14 June to 10 August.

The bedrock consists of pre-cambrian gneisses and granites, but the actual sites are characterized by a sediment basin with sandstone clay schists and limestone, with layers of volcanic materials (Battistini & Richard-Vinddard 1972). At Mimosa there is a deep mantle of weathered, leached materials giving rise to ferralitic soils. At Betafo there are recent basaltic eruptives (Choubert & Faure-Muret 1976) and the soil is very much influenced by volcanic activity. The weathered upland soils are often characterized by gigantic erosion forms, the so-called lavakas, which are created by landslides. Mimosa, itself, is situated on a large plain.

This land was previously used for a type of shifting cultivation, but it was not suitable for this type of use, since the tree vegetation was sparse. The cultivated area was limed and fertilized. At Betafo (École Biblique and Tritriva) the soil had been cultivated for a long time. This soil had not been limed previously. The soil for the experiments at the Phytotron was collected from 6 sites at Mimosa (ferralitic soil) and from 3 sites at Betafo (volcanic soil). From each site 40 kg soil was collected from a depth of 0–20 cm and 20 kg from 20–40 cm. It was necessary to pool the soil samples within the two main areas to obtain enough soil for a factorial experiment. Soil analysis was carried out before mixing the samples.

B. Soil and Plant Analysis

1. *Soil Analysis*

The following procedure was used for the soil analysis:

Grain size analysis: Pipet method according to Elonen (1971)

pH value (H_2O): soil/aq dest (1:2.5)

pH value ($CaCl_2$): 0.01 M $CaCl_2$ solution

Exchangeable Al: Extraction with 1M KCl and determined with the atomic adsorption spectrophotometer (AAS) according to Kamprath (1970)

Exchangeable H: Extraction with 1 M KCl and determined by titration with NaOH according to Kamprath (1970)

Extractable Al and Mn: Extraction with 0.02 M $CaCl_2$ and determined by AAS according to Hoyt & Nyborg (1972)

Exchangeable cations in 1 M NH_4-acetate: Determination of K, Na, Mg, Ca with an atomic absorption spectrophotometer at pH 7

Exchangeable acidity: Sum of exchangeable Al and H from KCl extraction.

Effective cation exchange capacity: Sum of cations from NH_4 acetate method and the exchangeable acidity.

Iqnition loss: Ignition at 550°C for 3–4 hours and gravimetric determination.

Organic C: Determined by dry combustion.

Total N determination: Kjeldahl analysis with a Tecator heating unit (Bremner 1965).

Easily soluble P, K, Ca, Mg in AL solution: (0.4 M acetic acid + 0.1 M NH_4 lactate). Determination of P by spectrophotometer; K by flame photometry; Ca and Mg by AAS according to Egner et al. (1960).

Acid soluble K: K in 1 M boiling HNO_3, determination by AAS according to Reitemeier *et al.* (1948).

Mn determination: Mn in 1 M NH_4-acetate, 0.2% hydrochinone, determination by AAS according to Øien (1974).

Cu determination: Cu in 0.01 M EDTA-solution with 5 g NH_4-chloride per dm^3, determination by AAS according to Øien (1974)

Zn determination: Zn in 0.2 M HCl, determination by AAS according to Øien (1974)

B determinaton: B in boiling water with the addition of 1,1- dianthrimid solution, determination by AAS according to Øien (1974).

The latter four methods are standard procedures for the analysis of micronutrients in the soil at The State Soil Investigation Laboratory, N-1432 Ås-NLH, Norway.

2. *Plant Analysis*

The chemical analysis of the plants was performed by the following methods:

Total N: Kjeldahl method in a Tecator heating block.

Total P: Kjeldahl method in a Tecator heating block; determination by spectrophotometry after adding molybdenum blue.

Ca and Mg: Determination after igniting the plant material at 550°C; a solution of ash in 1 M HCl with the addition of Sr-chloride followed by determination by the AAS method.

C. Characterization of soil and plant material

1. *Soil material*

Table 1 shows the means of analytical values for soil components in the two soils used in this investigation.

Table 1. Soil analysis of samples from the Antsirabe region, Madagascar

Soil analysis	Ferralitic soil	Volcanic soil
Clay, percent[1]	65.0	9.0
Silt, »	24.0	50.0
Sand, »	11.0	41.0
Org. C »	4.0	7.9
N »	0.3	0.6
Ignition Loss (%)	20.9	22.2
Exch. Ca, meq/100 g	1.3	7.8
» Mg, »	0.4	2.8
» K, »	0.3	0.3
» Na, »	0.015	0.096
» Al, »	0.85	0.03
» Acidity, »	1.16	0.17
Eff. CEC »	3.18	11.17
Al saturation (%)	26.7	0.3
pH (H_2O)	4.8	6.2
pH ($CaCl_2$)	4.4	5.5
Extr. Al mg/kg	9.2	0.5
» Mn »	26.0	2.3
P-AL, mg/100 g	0.3	0.2
K-AL, »	11.1	9.4
Mg-AL, »	5.3	31.0
Ca-AL, »	21.0	127.0
K-HNO_3 »	25.0	22.0
Mn, mg/kg	75.0	68.0
Cu, »	1.3	5.8
Zn, »	0.7	2.2
B, »	0.45	0.087

[1]) Grain size distribution after removal of iron.

There are very clear differences between the two soils. The organic carbon is almost twice as high in the volcanic soil as in the ferralitic soil. C/N ratios are rather similar, around 13. Exchangeable Ca and Mg are about 6 times higher, and the effective cation exchange capacity about 3.5 times higher in the volcanic soil as compared with the ferralitic soil. Aluminium saturation was 0,3% in the volcanic soil, but 26% in the ferralitic soil, which also had high amounts of extractable Al og Mn. According to PENNEY *et al.* (1981) concentration as low as 2 mg Al/kg of extractable Al are toxic to wheat roots under Zambian conditions. P-AL is extremely low in both soils, while Ca-AL is extremely low in the ferralitic soil. The ferralitic soil is a clay, the volcanic soil a loam.

2. *Plant material*

The wheat varieties used in the present study were Romany and PF 71131. Romany which has its origin in the Kenya highlands is a common variety used in Madagascar, while PF 71131 is a Brazilian variety which is assumed to be Al tolerant.

D. EXPERIMENTAL PROCEDURE AND DESIGN

1. *Soil preparation*

The soils were selected in November 1980. After arrival in Oslo the soil samples were heated to 50–60°C for 5 days for desinfection purposes. After soil analysis were performed, the soils were pooled and mixed in a concrete mixing machine to make one ferralitic and one volcanic type. The soil was placed in 3 dm^3 plastic pots, having a diameter of 18 cm at the top and 14 cm at the bottom with a height of 16 cm. Each pot was filled with 3 kg soil. It was necessary to compress the soil in order to obtain a 1–2 cm free rim at the top of the pot.

All nutrients were thoroughly mixed with the soil in each pot. Potassium was added as K_2SO_4, 0.3 g K/pot, and magnesium as $MgSO_4$, 0.03 g Mg/pot. A mixture of micronutrients including B, Mn, Zn, Cu, Mo and Fe was also added. Phosphorus was added as triple superphosphate, 0.36 g/pot, either as a complete mixtrue or in a ring at 5 cm depth (banded). Nitrogen was added as urea, 0.3 g/pot. Lime was added as $CaCO_3$, 6.0 g/pot.

In each pot 18 seeds were sown approximately 2 cm deep, watered with 1000 ml demineralized water and covered with a plastic sheet to avoid drying of the soil surface during the germination period. Three weeks after sowing the number of plants per pot was reduced to ten. During the growing period plant development was observed and plant length was measured. The soil was rather compact. One month after sowing, the soil was loosened and force aerated 5 times within a 2 week period.

2. *Growth chamber regulation*

The plants were grown in two fully climate conditioned growth rooms in the Phytotron, University of Oslo (NILSEN 1975). The photoperiod was 12 hrs daylight and the light source was flourescent tubes (Philips TLMF 33 RS, 140 W), which gave an irradiance of 65 W/m^2 (25,000 lux) measured with a light meter (Li-185, Lambda Instr. Corp., Lincoln, Neb., USA). The relative humidity was kept at 80 percent at all temperature regimes and the wind velocity was 0.5 m/s.

In one growth room, termed the low night temperature room, the minimum temperature during the night was 8°C. The other room, termed the high night temperature room, had a minimum temperature during the night of 16°C. Both rooms had a maximum day temperature of 32°C. During the interval between minimum and maximum temperatures, the temperature was changed automatically by a computer and by the climate regulator. The mean temperature of the high night temperature room was 24°C and it was 20°C in the low night temperature room. Fig. 2 shows the actual temperature in the two rooms over three 24 h cycles.

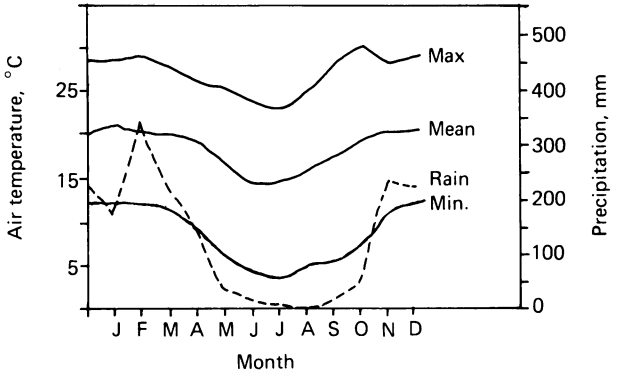

Figure 1. The annual minimum, maximum and mean temperature and precipitation of Mimosa (Ringlund 1975)

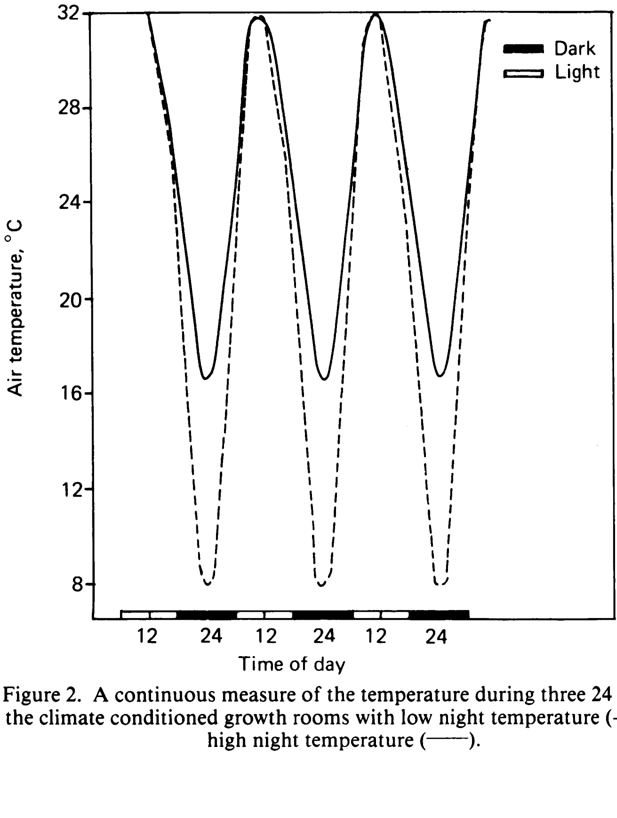

Figure 2. A continuous measure of the temperature during three 24 h cycles in the climate conditioned growth rooms with low night temperature (---) and a high night temperature (——).

The plants were watered with deionized water every other day. Because of the large differences in growth between different pots, each pot was watered separately. The upper limit of water application was approximately 80% of the container capacity.

3. *Factorial treatments*

The treatments were as follows:
J1 Ferralitic soil
J2 Volcanic soil

S1 Romany wheat variety
S2 PF 71131 wheat variety

T1 Minimum night temperature, 16°C
T2 Minimum night temperature, 8°C

P0 No P fertilizer
P1 47.6 kg P/ha, mixed*)
P2 47.6 kg P/ha, banded at 5 cm depth*)

N0 No N fertilizer
N1 100 kg N/ha as urea

Ca0 No lime
Ca1 4 tons/ha lime as $CaCO_3$

There were 2 replicates.

4. *Statistical analysis*

The research data were analysed statistically according to SNEDECOR & COCHRAN (1976), mainly by variance analysis.

III. RESULTS AND DISCUSSION

A. TEMPERATURE EFFECTS ON GROWTH PARAMETRES

The height of the plants were measured every second week during the vegetative stage. No effect of high night temperature (min. 16°C) nor low night temperature (min. 8°C) on height was found when Romany variety was cultivated on volcanic soil fertilized with urea and phosphorus. The low night temperature reduced the growth rate of the control plants (without nitrogen and phosphorus). However, they were allowed to grow for a longer period and reach the same height as the control plants at high night temperature (Figure 3). The growth of the control groups without lime cultivated on ferralitic soil was strongly reduced at both night temperatures. However, the low night temperature increased the plant height when the ferralitic soil was fertilized with phosphorus applied in a band, either without, or with urea or lime. Plants cultivated on limed ferralitic soil to which both nitrogen and phosphorus were added showed no night temperature effect (Fig. 4).

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*) in tables to follow 47.6 kg P is abbreviated to 48 kg P

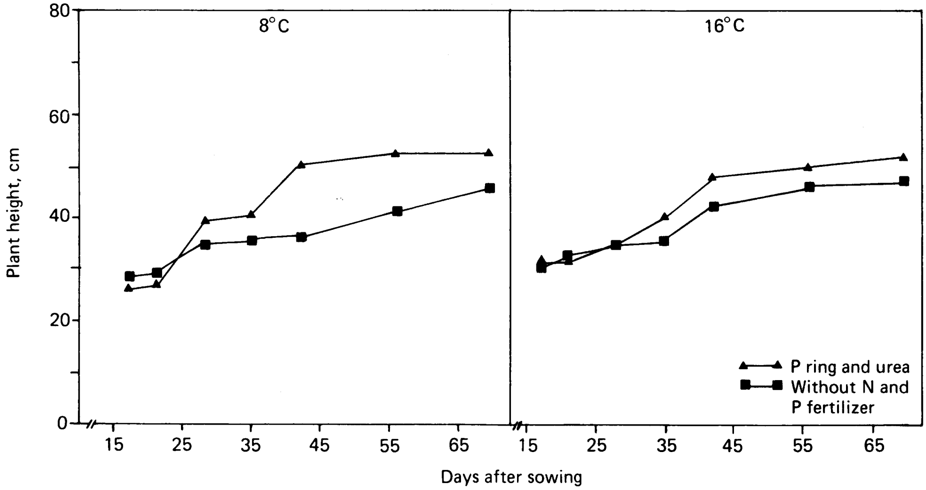

Figure 3. The height of Romany wheat variety when cultivated at low (8°C) and high (16°C) night temperature on volcanic soil with and without nitrogen (100 kg N/ha) and phosphorus (48 kg P/ha). P ring is the same as P banded. Mean value of 10 plants.

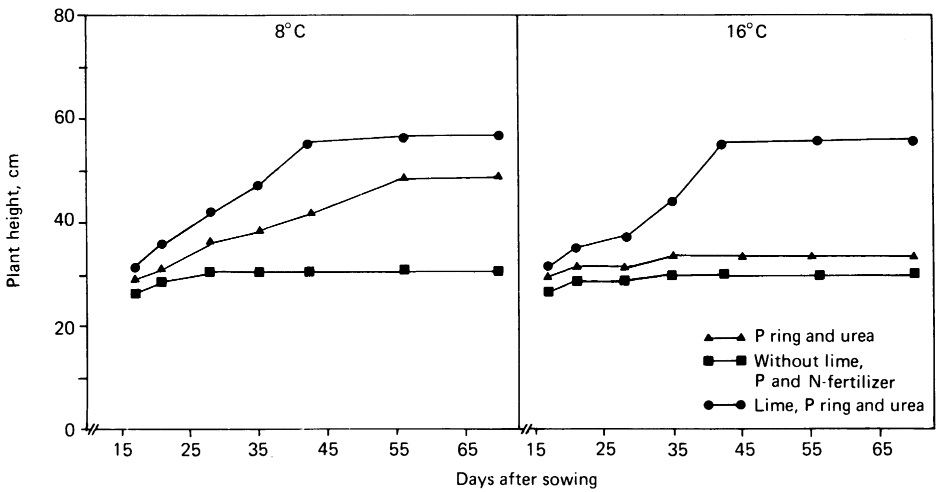

Figure 4. The height of Romany wheat variety when cultivated at low (8°C) and high (16°C) night temperature on ferralitic soil without and with different combinations of lime (4000 kg $CaCO_3$/ha), nitrogen (100 kg N/ha) and phosphorus (48 kg P/ha). P ring is the same as P banded. Mean value of 10 plants.

When the aluminium tolerant variety, PF 71131, was cultivated on volcanic soil, the two night temperatures had no effect on the growth of plants with optimal phosphorus conditions (Fig. 5). The growth of the control groups on the ferralitic soil was strongly reduced by both night temperatures (Fig. 6). It was clearly demon-

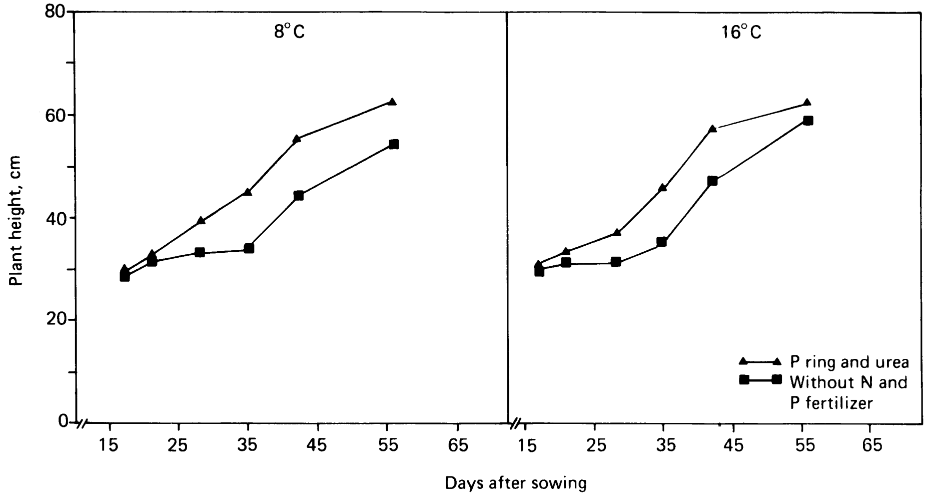

Figure 5. The height of PF 71131 wheat variety when cultivated at low (8°C) and high (16°C) night temperature on volcanic soil with and without nitrogen (100 kg N/ha) and phosphorus (48 kg P/ha). P ring is the same as P banded. Mean value of 10 plants.

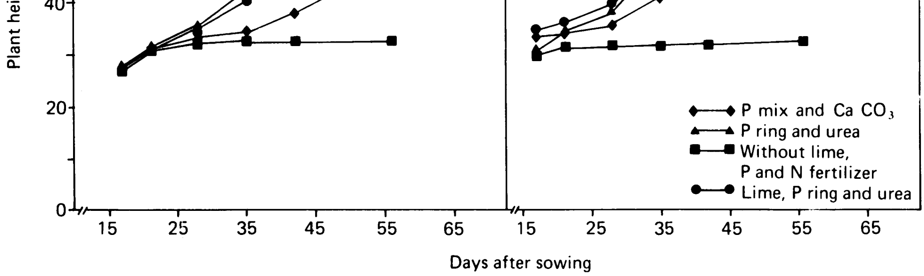

Figure 6. The height of PF 71131 wheat variety when cultivated at low (8°C) and high (16°C) night temperature on ferralitic soil, without and with different combinations of lime (4000 kg $CaCO_3$/ha), nitrogen (100 kg N/ha) and phosphorus (48 kg P/ha), mixed or banded (ring). Mean value of 10 plants.

strated that the high night temperature had a positive effect on the height of plants with the exception of the groups treated with a combination of lime, nitrogen and phosphorus or groups fertilized with phosphorus applied in a band, which showed a good growth rate at both night temperatures. (fig. 6, some data not shown.)

The production of straw (dry weight/pot) on volcanic soil was significantly affected by the temperature and the fertilizer treatment (Table 2). The low night temperature, nitrogen and phosphorus increased the straw yield, but the method of phosphorus application had no effect and no significant interaction were found.

Table 2. Significant main effects on straw yield of plants grown on volcanic soil.

Treatment	Straw yield, dry wt. g/pot
Night temperature:	
16°C	9.7
8°C	10.8
Nitrogen:	
0 kg/ha	9.2
100 kg/ha	11.3
Phosphorus:	
0 kg/ha	7.8
48 kg/ha, mixed	11.5
48 kg/ha, banded	11.4

When the wheat was cultivated on ferralitic soil, the straw yield was significantly affected by night temperature, lime and fertilizer type (Table 3). Low night temperature, nitrogen, phosphorus and lime increased the straw yield. The method of applying phosphorus to ferralitic soil was apparently an important factor for straw yield. The banded phosphorus produced a much higher yield than the mixed phosphorus.

Table 3. Significant main effects on straw yield of plants grown on ferralitic soil.

Treatment	Straw yield, dry wt. g/pot
Night temperature:	
16°C	9.6
8°C	10.4
Nitrogen:	
0 kg/ha	9.6
100 kg/ha	10.4
Phosphorus:	
0 kg/ha	5.6
48 kg/ha, mixed	9.9
48 kg/ha, banded	13.2
Lime:	
0 kg/ha	6.9
4000 kg/ha	13.2

Several significant interactions were also found by cultivation on ferralitic soil: night temperature × plant variety, N, P and lime treatments × plant variety and N, P and lime treatments × night temperature. The interaction, temperature × plant variety is shown in Table 4.

Table 4. The significant interaction, night temperature × plant variety, for straw yield (dry wt., g/pot) of plants grown on ferralitic soil.

Night temperature	Plant variety	
	Romany	PF 71131
16°C	8.3	10.9
8°C	11.1	9.7

Low night temperature increased the straw yield of the Romany variety by 34%, while the Al-tolerant variety gave a 10% reduction. When both soil types were evaluated together, a significant 3-way interaction was found, viz. soil type (without lime) × night temperature × plant variety (Table 5). It clearly shows that the Romany variety produced the highest straw yield at low night temperature regardless of soil type. On the whole the production was highest on volcanic soil when the soil was unlimed. The Al-tolerant variety, PF 71131, did not show the same temperature effect. When PF 71131 was cultivated on volcanic soil, the highest yield was produced at low night temperature, while the yield response on ferralitic soil was just the opposite.

Table 5. The significant interaction, soil type (without lime) × night temperature × plant variety, for straw yield (dry wt., g/pot).

Plant variety	Volcanic soil		Ferralitic soil	
	8°C	16°C	8°C	16°C
PF 71131	10.8	9.8	6.8	9.3
Romany	11.0	9.6	7.3	4.0

The number of ears produced was affected by temperature in the same way as vegetative plant development. When both soil types were evaluated together, significant interactions, such as plant variety × soil type (without lime) and plant variety × night temperature, were found (Tables 6 and 7). The Romany wheat variety was affected much more by soil type and night temperature than PF 71131.

Table 6. The significant interaction, plant variety × soil type (without lime), for number of ears per pot.

Plant variety	Soil type	
	Volcanic soil	Ferralitic soil
PF 71131	10.3	8.1
Romany	7.9	2.4

Table 7. The significant interaction, plant variety × night temperature for number of ears per pot.

Temperature	Plant variety	
	PF 71131	Romany
8°C	8.9	7.2
16°C	9.5	3.2

The main factors which affected the grain number per pot were plant variety, night temperature, phosphorus and lime (Table 8). On the volcanic soil the highest grain number was produced by the Al-tolerant variety, PF 71131, at low night temperature with added nitrogen and with P mixed. Banded phosphorus on the ferralitic soil was far more efficient than mixed phosphorus (Table 8).

Table 8. Significant main effects on the grain number per pot of wheat grown on volcanic and ferralitic soil.

Treatment	Soil type	
	Volcanic soil	Ferralitic soil
Plant variety:		
PF 71131	200	122
Romany	100	33
Night temperature:		
8°C	191	86
16°C	110	69
Nitrogen:		
0 kg/ha	135	125
100 kg/ha	165	141
Phosphorus:		
0 kg/ha	149	84
48 kg/ha, mixed	162	143
48 kg/ha, banded	139	181

The 1000 grain weight was unaffected by the temperature, plant variety and P, N and lime treatment on the volcanic soil. However, on the ferralitic soil these factors were significantly interdependent as shown by the 3-way interaction, N, P and lime treatment × plant variety × night temperature, in Table 9. Both plant varieties produced the highest 1000 grain weight at the low night temperature, although the general level for PF 71131 was higher. The low night temperature may have caused this increase by extending the filling period and reducing respiration. If both varieties are considered together, the grain weight was highest for the banded P treatment at both night temperatures.

Table 9. The significant interaction, plant variety × temperature × treatment, for the 1000 grain weight (g) of wheat grown on ferralitic soil.

Treatment	PF 71131		Romany	
	8°C	16°C	8°C	16°C
Nitrogen:				
0 kg/ha	20.7	17.6	13.5	10.1
100 kg/ha	23.9	20.1	15.1	10.3
Phosphorus:				
0 kg/ha	20.7	17.6	10.4	8.9
48 kg/ha, mixed	23.2	19.1	12.3	8.5
48 kg/ha, banded	27.5	22.9	19.6	13.1
Lime:				
0 kg/ha	22.7	19.2	11.3	4.3
4000 kg/ha	24.9	20.5	16.9	16.1

B. Grain yields, main effects and interactions

1. *Volcanic soil*

Night temperature, plant variety and nitrogen were the main factors significantly affecting grain yield on volcanic soil (Table 10). The Al-tolerant variety, PF 71131, produced the highest grain yield when it was cultivated at low night temperature or when fertilized with nitrogen (data not shown).

Table 10. Significant main effects on grain yield (dry wt., g/pot) of wheat grown on volcanic soil.

Treatment	Grain yield g/pot
Night temperature 16°C	2.6
» » 8°C	4.4
Variety Romany	2.2
» PF 71131	4.9
Nitrogen 0 kg/ha	3.1
» 100 kg/ha	4.0

Table 11 shows the interaction between night temperature and variety.

Table 11. The significant interaction, night temperature × wheat variety, for grain yield (dry wt., g/pot) of wheat grown on volcanic soil.

Night temperature	Variety	
	Romany	PF 71131
16°C	0.6	4.6
8°C	3.7	5.1

The results clearly show that Romany responded more strongly to high night temperature by producing a lower yield of grain than PF 71131. The lowest yield was produced by Romany with band placement of P and no N fertilizer. The highest yield was produced with the combination low night temperature × added phosphorus × added nitrogen (data not shown).

Table 12. The significant interaction, phosphorus (P) × night temperature, for grain yield (dry wt., g/pot) of wheat grown on volcanic soil.

Phosphorus treatment	Night temperature	
	16°C	8°C
0 kg/ha	2.9	4.1
48 kg/ha, mixed	2.5	4.7
48 kg/ha, banded	2.4	4.5

Table 12 shows that the yields were reduced with P application at 16°C, while they were increased with the addition of P fertilizer at 8°C.

2. *Ferralitic soil*

Night temperature, plant variety, P and lime were the main factors which significantly affected plants cultivated on ferralitic soil (Table 13).

Table 13. Significant main effects on grain yield (dry wt., g/pot) of wheat grown on ferralitic soil.

Treatment	Grain yield g/pot
Night temperature:	
16°C	2.2
8°C	3.6
Plant variety:	
Romany	1.7
PF 71131	4.0
Phosphorus:	
0 kg/ha	1.6
48 kg/ha mixed	2.9
48 kg/ha banded	4.1
Lime:	
0 kg/ha	1.7
4000 kg/ha	4.0

The interesting features are the strong effect of the lime and phosphorus treatments. There was a clear yield increase when P was mixed with the soil and a further increase when P at the same concentration was placed in a band (Table 13).

Table 14. The significant interaction, phosphorus (P) × night temperature, for grain yield (dry wt., g/pot) of wheat grown on ferralitic soil.

Phosphorus treatment	Night temperature	
	16°C	8°C
0 kg/ha	1.1	2.0
48 kg/ha, mixed	2.5	3.3
48 kg/ha, banded	2.8	5.4

Table 14 shows that mixed P caused about the same yield increase (1.3–1.4 g/pot) at both temperatures, while the response for band placement was twice as high for the low night temperatures as for the high one. The yield increase caused by lime was approximately 1.4 g/pot at 16°C and 3.1 g/pot at 8°C (data not shown). Finally there was an interesting 3-way interaction, variety × lime × P, as demonstrated in Table 15.

Table 15. The significant interaction, variety × lime × P, for grain yield (dry wt., g/pot) of wheat grown on ferralitic soil.

Phosphorus treatment	Romany		PF 71131	
	0 t/ha	4 t/ha	0 t/ha	4 t/ha
P, 0 kg/ha	0.2	1.8	0.4	3.8
P, 48 kg/ha mixed	0.03	3.4	2.5	5.8
P, 48 kg/ha banded	1.6	3.3	5.7	5.9

These results show that if limed, the application method of P is without significance, while the band placement is very important when not limed.

3. *The volcanic and ferralitic soils evaluated together*

It may be of interest to study the interactions, night temperature × soil, variety × soil, P × soil, and N × soil, which were found to be significant. Table 16 shows the first of these interactions.

Table 16. The significant interaction, night temperature × soil type (without lime), for grain yield (dry wt., g/pot).

Soil	Night temperature	
	16°C	8°C
Ferralitic	1.4	2.0
Volcanic	2.6	4.4

The yield increase produced at the low night temperature was 0.6 g/pot on the ferralitic soil (43%) and 1.8 g/pot on the volcanic soil (69%).

Concerning the interaction of variety × soil (without lime), the PF 71131 variety produced higher yields than Romany, 2.3 g/pot on the ferralitic soil and 2.7 g/pot on the volcanic soil (data not shown).

Table 17. The significant interaction, phosphorus × soil type (without lime), for grain yield (dry wt., g/pot).

Phosphorus treatment	Soil Type	
	Ferralitic	Volcanic
0 kg/ha	0.3	3.6
48 kg/ha, mixed	1.3	3.6
48 kg/ha, banded	3.6	3.5

Table 17 demonstrates the interaction P × soil and the large yield increase produced by the band placement of P on the ferralitic soil, while there was no phosphorus effect on the volcanic soil. The N × soil (without lime) interaction showed that while the yield increase for nitrogen was only 0.1 g/pot on the ferralitic soil, it was 0.9 g/pot on the volcanic soil (data not shown).

While the band placement of P seems to be of no use on the volcanic soil, it is of great significance on the ferralitic soil, except when limed. Finally it should be mentioned that the very highest yield was produced on limed ferralitic soil at low night temperature, which surpassed the highest yield produced on volcanic, unlimed soil.

C. Uptake of plant nutrients

The above ground parts were analyzed and the amounts of the plant nutrients, N, P, K, Ca, and Mg, were calculated as mg/pot by multiplying the concentrations found in the dry weight of the grain and straw with the yield per pot. The percentages of nitrogen and phosphorus were higher in this material than has generally been measured in wheat, especially in the grain, where the N content was 3.7% and the P content 0.6% on a dry weight basis. Normally 0.15–0.54 percent P is found in the grain and 0.03–0.17 percent P in the straw (Beeson 1941). Many of the grains had a wrinkled appearance due to a low starch content. Since the aleuron layer and the embryo contain considerable protein, the N and P concentration tended to be high. The average N concentration in the straw was 1.1%.

1. *Uptake of nitrogen*

N uptake on volcanic soil was usually higher at low night temperature than at high, higher for PF 71131 variety than for Romany, and as expected, higher with N fertilization than without N, as demonstrated by Table 18.

Table 18. Significant main effects on nitrogen uptake (mg/pot) of wheat grown on volcanic soil.

Treatment	Nitrogen mg/pot
Night temperature:	
16°C	187
8°C	208
Variety:	
Romany	185
PF 71131	210
Nitrogen:	
0 kg/ha	157
100 kg/ha	237

The nitrogen addition was 150 mg/pot. A considerable mineralization of organic N occurred in the soil as shown by the O N treatment. The increased uptake by plants receiving N fertilizer corresponds to 54% of the N added. The interaction of the three factors night temperature × variety × N was also significant as demonstrated in Table 19.

Table 19. The significant interaction, night temperature × variety × N, for nitrogen uptake (mg/pot) of wheat grown on volcanic soil.

Variety	Nitrogen kg/ha	Night temperature	
		16°C	8°C
Romany	0	132	171
»	100	189	248
PF 71131	0	160	166
»	100	266	248

While Romany was slightly more influenced by night temperature at 100 kg N than at 0 kg N, the PF 71131 variety was influenced very little by night temperature. This indicated that the root activity of the Romany variety or the root absorbing capacity for nutrients must have been limited by high night temperature.

The effect of P treatments on N uptake of the two varieties was dependent on the N level (Table 20).

Table 20. The significant interaction, N × P × variety, for nitrogen uptake (mg/pot) of wheat grown on volcanic soil.

Nitrogen kg/ha	Phorphorus kg/ha	Variety	
		Romany	PF 71131
0	0	149	162
0	48 (mixed)	157	167
0	48 (banded)	148	161
100	0	193	302
100	48 (mixed)	218	228
100	48 (banded)	245	251

The response of both wheat varieties to P treatment without N was small (Table 20). At 100 kg N per hectare the Romany variety increased its uptake in the order of no P to mixed P to banded P, while the Al-tolerant variety, PF 71131, had the highest uptake at O P.

The N uptake on the ferralitic soil was significantly effected by night temperature, plant variety, P fertilizer, N fertilizer and liming as shown in Table 21.

Table 21. Significant main effects on nitrogen uptake (mg/pot) of wheat grown on ferralitic soil.

Treatment	Nitrogen mg/pot
Night temperature:	
16°C	207
8°C	228
Variety:	
Romany	176
PF 71131	259
Phosphorus:	
0 kg/ha	154
48 kg/ha (mixed)	224
48 kg/ha (banded)	275
Nitrogen:	
0 kg/ha	195
100 kg/ha	240
Lime:	
0 kg/ha	156
4000 kg/ha	279

The highest level of N uptake occurred when the soil was treated with lime and banded phosphorus. Furthermore, the N uptake of PF 71131 was much higher than for Romany. There were several strong interactions. N uptake at 8°C night temperature was about 40 mg/pot higher than at 16°C when the plants were treated with 100 kg N per hectare. No night temperature effect was observed at 0 kg N. At the high night temperature the N uptake by PF 71131 was approximately twice that of Romany, while at the low temperature the difference was 18%. A comparison of nitrogen uptake on limed ferralitic soil showed an increase of 74% when no N was added and by 84% with 100 kg N/ha treatment (data not shown).

Table 22. The significant interaction, lime × phosphorus × plant variety, for nitrogen uptake (mg/pot) of wheat grown on ferralitic soil.

Lime kg/ha	Phorphorus kg/ha	Variety	
		Romany	PF 71131
0	0	54	96
0	48 (mixed)	74	215
0	48 (banded)	184	310
4000	0	210	264
4000	48 (mixed)	266	340
4000	48 (banded)	274	330

Table 22 shows that the Al-tolerant variety, PF 71131, had a high N uptake when P was banded, even without lime and about the same N uptake when P mixed and P banded were in combination with lime. The Romany variety did not absorb high N amounts on unlimed soil, except when P was applied in a band.

A comparision of volcanic and ferralitic soil shows that N uptake was 27 % higher for plants grown on the former. As with yields there is a very strong interaction between soil and P as demonstrated in Table 23.

Table 23. The significant interaction, phosphorus × soil (unlimed), for N uptake (mg/pot).

Phosphorus	Soil	
	Ferralitic	Volcanic
0 kg/ha	75	198
48 kg/ha (mixed)	145	192
48 kg/ha (banded)	247	201

While the effect of the P treatment on the N uptake of wheat grown on volcanic soil was negligible, it was very high on ferralitic soil. It should be remembered that the highest N uptake occurred on ferralitic soil with the combination low night temperature × banded P × added nitrogen, when comparing only unlimed soils.

2. *Uptake of phosphorus*

The main factors affecting the phosphorus uptake of wheat grown on volcanic soil are shown in Table 24.

Table 24. Significant main effects on phosphorus uptake (mg/pot) of wheat grown on volcanic soil.

Treatment	Phosphorus mg/pot
Night temperature:	
16°C	25
8°C	29
Variety:	
Romany	24
PF 71131	30
Phosphorus:	
0 kg/ha	25
48 kg/ha (mixed)	27
48 kg/ha (banded)	28
Nitrogen:	
0 kg/ha	24
100 kg/ha	30

The effects of night temperature, variety and nitrogen were significant, while the effect of P was not (Table 24). However, the increased uptake by Romany in response to P fertilization was significant. The three-way interaction, night temperature × variety × P, showed that the lowest uptake was found for the combination O P × 16°C night temperature by Romany (15 mg P/pot), while the uptake of the Al-tolerant variety, PF 71131, was generally high, except with O P at 8°C night temperature. The interaction, night temperature × variety × N, was significant. Romany had the highest uptake at low night temperature and 100 kg N/ha, while the uptake of PF 71131 was highest at high nights temperature and 100 kg N/ha. Furthermore, Romany had the highest uptake with banded P at 100 kg N/ha, while PF 71131 was influenced very little by P treatment at 100 kg N/ha (data not shown).

Table 25 shows the main factors which significantly affected phosphorus uptake on ferralitic soil.

Table 25. Significant main effects on phosphorus uptake (mg/pot) of wheat grown on ferralitic soil.

Treatment	Phosphorus mg/pot
Night temperature:	
16°C	23
8°C	25
Variety:	
Romany	19
PF 71131	29
Phosphorus:	
0 kg/ha	14
48 kg/ha (mixed)	24
48 kg/ha (banded)	34
Lime:	
0 kg/ha	16
4000 kg/ha	32

The data show that plant variety, P and lime treatments resulted in a large increase in P uptake. There was a strong interaction between night temperature and wheat variety as shown in Table 26.

Table 26. The significant interaction, night temperature × variety, for phosphorus uptake (mg/pot) of wheat grown on ferralitic soil.

Night temperature	Variety	
	Romany	PF 71131
16°C	15	31
8°C	23	27

While low temperature resulted in an increase in P uptake by the Romany variety, it was the opposite for the Al-tolerant variety, PF 71131. As for the yield results and the N uptake it seems that the PF 71131 variety is Al-tolerant because its root absorbing capacity is increased by the warm nights. Thus, it might also be characterized as a heat tolerant variety.

An interesting interaction of factors, variety × P × lime, is shown in Table 27.

Table 27. The significant interaction, lime × P × variety, for phosphorus uptake (mg/pot) of wheat grown on ferralitic soil.

Lime (kg/ha)	Phosphorus (kg/ha)	Variety	
		Romany	PF 71131
0	0	3	7
0	48 (mixed)	5	20
0	48 (banded)	22	41
4000	0	20	27
4000	48 (mixed)	32	40
4000	48 (banded)	32	40

It appears that the Romany variety requires both lime and P in order to obtain high P uptake. PF 71131 requires only banded P to obtain the same uptake level as with lime and P.

If we consider both soils together some interesting features become evident. While the average P uptake for the unlimed ferralitic soil was 16 mg/pot, it was 27 for the volcanic soil. The average uptake on the limed ferralitic soil was 32 mg/pot. However, looking again at the unlimed soils the highest uptake on the ferralitic soil was 41 mg/pot for the combination, PF 71131 variety × banded P, while the highest P uptake on the volcanic soil was 31 mg/pot for the same combination of factors.

It did not matter whether P was banded or mixed on the volcanic soil, while this was a decisive factor on the ferralitic soil.

3. *Uptake of calcium*

The main effects of treatment on the uptake of calcium by wheat grown on volcanic soil are presented in Table 28. There are no dramatic effects on Ca uptake, except for the N treatment. However, the P and plant variety effects were also significant. The effect of night temperature was not significant, because the varieties reacted differently, Romany had about 3 mg/pot higher uptake at the low night temperature, while the Al-tolerant variety, PF 71131, did not respond to temperature (data not shown).

Table 28. Significant main effects on calcium uptake (mg/pot) of wheat grown on volcanic soil.

Treatment	Calcium mg/pot
Night temperature:	
16°C	20
8°C	21
Variety:	
Romany	23
PF 71131	19
Phosphorus:	
0 kg/ha	19
48 kg/ha (mixed)	22
48 kg/ha (banded)	22
Nitrogen:	
0 kg/ha	18
100 kg/ha	24

The main effects of treatment on calcium uptake of wheat grown on ferralitic soil are given in Table 29. The Ca added with the lime treatment correponded to 2.4 g/pot. The difference in Ca uptake is, as expected, highest with lime treatment. Next to this effect, the P treatments have resulted in considerable effects. In addition to these two, the variety and nitrogen effects were significant.

There was a strong interaction of variety × night temperature when the wheat was cultivated on ferralitic soil. At the high night temperature the rate of Ca uptake was 18% higher by the PF 71131 variety than by Romany, while Romany had a 33% higher uptake than PF 71131 at low night temperature. The Ca uptake of the Al-tolerant variety, PF 71131, at its optimal high night temperature was about 9% lower than that of Romany during its cool nights (data not shown).

Table 29. Significant main effects on calcium uptake (mg/pot) of wheat grown on ferralitic soil.

Treatment	Calcium mg/pot
Night temperature:	
16°C	30
8°C	31
Variety:	
Romany	32
PF 71131	30
Phosphorus:	
0 kg/ha	21
48 kg/ha (mixed)	32
48 kg/ha (banded)	39
Nitrogen:	
0 kg/ha	28
100 kg/ha	34
Lime:	
0 kg/ha	17
4000 kg/ha	44

Nitrogen application to ferralitic soil increased the Ca uptake, and this increase was about 33% at low night temperature, while it was about 10% at high night temperature (data not shown). As expected the interaction, P × lime, was significant as demonstrated by Table 30.

Table 30. The significant interaction, phosphorus × lime, for calcium uptake (mg/pot) of wheat grown on ferralitic soil.

Phosphorus	Lime	
	0 t/ha	4 t/ha
0 kg/ha	9	34
48 kg/ha (mixed)	16	48
48 kg/ha (banded)	28	50

Without lime the effect of banding is large, while this is not so with lime. The very highest Ca uptake, 65 mg/pot, was found with the combination, banded P × lime × nitrogen, by the Romany variety. The lowest Ca uptake was also by Romany with the combination, 0 P × 0 N × 0 lime, and the amount was 6 mg/pot, i.e. tenth of the highest (data not shown).

4. *Magnesium uptake*

Magnesium uptake by wheat grown on volcanic soil was strongly affected by N, but plant variety and phosphorus were also significant factors (Table 31). On the ferralitic soil the difference between plant variety was more pronounced, as the Mg uptake by the PF 71131 variety was about 6 mg/pot higher than the Romany variety. The effects of P fertilizer on Mg uptake was greater on the ferralitic than on the volcanic soil, while the effect of nitrogen was less. Furthermore, liming caused a pronounced increase in uptake when applied to ferralitic soil. Romany grown on ferralitic soil responded positively to liming, regardless of night temperature. Liming strongly increased the Mg uptake of the Al-tolerant variety, PF 71131, but only at the low night temperature. PF 71131 cultivated on unlimed plots had the highest Mg uptake at high night temperature, while Romany had the highest uptake at low night temperature.

Table 31. Significant main effects on magnesium uptake (mg/pot) of wheat grown on volcanic and ferralitic soils. The volcanic soil was not limed.

Treatment	Soil	
	Volcanic	Ferralitic
Night temperature:		
16°C	23	17
8°C	24	18
Variety:		
Romany	22	15
PF 71131	25	21
Phosphorus:		
0 kg/ha	20	11
48 kg/ha (mixed)	24	19
48 kg/ha (banded)	25	24
Nitrogen:		
0 kg/ha	19	16
100 kg/ha	27	19
Lime:		
0 kg/ha		13
4000 kg/ha		22

D. Soil analysis after the growing season

The limed ferralitic soil had a pH of 5.5 (H_2O) after the first growing season, and a Ca-AL number of 75. The unlimed ferralitic soil had a pH of 5.0 and a Ca-AL of 22. The N fertilized treatment resulted in a pH decrease of 0.2 units on account of the acidifying effect of NH_4 fertilizers.

E. Discussion

The height of plants of the Romany variety cultivated on volcanic soil showed no night temperature effect. Either the same growth rate was found, or an extended growth period at low night temperature resulted in the same height of plants within the different treatment groups. Nevertheless, it was clearly demonstrated that low night temperature increased the height of plants cultivated on ferralitic soil with phosphorus applied in a band, added separately, or in combination with urea or lime. Others have also demonstrated that wheat plants grow taller at lower temperature (Campbell & Read 1968, Evans & Wardlaw 1978). Campbell & Davidson (1979) have pointed out that the dry matter accumulation in the vegetative parts of wheat plants was inversely related to temperature. In agreement with these results the dry weight of the straw was higher on both soils at the low night tempertature.

The height of plants was not affected by the night temperature when the PF 71131 variety was cultivated on volcanic or ferralitic soil with optimal phosphorus conditions. PF 71131 varity grown on ferralitic soil with phosphorus as a limiting factor produced significantly higher wheat plants at the high night temperature. Even the vegetative production was higher at high night temperature. The PF 71131 variety from the Brazilian breeding programme was adapted to soils with low pH-value, high exchangeable aluminium content and low available soil phosphorus. Thus, this aluminium tolerant wheat variety either tolerates a higher concentration of aluminium or may have a more effective uptake of phosphorus. The relationship between temperature, root growth and nutrient uptake could explain a higher phosphorus uptake and a better growth at the high night temperature.

The low night temperature increased the grain yield of both wheat varieties, with the most dramatic response by the Romany variety. The high night temperature reduced the number of ears, the number of grain and the 1000-grain weight of Romany. Several investigations have shown the positive effect of lower temperature on the grain yield, since the higher temperatures hasten senescence of the wheat plant and shorten the growth period (Thorne *et al.* 1968, Sofield *et al.* 1974, Spietz 1974, Ford & Thorne 1975, Spietz 1977, Campbell *et al.* 1981). Unlike these studies, our experiments only involved a difference in night temperature.

The increased yield of PF 71131 may have been due to a reduction in respiration rate, growth rate and a longer filling period, since only small variations in the number of ears and grain were found, but the 1000-grain weight was higher at the low night temperature. On the other hand, the increase in yield of the Romany variety was too high to be explained by a reduction in respiration, longer grain filling period and higher 1000-grain weight. The low night temperature seemed to directly affect the number of ears, the number of flowers and seed setting. Reduced seed setting due to an increase in temperature has been reported for two Norwegian wheat varieties, while a Mexican variety did not respond to the higher temperatures. In these studies the different temperatures were constant during the day and throughout the growing season (Kolderup 1970, 1975), unlike the experiments in the present study where different day and night temperatures were used.

The two wheat varieties, Romany and PF 71131, are quite different in their response to the night temperature. It seems as though PF 71131 is addapted during the breeding programme to a wider range of climatic conditions, especially to the temperature and to the aluminium concentration in the soil. The grain yield of the

Romany variety is limited by the temperature. A high yield requires a low night temperature.

The average yields, as well as the average nutrient content of the soil and nutrient uptake by plants are on the average higher for the volcanic soil than for the ferralitic soil. However, if we consider special treatment combinations, we find in many cases higher dry matter yields, as well as higher nutrient uptake by plants cultivated on the ferralitic soil. The limed ferralitic soil, thus, has produced higher dry matter yields and greater nutrient uptake of nitrogen, phosphorus and calcium than the unlimed volcanic soil.

It must be remembered that the ferralitic soil was given adequate amounts of secondary nutrients and micronutrients not included in the experimental treatments. Furthermore, the nutrients storage capacity is very limited in the ferralitic soil. Still, one cannot avoid noting that the plant growth potential is higher on ferralitic soils, if treated according to needs. It may be stated that these soils have a low buffering capacity, and once inherent toxic materials are removed, they must be treated similar to sandy soils with regard to soil fertility. The soils are high in clay, but have a low charge.

Adaptation of agronomy procedures to climate and soil conditions is a necessary part of agriculture. Plant breeding generally involves stages with selection procedures. It is natural that the climatic and soil factors will exert a selection pressure as soon as the plants are exposed to field conditions in the breeding institute. Previously, wheat breeding often took place under temperate climate or in tropical highlands, and in most cases the selection was carried out on non-ferralitic soils. Therefore, it is not surprising that wheat varieties developed under hot, tropical conditions on ferralitic soils are better adapted to these conditons than the old varieties.

Finally, a very important point to be considered, is the usefulness of information obtained from phytotron experiments. The phytotron is a facility that is used to produce specific climatic conditions which allows for the study of the effect of different climatic parameters on the development and growth of plants. Since all experiments are performed under controlled conditions with only one factor varied per experiment, the causal relationship is easier to discover. Furthermore, these results can be used to support field studies, but care must be taken when making extrapolations. The inferences made in this study from experiments using different fertilizers in combination with low and high night temperature can be used to develop appropriate wheat growing practices. These results could not have been obtained in field experiments.

IV. SUMMARY

A pot experiment with wheat (*Triticum aestivum* L.) was carried out on a ferralitic and a volcanic soil from the plateau of Antsirabe, Madagascar in the Phytotron at the University of Oslo, as a joint project between its Department of Biology and the Department of Soil Fertility and Management of the Agricultural University of Norway.

The experiment included two varieties, one Al-tolerant variety from Brazil (PF 71131), and one variety from the Kenya highlands (Romany). The latter is a common

wheat variety in the Antsirabe region. These were treated with nitrogen (0 and 100 kg/ha N in urea), phosphorus (0 and 48 kg/ha P mixed or banded; both added as triple superphosphate), lime (0 and 4 t/ha of $CaCO_3$), and minimum night temperature (8°C and 16°C). Treatment of volcanic soil did not include liming. All treatments were given in addition to other macronutrients (Mg, K and S) and micronutrients (B, Cu, Zn, and Mo). The maximum day temperature was 32°C, light irradiation 65 W/m^2, (25,000 lux) and 12 hr daylength.

The results can be summarized as follows. When the Romany variety was grown on the ferralitic soil a decrease in night temperature from 16°C to 8°C noticeably increased the number of ears produced. At high night temperature (16°C) the number of ears decreased to almost nil when the ferralitic soil was not limed. The number of grains per pot produced by the Romany variety was higher at low night temperature. The Al-tolerant variety, PF 71131, was unaffected by night temperature with regard to grain number, but at low night temperature the 1000-grain weight increased on the ferralitic soil. The low night temperature resulted in a strong increase in grain yield for Romany grown on volcanic soil, while only a slight increase in yield was produced by PF 71131.

Phosphorus treatments increased the yields on the ferralitic soils receiving mixed and banded P by 165 and 270%, respectively, when wheat was grown at low night temperature. The yields were much lower and the differences between the two P application methods were quite small at the high night temperature. Furthermore, while both wheat varieties grown on unlimed soil produced the highest yield when the soil was fertilized with banded P, the difference between the two methods of P application disappeared with liming. PF 71131 produced top yields with the combination, unlimed × banded P, which was equal to that obtained with lime × mixed P and lime × banded P. Romany produced very low yields without lime, although the combination unlimed × banded P resulted in about the same yield as lime × O P.

Nitrogen uptake (grain + straw) by both wheat varieties grown on volcanic soil at low night temperature was 45–50% higher at 100 kg/ha N as compared to 0 kg/ha N. The N uptake by Romany was much lower than PF 71131 with high night temperature. Furthermore, Romany increased its uptake with P application, while PF 71131 did not. On the ferralitic soil the greatest increases in N uptake by both wheat varieties resulted from the combined lime and P additions, but PF 71131 also had a high uptake with banded P on unlimed soil. The P uptake on volcanic soil was not dependent upon P fertilization. It was highest for PF 71131 treated with 100 kg/ha N. On the ferralitic soil Romany had a much higher P uptake at low, than at high night temperature, while this was not the case for PF 71131. The high P uptake by Romany corresponded to the combined application of lime and P. PF 71131, which had a higher P uptake at all lime and P levels, required only banded P.

The calcium uptake by wheat grown on volcanic soil was influenced very little by other treatments, except fertilization with N, which increased the uptake. On the ferralitic soil the calcium uptake increased strongly with the addition of P and lime. At the high night temperature PF 71131 had a 18% higher Ca uptake than Romany, while at the low night temperature Romany had a 33% higher uptake than the other. The effect of banding P was high when lime was not added.

The uptake of magnesium was highest for PF 71131, higher with than without P (highest with banded P), higher with than without N, and on ferralitic soil it was higher with than without lime.

V. SAMMENDRAG

Et dyrkningsforsøk med hvete (*Triticum aestivum* L.) ble utført ved Fytotronanlegget, Universitetet i Oslo, i potter med ferralittisk og vulkansk jord fra høysletteområdet ved Antsirabe på Madagaskar. Dette var et samarbeidsprosjekt mellom Institutt for biologi, Universitetet i Oslo og Institutt for jordkultur, Norges landbrukshøgskole.

Det ble gjort forsøk med to hvetesorter, en Al-tolerant sort fra Brasil (PF 71131) og en sort fra Kenya (Romany). Den siste er en vanlig hvetesort i Antsirabe området. I forsøket inngikk følgende parametre: nitrogen (0 og 100 kg/ha, N som urea), fosfor (0 og 48 kg/ha, P blandet og plassert i ring, P som trippel superfosfat), kalk (0 og 4 t/ha av $CaCO_3$) og minimumstemperaturer om natten (8°C og 16°C). Den vulkanske jorden ble ikke kalket. Alle behandlingsleddene ble grunngjødslet med makroelementene Mg, K og S og mikroelementene B, Cu, Zn og Mo. Maksimumstemperaturen om dagen var 32°C, lysintensiteten 65 W/m^2 (25 000 lux) og daglengden 12 timer.

Følgende sammenfatning av resultatene kan gis. Det ble funnet en markert økning i antall aks når minimumstemperaturen om natten sank fra 16°C til 8°C og Romany hvetesorten ble dyrket på ferralittisk jord. Ved høy nattemperatur (16°C) ble antall aks redusert til nesten null når jorden ikke ble kalket. Det samme forholdet ble funnet for antall korn pr. potte. Den Al-tolerante hvetesorten, PF 71131, viste ingen virkning av lav nattemperatur på antall korn, men 1000-kornvekten økte. Lav temperatur om natten resulterte også i stor økning i kornavlingen når Romany sorten ble dyrket på vulkansk jord, men det ble bare funnet en liten økning i avlingen for PF 71131 sorten.

Fosforbehandlingene, blandet og i ring økte avlingene henholdsvis med 165% og 270% når hveten ble dyrket ved lav nattemperatur og på ferralittisk jord. Avlingene var mindre og forskjellen mellom de to tilførselsmetodene for fosfor meget små ved høy nattemperatur. Men når begge hvetesortene ble dyrket på ferralittisk jord uten kalk, ble den høyeste avlingen funnet når fosfor ble lagt i ring. Denne positive virkningen av tilførselsmetoden for fosfor forsvant når jorden ble kalket. Behandlingskombinasjonene, ukalket × P ring, kalk × P blandet og kalk × P ring ga den samme høye avlingen for PF 71131 sorten. For Romany sorten ga behandlingskombinasjonene, ukalket × P ring og kalk × OP omtrent den samme avlingen, selvom denne sorten generelt ga meget lave avlinger når jorden ikke var kalket.

Nitrogenopptaket (korn + halm) var 45–50% høyere ved 100 kg N/ha enn 0 kg N/ha for begge hvetesortene når de ble dyrket ved lav nattemperatur og på vulkansk jord. Ved sammenlikning av nitrogenopptaket ved høy nattemperatur, hadde PF 71131 et mye høyere opptak enn Romany. Men i motsetning til PF 71131 økte Romany sitt nitrogenopptak ved fosforgjødsling. Når hveten ble dyrket på ferralittisk jord, ble den største økningen i nitrogenopptaket for begge hvetesortene funnet for kombinasjonen, kalk × P. Men det viste seg at sorten PF 71131 hadde et høyt nitrogenopptak på ukalket jord med fosfor lagt i ring.

På den vulkanske jorden var fosforopptaket uavhengig av tilsetningsmåten for fosfor, og det var høyest for PF 71131 når 100 kg N/ha var tilsatt. Dyrkning av Romany sorten på ferralittisk jord ga som resultat at fosforopptaket var mye høyere ved lav enn ved høy nattemperatur, mens den samme temperaturavhengighet ikke ble funnet for PF 71131. Kombinasjonen kalk × P ga et høyt fosforopptak for

Romany, men høyere fosforopptak ble funnet for PF 71131 ved kalk og fosfor tilsettning eller bare fosfor lagt i ring.

Når hveten ble dyrket på vulkansk jord ble kalsiumopptaket lite berørt av de forskjellige behandlingene unntatt ved nitrogentilsetning som økte opptaket. På den ferralittiske jorden økte kalsiumopptaket sterkt med tilsetning av kalk og fosfor. Ved høy nattemperatur hadde PF 71131 18% høyere opptak av Ca enn Romany, mens det motsatte forhold (33%) ble funnet ved lav nattemperatur. Stor effekt av fosfor plassert i ring ble vist når jorden ikke var kalket.

Opptaket av magnesium var høyest for PF 71131 og høyere med enn uten fosfor (høyest med P ring) og med nitrogen. På ferralittisk jord økte kalkingen magnesiumopptaket.

VI. ACKNOWLEDGEMENT

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VII. REFERENCES

ALSTON, A.M., 1976. Effects of depth of fertilizer placement on wheat grown under three water regimes. Aust. J. of Agric. Res. 27:1-10.

BATTISTINI, R. & G.R. RICHARD-VINDARD, 1972. Biography and ecology in Madagascar. Vol. 21, Dr. W. Junk B.V., Publ., Haag.

BEESON, K.C., 1941. The mineral composition of crops with particular reference to the soils in which they were grown. USDA Misc. Publ. No. 369.

BJOR, T., 1975. La Culture du Blé, saison pluviale 1975.

- 1980. Communication personell (pas publié). Calculations des résultats expérimentaux sur le blé 1978-1979, á FIFAMANOR, Antsirabe.

BOYER, J., 1972. Soil studies in French-speaking tropical Africa. Soils of the humid tropics. Committee on Tropical Soils. Agricultural Board. National Research Council. Natl. Acad. of Sciences, Washington, D.C.: 206-208.

- 1982. Les sols ferrallittiques. Tome X. Facteurs de Fertilité et utilisation des sols. ORSTOM, Paris Initiations-Documentations Techniques No. 52, 384 pp.

BREMNER, J.N., 1965. Methods of soil analysis. In: C.A. Black, 1965 Ser. Agronomy No. 9, Am. Soc. Agron. Vol 2: 1185-1191 and 1339-1341.

CACKETT, K.E. & WALL, P.C., 1971. The effects of altitude and season length on the growth and yield of wheat (Triticum aestivum) in Rhodesia. Rhodesia J.agric.Res. 9: 107-120.

CAMPBELL, C.A. & READ, D.W.L., 1968. Influence of air temperature, light intensity and soil moisture on the growth, yield and some growth analysis characteristics of Chinook wheat grown in the growth chamber. Can. J. Plant Sci. 48:299-311.

CAMPBELL, C.A. & DAVIDSON, H.R., 1979. Effect of temperature nitrogen fertilization and moisture stress on growth, assimilate distribution and moisture use by Manitou spring wheat. Can. J. Plant Sci. 59:603-626.

CAMPBELL, C.A., DAVIDSON, H.R. & WINKLEMAN, C.E., 1981. Effect of nitrogen, temperature, growth stage and duration of moisture stress on yield components and protein content of Manitou spring wheat. Can. J. Plant Sci. 61:549-563.

CANNEL, R.Q., 1969. The tillering pattern in barley varieties. The effect of temperature, light intensity and daylength on the frequency of occurrence of the coleoptile node and second tillers in barley. J.Agric.Sci., Cambridge. 71: 423-35.

CHOUBERT, G. & FAURE-MURET, A., 1976. Atlas Geologique du Monde. UNESCO, Paris.

COBRA NETTO, A., CHIMENTI JR., H., FINDTI, D., 1977. Efeito do aluminio trocavel na producâo de trigo (var. Sonora 63). Escola Superior de Agricultura «Luiz de Queiroz». Piracicaba, Sâo Paulo, Brazil. Revista de Agricultura. Piracicaba, Brazil. 52(4):179-182.

DUDAL, R., 1977. Plant nutrient relationships in major soil regimes. Proc. Int. Seminar on Soil Environment and Fertility Management in Intensive Agriculture. Tokyo (1979): 78-88.

EGNÉR, H., RIEHM, H. & DOMINGO, W.R., 1960. Untersuchungen über die chemische Bodenanalyse als Grundlage für die Beurteilung des Nährstoffzustandes der Böden. II. Chemishe Etraktionsmethoden für Phosphor- und Kalsiumbestimmung. Kungl. Lant. br. högsk. Ann. 26: 199-215.

ELONEN, P. 1971. Particle analysis of soil. Acta Agralia Fennica 122. 122 p.

EVANS, L.T. & WARDLAW, T.F., 1976. Aspects of the comparative physiology of grain yield in cereals. Adv. Agron. 28:301-359.

FAO-UNESCO, 1974. Soil map of the world, 1:500,000. Vol. I. Legend. Paris.

FORD, M.A. & THORNE, G.N., 1975. Effects of variation in temperature and light intensity at different times on growth and yield of spring wheat. Ann. Appl. Biol. 80:283-299.

FRIEND, D.J.C., 1966. The effects of light and temperature on the growth of cereals. In: The growth of cereals and grasses. Hilthorpe, F.L. and Ivins, J.D. (eds.). Butterworths, London, p. 359.

GARGANTINI, H., 1974. Effects of particle size, forms and quantities of amendments on soil acidity Bragantia (Sâo Paulo, Brasil) 33:87-96.

GOEDERT, W.J., LOBATO, E. & RESENDSE, M., 1982. Management of tropical soils and world food prospects. In: «Whither Soil Research»: 338-364. Trans. 12th Int. Congr. Soil Sci., New Dehli 8-16, February 1982.

HOYT, P.B. & NYBORG, M., 1972. Use of dilute calcium chloride for the extraction of plant-available aluminium and manganese from acid soil. Can. J. Soil. Sci. 52: 163-167

KAMPRATH, E.J., 1970. Exchangeable aluminium as a criterion for liming leached mineral soils. Soil Sci. Soc. Am. Proc. 24:252-254.

KOLDERUP, F., 1970. Effect of temperature and daylength on seed setting and ear size in wheat. Meld. Norg. Landbr. Høgsk. 49(32): 1-10.

- 1975. Effect of soil moisture, air humidity and temperature on seed setting and ear size in humidity and temperature on seed setting and ear size in wheat. Acta Agr. Sca. 25: 97-102.
- 1979. Application of different temperatures in three growth phases of wheat. II Effects on ear size and seed setting. Acta Agr. Scand. 29: 11-16.

KOPETZ, L.M., 1960. Die Kultur des Weizens. Progressive wheat production. Centre d'Étude de l'Azote, Genève, 67-93.

LUPTON, F.G.H. & KIRBY, E.J.M., 1968. Applications of physiological analysis to cereal breeding. Rep. PI. Bred. Inst. Cambridge for 1966-67. pp. 5-26.

MARTINI, J.A., KOCHMANN, R.A., GOMES, E.P., & LANGER, F., 1977. Response of wheat cultivars to liming in some high Al oxisols of Rio Grande do Sul, Brazil. Passo Fundo Exp. Stat., Passo Fundo, Rio Grande do Sul, Brazil. Agronomy J. 60:612-616.

MEREDITH, P. & JENKINS, L.D., 1976. The developing starch granule. 3. The filling of the wheat grain. N. Z. J. Sci. 19(1):115-123.

MUZILLI, O., ALCOVER, M., IGUE, K. & VAN RAIJ, B., 1976. Wheat response to N, P and K in soils of Panama. Publ.: Campinas, Brazil, Brazilian Society of Soil Science 1976, 239-243.

NILSEN, S., 1975. The phytotron of the Oslo University (Norway). Phytotronic Newslett. 11: 22-24.

NJØS, A. & RYAN, J., 1980. La fertilization du blé dans les régions tropicales humides. Colloque Internationale sur le Blé 1-3 September 1980. L'Etablissement d'Enseignement Supérieur des Sciences Agronomiques d'Antanarivo, Madagascar 30-37.

PENNEY, D.D., HODGINS, L.W. & AULAKH, B.S., 1981. Zambia-Canada Wheat Project. Report 1981. Lusaka/Kasama, Zambia.

RAKOTONDRAMANANA, M.M. & LARSSON, H., 1982. Rapport des essais 1980-81 Ministére de la Production Agricole et de la Réform Agraire & FIFAMANOR, 114 pp.

RANDRIANARISON, M.R., 1975. Les essais dans le blé. FIFAMANOR, Rapports des essais 1974-75. FIFAMANOR B.P. No. 198. Antsirabe, Madagascar: 16-22 (Mineographe).

RAUNET, M., 1980. Les Bas-Fonds et Plaines Alluviales des haute Terres de Madagascar. Reconnaissance morpho-pédologique et hydrologique. IRAT-Pédologie, 166 pp.

RAWSON, H.M., 1971. Tillering patterns in wheat with special reference to the shoot at the coleoptile node. Aust. J. Biol. Sci. 24: 829-841.

REITEMEIER, R.F., HOLMES, R.S., BROWN, I.C. LORAINE, W., KLIPP, L.W. & PARKS, R.Q., 1948. Release of non-exchangeable potassium by greenhouse, Neubauer, and laboratory methods. Soil Sci. Soc. Amer. Proc. 12:158-162.
RINGLUND, K., 1973. Rapport sur les essais de blé et d'avoine en 1973. FIFAMANOR, B.P., No. 198, Antsirabe, Madagascar, 11 pp. (Mineographe).
- 1975. Rapport de l'Activité de l'Année 1975. FIFAMANOR. (Mineographe)
RITCHEY, K.D., DIALMA, M.G., LOBATO, E. & CORREA, O., 1980. Calcium leaching to increase rooting depth in a Brazilian savannah oxisol. Agron. J. 72:40-44.
SANCHEZ, P.A., 1977. Advances in the management of oxisols and ultisols in tropical South America. Proc. Int. Seminar on Soil Environment and Fertility in Intensive Agriculture. Tokyo-Japan, 1977: 535-566.
SANCHEZ, P.A. & SALINAS, J.G., 1981. Low-input technology for managing oxisols and ultisols in tropical America. Adv. Agron. 34:279-406.
SNEDECOR, G.W. & COCHRAN, W.G., 1976. Statistical Methods. 9. ed. Ames, Iowa, USA, 593 pp.
SOFIELD, I., EVANS, L.T. & WOODLAW, I.F., 1974. The effects of temperature and light on grain filling in wheat. In: Mechanisms of regulation of plant growth. Bull. Royal Soc. N. Z. 12: 909-915.
SPIERTZ, J.H.J., 1974. Grain growth and distribution of dry matter in the wheat plant as influenced by temperature, light energy and ear size. Neth. J. Agric. Sci. 22:207-220.
- 1977. The influence of temperature and light intensity on grain growth in relation to the carbohydrate and nitrogen economy of the wheat plant. Neth. J. Agric. Sci. 25:182-197.
THORNE, G.N., FORD, M.A. & WATSON, D.J., 1968. Growth, development and yield of spring wheat in artificial climates. Ann. Bot. 32:425-445.
THORNE, G.N., 1973. Physiology of grain yield of wheat and barley. Rep. Rothamsted Exp. Stn. Part 2:14-18.
USDA SOIL CONSERVATION SERVICE, 1974. Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. Soil Survey Staff, Washington, D.C.
VAN WAMBEKE, A., 1972. Soil studies in the Republic of the Congo (Kinshasa). Soils of the Humid Tropics. Committee on Tropical Soils, Agricultural Board. National Research Council. Natl. Acad. of Science, Washington, D.C.: 211-212.
VELLY, J., CELTON J. & MARQUETTE, J., 1973. Experimentation menée sur le blé en 1972. Institut de recherches agronomiques á Madagascar. Doc. No. 358, 37 pp.
WARDLAW, I.F., 1970. The early stages of grain development in wheat: Response to light and temperature in a single variety. Aust. J. Biol. Sci. 23: 765-774.
WINKLER, H., 1976. Effektivität der Kalkung und Stickstoffdüngung bei Weizen auf vier verschiedenen Böden im Bundesstaat Santa Catarina, Brazilien. Tropenlandwirt 77 (April): 95-109.
ØIEN, A., 1974. Forelesninger i kjemiske jordanalyser. Institutt for jordbunnslære (State Soil Investigation Laboratory). N-1432 Ås-NLH. 53 p.

APPENDIX I.

Classification de sols en systeme FAO; Systeme USDA, Systeme Français

FAO	USDA	Francais
Acrisols	Ultisols (en partie)	Sols ferrallitiques fortement désaturés
Nitosols	Ultisols (en partie)	Sols lessivés
Ferralsols	Oxisols	Sols ferrallitiques

(Forts. fra omslagets 2. side)

3. Manuskriptet, om mulig også tabellene, skal skrives med maskin. Når det sendes inn, skal det være i trykkferdig stand, komplett med tabeller, figurer og innholdsliste. En bør som regel unngå å framstille samme tallmateriale både i tabeller og figurer. Forfatterne bør gjennomgå manuskriptene nøye før de sendes inn, slik at en unngår endringer i korrekturen.

4. Tekst som det er av særlig betydning å få fremhevet, skal settes med *kursiv* og markeres i manuskriptet med en enkel understrekning. Forfatternavn i samband med litteraturhenvisninger settes med kapiteler og skrives i manuskriptet med STORE BOKSTAVER.

5. Tabeller gis en kort, dekkende overskrift og nummereres med arabiske tall: 1, 2, 3, osv. Figurtekst skal skrives på eget ark og nummereres som figuren. Tabeller og figurer bør i størst mulig utstrekning kunne leses uavhengig av teksten forøvrig. Plass for tabeller og figurer markeres i manuskriptet. Store tabeller, spesielt hvis det er flere slike, bør skrives på maskin, så de uten korrektur kan gå direkte inn på offset.

6. Litteraturhenvisningene kan gjøres etter Harvardsystemet eller etter nummersystemet. Dersom Harvardsystemet nyttes, skjer henvisningene ved forfatternavn og årstall: enten SKAARE (1958) eller (SKAARE 1958). Dersom nummersystemet nyttes, skjer henvisningene i teksten enten bare ved tilføyelse av det nummer avhandlingen har i litteraturlisten (1, 2) eller ved forfatternavn tilføyd nummeret: KVIFTE & HELDAL (1), SKAARE (2).

7. Liste over sitert litteratur settes til slutt i avhandlingen. Listen ordnes alfabetisk etter forfatternavnene og under disse i kronologisk orden. Dersom nummersystemet nyttes, gis de enkelte avhandlinger og meldinger nummer i den rekkefølge de kommer i litteraturlisten.

   1. KVIFTE, G. og B. HELDAL, 1958. Ås klimaet. Meld. Norg. LandbrHøgsk. 37 (8).

   2. SKAARE, S. 1958. Forsøk med søtlupin. Forsk. Fors. Landbr. 9: 629–641.

   Dersom det refereres til avhandlinger som har flere forfattere, skal bare første navn inverteres: KVIFTE, G. og B. HELDAL. Dersom det refereres til flere arbeid av samme forfatter, nyttes gjentakstegn:
   - 1972.

8. Manuskripter sendes redaksjonen for «Meldinger fra Norges landbrukshøgskole», 1432 Ås-NLH, med følgeskriv fra institusjonens ansvarlige leder. Ekstraeksemplarer (særtrykk) kan bestilles til selvkost. All korrespondanse sendes til redaksjonen, ikke til trykkeriet.