THE NUTRIENT STATUS OF TWO SOIL FORMS OF THE ORANGE RIVER DEVELOPMENT PROJECT

by

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FOR D. P. SMITH, WHO
FIRST SHOWED ME THE SOIL.

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ABSTRACT

Mainly two types of soil viz. the red sandy soils (Hutton form) and the yellow sandy soils (Clovelly form) were recommended by Van Rooyen (1965, 1967) for irrigational purposes under the Orange River Development Project. Fifteen soil profiles, comprising these two soil forms, were analysed for calcium, magnesium, potassium, sodium, phosphorus, sulphur, copper, zinc and manganese.

A pot experiment, including a representative sample from each soil form and different levels of potassium and phosphorus, was conducted to test the reactions of these soils to phosphorus and potassium applications.

Phosphate potential studies were conducted on selected samples from each soil form.

These soils were found to be deficient in phosphorus, potassium, copper and zinc. A difference in the reaction of these soils to applied phosphorus and potassium was indicated.

An extremely interesting relationship between the resin-P-content and phosphate potentials of these soils was found.

CHAPTER 1

INTRODUCTION

In 1777 the Orange River was named by Lieut. Gordon, a Dutchman, in the honour of the Prince of Orange. Thereafter a hundred years passed before the first mention was made of investigational work directed to the development of the water resources of the river. In 1872 a survey was made of a portion of the present Boegoeberg Government Water Scheme, but intensive survey work commenced only in 1919. The construction of the Boegoeberg Dam started in 1929. Mention was made of further survey work on the Orange River undertaken in 1944 and 1948, which was completed in 1953. Investigations continued in 1959 and attention was concentrated on collecting data for a development plan intended to develop the Orange River to its maximum potential (Report on The Proposed Orange River Development Project, 1962-63).

In the meantime, soil surveys were carried out by Meyer (1931), Rosenstrauch (1935), Van Rooyen (1965) and Van Rooyen (1967). The Secretary for Water Affairs, in his report for the year 1962-63, stated that: "Investigations carried out by the Department of Water Affairs over many years have proved that there is insufficient economically situated irrigable soil in the catchment of the Orange River to allow of the water resources being fully utilized" (Report on the proposed Orange River Development Project, 1962-63). This was disproved by the report of Van Rooyen (1965, 1967), after completing a reconnaisance survey of the area and compiling a soil map.

Van Rooyen (1965, 1967) recommended mainly two types of soil for irrigation purposes, viz. the red sandy soils and the yellow sandy soils, denoted as the Hutton and Clovelly forms respectively in the present South African soil classification system (Van der Eyk, Macvicar & de Villiers, 1969).

Unlike the soils of the Hutton form, which occur scattered throughout the entire area of the Orange River Project, the soils of the Clovelly form have a limited occurence. These soils have a characteristic position in the area, in that they are limited to the eastern and south-eastern banks of the Orange River (Van Rooyen, personal communication).

Soils of the Hutton form are utilized extensively for both dryland and irrigational cropping in South Africa. The irrigated soils of the Vaalharts Irrigation Scheme comprise almost entirely soils of the Hutton form, and a large percentage of the soils of the Riet River and Sandvet Irrigation Schemes belong to this soil form. At present small areas of the Clovelly form are under irrigation.

These fine sandy soils of the abovementioned irrigation schemes are known to be well suited to irrigation, but require careful managing for optimum production. They are known to respond to fertilization, especially with regard to nitrogen and phosphorus. Less is known about their trace element content, although responses to zinc fertilization have been reported from various locations. At Vaalharts, certain maladies of crops have appeared during recent years and these may be associated with nutrient deficiencies. The most notable of these maladies are the so-called red leaf disease of cotton, leaf scorch of ground nuts etc.

In view of the proposed development of some 200,000 ha. of Hutton and Clovelly soils, an evaluation of the nutrient status of a selection of these soils seemed obvious. Therefore this study was undertaken to evaluate the nutrient status of the recommended soils of the Orange River Project. "Soil analysis can be of great value for indicating the possibilities of deficiencies occurring, even before any crop is planted, thus providing valuable forward information" (Wallace, 1961).

It is foreseen that the Orange River Development Project will develop into one of the country's greatest intensively cultivated areas. This project represents a very large investment of capital and when soils are subjected to irrigation, maximum production is expected as a return on the investment made.

Very little knowledge exists on the nutrient status of these soils. The necessity to provide this knowledge before irrigation is undertaken, justifies this study. Hidden hunger effects could be detected in this way before economic losses in crops occur. "By the time noticeable symptoms appear in a crop, the grower has lost greatly in profits" (Nelson & Barber, 1964).

Because the soils that will eventually be irrigated under this project will most probably be those of the Hutton and Clovelly forms, as recommended by Van Rooyen (1965, 1967), it was decided to make a thorough investigation of their nutrient status. Therefore soil series comprising only these two soil forms were selected for analysis.

CHAPTER II

GENERAL PROPERTIES OF THE SOILS AND ANALYTICAL PROCEDURES

2.1 THE SOILS

Both soil forms are predominantly of a sandy nature. According to Van Rooyen (personal communication) these soils are of aeolian origin. The only distinguishing criterion between these forms is the colour of the Apedal B horizon, viz. red for the Hutton and yellow for the Clovelly. A generalized definition for these soils is an orthic A horizon overlying a red (Hutton) or yellow (Clovelly) apedal B horizon. (Van der Eyk, Macvicar & de Villiers, 1969).

Soil series investigated in this study are:

HUTTON FORM	CLOVELLY FORM
Goudam	Vaalbank
Zwartfontein	Tourquay
Shorrocks	Orange

The series within each form are distinguished on the basis of clay content and sand grade only, other distinguishing criterion being constant for these soils. All three series of the Hutton form are non-calcareous and have Clay/S ratios of less than 7. On the other hand, the three series of the Clovelly form are all calcareous with Clay/S ratios of less than 7.

Samples representative of the above forms were selected for this study. Since the exact identification of each series could only be established by laboratory analysis, it was impossible to realise an equal number of profiles for each series. Furthermore this study was directed to a broad generalisation of nutrient trends in soils of a large area. Therefore the main interest was focused upon a characterisation and comparison between soils of the two forms rather than series. As can be seen from the general analytical data (Appendix I), no striking differences between series of the same form are evident.

Although the analytical data are listed under the different series, the purpose of this study was to obtain a generalised picture of the soils with the planning of an irrigation scheme in mind. More detailed studies, at series and at crop level, are required for advisory purposes.

Fifteen randomized soil profiles, ten of the Hutton form and five of the Clovelly form, were selected. Samples of the various horizons were collected and prepared in the usual way for laboratory investigations. Special care was taken to prevent contamination of especially the trace elements.

2.1.1 SOILS OF THE HUTTON FORM

Because of their aeolian origin, these soils show rather poor horizon differentiation. A typical profile of the Shorrocks series is given as an example:

Profile No. 2 Shorrocks series.

Location	:	Farm Driehoek No. 218, District Koffiefontein.
Site	:	upper slope of gently sloping pediment, 2 - 3% slope.
Vegetation	:	Mixed Karroo veld.
Parent material	:	sand of aeolian origin.

Horizon	Depth (cm)	Description
Orthic A_1	0-22	2.5 $YR^4/6$ (dry) red, fine sandy loam; friable; apedal, gradual transition
Apedal B_{21}	22-60	2.5 $YR^4/6$ (dry) red, fine sandy clayloam, friable; weak to moderate coarse sub angular to blocky; gradual transition
Apedal B_{22}	60-105	2.5 $YR^4/6$ (dry) red; fine sandy clay loam; hard;weak to moderate sub angular to blocky; gradual transition
Apedal B_{23}	105-160	2.5 $YR^4/8$ (dry) red; fine sandy clay loam; very hard; weak to moderate sub angular blocky

2.1.2 SOILS OF THE CLOVELLY FORM

Characterized by their yellow colour and the presence of calcareous material in the profile, a typical profile of the Tourquay series may be described as follows:

Profile No. 5 Tourquay series.
Location : Farm Tourquay No. 339 District Douglas
Site : middle slope of gently sloping pediment
Vegetation : mixed Karrooveld
Parent material : aeolian sand.

Horizon	Depth (cm)	Description
Orthic A_1	0-23	7.5 YR^4/4 (dry) yellow brown; sand to sandy loam; apedal; friable to loose; rare small calcium carbonate concretions; rare small lava fragments; gradual transition
Apedal B_{21}	23-55	7.5 YR^4/4 (dry) yellow brown; sand to sandy loam; apedal; friable to loose; frequent small calcium carbonate concretions; rare small lava fragments; gradual transition
Apedal B_{22}	55-83	7.5 YR^4/4 (dry) yellow brown; sand to sandy loam; apedal; friable to loose; abundant small calcium carbonate concretions; rare small lava fragments; clear transition
Apedal B_{23}	83-123	7.5 YR^5/4 (dry) brown; sand to sandy loam; apedal; friable to loose; abundant small calcium carbonate concretions; rare small lava fragments.

The general properties of the soils investigated are listed in Appendix I. Average values for the two soil forms and series are presented in Appendix 4.

Considering the average values presented in Appendix 4, it will be noted that the Clovelly soils have a definite alkaline pH of 8.2 and an average electrical resistance of 916 Ohms. The calcareous nature of the Clovelly soils is responsible for the relatively high pH. The average pH of the Hutton soils is 6.8 and their electrical resistance (average 1400 Ohms.) is somewhat higher than that of the less leached Clovelly soils.

The pH and electrical resistance of the different series of the Clovelly form are quite uniform (Appendix 4).

This is not true of the Hutton form. The much lower electrical resistance (887.89 Ohms.) and slightly higher pH (pH 7.02) of the soils of the Shorrocks series suggest that they are leached to a lesser extent than those of the Zwartfontein and Goudam series. The higher clay content of these soils may be responsible for the larger differences in electrical resistance between the different series of the Hutton form, when compared to those of the Clovelly form.

Although the Hutton form includes series within the classes of 6-15% and 15-35% clay, the average clay content of all Hutton samples (57) is only 10.5%. In the case of the Clovelly form, series within the classes of 0-6% and 6-15% are included with an average clay content for all samples (23) of 8.3%. This is a fair indication of the very sandy nature of all soils investigated. Average sand grades (Appendix 4) indicate that these soils are all more or less of the same textural class, viz. fine sandy to fine sandy loam, the exception being Goudam series which is a medium sand (Appendix 4).

The soils of both these soil forms have excellent drainage properties. The Clovelly soils are somewhat draughty compared to the Hutton soils (Van Rooyen, personal communication).

2.2 ANALYTICAL PROCEDURES

2.2.1 Calcium, Magnesium, Potassium and Sodium

The neutral normal ammonium acetate method was used to extract soluble and exchangeable calcium, magnesium, potassium and sodium from the soils. The sodium saturation method, as described by the United States Salinity Laboratory Staff (1954), was used for the determination of cation exchange capacities.

Calcium and Magnesium in the ammonium acetate extracts were determined with a Techtron AA3 atomic absorption spectrophotometer. Sodium and potassium were determined with a Zeiss PF5 flame photometer.

2.2.2 Phosphorus and Sulphur

Phosphorus and sulphur were determined in the same extract after extraction with an anion exchange resin ("De-Acidite" FFSRA 59, chloride form), according to the method employed by Du Plessis & Burger (1966) and Du Plessis (1964).

Although Morgan's and Bray's methods are usually used for the extraction of sulphur, no objection to the use of an anion exchange resin for this purpose could be found in literature. Throughout the literature, it was evident that the same reagents were often used for extracting both sulphur and phosphorus.

Kilmer & Nearpass (1960) advocated the use of $NaHCO_3$ (pH 8.5) for extraction of sulphur from soils. This method is the same as Olsen's method for extracting phosphorus from soils.According to Eaton (1966), Arkley found a correlation coefficient of $r = 0.86$ between sulphur extracted with Morgan's (pH 4.8) sodium acetate and plant growth and sulphur uptake. The same method is employed for the extraction of phosphorus (Bingham, 1966).

Phosphorus was determined using the molybdenum blue method of Fogg & Wilkinson (1958), and sulphur by the turbidimetric method described by Bartlett & Neller (1960).

2.2.3 Copper, Zinc and Manganese

Copper and zinc were extracted with 0.1N HCl according to the method employed by Stanton (1964) for zinc. Easily reducible manganese was extracted with neutral 1N NH_4OAc containing 0.2% hydroquinone according to the method described by Adams (1965).

Atomic absorption spectrophotometry was used in the determibation of all three elements, using a Techtron AA3 instrument.

CHAPTER III

THE NUTRIENT CONTENT OF THE SOILS

The „available" contents of all the aforementioned nutrients are given in Appendix 2. Summarising tables, giving highest, lowest and average values, are included in the discussions on each element. Relevant literature is referred to under each heading and results obtained elsewhere on similar soils are compared with those of the present investigation, especially with regard to comparable soils at the Vaalharts, Riet River and Sandvet Irrigation Schemes.

Particular attention is focused upon nutrient deficiencies in these soils with a view to correction measures to be taken from the outset. As stated earlier, this study was not intended to serve as a basis for individual advisory purposes, but to find a broad basis for detail investigations at a series or crop level.

Comparisons may be drawn with soils of existing irrigation projects, e.g. Vaalharts, Riet River etc., where similar series occur extensively. These soils have been subjected to cropping, fertilising and irrigation for up to 30 years. This may serve to predict the future behaviour of these soils under similar treatment. Errors of the past may be avoided when forward information on these soils is available.

3.1 MACRONUTRIENTS

In view of the changing trends in fertiliser practices over the past few years, e.g. increasing use of double superphosphate, liquid ammonia and ammonium nitrate etc., soil scientists are compelled to pay attention to such "neglected" nutrients as sulphur, calcium and magnesium. Therefore particular attention was paid to evaluate these soils also with regard to these elements.

3.1.1 Calcium

Calcium nutrition of crops has seldom attracted more than cursory attention on soils fertilised with large applications of superphosphate. On acid soils lime applications serve to correct the pH and simultaneously correct any deficiencies in calcium as a plant nutrient.

According to Chapman (1966) calcium deficiencies may be expected on sandy soils, acid soils and particularly soils of humid regions where the rainfall exceeds 750 mm per annum; also soils in which the dominant clay minerals are montmorillonitic rather than kaolinitic.

Calcium excess is usually associated either with excess of soluble salts or calcium carbonate (Chapman, 1966). Calcium excess is most prevalent in the following soils: Saline soils in which excessive amounts of gypsum, calcium chloride or other soluble calcium salts have accumulated, and soils containing calcium carbonate. The accumulation of these salts may be the result of capillary rise from ground waters, application of irrigation waters containing excessive amounts of calcium salts, or from wheathering and lack of leaching.

3.1.1.1 Results

Because of the presence of free lime in the Clovelly soils, they have a markedly higher calcium status than those of the Hutton form (Table 1). This is also reflected in a higher average pH (8.2) of the Clovelly soils compared to an average pH of 6.8 of the Hutton soils (Appendix 4), and a lower average electrical resistance of the former (916 Ohms as against 1400 Ohms).

TABLE 1. Calcium content of the Hutton and Clovelly soils (me Ca^{++}/100g soil)

HUTTON			CLOVELLY		
HIGHEST	LOWEST	AVERAGE	HIGHEST	LOWEST	AVERAGE
7.13	0.25	2.47	59.38	3.75	27.60

The presence of free lime in the profiles of Clovelly soils is reflected in the generally high to extremely high (for these sandy soils) extractable Ca^{++}. No attempt was made to determine "true" exchangeable Ca^{++} in these samples, since this is regarded as a doubtful figure. If it is accepted that the CEC of these samples is fully saturated with bases, it is evident that Ca^{++} alone exceeds the CEC.

Only three surface samples and two subsurface samples do not contain free lime, showing correspondingly lower extractable Ca^{++} values. Their lower horizons nevertheless contain free lime, which may act as a source for plant nutrition of deeprooted crops.

It is noteworthy that some of these Clovelly profiles, which most probably have the same origin, viz. calcareous river borne sands blown from the Orange River bed by prevailing westerly winds (Van Rooyen, personal communication), have surface horizons deficient in free lime. This probably, is an indication of some measure of leaching. These soils may be expected to lose lime at an accelerated rate upon irrigation. One topsoil already contains less than 4 me Ca^{++}/100g. It is therefore necessary to bear in mind that even these generally calcareous soils may become calcium deficient in time, and especially when cultivated.

Considering the Hutton soils, it is evident that they have a generally lower calcium status than the Clovelly soils. Although this group of soils is also of aeolian origin (Van Rooyen, personal communication), their parent material is non-calcareous and almost entirely siliceous in nature. These soils contain very little, if any, weatherable minerals. Despite the fact that they were formed under semi-arid climatic conditions, even the deepest horizons of the solum contain no free lime. Some of these sandy soils, however, lie on hard lime sediments, with practically no admixture of lime with the overlying soil.

The calcium content of all profiles show very little variation with depth, but vary between profiles according to their clay contents and CEC. Thus profiles of the Shorrocks series, with clay contents between 15 and 28%, have correspondingly higher calcium contents. None of these soils has an extractable calcium content exceeding the CEC value. No definite indications of leaching of Ca^{++} down the profile are evident. The slight increases merely reflect increasing clay content with depth.

Two Hutton profiles, viz. one of Goudam series and one of Zwartfontein series, show a strikingly low calcium status, with averages of 0.6 and 0.8 me Ca^{++}/100g respectively.

In general terms it might be states that these Clovelly soils are adequately supplied with calcium. Some of the Hutton soils are also in this class, but others appear to be in or near the calcium deficient range with values of less than 2.5 me Ca^{++}/100g soil. Reed & Sturgess (according to Chapman, 1966) established levels below which calcium deficiencies on fine sandy loams and sands are indicated for cotton. These levels were 2.5 me and 1.5 me Ca^{++}/100g, extracted with 0.05N HCl. This category of extracted Ca^{++} may be taken as exchangeable. Since other factors, such as pH, calcium saturation, magnesium saturation, CEC etc. also affect calcium absorption by plants, an evaluation of the calcium status of soils on a basis of level of exchangeable calcium only, is not adequate. These considerations will be discussed at the end of this chapter.

3.2.1 Magnesium

As early as 1860 investigations were undertaken which showed that magnesium was an essential element for plant growth (Embleton, 1966). "That magnesium is an essential plant nutrient is indicated by the fact that it is a constituent of the chlorophyl, proto chlorophyl, pectein and phytin". (Von Uexküll, 1963). Recently increasing attention has been paid to magnesium as a plant nutrient, because magnesium deficiency in arable crops is increasing and may become more common in future (Cooke, 1967). This could be attributed to the definite trend towards the use of high analysis fertilizers which are acid forming, low in calcium and practically void of magnesium. This means that soils must be tested rather frequently for acidity and magnesium (Luckhardt & Ensminger, 1968).

According to Embleton (1966) magnesium deficiency most commonly occurs in acid, sandy soils, in areas of moderate to high rainfall. Magnesium deficiency has also been reported in alkaline soils of Israel, Florida and

British Columbia. Drosdoff & Kenworthy (1944) reported magnesium deficiency in imperfectly drained soils.

Whereas magnesium deficiency in soils has been reported quite often, magnesium excess in soils rarely occur. In a review of the literature on magnesium deficiency and excess, only one investigator reported magnesium excess in a soil. This was a heavy clay soil from California in which more than 90 percent of the cation exchange capacity was saturated with magnesium. Consequently this soil was almost totally unproductive (Embleton, 1966).

The presence of magnesium in soils depends upon the decomposition of rocks containing such minerals as olivine, serpentine, dolomite, biotite, chlorite etc. Magnesium is slowly released from these minerals and is absorbed by the surrounding clay particles and organic exchange materials. "The available magnesiun in soils is largely contained in the exchange materials of both clay and organic matter" (Berger & Pratt, 1963).

3.1.2.1 Results

The present investigation revealed that the Clovelly soils contain twice as much magnesium in the soluble and exchangeable form as the soils of the Hutton form (Table 2).

Table 2 Magnesium content of the Hutton and Clovelly soils (me/100g Soil)

HUTTON			CLOVELLY		
Highest	Lowest	Average	Highest	Lowest	Average
5.313	0.288	2.086	8.813	2.150	4.765

It is evident (Appendix 4) that the Shorrocks series, with the highest clay content, has the highest average magnesium content amongst the Hutton soils. In the case of the Clovelly soils, the opposite is true. The Vaalbank series, with the highest clay content, has the lowest average magnesium content. (Appendix 4). This may be due to a difference in the stage of weathering of these soils. As stated earlier the Clovelly soils contain large quantities of weatherable minerals, whereas the Hutton soils contain very little of these minerals. From the distributions of magnesium in the profiles no general pattern emerges. Only two profiles of the Clovelly form, viz. No's 6 and 7 show a definite increase in magnesium content with depth. Magnesium in the other profiles have a rather erratic distribution (Appendix 2).

Bray (according to Embleton, 1966) stated: "Roughly, soils containing less than 100 pounds per acre of exchangeable magnesium are probably deficient in magnesium". Hester, Smith & Shelton (1947), earlier reported magnesium deficiency symptoms in crops grown in sandy soils with less than 100 pounds of replacable magnesium per acre (o.4 me/100g). The deficiency symptoms did not occur in soils that averaged 132 or more pounds of replacable magnesium per acre (0.54 me/100g).

Van Garderen (1953) reported an average value of 1.20 me/100g of exchangeable magnesium for comparable soils at Vaalharts Irrigation Scheme. Considering average values of 2.1 me/100g for the Hutton soils and 4.8 me/100g for the Clovelly soils, the magnesium status of these soils appear to be adequate.

The availability of magnesium, however, seems to depend upon factors sych as pH, the presence of sulphate and sodium, etc. Yamasaki (according to Embleton, 1966) reported that the efficiency of magnesium supply depended upon the exchangeable magnesium-potassium ratio in the soil rather than upon total exchangeable magnesium. This is supported by the work of Pratt, Jones & Bingham (1957), who found that the best estimate of magnesium availability to citrus trees can be determined from the exchangebale potassium-magnesium ratio. A discussion of these considerations follows at the end of this chapter.

3.1.3 Potassium

The essentiality of potassium for the growth of plants was first recognised about one hundred years ago. Since then numerous workers have demonstrated the beneficial effects of potassium on the growth of plants (Ulrich & Ohki, 1966) "Potassium is absorbed by plants in larger amounts than is any other mineral element except nitrogen and perhaps calcium" (Tisdale & Nelson, 1966). Although plants require large amounts of potassium, its functions in the plant are not yet fully understood (Von Uexküll, 1963). Fujiwara & Iida (according to Barber & Humbert, 1963) summarized the physiological functions of potassium as follows: effect on carbohydrate metabolism or formation; breakdown and translocation of starch; effect on nitrogen metabolism and protein synthesis; neutralising physiologically important organic acids; as an activator of various enzymes and promoting the growth of young meristem. Considering the diversity of the functions of potassium in growing plants, it can be realised why plants need such large quantities of potassium for normal growth.

Excluding the amounts of potassium added to a soil in fertilizers, the potassium contained in soils originates from the decomposition of rocks containing potassium bearing minerals. The primary minerals that are generally considered to be sources of potassium are the potash feldspars, muscovite and biotite (Tisdale & Nelson, 1966). The potassium contained in these minerals are not directly available to plants, but only becomes available upon the decomposition of these minerals. Another primary source of potassium is the clay minerals, particularly those derived from micas. Potassium contained in clay minerals may be slowly released upon weathering (Russell, 1961).

On the basis of availability, the various forms of potassium in soils can be classified in three general groups: (1) unavailable (2) slowly available and (3) readily available. Unavailable potassium includes potassium present in primary minerals as stated earlier. The slowly available potassium represents potassium in fixed positions on exchange materials and readily available potassium includes exchangeable potassium and potassium present in the soil solution. The equilibrium among the various forms of potassium in a soil is of primary importance in the potassium nutrition of plants (Buckman & Brady, 1969). The equilibrium among the different forms and the availability of potassium to plants are influenced by such factors as pH, nature of cation-exchangers in the soil, state of soil weathering, water content of the soil and soil temperature. (Thomas & Hipp, 1968). These factors and the implication thereof will be considered at the end of this chapter.

Although abundant in soils, potassium deficiencies have been reported by various workers. According to Bear (1953) potassium deficiency commonly occurs on light sandy soils which are easily leached, soils derived from rocks poor in potassium bearing minerals and highly weathered soils. Ulrich & Ohki (1966) adds organic soils, soils that have been heavily cropped, leached and eroded, and soils that fix potassium into the non-replaceable form to this list.

Very few crops exhibit toxicity symptoms of potassium, the orange being about the only known one (Ulrich & Ohki, 1966).

3.1.3.1 Results

As a result of their advanced stage of weathering, the Hutton soils generally contain twice as much potassium in the exchangeable and soluble form as the soils of the Clovelly form (Table 3).

Table 3: Potassium content of the Hutton and Clovelly soils (me/100g soil).

HUTTON			CLOVELLY		
HIGHEST	LOWEST	AVERAGE	HIGHEST	LOWEST	AVERAGE
0.670	0.135	0.308	0.300	0.095	0.154

As can be expected the highest value for the Hutton form is recorded by the Shorrocks series with the highest clay content. This is repeated in the Clovelly form where the Vaalbank series, with the highest clay content, has the highest exchangeable potassium content (Appendix 4).

There is a very slight tendency towards potassium accumulation in the upper horizons of each profile (Appendix 2), except for profile No. 2, where a definite increase in potassium content with depth is evident. Except for the Vaalbank, the averages for the different soil series are very similar (Appendix 4).

According to Ulrich & Ohki (1966) the chances of securing beneficial effects from potassium fertilization would be good on all soils containing less than 0.16 me/100g of exchangeable potassium. On the other hand if a soil contains more than 0.38 me/100g of exchangeable potassium very few crops would be likely to respond to potassium fertilization (Ulrich & Ohki, 1966).

Values of 0.22 me K/100g in topsoil samples were reported by Van Garderen (1933) for comparable soils from the Vaalharts and Riet River Irrigation Schemes. Samples analysed since 1968 indicate an average of 0.34 me/100g of potassium in the same soils (Van der Merwe, personal communication). This suggests an increase in potassium status of these soils. It is recommended by Van der Merwe (personal communication) that the potassium status of the sandy soils of the lower Orange River be raised to 0.31 me/100g.

Considering the above it would seem that the soils of the Hutton form have a favourable potassium status at the moment and the potassium status of the Clovelly soils must be increased to 0.31 me/100g by judicious fertilization.

3.1.4 Sodium

"Sodium does not seem to be an essential element for any crop, even for salt marsh plants, yet certain crops undoubtedly grow better in the presence of available sodium supplies than in their absence, the sodium in these cases appearing to carry out some of the functions that potassium usually fulfils" (Russell, 1961). Sodium seems to play an important part in soil-plant relationships, especially in arid and semi-arid regions (Lunt, 1966). This is not because of its nutritional effects but because of the effect of sodium on the availability of other cations in the soil. Due to the fact that sodium is not a "normal" plant nutrient, it will only be considered briefly in this section and the beneficial and detrimental effects of sodium upon other cations will be considered at the end of this chapter.

3.1.4.1 Results

The sodium status of the Hutton and Clovelly soils are of a similar order of magnitude (Table 4).

Table 4: Sodium content of the Hutton and Clovelly soils (me/100g)

HUTTON			CLOVELLY		
HIGHEST	LOWEST	AVERAGE	HIGHEST	LOWEST	AVERAGE
0.390	0.170	0.245	0.500	0.240	0.325

This trend is also clear when the averages for the series are inspected (Appendix 4). Apart from the Tourquay series, which has a slightly higher average sodium content than the other series, no great differences between series exist. Although profile No. 6 of the Tourquay series shows a definite increase in sodium content with depth, this is not a general trend. The only other profiles showing a definite vertical downward increase of sodium content are profiles No's. 157 and 19, both of the Shorrocks series (Appendix 2). A general increase in the middle horizons of the profiles indicates that some leaching has taken place.

The United States Salinity Laboratory Staff (1954) recognises a boundary limit of 15 percent exchangeable sodium percentage between non-alkali and alkali soils. The cation exchange capacities of these soils (Appendix 2) clearly show that the soils of the Hutton and Clovelly forms are non-alkaline and can be regarded as normal soils with respect to sodium.

Values of 0.26 me/100g for topsoil samples and 0.29 me/100g for subsoil samples are reported for normal productive sandy soils of Georgia by Giddens, Perkins & Carter (1958).

Averages of 0.1 me/100g (Laker, personal communication) and 0.08 me/100g (Van Garderen, 1953) are reported for soils at Vaalharts. In view of the sandy nature and generally deep profiles of these soils, sodium is not considered to be hazardous to cropping practices in the Hutton and Clovelly soils. Provided that irrigation water is of the same quality as presently used at Vaalharts, no problems with regard to salinity and alkalinity are anticipated for these soils. Irrigation of arid-region soils should nevertheless always be closely guarded against sodium hazards. The sodium status of these soils therefore warrants careful observation at all stages of their development.

3.1.5 Phosphorus

The importance of phosphorus in plant nutrition has been illustrated repeatedly. Russell (1961) points out that phosphorus is a constituent of the cell nucleus and is essential for cell division and for the development of meristem tissue.

"Phosphate deficiency is very widespread in the world, and in many countries such as Australia and South Africa crop production is limited over enormous areas by phosphate supply" (Russell, 1961). According to Malherbe (1956) virgin soils in South Africa are always poor in phosphate. The low phosphorus status of South African soils is well illustrated by the work of Van Garderen (1953). In an experiment with lucerne, the yield was doubled by increasing phosphorus application from 200 to 600 kg/ha on Vaalharts soils.

According to Bingham (1966) phosphorus deficiency commonly occurs on the following soils: highly weathered soils, calcareous soils and peat soils, because their phorphorus may not be readily available to plants, even though the total content may be high. Highly weathered soils derived from parent materials poor in phosphorus may have an absolute P-deficiency.

In determining the phosphorus status of any soil, an evaluation of the plant-available phosphate is essential. Various procedures for extracting available phosphate are employed. "Any method, however, is useless unless it correlates with the percent yield or with the total uptake...." (Du Plessis, 1964). Comparing various chemical extraction methods for the evaluation of phosphate availability in soils, Du Plessis & Burger (1966) showed that the Na HCO_3 and anionic exchange resin extractants were almost equally suitable for the evaluation of "plant available" phosphate status of a large number of soils from the Orange Free State Region. In the present investigation an anion exchange resin was used to estimate available phosphorus in these soils, because of the simplicity and rapidity of this method compared to the Na HCO_3 procedure. For comparative purposes it must be borne in mind that different extractants differ in their ability to extract phosphate from soils.

3.1.5.1 Results

It is evident that the Clovelly soils have a much higher average P content than the Hutton soils (Table 5).

Table 5 : P Content of the Clovelly and Hutton soils (ppm)

HUTTON			CLOVELLY		
HIGHEST	LOWEST	AVERAGE	HIGHEST	LOWEST	AVERAGE
3.95	0.100	0.88	3.50	0.500	1.48

The Vaalbank (Clovelly) and Shorrocks (Hutton) series with higher clay contents have much higher P contents than the other series in the respective soil forms (Appendix 4). No general trend in the distribution of phosphorus within the different profiles is evident (Appendix 2). Individual values can be devided into two categories, viz. those between 0.1 and 2 ppm and those between 2 and 4 ppm, most of the soils falling in the former category.

Using an anionic exchange resin as extractant for phosphorus, Du Plessis & Burger (1966) reported average values of 11.0, 10.9 and 1.6 ppm of phosphorus for comparable soils at Vaalharts, Riet River and Sandvet Irrigation Schemes. As stated earlier all these soils were initially low in available phosphorus. Soils at Vaalharts and Riet River have, however, been cultivated and fertilized with phosphorus for up to 30 years. At the time when Du Plessis & Burger (1966) made these investigations, the Sandvet soils could be regarded as practically virgin soils. Therefore their phosphorus content was still at a very low level, whereas a considerable built-up of available phosphorus took place in the soils which were under cultivation for a number of years. This is not unexpected since Vaalharts farmers apply up to 800 kg superphosphate per hectare annually.

It may be foreseen that the presently investigated Clovelly and Hutton soils, being initially low in available phosphorus, will also respond to applications of phosphatic fertilizers. Furthermore a gradual build-up of available phosphorus in these soils may also be expected, once they are brought under cultivation.

The relatively even distribution of phosphorus in the profiles of these soils is not unexpected, in view of their origin and in view of the immobility of phosphorus compounds. It is significant that a cultivated topsoil from Vaalharts has an available P content (anion exchange resin) of 190 ppm, while the subsoil (22cm - 28cm) has less that 2 ppm (Eloff, personal communication, 1970).

Soil conditions affecting the availability of soil phosphorus will be reviewed at the end of this chapter.

3.1.6 Sulphur

So far little attention has been given to sulphur as a plant nutrient in fertilizer treatment. "This is probably due, on the one hand, to a quite large natural reserve of sulphur in most soils and to the fact that most fertilizers contain considerable quantities of sulphate....." (Von Uexküll, 1963). Additions of sulphur to soils in sulphur bearing superphosphate, ammonium sulphate and atmospheric sulphur dioxide have supplied large quantities of this element to both soils and plants. "Thus by seemingly incidental means the sulphur needs of crops in the past have been largely satisfied, especially in areas near industrial centres" (Buckman & Brady, 1969).

Although sulphur received little attention as a nutrient in fertilizers the essentiality of sulphur for plant and animal growth has long been known. "Sulphur has been known to be essential for plant growth for well over 100 years, and for nearly this long it has been known to be accumulated from the soil largely in the form of sulphate ion" (Eaton, 1966). Much is yet to be learned about the functions of this element in plants, although it is already known to be essential for many reactions in every living cell (Buckman & Brady, 1969). "Sulphur is an essential plant food because it is a constituent of all proteins" (Malherbe, 1956).

Sources such as soil minerals, atmospheric sulphur and organic bound sulphur contribute large quantities of sulphur to soils and plants. However, losses of sulphur through crop removal, erosion and drainage are equally large. The amount of sulphur removed in crops is about equal to that of phosphorus (Alway, 1940). The work of Lipman as presented by Alway (1940) indicates an annual loss of 0.3 kg of phosphorus per ha against a loss of 30 kg of sulphur per ha through leaching and erosion. Crocker (1945) emphasizes the rapid loss of sulphur from virgin soils after these are brought under cultivation.

The enormous losses of sulphur from soils probably cause the numerous reports on sulphur deficiency from all over the world. The eastern and western coastal regions of the United States, especially, are frequently sulphur deficient. Sulphur deficiencies have also been reported from France, Germany, Norway, Canada, Japan, Australia and New Zealand to name but a few (Buckman & Brady, 1969). Malherbe (1956) states that: "In South Africa, soils that contain too little sulphur and require sulphur application have not yet been found". Recently sulphur deficiencies have been reported in Natal (Croft & Graven, 1969).

3.1.6.1 Results

The Clovelly and Hutton soils seem to be adequately supplied with sulphur (Table 6).

Table 6: Sulphur content of the Hutton and Clovelly soils (ppm)

HUTTON			CLOVELLY		
HIGHEST	LOWEST	AVERAGE	HIGHEST	LOWEST	AVERAGE
24.72	6.96	15.80	22.64	3.04	13.97

The distribution of sulphate sulphur in these profiles exhibits no definite trends. Although certain horizons are significantly lower in sulphur content than either those above or below, each profile as a whole, appears to be adequately supplied with an average of approximately 15 ppm (Appendix 2). Only a few profiles have a slight accumulation of sulphate in the deepest horizons. It is known that other soils of this region often contain gypsic horizons, but apparently these sandy soils contain too little soluble salts to allow accumulation of gypsum deposits.

The factors that should be appraised when drawing up a balance sheet of the sulphur status of the soils of any region, will be considered at the end of this chapter.

3.2 MICRO-NUTRIENT CATIONS

Nutrient balance among the trace elements is essential, but perhaps even more difficult to maintain than for the macro-nutrients. The spesific role of the various micronutrients in plants and microbial growth processes is not very well understood, but indications are that several trace elements are effective through certain enzyme systems (Buckman & Brady, 1969).

This section deals with the copper, zinc and manganese contents of the soils investigated.

3.2.1 Copper

According to Devlin (1967) there is little doubt as to the necessity of copper for plant metabolism.. Copper acts as a component of several enzymes and its role as a part of these enzymes probably represents the most important function of copper in plants (Devlin, 1967). Copper is also required by plants for oxidation and reduction and appears to promote the formation of Vitamin A (Von Uexküll, 1963).

Copper is present in soils as metallic Cu, cupriferous minerals, insoluble salts such as silicates, phosphates, hydroxides and basic carbonates, water soluble compounds, copper absorbed by clay minerals and copper-organic compounds.

The exchangeable Cu is generally considered that which occurs as metallo-organic complexes and some of that absorbed by clay minerals in the soil. Water soluble and exchangeable Cu are probably available to plants. The amount of available copper is somewhat dependent upon the soil pH. (Berger & Pratt, 1963).

"Copper deficiencies have been reported in many countries of the world.....Most of these deficiencies appear on organic soils but examples of copper deficiency have been found on mineral soils in some countries" (Tisdale & Nelson, 1966). According to Reuther & Labanauskas (1966) copper deficiency occurs on the following mineral soils: Alkaline and calcareous soils, but especially on sandy types viz. leached sandy soils, and calcareous sands. Copper deficiency has been reported on leached acid sandy soils from the George-Knysna-Mosselbay area (Roach & Beyers, 1960).

Copper toxicities have been reported in soils derived from or influenced by copper ore sources, and soils on which crops, heavily sprayed with Bordeaux sprays for disease control, have been grown over a long period.

3.2.1.1 Results

The Hutton and Clovelly soils have acid extractable copper contents ranging from 0.40 to 2.80 and from 1.05 to 2.30 ppm for the two soil forms respectively (Appendix 3 and Table 7).

Table 7 : Copper content of the Hutton and Clovelly soils (ppm)

HUTTON			CLOVELLY		
HIGHEST	LOWEST	AVERAGE	HIGHEST	LOWEST	AVERAGE
2.80	0.40	1.19	2.30	1.05	1.60

The three series of the Clovelly form show very little difference in their average copper content. The Shorrocks series of the Hutton form, however, has a relatively much higher copper content than the Goudam and Zwartfontein series. The copper content of the different profiles have a rather random distribution, only two profiles, viz 1 and 4, showing a definite increase in copper content with depth.

Eight of the profiles contain more copper in the lowest horizon than in the topsoil horizon. Two profiles have equal amounts of copper in those horizons and five profiles have more copper in the topsoil than in the lowest horizon (Appendix 3).

Acid extractable copper in the Hutton soils are highly correlated with clay content ($r = 0.6489$, Appendix 5). The same correlation coefficient was found to be insignificant for the Clovelly soils (Appendix 5). This may suggest that copper in the Hutton soils are closely associated with the exchangeable form. It would seem that the acid extractable copper in Clovelly soils are associated with easily weatherable minerals present in these soils.

Du Plessis (1970) investigated the copper status of the soils of the principle citrus areas of the Republic of South Africa. These soils included sandy and sandy clay soils. For virgin soils, in the vicinity of citrus orchards from Nelspruit, he reported values of 11.0 to 24.0 ppm in topsoil samples. From 68 orchard-soils investigated, 35% contained from 0 to 10 ppm acid extractable copper.

Cheng & Bray (1953) using 0.1N HCl, extracted between 2.0 and 11.4 ppm copper from a number of soils. According to Reuther & Labanauskas (1966) Reuther & Smith found Florida sandy virgin soils to contain 3 ppm of copper. With the same extractant Williams & Moore (1952) reported a copper content of 0.1 ppm in recent aeolian unconsolidated calcareous sand and 4.6 ppm in loamy fine sand. According to Swaine (1955), a coarse sandy soil analysed by Bould, Nicholas, Tolhurst, Wallace & Potter contained 0.9 ppm of 0.1N HCl extractable copper.

"The copper content of soils ranges from values of 1 to 3 ppm, in soils where Cu deficiency characteristically occurs, to values of 200 ppm or more, in soils where excessive Cu has accumulated from residues of Cu-bearing sprays or dusts or from other sources" (Fiskell, 1965).

It would seem therefore that copper additions would be needed on both the Clovelly and Hutton soils.

3.2.2 Zinc

The essentiality of zinc for plant life was not fully realized until the early 1930's, when Chandler, Hoogland & Hibbard (according to Chapman, 1966) were able to correct little-leaf of peaches with zinc compounds. Since then the beneficial effects of zinc have been illustrated by numerous workers. Zinc toxicity was recognised much earlier and many reports of its effects were summarised by Brenchly (according to Chapman, 1966).

From a review of the literature (Nicholas, 1961), on the role of zinc in plants it is evident that zinc is closely associated with hormones in plants. Evidently zinc plays an important part in the activation and production of tryptophan and auxin. It is known that the decrease in auxin content of the plant is associated with deficiency symptons of zinc occuring in plants (Devlin, 1967).

Zinc participates in the metabolism of plants as an activator of several enzymes. Carbonic anhydrose was the first zinc-containing enzyme to be discovered (Devlin, 1967). A striking characteristic of zinc deficiency is the accumulation of soluble nitrogen compounds such as amino acids and amides in the plant. "One can assume from this observation that zinc must play an important role in protein synthesis" (Devlin, 1967).

Zinc deficiency most commonly occurs on acid, leached sandy soils where total zinc is low; alkaline soils where zinc availability is decreased; soils derived from granites; gneisses etc. and some organic soils where zinc is tied up in forms that are not easily available to plants (Chapman, 1966).

Zinc excess has been reported on acid peat soils and soils derived from rocks and materials that are high in zinc (Swaine, 1955).

3.2.2.1 Results

Soils of the Clovelly form contain about twice as much acid extractable zinc as those of the Hutton form (Table 8). There is practically no difference in the zinc contents of the different series within each soil form.

Table 8: Zinc content of the Hutton and Clovelly soils (ppm)

HUTTON			CLOVELLY		
HIGHEST	LOWEST	AVERAGE	HIGHEST	LOWEST	AVERAGE
2.20	0.30	0.89	3.02	0.90	1.57

The distribution of zinc in these soil profiles does not reveal any general pattern. (Appendix 3). Not one of the profiles examined showed either a definite increase or decrease of zinc content with depth (Appendix 3).

The zinc content of both the Hutton and Clovelly soils are not significantly correlated with clay content (Appendix 5).

Using 0.1 N HCl as an extractant for zinc Stanton (1964) investigated the zinc status of various selected Orange Free State soils and found virgin Semi-arid Brown soils to contain an average of 0.56 ppm of zinc. He concluded that these soils are low in Zn. Van der Merwe (personal communication, 1970) reports values of 1.7 ppm and 2.8 ppm for Vaalharts and Sandvet soils respectively.

Tucker & Kurtz (1955) reported values ranging from 2.2 to 3.3 ppm for soils on which no zinc responses were obtained. Wear & Sommer (1948), for Alabama soils, found a good correlation between the amount of zinc extracted with 0.1 N HCl and the presence or absence of deficiency symptoms. Where deficiency symptoms occurred the zinc content ranged from 0.50 to 0.90 ppm and where no deficiency symptoms were evident the values ranged from 1.20 to 4.70 ppm of zinc. Viets, Boawn and Crawford (1954) found 0.80 to 1.3 ppm of 0.1 N HCl extractable zinc in soils where various field crops showed zinc deficiency symptoms, as against 1.3 to 1.8 ppm in soils where no deficiency symptoms occurred.

From the above it is evident that the Clovelly soils (average 0.89 ppm) are definitely zinc deficient. The Hutton soils seem to be intermediate soils when compared to values cited previously and the zinc contens of these soils will have to be closely observed to avoid deficiency of zinc.

3.2.3 Manganese

Before manganese was isolated in 1778, manganese compounds were mistaken for those of iron. The work of McHargue (according to Labanauskas, 1966) proved without any doubt that manganese was an essential element for normal plant growth. Numerous experiments, in both water cultures and soils, have shown that manganese increases the growth of plants (Labanauskas, 1966).

Manganese seems to be an essential factor in respiration and nitrogen metabolism and in both processes it functions as an enzyme activator (Devlin, 1967).

Manganese is one of the most abundant of the essential micronutrients in soils and is mostly present in oxide and hydroxide forms (Berger & Pratt, 1963). Exchangeable and easily reducible manganese are considered to be available to plants (Labanauskas, 1966).

Toxic concentrations of this element commonly occur in strongly acid soils and poorly aereated soils. Under anaerobic conditions manganic compounds are reduced to soluble manganous forms with a resultant accumulation of manganous ions.

Deficiency of manganese is commonly found in the following soils: Alluvial soils and marsh soils derived from calcareous materials, such as calcareous silts and clays, poorly drained calcareous soils with a high content of organic matter, calcareous black sands and reclaimed acid heath soils and very sandy acid mineral soils that are low in native manganese content (Labanauskas, 1966).

3.2.3.1 Results

The Clovelly soils have a much higher average manganese content than the Hutton soils (Table 9).

Table 9: Easily reducible manganese content of the Hutton and Clovelly soils (ppm)

HUTTON			CLOVELLY		
HIGHEST	LOWEST	AVERAGE	HIGHEST	LOWEST	AVERAGE
193	14.5	73.54	176	89	122.11

The average manganese content for the three series of the Clovelly form are of a similar order, but the Shorrocks series has a much higher average than the other two series of the Hutton form (Appendix 4). The relatively low manganese content of profiles No's 157 and 67 are responsible for the low averages of the Zwartfontein and Goudam series respectively (Appendix 3). All the profiles examined, showed a decrease in manganese content with depth (Appendix 3).

The significant correlation between easily reducible manganese content and clay content ($r = 0.5747$) of the Hutton soils, once again suggests a close association with the exchange complex of the soil colloids. The same correlation for the Clovelly soils was found to be insignificant (Appendix 5).

Healy (according to Labanauskas, 1966) showed that peach trees on silt loam (pH 7.5 to 7.9) with less than 44 to 54 ppm of easily reducible manganese were manganese deficient. According to Labanauskas (1966) Leeper considered the quantity of easily reducible manganese to be of great importance for normal plant growth. "He found that any soil with less than 15 ppm of easily reducible manganese dioxide was deficient in manganese for plant growth. On the other hand soils having more than 100 ppm of easily reducible manganese dioxide were amply supplied" (Labanauskas, 1966). Sherman, McHargue & Hodgkiss (1942) concluded that soils with less than 25 ppm of easily reducible manganese would not supply plants with sufficient manganese for normal growth.

It can therefore be concluded that soils of both the Hutton and Clovelly forms generally have adequate supplies of plant-available manganese. There are, however, members of the Hutton form which are expected to become manganese deficient under cropping, notably members of the Zwartfontein and Goudam series (Appendix 3).

3.3 PROBABLE NUTRITIONAL EFFECTS IN THE HUTTON AND CLOVELLY SOILS

Growth factors are decisive in plant life and include climatic conditions, physical conditions of the soil and plant nutrients (Teusher & Adler, 1960). The latter will be briefly discussed here, together with soil conditions affecting their availability and their relation to each other.

Apart from the various sources of nutrients, soil reaction (pH) must be considered as one of the greatest factors influencing the availability of plant nutrients. According to Von Uexküll (1963) the availability and effect of many plant nutrients, particularly phosphorus and the trace elements, depend to a large extent on the prevailing pH of the soil.

The soils investigated have average pH values of 8.2 (Clovelly) and 6.8 (Hutton). It is generally accepted that the pH range between 6 and 7 is the most favourable for the availability and effectiveness of most plant nutrients (Von Uexküll, 1963). However, lately it has been pointed out by several research workers that the availability and uptake of trace elements are restricted at pH levels above 6.0 to such an extent that deficiencies may occur. This is especially true of zinc (e.g. Stanton, 1964; Laker, 1964) and even more so in sandy soils. Van Niekerk & Pienaar (1967) even prefer a pH value of 5.5 as the ideal pH at which to grow deciduous fruit.

It is thus evident that the pH values of the soils of both forms investigated are such that restriction of trace element uptake may be expected. In the soils of the Clovelly form this effect is expected to be extremely severe. For the macronutrients no such effects are expected, except in the case of phosphorus, which will be discussed later.

A further important consideration concerning pH is that it is generally found that the pH values of irrigated soils increase with time or at best retain their initial levels. Since the pH values of these soils are initially high, as stated earlier, preventative measures to keep these values from increasing further under irrigation practices should enjoy priority. This would include use of fertilizers which are known to acidify soils, etc.

The resin-extractable phosphorus content of the soils of both forms are deficient. Cooke & Hislop (1963) found a soil containing approximately 10 ppm resin-P to be highly responsive to phosphorus applications. Liberal applications of phosphatic fertilizers will consequently be essential during the initial stages. However, analytical data of soils from Vaalharts indicate that the phosphorus status of these sandy soils can easily be raised to very high levels by normal phosphorus applications (unpublished data - O.F.S. Region, Glen). Once the phosphorus status of these soils have been sufficiently raised the applications must be minimized. This is not only sound economic policy, but it is also known that excessively high phosphorus concentrations in soils limit the uptake of micro-nutrients such as zinc and copper (e.g. Stanton, 1964).

Since optimal uptake of phosphorus takes place in the pH region between 6 and 7, the position with the Hutton soils are favourable in this respect. Von Uexküll (1963) indicated that phosphorus seems to be the least available to plants in the immediate region below and above pH 8.5. Because their pH values are in this region, availability of phosphorus may be limited in the Clovelly soils. It is also known (Cooke, 1967) that at the pH levels found in these soils the less soluble forms of phosphatic fertilizers are inefficient. Consequently water-soluble phosphatic fertilizers are to be recommended on these soils.

Loss of phosphorus through leaching is not expected to be significant as phosphorus is known to be immobile in soils. This was actually demonstrated to be true for a comparable sandy soil from the O.F.S.-Region (Laker, 1964). On the other hand it means that phosphorus applied to topsoils will not ne transported into subsoils by irrigation waters. Therefore, serious consideration must be given to subsoil applications of phosphorus for deep-rooted crops.

These soils are expected to supply adequate sulphur to plants initially. However, sulphur is much more mobile and less firmly adsorbed than phosphorus in soils. The result is that enormous losses through leaching can take place under either high rainfall or over-irrigation practices. As stated earlier, losses of sulphur from soils are 100 times as high as those of phosphorus. Apart from the sources of sulphur mentioned earlier, additions through irrigation waters must also be considered. Alway (1940) reports an annual gain of 249 kg/ha of sulphur from irrigation waters.

The availability of the macronutrient cations (Ca^{++}, Mg^{++}, Na^{+} and K^{+}) is very closely associated with the cation exchange capacity of soil colloids, the type of colloids present in the soil and the ratios of the different cations present.

Calcium and magnesium constitutes the greater proportion - $>$50% for the lowest degree of saturation - of the CEC of both the Clovelly and Hutton soils. Furthermore the Clovelly soils contain free lime and calcium should therefore not present any nutritional problems in these soils for a number of years to come. The high concentrations of calcium and to a lesser extent of magnesium may, however, adversely affect the potassium nutrition of crops on these soils. It is known (Ulrich & Ohki, 1966) that excessively high concentrations of calcium and magnesium have a limiting influence on the availability of potassium especially when the latter is in short supply. The Clovelly soils have an average potassium of only 0.15 me/100g, which is considered to be low compared to the calcium and magnesium values. Attention should therefore be paid to the potassium fertilization of these soils from the outset. Additions of calcium and magnesium compounds in fertilizers must be kept in mind. Increased wheathering of calcium bearing minerals under favourable moisture conditions must also be considered.

Although calcium and magnesium also constitutes the greatest proportion of the CEC of the Hutton soils, they are not present in excessively high concentrations compared to potassium as to limit potassium uptake from these soils. Experiments with high levels of potassium fertilization at Vaalharts showed that with heavy applications of potassium red-death of cotton on these sandy soils can be limited (Laker, 1970).

It is well known that the ratios between different cations are very important in plant nutrition. For instance it has been shown that when the Ca/Mg ratio becomes too wide crops will suffer from a lack of magnesium even though considerable quantities are present in the soil. Ca/Mg ratios as wide as 156 : 1 have been reported, resulting in magnesium deficiency (Berger & Pratt, 1963).

Although the Clovelly soils contain free lime the widest average Ca/Mg ratio is 6.64 : 1 for the Torquay series (Appendix 4). However, this is not expected to result in magnesium deficiency on these soils.

Apart from the low phosphorus status of both soil forms and the low average potassium status of the Clovelly soils (Appendix 4), these sandy soils have a rather favourable macronutrient status. Careful consideration of fertilizer applications will contribute largely to ensuring optimal yield from these soils.

Unfortunately the micro-nutrient cation status of these soils does not present such a healthy picture. Of the micronutrients determined in this investigation only manganese seems to be present in favourable quantities. It was found that both soil forms are definitely copper deficient. Evidently the Clovelly soils are also zinc deficient and the Hutton soils are intermediate as far as zinc content is concerned (See section 3.2.2).

Each of the micronutrient cations are influenced in a characteristic way by their soil environment. However, there are certain soil factors that have the same general effects on the availability of all of them (Buckman & Brady, 1969).

As stated earlier the high pH (8.2) of the Clovelly soils will restrict micronutrient uptake from the Clovelly soils. Being more soluble under acid conditions the micronutrient cations are changed to insoluble hydroxides and oxides when the pH is increased.

In general high pH values favour oxidation and low pH values favour reduction of cations present in more than one valence state, viz. copper and manganese. Furthermore it is known that the oxidized states of manganese and copper are less soluble at pH values common in soils and therefore less available to plants. The Clovelly soils (average pH 8.2) therefore favour oxidized states of manganese and copper and availability of these elements may be restricted in these soils.

Recent analytical data (unpublished data, U.O.F.S.) already show rather low copper content in wheat straw grown in comparable soils at Vaalharts. The soils of the Hutton and Clovelly soils are already deficient in copper and therefore copper fertilization on these soils must receive attention at the outset.

The adverse effect of large applications of phosphate fertilizers on the availability of some of the micronutrients are well known. Of the micronutrient cations zinc appears to be the most affected by the presence of excessive amounts of phosphorus. Stiles (1961) suggests that this effect of phosphorus is due to the production of relatively insoluble zinc phosphate in the soil. Jurinak & Inouye (1962) indicated the formation of zinc othophosphate and that copper precipitated as the basic phosphate $Cu_5(H_2PO_4)_2(OH)_8$. They concluded that the basic copper phosphate was less soluble than zinc orthophosphate at all levels of pH from 3.73 to 10.93. There is some evidence (Stiles, 1961) that additions of calcium hydrogen phosphate to a sandy soil increased manganese uptake.

Although the application of liberal amounts of phosphate fertilizers to these soils are advocated here, it must be expected that excess phosphorus will restrict zinc nutrition. Zinc applications to these soils are therefore just as important as the application of phosphorus. Reaction to zinc fertilization have recently been reported on comparable soils from the Vaalharts and Riet River areas (unpublished data: Glen and U.O.F.S.)

From the results of Langin, Ward, Olson & Rhoades (1962) it is evident that the effect of P applications to aggravate Zn deficiencies is greatest on calcareous soils.

This statement would be fully applicable to the calcareous Clovelly soils. They indicated that supplemental zinc must be applied to such soils whenever P is added to soil where the level of Zn availability is uncertain.

In view of the expected irrigation of the soils studied, and keeping in mind certain problems which presently occur at Vaalharts and Sandvet, the results of Ward, Langin, Olson & Stukenholtz (1963) also warrant consideration. They found that where P application reduced Zn concentrations in maize, increasing soil compaction and soil moisture level caused further depressions of Zn concentration. Research by Van der Merwe (unpublished) has indicated that the sandy Hutton soils are extremely susceptible to compaction under irrigational cropping and consequently results of the nature of those obtained by Ward et al (1963) may be expected on these soils. Chapman (1966) also warned that field crops grown on newly levelled land should always be checked for zinc deficiency. Any levelling of land for irrigational purposes will, therefore, enhance this problem.

While zinc fertilization is seen as a basic requirement for optimum crop production on the studied Hutton and Clovelly soils, uncontrolled continuous application of zinc cannot be advocated. Chapman (1966) indicated that the latter practice may produce zinc toxicity, a problem which has already occurred in Florida.

The fixation of manganese by 2 : 1 type clay minerals is apparently of little significance because of the presence of adequate amounts of manganese in soils. Zinc fixation by these clay minerals are somewhat more serious because zinc is present in such low concentrations in soils (Buckman & Brady, 1969). The Clovelly (1.57 ppm) and Hutton soils (0.89 ppm) are both deficient in zinc. Upon application of zinc to these soils some fixation may be expected. Stanton (1964) postulated that the phosphated hydrous oxides of Fe and Al sorb Zn through the medium of polyvalent phosphate ions present in soils.

According to Stiles (1961) there is an antagonistic effect between calcium and manganese. The high average concentrations of calcium (27.6 me/100g) present in Clovelly soils can therefore reduce manganese uptake from these soils. The lower average concentrations of calcium (2.474 me/100g) in the Hutton soils is not expected to have the same effect. Once again the application of calcium compounds in fertilizers must be emphasised here. It is clear that the calcium content of especially the Clovelly soils will have to be watched carefully in order to avoid deficiencies of elements such as magnesium and manganese.

The Orange River Project is a long term investment and therefore long term fertilizer practices are advocated here. Once a nutrient deficiency is detected in a crop, the producer has already lost greatly in profits. Thus by avoiding possible nutrient deficiencies in crops the return on such a large investment of capital can be so much more rewarding.

CHAPTER IV

POT EXPERIMENT WITH DIFFERENT PHOSPHORUS AND POTASSIUM LEVELS

From the previous chapters it is evident that the plant nutrient status of the soils of the Hutton form differs markedly from those of the Clovelly form in several respects. From these results it is clear that nutrient deficiencies occur in these soils and that it can be expected that plants will react upon certain fertilizer treatments on these soils. Of the macroelements the most significant deficiencies appear to be those of phosphorus and potassium.

A pot experiment, in which different phosphorus and potassium levels were included, was therefore conducted. One representative sample of each of the two soil forms was included in order to study the reactions within each form and to compare the relative reactions of the two soil forms.

4.1 MATERIALS AND EXPERIMENTAL PROCEDURE

4.1.1 Materials

Samples 566 (Hutton form) and 574 (Clovelly form) were selected for this experiment. Relevant analytical data for these two samples are presented in table 10.

TABLE 10: ANALYTICAL DATA OF THE SAMPLES INCLUDED IN THE POT EXPERIMENT

SAMPLE NO.	CLAY %	CEC (me/ 100g)	pH (2:5 H_2O)	P (ppm)	Ca (me/ 100g)	Mg (me/ 100g)	Na (me/ 100g)	K (me/ 100g)
566	8	3.50	6.60	2.25	1.25	1.33	0.24	0.25
574	8	12.20	7.85	1.65	7.75	4.25	0.28	0.12

The most significant differences between the two samples are (table 10) that the Hutton soil contains more phosphorus and potassium than the Clovelly soil. Furthermore, the Clovelly soil has a much higher calcium and magnesium content, resulting in a much higher pH. Although both samples have the same clay content, the Clovelly soil has a much higher cation exchange capacity.

Rye (Secále cereále L., cultivar Polko) was used as test crop.

4.1.2 Procedure

4.1.2.1 Preparation of soil-sand mixtures

The bulk soil samples were passed through a 2 mm sieve and only the smaller than 2 mm fractions were used in the experiment.

The 1 to 2 mm fraction of pure quartz sand was obtained by sieving and then acid-treated to remove any free plant nutrients from the sand. The acid treatment comprised the following: Excess concentrated HCl was added to bulk samples of the sand and left for 8 hours, during which time it was periodically stirred. The HCl was then decanted. After this the sand was washed with tap water to remove any remaining acid and then washed repeatedly with distilled water until free of chlorides (according to the silver nitrate test). This was taken as an indication that all free salts were removed. The sand was then air-dried.

Quantities of 340g air-dry <2 mm soil plus 340g air-dry acid-washed sand were mixed, together with the appropriate quantities of plant nutrients, and brought over into waxed paper pots of 500 ml capacity. Deist (1961) pointed out that these containers gave identical results to pots twice this size. Prior to filling with the soil-sand mixtures the pots were painted with black bitumen paint and their bottoms perforated to facilitate drainage of any excess water applied during the experiment.

The treatments consisted of 2, 6 and 10 mg P/pot (as $Ca\ (H_2PO_4)_2\ H_2O$) and 0, 5 and 10 mg K/pot (as KCl) applied in all combinations to each soil. Five replicates of each treatment was applied. It was thus a 2(soil) x 3(P-level) x 3 (K-levels) factorial experiment with 5 replications. A randomized block design was used. All pots received a standard nitrogen application. This will be discussed later.

4.1.2.2 Germination of seeds and growing of plants

Seeds were treated with 0.1% mercury chloride, thoroughly washed with distilled water and placed on moist paper towels. The towels were carefully folded, placed in

500 ml beakers and covered with plastic material. Germination was completed in a constant temperature incubator at 30°C.

Prior to planting, each pot was moistened with 50 ml of a solution containing 10mg of nitrogen (as NH_4 NO_3). Seven germinated seeds were than planted in each pot. After planting 30 ml of distilled water was applied per pot to settle the soil. The soil was kept moist until all the seeds were sprouted.

After 10 days the seedlings were thinned out to four uniform plants per pot. Due to high evaporation in the greenhouse, the plants were watered every day. During the third week (after planting) the tips of older leaves showed yellowing and appeared to die. Another nitrogen treatment of 10 mg N (as NH_4 NO_3)/pot was applied. The plants were allowed to grow for another three weeks.

In an attempt to minimise shading and temperature effects, the trollies (each representing a block) were rotated once a week, without shifting them from their original positions.

4.1.2.3 Harvesting of plants

The aerial parts of plants were harvested 6 weeks after planting by cutting it 3 mm above the ground with a scissors. The yield of every pot was carefully washed with distilled water, placed in paper bags and dried in an oven at 80°C for 48 hours. The dried plant material was cooled in desiccators, ground to pass a 40 mesh sieve and weighed.

4.1.2.4 Ashing and chemical analysis of the samples

It is customary to ash only a chosen mass of plant samples rather than complete samples. But, after only 6 weeks of growing, the yield of every pot was so small that it was decided to ash the complete sample from every pot. Samples were dry-ashed in a muffle furnace at 550°C, using concentrated HNO_3 as an ashing aid. The actual ashing procedure comprised the following: Samples were kept at 550°C in a muffle furnace for 5-10 minutes. After allowing the samples to cool, a few drops of concentrated HNO_3 were added to each sample. The samples were than left on a boiling water bath for 30 minutes and then put back into the muffle furnace at 550°C for another 5-10 minutes. For samples not completely ashed, the treatment was repeated.

The residue was taken up in 10 ml 1:2 HNO_3 and 20 ml distilled water by heating it on a boiling water bath for 20 minutes. The solutions were then transferred to 50 ml volumetric flasks and brought to volume with distilled water.

These solutions were directly analysed for potassium, using a Zeiss PF5 flame photometer. Phosphorus was determined colorimetrically by means of the yellow method as described by Piper (1950).

4.2 RESULTS AND DISCUSSION

The results were statistically analysed according to the method described by Steel & Torrie (1960) for factorial experiments. The different treatments were compared at the five percent level of significance according to Tukey's (Steel & Torrie, 1960) procedure. The same procedure was followed in comparing the two soils.

4.2.1 Plant masses

In the analysis of variance completed on the plant masses, only soil and the soil-P interaction were significant. Therefore the soil-P interaction required further statistical analysis to determine differences.

The average plant masses at the different levels of phosphorus application for the two soils are presented in Table 11.

TABLE 11: MASSES OF OVEN-DRY PLANT MATERIAL AT DIFFERENT LEVELS OF P-APPLICATION FOR THE TWO SOILS (g/Pot)

P-LEVEL	HUTTON	CLOVELLY
P1	0.3305	0.5283
P2	0.4161	0.3901
P3	0.3296	0.4321
General mean	0.3590	0.4635

$W_{(0.05)}$ for P-levels within soils : 0.1075

$W_{(0.05)}$ for soils within treatments: 0.0895

It is clear that oven-dry plant masses at the P_1-and P_3-levels of phosphorus application for the Hutton soil were identical. Although the average value at the P_2-level was notably higher than the averages for the P_1- and P_3-levels, this difference was not statistically significant.

For the Clovelly soil plant masses at the P_2- and P_3-levels were similar, but at the P_1-level the plant masses were significantly higher than the masses at the former two levels of P-application. This adverse effect of high levels of P-application on plant growth might have been the result of induced trace element deficiencies. This type of effect is a distinct possibility on the Clovelly soil, as was pointed out in section 3.3.

At both the P_1- and P_3-levels of P-application oven-dry plant masses for the Clovelly soil were significantly higher than those for the Hutton soil. As a result of these differences the general mean for the Clovelly soil was also higher than that for the Hutton soil. At the P_2-level of P-application the plant masses for the two soils were similar. It should be noted here that P-uptake from the Clovelly soil at the P_2-level of P-application was much more lower relative to P-uptake from the Hutton soil than at the other two P-levels of P-application. This is illustrated in section 4.2.2 (Table 12).

Potassium applications had no significant effect on oven-dry plant masses.

4.2.2 Phosphorus

The results illustrating the effect of P-treatment on phosphorus uptake by plants are presented in Table 12.

TABLE 12: P-CONTENT OF OVEN-DRY PLANT MATERIAL AT DIFFERENT LEVELS OF P-FERTILIZATION

	SOIL FORM			
	HUTTON		CLOVELLY	
P-LEVEL	mg P/POT	%P	mg P/POT	%P
P_1	1.058	0.2807	0.759	0.1480
P_2	4.459	1.0247	1.973	0.5099
P_3	3.608	1.0733	4.133	0.9670

$W_{(0.05)}$ for P-levels within soils : mg P/pot = 1.1660
: % P = 0.1520
$W_{(0.05)}$ for soils within treatments: mg P/pot = 0.9707
: % P = 0.1266

It is evident that much higher P-uptake (expressed as mg P/pot) was found at the P_2- and P_3-levels of phosphorus application than at the P_1-level for both soils. This is not unexpected for soils with such low initial P-content. The most interesting and important feature, however, is the striking difference in the pattern of reaction between the two soils. At the P_1-level, P-uptake did not differ significantly between the two soils. At the P_2-level P-uptake from the Hutton soil was 4.2 times higher than at the P_1-level, whereas the corresponding factor for the Clovelly soil was only 2.6. At the P_2-level, P-uptake was consequently significantly higher from the Hutton than from the Clovelly soil. P-uptake from the Clovelly soil was, furthermore, significantly higher at the P_3-level than at the P_2-level. For the Hutton soil P-uptake levelled off at the P_2-level and there was no significant difference between the P_2- and P_3-levels, with the value for the latter actually a bit lower. It is interesting to note that the value of P-uptake for the Clovelly soil, reached at the P_3-level, was similar to those of the P_2- and P_3-levels for the Hutton soil.

These results are also presented in Figure 1.

The differences between the two soils are well illustrated in Fig. I. It is clear that a linear relationship between P-uptake and P-application for the Clovelly soil exists.

Within any of the two soils the patterns and significant differences found for phosphorus concentration in the plants (as % P) between treatments, were similar to those found for P-uptake. This is illustrated in Table 12 and Figure 2.

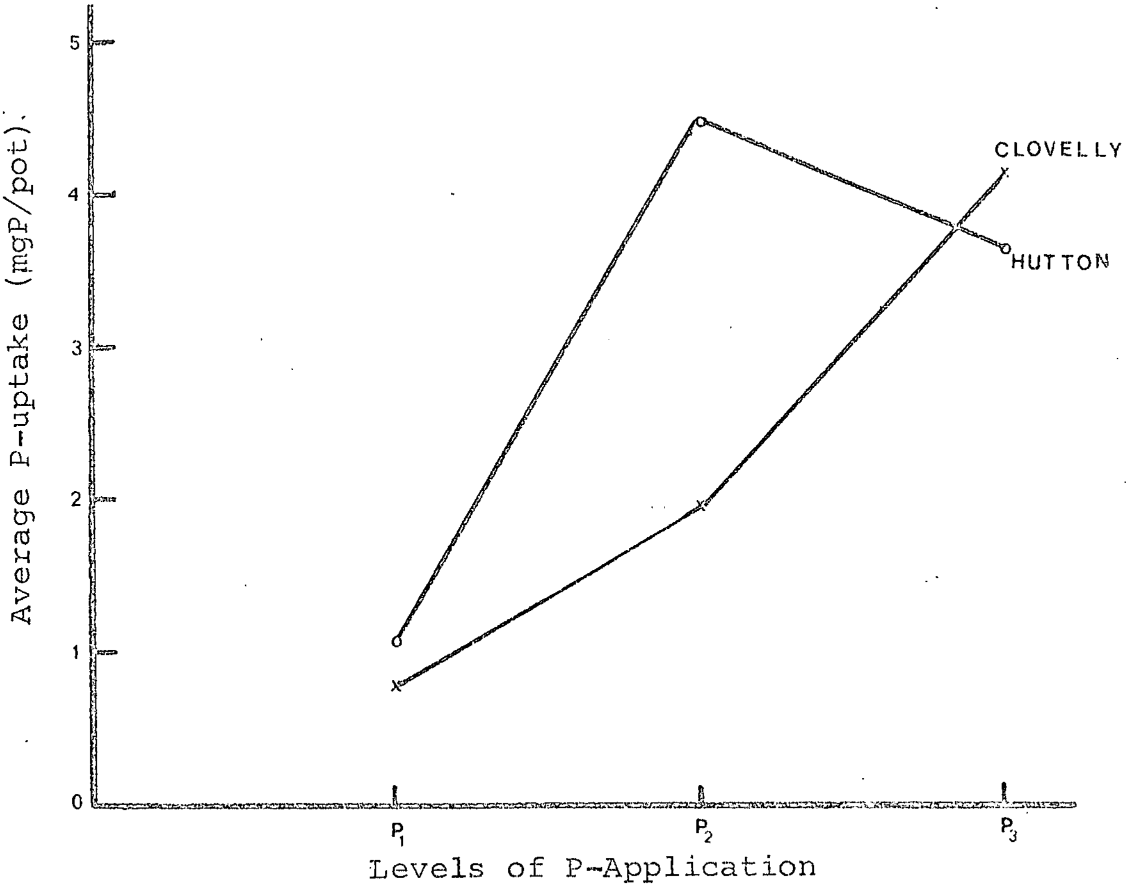

Fig. 1 Average P-uptake from the two soils at different levels of P-application.

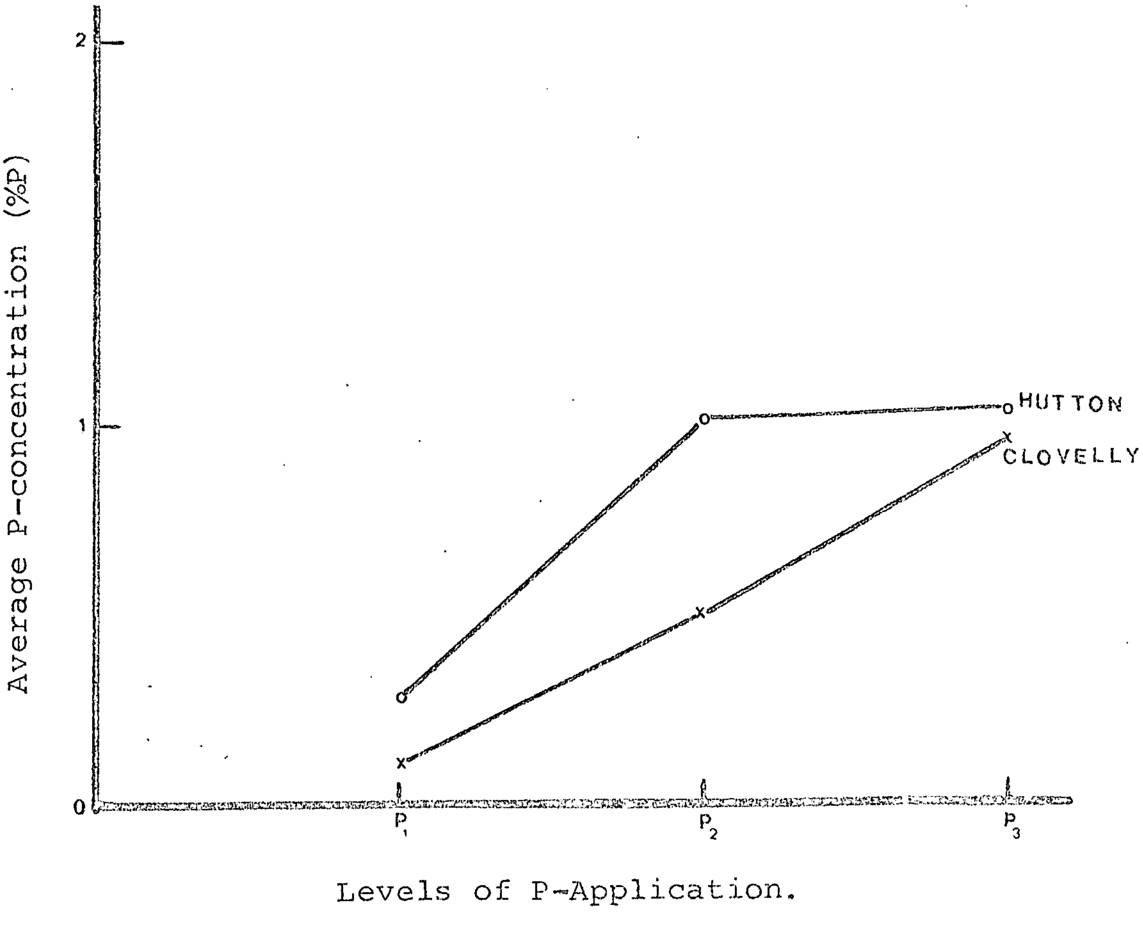

Fig. 2 Average P-concentration of plants grown in the two soils at different levels of P-application.

For P-concentration the differences between the two soils differed from those for P-uptake (Table 12). At both the P_1- and P_2-levels of phosphorus application the P-concentrations of the plants grown in the Clovelly soil were significantly lower than those grown in the Hutton soil. At both these levels of P-application the P-concentrations of the plants grown in the Hutton soil actually were about twice as high as those of the plants grown in the Clovelly soil. P-uptake (as mg P/pot) differed significantly between the two soils only at the P_2-level, as was indicated. As in the case of P-uptake, P-concentration in the plants did not differ between the soils at the P_3-level.

That such a good correlation exists between P-uptake and P-concentration in the plants, is a result of the fact that improved P-uptake, due to increased P-fertilization, did not cause corresponding increases in plant growth.

It is noteworthy that the ratio describing the relative P-uptake (mg P/pot), at the P_1-level of phosphorus application from the two soils, was 1.376. The ratio between the initial P-content of the soils was 1.364. This means that P-uptake at the P_1-level was related to the resin-extractable P-content of the two soils, since the two ratio's are practically identical.

The different patterns found for the two soils at the higher P-applications (P_2 and P_3) can consequently not be ascribed primarily to the differences in initial P-content of the soils. That the Clovelly soil required a higher P-application to attain optimum P-uptake than was the case with the Hutton soil, may be related to differences between the phosphorus fixation capacities and mechanisms of the two soils. In this respect the much higher pH of the Clovelly soil (Table 10) may be important. The CEC of the clay fraction of the Clovelly soil is also much higher than that of the Hutton soil (Table 10).

Indications are that montmorilonitic type clay minerals are present in the Clovelly soils. (Unpublished data, U.O.F.S.). It is suspected that this type of clay mineral play a part in the fixation of phosphorus.

From the results obtained, it is evident that any results from field experiments concerning phosphorus fertilization, conducted on a representative soil of any one of these two soil forms will not be applicable to soils of the other form.

Finally it should be noted that the level of potassium application caused no significant differences in either P-uptake or P-concentration in the plants at any level of P-application or in any one of the soils.

When the P-concentrations in the plants are compared to results summarized by Bingham (1966) it is clear that the values obtained are high.

4.2.3 Potassium

Averages for the different levels of potassium application are presented in Table 13.

TABLE 13: K-CONTENT OF OVEN-DRY PLANT MATERIAL AT DIFFERENT LEVELS OF K-FERTILIZATION.

	SOIL FORM			
	HUTTON		CLOVELLY	
K-LEVEL	mg K/POT	% K	mg K/POT	% K
K_o	8.3613	1.9775	7.1362	1.6256
K_1	8.1854	2.3359	8.6209	1.8523
K_2	8.2441	2.5514	9.3715	2.0853

$W_{(0.05)}$ for K-levels within soils : mgK/pot = 2.8689
: % K = 0.2911

$W_{(0.05)}$ for soils within treatments : mgK/pot = 2.3880
: % K = 0.2423

K-uptake (mgK/pot) from the Hutton soil was similar at all three levels of K-application (Table 13 and Figure 3). K-uptake from the Clovelly soil increased with increasing level of K-application, but the increase was so small that the difference between any two K-levels was not statistically significant.

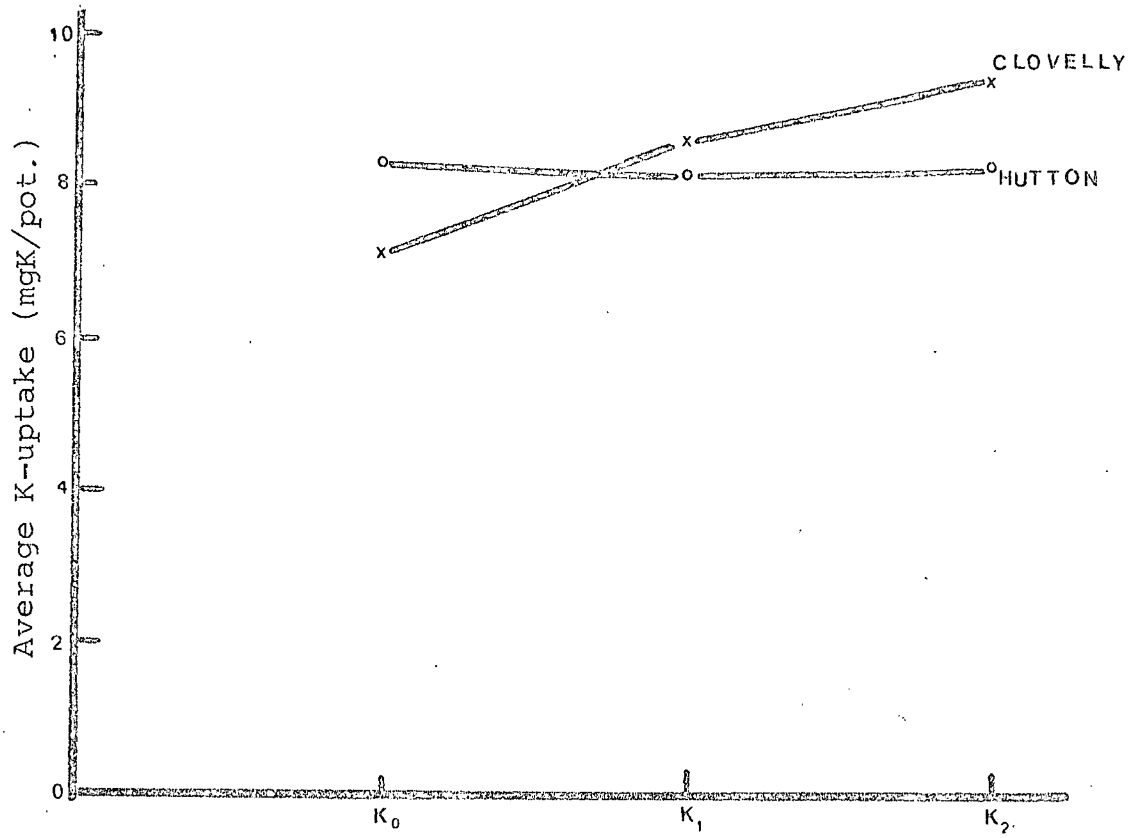

Fig. 3 Average K-uptake from the two soils at different levels of K-application.

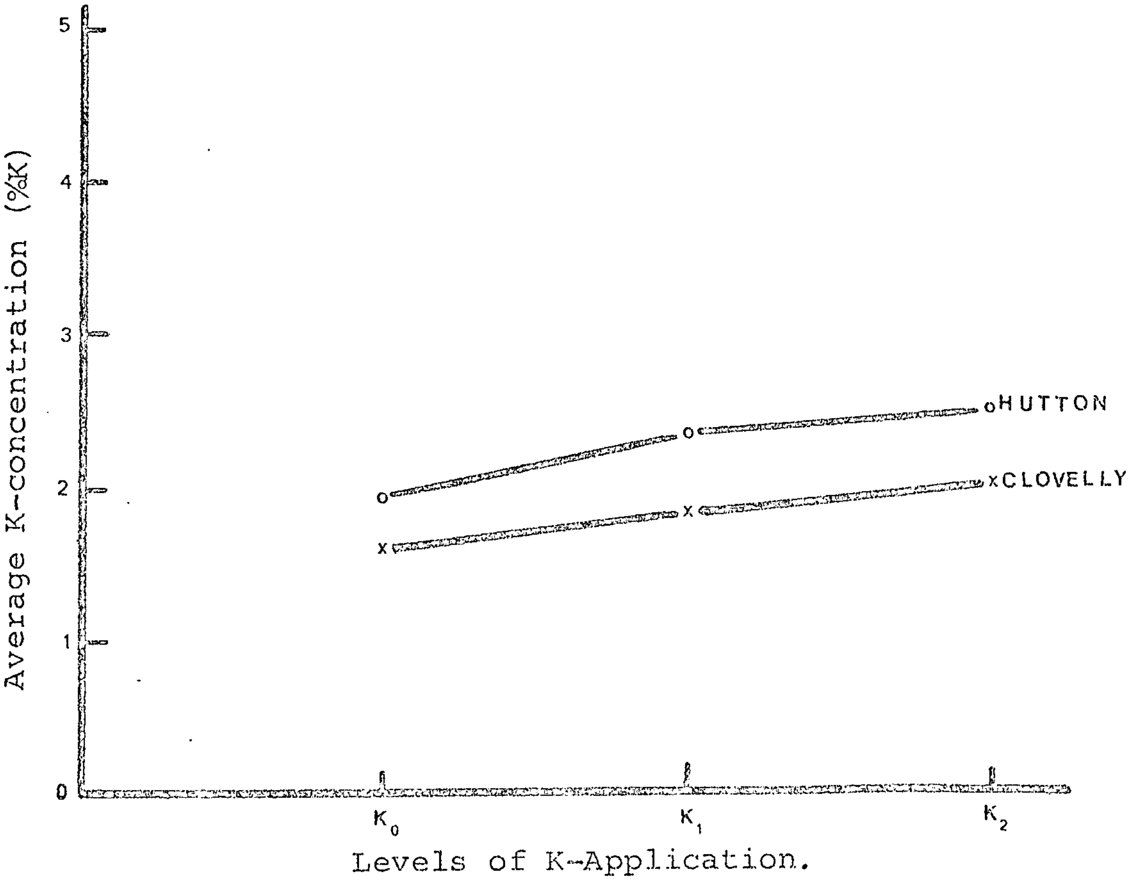

Fig. 4 Average K-concentration of plants grown in the two soils at different levels of K-application.

At the K_o-level of K-application, K-uptake from the Clovelly soil was somewhat lower than from the Hutton soil. For the K_1- and K_2-levels the reverse was true. None of these differences were statistically significant, however.

The concentration (as % K) of potassium in the plants growing in the Hutton soil are significantly higher at the K_2- and K_1-levels than at the K_o-level of potassium application. However, no significant differences between the potassium concentrations in plants growing in the Hutton soil at the K_2 and K_1-levels of potassium application existed.

At the K_2-level of potassium application, the potassium concentrations in plants growing in the Clovelly soil, differed significantly from the concentrations at the K_o-level of application. No significant differences between the concentrations of potassium at the K_2 and K_1-levels of applications are evident. The potassium concentrations in plants growing in the Clovelly soil at the K_o and K_1-levels of application also did not differ significantly from each other. For the Clovelly soil this increase in K-concentration with increasing K-level was linear, but not in the Hutton soil (Figure 4).

At each level of potassium application the concentration of potassium in plants growing in the Hutton soil was significantly higher than those of plants growing in the Clovelly soil.

No main effect of P-application on either K-uptake or K-concentration was found.

4.3 Conclusions

The absence of positive growth responses to increased P-level at the higher P-applications is not regarded as an indication that the original field samples contained sufficient available phosphorus. It is rather attributed to secondary effects in the pots.

The results regarding P-uptake and K-uptake indicated differences between the two soils which are of such a nature that they warrant further intensive investigations on the P and K-nutritional status of these soils.

CHAPTER V

PHOSPHATE POTENTIAL STUDIES

5.1 PURPOSE

The results from the pot experiment (Chapter 4) indicated that there was a difference in the reaction of the two soil forms to applied phosphorus. It has been suggested (Schofield, 1955; White & Beckett, 1964) that phosphate potentials may be used as an indication of soil phosphate availability. This experiment was therefore conducted to determine whether the phosphate potential concept would not provide a possible explanation for the difference between the two soils in their reaction to applied phosphate.

5.2 THEORETICAL

Schofield (1955) suggested that the phosphate potential, defined as the negative chemical potential of mono-calcium phosphate ($\frac{1}{2}$p Ca + pH_2 PO_4), could be used as an index of soil phosphate availability. This was later supported by the work of Le Mare (1960).

The phosphate potential of a soil as defined by Schofield (1955), however, cannot be determined directly. The phosphate concentration in the soil solution, as well as the calcium concentration, however, can be measured. These two measurements, together with the pH of the solution, supplies the key to the calculation of the phosphate potential.

According to White & Beckett (1964) $\frac{1}{2}$p Ca is calculated from:

$$\tfrac{1}{2}\text{p Ca} = -\tfrac{1}{2}\,(\log_{10} \text{conc.}_{Ca} + \log_{10} f) \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where: $\text{conc.}_{Ca} = 0.01M$

$$\text{and } \log_{10} f = \frac{-AZ^2\sqrt{\mu}}{1 + aB\sqrt{\mu}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

In equation (2): A = 0.5

Z = the valency of the ion

μ = the ionic strength of the solution

and aB = 1.5

Likewise pH_2PO_4 is calculated from:

$$pH_2PO_4 = -(\log_{10}\text{conc.}_{H_2PO_4} + \log_{10}f) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where: $$-\log_{10}\text{conc.}_{H_2PO_4} = p(P) + p\left(\frac{H}{K'' + H}\right) \quad \ldots\ldots\ldots\ldots (4)$$

In equation (4) : (P) = the total P concentration in the solution

K" = the apparent second dissociation constant of phosphoric acid

and H = the hydrogen ion concentration in the solution.

All concentrations must be given as moles per litre.

According to White & Beckett (1964) Schofield's Ratio Law requires that for a given soil with a given complement of calcium and phosphate ions, the activity product ($a^{\frac{1}{2}}$ Ca x $a_{H_2PO_4}$) in the soil solution must be independent of the electrical potential and therefore independent of the other ions present in the soil solution.

The validity of the Ratio Law depends on the following assumptions:

(1) For the Ratio Law to apply, the concentration of the soil solution must not be too high, and the density of the negative charges on the soil surfaces must not be too low. It was pointed out by Schofield (1955) that the Ratio Law does not apply to a soil with many positive charges.

(2) An implicit condition of the Ratio Law is that the ions which control the phosphate potential, viz. phosphate and calcium, must be present on the same surfaces in the soil. If they are present on different surfaces there must be a constant difference in electrical potential between the two kinds of surfaces. "This condition is easily met for soils in which the main reserves of calcium and phosphate are co-adsorbed onto negatively charged colloid surfaces" (White & Beckett, 1964).

For the application of the phosphate potential as a measure of the availability of phosphates, the following assumptions must be met:

(1) The soils of which the phosphate potential is measured, must conform to the Ratio Law. If not, the value of the phosphate potential measured, will not only depend on the amount and form of combination of the labile phosphate and calcium in the soil, and will be subject to unpredictable variations.

(2) The chemical potential of calcium must be much less variable than the chemical potential of phosphate in the soil. "When comparing the phosphate potentials of tropical or virgin soils with those of agricultural soils of temperate regions, care must be taken not to compare soils of widely different calcium status." (White & Beckett, 1964).

(3) The chemical potentials of phosphate and calcium, or the chemical potential of complementary ions such as Fe^{3+}, Al^{3+} or OH^-, which also affects the value of the activity product, must not be altered by the act of measurement (White & Beckett, 1964).

From the literature it is evident that phosphate potentials are subject to variations which are caused by certain soil conditions. Anaerobic conditions, changes in temperature and drying of the soil all seem to have an effect on phosphate potentials (White & Beckett, 1964). It was pointed out by White (1964) that microbial activity, by disturbing phosphate equilibrium conditions in the soil, has an influence on phosphate potentials. Le Mare (1960) postulated a linear relationship between phosphate potential and pH. He also indicated that some correlation exists between phosphate potential and organic substances. "The level of organic matter may be important in this respect since it has been shown that organic substances may play an important part in preventing precipitation of phosphate by iron and aluminium because of their ability to form stable complexes with these metals". (Le Mare, 1960).

According to White & Beckett (1964) the phosphate potential of a soil seems to be a reflection of the availibility of phosphates, but does not reflect the phosphate status of a soil. "The use of the phosphate potential as a measure of the phosphate status has been examined by other workers, but no general conclusions regarding the relationship between potential and status have arisen from their work" (Larsen & Court, 1960).

5.3 MATERIALS AND EXPERIMENTAL PROCEDURE

5.3.1 The soils

The two samples used in the pot experiment (Chapter 4) viz. No's 566 (Hutton) and 574 (Clovelly), were included in this experiment. Two additional virgin soil samples of each soil form, viz. No's 578 and 582 (Clovelly) and No's 55 and 559 (Hutton) were also included. For comparative purposes a sample (P), of the Clovelly form, with a much higher resin-P content because of previous enrichment with P, was included. Some relevant properties of the seven soil samples are grouped in Table 14.

TABLE 14: RELEVANT PROPERTIES OF SAMPLES USED FOR DETERMINING PHOSPHATE POTENTIALS

SOIL FORM	LAB.NO.	RESIN-P (ppm)	CLAY %	CEC (me/100g)	pH (2:5 H_2O)	Ca (me/100g
CLOVELLY	574	1.65	8	12.20	7.85	7.750
	578	0.50	8	11.00	8.20	17.625
	582	1.30	4	9.90	8.05	8.250
	P	17.1	-	11.00	-	8.000
HUTTON	566	2.25	8	3.50	6.55	1.250
	55	0.30	6	3.30	6.10	1.125
	559	0.90	12	4.60	6.20	1.250

5.3.2. PROCEDURE

The procedure employed to determine the phosphate potentials of the abovementioned samples was essentially that of White & Beckett (1964) with some minor modifications. Throughout this experiment 10g of soil was shaken with 100 ml of 0.01 M $CaCl_2$ solution of known phosphate (calcium dihydrogen phosphate) concentration (Table 15) on a mechanical wrist action shaker for one hour. After one hour of shaking the suspensions were filtered and the filtrate collected in polythene bottles. The shaking and filtering of the samples were carried out in a constant temperature room at 20°C. Immediately after filtering the suspension, the pH of the supernatant solutions were determined. A drop of $CHCl_3$ was added to all the solutions and the polythene bottles stoppered and stored.

Calcium in the solutions was determined atomic absorption photometrically and phosphate by the method of Fogg & Wilkinson (1958).

TABLE 15: PHOSPHATE CONCENTRATIONS OF THE EQUILIBRATING SOLUTIONS

SOLUTION NO.	P-CONCENTRATION (moles/Litre)
1	0
2	1×10^{-6}
3	2×10^{-6}
4	3×10^{-6}
5	4×10^{-6}
6	5×10^{-6}

5.4 RESULTS AND DISCUSSION

The phosphate potential graphs, i.e. the graphs illustrating the relationships between P and P-potential for the different soil samples, are presented in Appendix 6 (Figures 7 -13). All lines were fitted by calculation.

The phosphate potentials and resin-P content of the samples used in this experiment are presented in Table 16. The samples of each soil form are grouped together on a basis of decreasing P-potentials within each form.

TABLE 16: P-POTENTIALS AND RESIN-P CONTENT FOR SAMPLES FROM EACH SOIL FORM IN ORDER OF DECREASING P-POTENTIALS

SOIL FORM	LAB. NO.	RESIN-P (ppm)	P-POTENTIAL
CLOVELLY	578	0.50	7.79
	582	1.30	7.59
	574	1.65	7.58
	P	17.1	6.50
HUTTON	55	0.30	8.70
	559	0.90	7.59
	566	2.25	7.50

It is evident that, within each soil form, without any exception, the phosphate potentials decrease with increasing resin-P values. Since a low phosphate potential is indicative of high phosphate availability, the observed trend indicates that both resin-P content and phosphate potential basically follows the same pattern regarding the available phosphorus content of the different samples.

In section 4.2.2 it was pointed out that a good relationship exists between the resin-P content of samples 574 and 566 and P-uptake at the lowest level of P-application in the pot experiment. Furthermore, it is clear that the relative difference between the P-potentials of these two samples is much smaller than the difference between their resin-P content and between P-uptake from the samples (Table 12). Thus it can be inferred that the resin-P content of a soil will provide a better measure than the phosphate potential of the same soil, for predicting P-uptake effects. The phosphate potentials and the slopes of the P-potential lines for these two samples were much too similar to provide a satisfactory explanation for the large differences in P-uptake at the higher levels of P-application (Section 4.2.2). The slopes were -10.63 (sample 574) and -11.10 (sample 566) respectively.

The P-potential of all the samples, irrespective of soil form, are presented in decreasing order in Table 17. The definite trend for P-potentials to decrease with increasing resin-P content, irrespective of soil form, is well illustrated here.

TABLE 17: P-POTENTIALS AND RESIN-P CONTENT FOR ALL SAMPLES IN ORDER OF DECREASING P-POTENTIALS

SAMPLE NO.	RESIN-P (ppm)	P-POTENTIAL
55	0.30	8.70
578	0.50	7.79
559	0.90	7.59
582	1.30	7.59
574	1.65	7.58
566	2.25	7.50
P	17.10	6.50

The relationship between P-potential and resin-P content of the virgin samples studied are illustrated in Figure 5. Since no general equation could be found which fitted the whole graph satisfactorily, it was decided to resolve the graph into two linear parts. The lower part of the graph consists of a region where resin-P values are extremely low. In this region large decreases in P-potentials are found upon relative small increases in resin-P content.

The former is followed by another linear part of the graph in which P-potentials change very little upon increases in resin-P content. The result for the enriched sample (P) is included in Figure 6. The point for this sample fitted the linear relationship between resin-P content and P-potential, found for the virgin soils with the higher resin-P content, well. This latter linear relationship between resin-P and P-potential can be expected to describe the relationship between these two parameters for most field samples of these two soil forms.

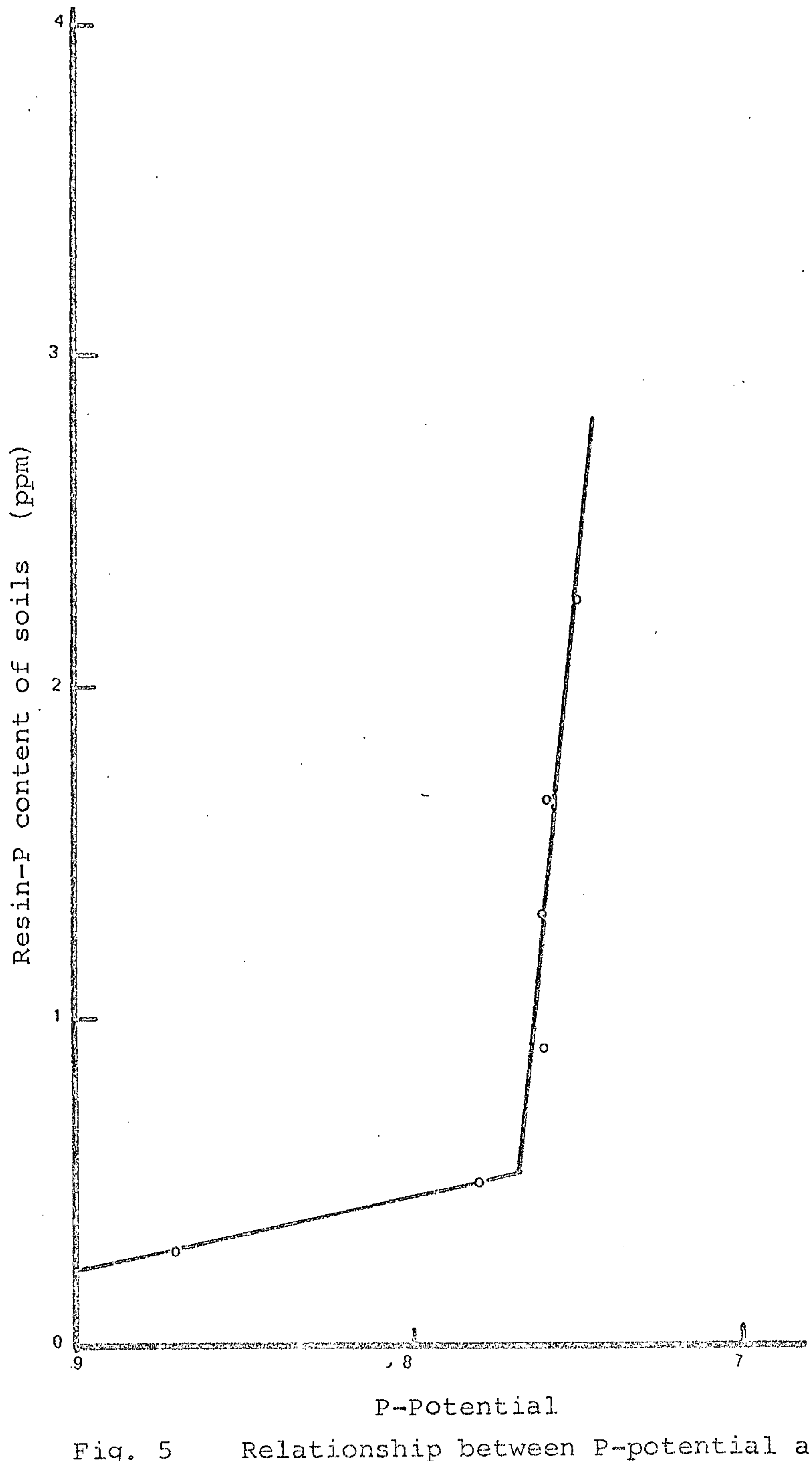

Fig. 5 Relationship between P-potential and resin-P content for virgin soils.

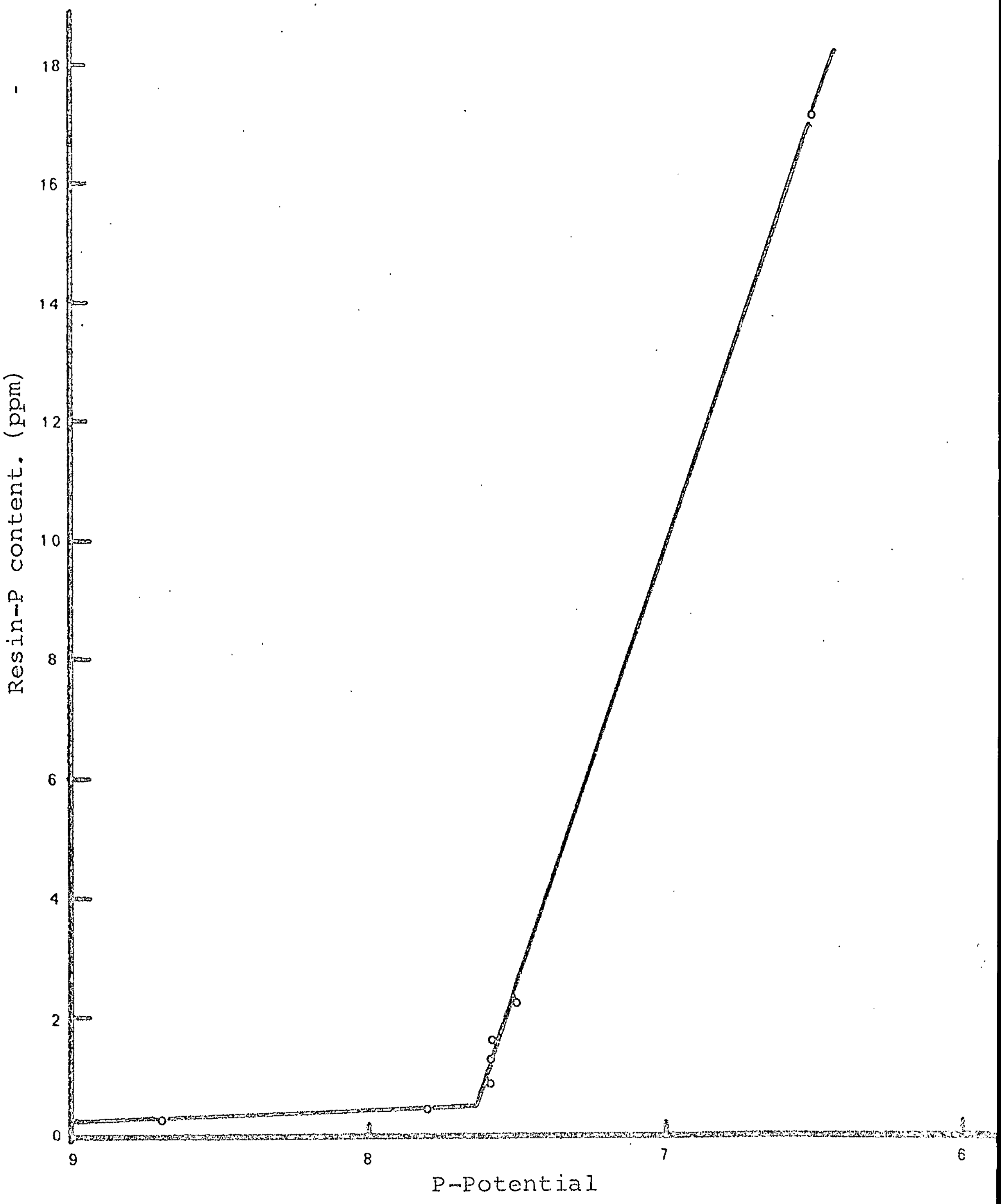

Fig. 6 Relationship between P-potential and resin-P content for all samples, including a previously enriched sample.

CHAPTER 6

CONCLUSIONS

In the final evaluation of the plant nutrient status of the soils of the Hutton and Clovelly soil forms, it is clear that these soils are deficient in phosphorus, potassium, copper and zinc. Furthermore, it is clear that the application of fertilizer materials and irrigation water to these soils warrant careful consideration.

The results obtained from the pot experiment showed clearly that there is a difference in the reaction of these two soil forms to applied phosphorus and potassium. It seems, at this stage, that the Clovelly soil form, due to calcareous material present in the soil, higher average pH values, etc., has a greater fixation capacity for these elements than the Hutton soils.

From the phosphate potential studies it was evident that the resin-P contents of these soils gave a more useful indication of available phosphorus than the phosphate potential concept. The interesting linear relationship which was found between resin-P contents and P-potentials is of basic importance.

It must be emphasized here that the purpose of this study was not to serve as a basis for advisory purposes. For this purpose it is recommended that further studies at a series and crop level be conducted.

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APPENDICES 1 - 6

THE NUTRIENT STATUS OF TWO SOIL FORMS OF THE ORANGE RIVER DEVELOPMENT PROJECT

by

T. BOTHA

APPENDIX I

GENERAL ANALYTICAL DATA

FORM	SERIES	PROFILE NO.	HORIZON DEPTH (cm)	LAB. NO.	COARSE SAND %	MEDIUM SAND %	FINE SAND %	SILT %	CLAY %	pH ($2:5\ H_2O$)	ELECTRICAL RESISTANCE (OHMS)
HUTTON	SHORROCKS	14	0-28	49	6.42	20.34	54.88	4	16	6.80	1020
			28-56	50	5.70	19.82	55.40	3	17	7.45	650
HUTTON	SHORROCKS		56-79	51	4.22	16.44	60.20	4	17	7.65	660
			79-112	52	6.42	20.68	55.60	3	16	7.95	820
			112-147	53	6.96	19.82	60.62	1	11	8.05	840
			147-185+	54	10.10	27.74	53.10	0	8	8.00	860
HUTTON	SHORROCKS	19	0-18	70	0.26	10.30	73.28	2	16	6.20	1080
			18-41	71	0.41	12.52	70.14	2	18	6.45	760
			41-69	72	0.27	10.54	71.18	2	18	6.55	740
			69-99	73	0.28	8.82	74.38	2	16	6.65	970
			99-132	74	0.32	10.64	75.10	3	12	6.80	1140
			132-173	75	0.26	10.64	73.14	1	14	6.90	1020
HUTTON	SHORROCKS	1	0-23	559	0.42	16.32	70.26	3	12	6.20	1520
			23-69	560	0.50	18.36	61.94	2	18	6.90	1080
			69-147	561	1.30	13.56	61.12	1	25	7.10	910
HUTTON	SHORROCKS	2	0-23	562	1.44	17.10	63.84	3	17	6.75	870
			23-61	563	1.18	13.02	61.44	2	24	6.80	720
			61-107	564	1.04	11.20	59.20	2	28	6.75	400
			107-163	565	1.32	12.06	64.68	6	18	7.40	810
HUTTON	ZWARTFONTEIN	3	0-23	566	1.14	33.54	56.42	2	8	6.60	1700
			23-64	567	0.94	31.20	53.36	0	14	6.75	1160
			64-107	568	0.62	27.02	59.52	1	13	7.20	1220
			107-150	569	0.52	23.36	63.12	1	13	7.30	1340
HUTTON	ZWARTFONTEIN	148	0-23	124	1.23	25.12	62.63	1	8	6.90	950
			23-51	125	1.48	28.44	60.10	0	8	6.85	1100
			51-81	126	1.24	25.53	61.86	0	9	6.80	1320
			81-114	127	1.50	28.92	59.02	0	9	6.70	1480
			114-152	128	1.50	26.86	59.04	0	10	6.45	1220
			152-188	129	1.30	27.78	61.22	3	5	6.45	1440
			188-216	130	1.02	25.58	67.21	0	4	6.00	1340

APPENDIX I (Continued)

FORM	SERIES	PROFILE No	HORIZON DEPTH (cm)	LAB. NO.	COARSE SAND %	MEDIUM SAND %	FINE SAND %	SILT %	CLAY %	pH (2:5 H_2O)	ELECTRICAL RESISTANCE (OHMS)
HUTTON	ZWARTFONTEIN	157	0-28	161	3.62	25.80	63.88	0	8	6.10	2340
			28-76	162	4.00	27.76	60.98	0	8	6.35	2360
			76-130	163	6.84	30.36	55.68	0	8	6.40	2340
			130-180	164	4.74	27.04	60.48	1	9	6.25	2220
			180-229	165	4.32	23.96	64.86	0	8	6.75	2280
			229-282	166	4.32	25.25	63.48	0	8	6.90	1900
			282-345	167	5.56	28.72	57.94	0	8	7.05	1820
HUTTON	GOUDAM	10	0-18	21	7.34	49.70	38.04	0	5	6.35	2540
			18-41	22	8.88	53.23	33.00	0	6	6.40	2500
			41-64	23	9.22	52.92	31.92	1	6	6.40	2060
			64-91	24	12.55	56.93	24.91	1	6	6.35	1520
			91-122	25	12.80	45.54	39.95	0	6	6.25	1340
			122-147	26	6.68	47.88	38.97	0	6	6.30	1220
			147-198+	27	6.47	47.50	39.44	1	6	6.55	1440
HUTTON	GOUDAM	17	0-18	55	12.12	21.26	69.92	1	6	6.10	2400
			18-46	56	2.86	27.74	62.04	1	6	6.60	1840
			46-71	57	3.82	29.87	58.45	1	6	7.00	1480
			71-99	58	2.16	23.12	65.93	1	7	7.15	1400
			99-130	59	1.82	20.86	68.98	1	5	6.70	1260
			130-165	60	2.86	29.84	59.28	1	7	6.80	1460
			165-198	61	2.46	22.94	66.12	0	8	6.90	1340
HUTTON	GOUDAM	67	0-23	82	2.27	51.42	41.86	1	5	6.75	1840
			23-48	83	1.84	43.54	48.82	1	6	6.70	1620
			48-81	84	2.16	45.10	49.60	0	6	6.95	1800
			81-107	85	2.00	41.62	49.36	0	7	7.25	1640
			107-147	86	2.30	43.68	47.30	0	6	7.45	1640
			147-183	87	1.82	38.87	51.84	1	6	7.65	1520
CLOVELLY	TOURQUAY	5	0-23	574	3.06	26.04	59.26	4	8	7.85	1080
			23-56	575	2.88	23.82	60.60	4	8	8.25	750
			56-84	576	2.72	22.30	61.28	7	8	8.45	770
			84-124	577	3.46	23.96	60.04	5	7	8.50	770
CLOVELLY	TOURQUAY	6	0-25	578	4.12	26.96	57.98	4	8	8.20	920
			25-64	579	4.12	25.02	56.82	5	10	8.45	860
			64-94	580	3.84	24.06	58.72	5	10	8.50	890
			94-130	581	3.46	23.28	58.06	8	8	8.65	960

APPENDIX I (Continued)

FORM	SERIES	PROFILE NO.	HORIZON DEPTH (cm)	LAB NO.	COARSE SAND %	MEDIUM SAND %	FINE SAND %	SILT %	CLAY %	pH (2:5 H_2O)	ELECTRICAL RESISTANCE (OHMS)
CLOVELLY	TOURQUAY	8	0-13	8	1.02	33.06	57.64	1	8	8.10	1160
			13-56	9	1.18	32.66	56.88	1	8	8.20	890
			56-71	10	1.24	33.76	53.22	2	10	8.35	910
			71-102	11	1.52	35.82	51.62	2	10	8.15	860
			102-130	12	1.02	29.46	57.14	4	10	8.30	840
			130-157	13	0.80	28.20	57.40	4	10	8.25	760
			157 +	14	0.94	39.42	52.12	0	8	8.05	1000
CLOVELLY	VAALBANK	4	0-25	570	0.84	13.38	75.96	2	10	7.15	970
			25-61	571	1.16	19.46	69.44	2	10	7.35	1180
			61-86	572	1.40	18.40	68.16	2	12	8.25	820
			86-127	573	1.12	17.30	70.28	2	10	8.40	860
CLOVELLY	ORANGE	7	0-23	582	1.34	31.78	59.10	4	4	8.05	1060
			23-56	583	1.56	33.82	55.50	6	4	8.30	900
			56-94	584	1.44	33.74	55.44	5	5	8.55	980
			94 +	585	1.70	35.18	54.90	3	5	8.50	890

APPENDIX 2

MACRO NUTRIENT CONTENTS OF THE SOILS

FORM	SERIES	PROFILE NO.	LAB.NO.	Ca (me/100g)	Mg (me/100g)	Na (me/100g)	K (me/100g)	S VALUE (me/100g)	CEC (me/100g)	P (ppm)	$SO_4^=$ (ppm)
HUTTON	ZWARTFONTEIN	148	124	1.625	2.188	0.290	0.440	4.543	4.90	0.90	16.80
			125	1.375	2.250	0.390	0.395	4.410	4.70	1.25	19.12
			126	1.250	2.300	0.410	0.315	4.275	4.60	1.90	24.72
			127	1.250	2.300	0.345	0.275	4.170	4.60	1.25	15.84
			128	1.675	2.250	0.325	0.455	4.705	4.97	1.75	18.96
			129	1.675	1.275	0.265	0.340	3.555	3.90	1.45	14.80
			130	1.125	0.788	0.225	0.200	2.338	3.00	1.45	21.12
HUTTON	ZWARTFONTEIN	157	161	0.900	0.288	0.180	0.280	1.648	2.90	0.60	13.60
			162	0.900	1.050	0.175	0.325	2.450	2.80	0.40	13.20
			163	1.000	1.075	0.180	0.310	2.565	3.20	0.45	15.60
			164	0.750	1.238	0.195	0.275	2.458	3.00	0.45	21.28
			165	0.750	1.527	0.240	0.255	2.502	2.70	0.70	17.20
			166	0.750	1.350	0.245	0.265	2.610	2.90	0.55	15.20
			167	0.625	0.988	0.235	0.290	2.138	3.40	0.10	15.04
HUTTON	ZWARTFONTEIN	3	566	1.250	1.425	0.240	0.250	3.065	3.50	2.25	12.48
			567	1.500	2.188	0.170	0.220	4.078	5.30	0.95	20.32
			568	2.125	2.488	0.225	0.240	5.078	5.50	0.25	14.64
			569	1.625	2.413	0.228	0.258	4.524	5.30	0.40	15.60
HUTTON	GOUDAM	10	21	0.600	0.400	0.230	0.280	1.510	2.21	0.50	15.40
			22	0.250	0.413	0.185	0.285	1.133	2.10	0.25	16.16
			23	0.600	0.788	0.185	0.335	1.908	2.30	0.35	16.00
			24	0.750	0.963	0.215	0.275	2.203	2.50	0.55	16.40
			25	0.625	1.050	0.230	0.220	2.125	2.30	0.25	10.88
			26	0.475	0.813	0.230	0.200	1.718	2.30	0.75	13.20
			27	0.750	1.238	0.210	0.215	2.413	2.60	0.55	17.84
HUTTON	GOUDAM	17	55	1.125	0.950	0.260	0.435	2.770	3.30	0.30	16.40
			56	1.675	1.300	0.275	0.355	3.555	3.80	0.70	17.20
			57	1.675	1.450	0.265	0.305	3.695	4.10	0.25	8.32
			58	1.875	1.588	0.225	0.265	3.953	4.40	0.35	14.40
			59	1.875	1.588	0.230	0.255	3.948	4.50	0.60	14.00
			60	1.875	1.563	0.275	0.235	3.948	4.10	0.40	14.80
			61	2.500	1.638	0.225	0.220	4.583	4.30	0.40	13.44

APPENDIX 2 (Continued)

FORM	SERIES	PROFILE NO.	LAB.NO.	Ca (me/100g)	Mg (me/100g)	Na (me/100g)	K (me/100g)	S VALUE (me/100g)	CEC (me/100g)	P (ppm)	$SO_4^=$ (ppm)
HUTTON	GOUDAM	67	82	1.625	0.913	0.225	0.395	3.158	2.80	0.95	10.32
			83	1.675	0.825	0.210	0.445	3.155	3.50	0.30	13.04
			84	1.675	0.938	0.195	0.455	3.263	3.40	0.65	16.16
			85	2.250	1.176	0.220	0.448	4.094	3.60	0.40	14.80
			86	2.500	1.300	0.235	0.370	4.405	3.50	0.35	18.40
			87	3.000	1.325	0.390	0.345	4.715	4.10	0.15	20.72
HUTTON	SHORROCKS	14	49	5.000	4.063	0.250	0.280	9.593	9.40	2.90	13.44
			50	6.625	4.688	0.275	0.275	11.863	11.30	3.95	17.84
			51	7.125	4.625	0.265	0.245	12.260	11.20	2.40	14.24
			52	6.625	4.313	0.230	0.210	11.378	11.10	2.70	17.84
			53	6.625	3.250	0.235	0.150	10.260	9.50	2.60	12.88
			54	6.500	3.250	0.215	0.135	10.100	9.30	2.00	13.04
HUTTON	SHORROCKS	19	70	4.875	2.750	0.205	0.215	8.045	8.60	0.75	17.26
			71	5.125	2.700	0.215	0.220	8.260	9.50	0.30	15.84
			72	5.375	3.300	0.235	0.245	9.155	10.60	0.85	21.68
			73	5.375	3.750	0.230	0.240	9.595	10.10	0.70	6.96
			74	4.375	3.500	0.230	0.235	8.340	9.00	0.25	14.40
			75	4.120	5.500	0.245	0.200	10.065	9.50	0.10	14.80
HUTTON	SHORROCKS	1	559	1.250	1.313	0.250	0.325	3.138	4.60	0.90	16.40
			560	2.250	2.813	0.305	0.175	5.543	6.50	1.50	18.24
			561	3.250	2.888	0.310	0.480	6.928	8.10	0.33	18.80
HUTTON	SHORROCKS	2	562	2.750	1.688	0.220	0.455	5.113	6.10	0.50	16.40
			563	3.375	2.888	0.295	0.445	7.003	8.90	0.33	16.80
			564	4.375	5.063	0.315	0.600	10.353	10.00	0.40	9.12
			565	4.500	5.313	0.235	0.670	10.718	10.50	0.50	20.88
CLOVELLY	TOURQUAY	5	574	7.750	4.250	0.280	0.115	12.395	12.20	1.65	10.88
			575	10.375	4.938	0.345	0.110	15.768	12.80	0.85	13.20
			576	26.875	6.250	0.395	0.115	33.635	12.80	1.45	4.96
			577	33.125	7.875	0.355	0.140	41.495	13.10	1.40	22.64
CLOVELLY	TOURQUAY	6	578	17.625	2.488	0.285	0.135	20.533	11.00	0.50	18.40
			579	50.000	3.438	0.385	0.135	53.958	10.95	0.70	11.44
			580	59.375	5.063	0.455	0.155	65.048	10.50	0.90	3.04
			581	59.375	6.250	0.500	0.155	66.280	9.90	0.90	16.80

APPENDIX 2 (Continued)

FORM	SERIES	PROFILE No.	LAB. NO.	Ca (me/100g)	Mg (me/100g)	Na (me/100g)	K (me/100g)	S VALUE (me/100g)	CEC (me/100g)	P (ppm)	$SO_4^{=}$ (ppm)
CLOVELLY	TOURQUAY	8	8	10.500	2.150	0.260	0.170	13.080	9.60	2.10	12.88
			9	17.688	3.157	0.305	0.123	21.273	10.50	1.19	15.04
			10	42.500	4.938	0.350	0.170	47.958	11.58	0.95	4.96
			11	48.125	5.563	0.385	0.170	54.243	10.80	0.60	3.84
			12	51.250	7.438	0.410	0.170	59.268	11.60	0.50	14.80
			13	50.625	8.813	0.425	0.135	59.998	11.30	1.25	21.62
			14	11.125	2.188	0.260	0.150	13.723	10.10	2.30	10.88
CLOVELLY	VAALBANK	4	570	3.750	2.525	0.240	0.300	6.815	7.40	3.50	12.24
			571	4.250	3.150	0.240	0.260	7.900	8.50	3.00	12.88
			572	12.125	3.875	0.260	0.155	16.415	9.60	2.75	17.84
			573	22.625	5.438	0.285	0.155	28.503	9.60	2.60	19.94
CLOVELLY	ORANJE	7	582	8.250	2.188	0.260	0.175	10.873	9.90	1.30	17.36
			583	24.375	4.688	0.320	0.150	29.533	9.80	1.13	12.24
			584	32.500	6.063	0.240	0.110	38.913	10.15	1.43	20.72
			585	30.625	6.875	0.240	0.095	37.835	9.70	1.18	22.64

APPENDIX 3

MICRO NUTRIENT CONTENTS OF THE SOILS

FORM	SERIES	PROFILE NO.	LAB. NO.	CLAY %	COPPER (ppm)	ZINC (ppm)	MANGANESE (ppm)
HUTTON	SHORROCKS	14	49	16	2.15	0.94	193
			50	17	2.80	0.78	192
			51	17	2.15	1.30	189
			52	16	1.80	0.80	168
			53	11	1.30	0.80	125
			54	8	1.40	0.40	110
HUTTON	SHORROCKS	19	70	16	1.80	1.50	157
			71	18	1.80	0.74	160
			72	18	1.80	1.94	160
			73	16	1.15	0.60	169
			74	12	1.55	0.64	149
			75	14	1.40	1.10	153
HUTTON	SHORROCKS	1	559	12	1.55	1.50	125
			560	18	1.73	1.44	143
			561	25	2.05	0.74	69.5
HUTTON	SHORROCKS	2	562	17	1.55	0.54	84
			563	24	1.55	0.70	68
			564	28	1.40	0.40	73
			565	18	0.80	0.50	62
HUTTON	ZWARTFONTEIN	3	566	8	1.15	0.54	80
			567	14	0.80	0.50	59
			568	13	1.18	0.80	62
			569	13	1.65	2.20	71
HUTTON	ZWARTFONTEIN	148	124	8	1.05	0.80	61
			125	8	1.05	1.74	61
			126	9	1.30	1.54	49
			127	9	1.40	0.94	45
			128	10	1.05	0.68	50
			129	5	0.90	0.74	54
			130	4	0.90	0.73	44
HUTTON	ZWARTFONTEIN	157	161	8	0.80	0.60	35
			162	8	1.05	1.70	25
			163	8	0.65	0.44	23
			164	9	0.90	0.40	20

APPENDIX 3 (Continued) MICRO NUTRIENT CONTENTS OF THE SOILS

FORM	SERIES	PROFILE NO.	LAB. NO.	CLAY %	COPPER (ppm)	ZINC (ppm)	MANGANESE (ppm)
HUTTON	ZWARTFONTEIN	157	165	8	0.50	0.60	14.5
			166	8	0.50	0.44	19.0
			167	8	0.90	1.14	21.0
HUTTON	GOUDAM	10	21	5	0.90	1.00	63
			22	6	0.90	0.40	64
			23	6	0.85	0.55	63
			24	6	0.50	0.44	48
			25	6	0.40	0.64	43
			26	6	0.65	0.30	43
			27	6	1.40	0.84	44
HUTTON	GOUDAM	17	55	6	0.80	1.24	73
			56	6	0.80	0.74	55
			57	6	1.05	0.68	44
			58	7	1.30	0.94	40
			59	5	1.55	0.68	37
			60	7	1.15	0.90	31
			61	8	0.90	0.40	40
HUTTON	GOUDAM	67	82	5	1.05	1.50	31
			83	6	0.50	0.50	31
			84	6	0.65	0.44	24
			85	7	0.90	1.50	27
			86	6	0.90	1.20	26
			87	6	1.05	1.74	25
CLOVELLY	TOURQUAY	5	574	8	1.90	1.90	176
			575	8	1.90	1.34	168
			576	8	1.65	1.80	157
			577	7	2.30	1.50	153
CLOVELLY	TOURQUAY	6	578	8	1.90	1.00	141
			579	10	1.90	1.20	116
			580	10	1.55	1.20	115
			581	8	1.05	0.90	89

APPENDIX 3 (Continued) MICRO NUTRIENT CONTENTS OF THE SOILS

FORM	SERIES	PROFILE NO.	LAB. NO.	CLAY %	COPPER (ppm)	ZINC (ppm)	MANGANESE (ppm)
CLOVELLY	TOURQUAY	8	8	8	1.40	1.10	117
			9	8	1.30	2.64	120
			10	10	1.55	3.02	114
			11	10	1.40	1.24	106
			12	10	1.65	2.54	116
			13	10	1.15	1.64	124
			14	8	1.40	0.95	123
CLOVELLY	VAALBANK	4	570	10	1.30	1.10	111
			571	10	1.73	1.60	131.5
			572	12	1.90	1.52	123
			573	10	2.05	1.94	103
CLOVELLY	ORANJE	7	582	4	1.15	1.04	117
			583	4	1.30	1.04	90
			584	5	1.80	1.00	90
			585	5	1.55	2.80	108

APPENDIX 4

AVERAGES FOR SERIES AND FORMS

SERIES	% COARSE SAND	% MEDIUM SAND	% FINE SAND	% SILT	% CLAY	pH	RESISTANCE (OHMS)	Cu (ppm)	Zn (ppm)	Mn (ppm)
SHORROCKS	2.57	15.26	64.18	2.42	16.89	7.02	887.89	1.67	0.91	134.03
ZWARTFONTEIN	2.55	27.35	60.60	0.50	8.78	6.66	1640.56	0.99	0.92	44.08
GOUDAM	4.47	39.68	49.29	0.60	6.10	6.73	1693.00	0.91	0.83	42.61
AVERAGE FOR HUTTON FORM	3.23	27.64	57.83	1.18	10.54	6.80	1408.07	1.19	0.89	73.54
VAALBANK	1.13	17.13	70.96	2.00	10.50	7.79	957.50	1.75	1.54	117.13
TOURQUAY	2.36	28.52	57.25	3.73	8.73	8.28	894.67	1.60	1.60	129.00
ORANJE	1.51	33.63	56.21	4.50	4.50	8.35	957.50	1.45	1.47	101.25
AVERAGE FOR CLOVELLY FORM	2.00	27.43	59.46	3.57	8.30	8.21	916.52	1.60	1.57	122.11

	Ca (me/100g)	(Mg (me/100g)	Na (me/100g)	K (me/100g)	S VALUE	CEC	P (ppm)	$SO_4^=$ (ppm)
SHORROCKS	4.710	3.561	0.251	0.305	8.827	9.15	1.261	15.63
ZWARTFONTEIN	1.231	1.627	0.254	0.299	3.395	3.95	0.947	16.97
GOUDAM	1.469	1.111	0.233	0.317	3.113	3.29	0.450	14.89
AVERAGE FOR HUTTON FORM	2.474	2.086	0.245	0.308	5.122	5.45	0.88	15.80
VAALBANK	10.688	3.747	0.256	0.218	14.908	8.78	2.96	15.73
TOURQUAY	33.088	4.987	0.360	0.143	38.577	11.25	1.15	12.36
ORANJE	23.938	4.954	0.265	0.133	29.289	9.89	1.26	18.24
AVERAGE FOR CLOVELLY FORM	27.601	4.765	0.325	0.154	27.601	10.58	1.48	13.97

All averages for each series computed from individual values from Appendices 1,2 and 3.

Averages for each soil form computed from totals of individual values from Appendices 1,2 and 3.

APPENDIX 5

CORRELATION COEFFICIENTS BETWEEN
Cu, Zn AND Mn RESPECTIVELY vs. CLAY CONTENT

SOIL FORM	Cu	Zn	Mn	r
HUTTON (n = 57)	0.6489 *	0.0241	0.5747 *	5% : 0.4144 1% : 0.5269
CLOVELLY (n = 23)	0.1850	-0.0380	0.1229	5% : 0.2617 1% : 0.3396

* Significant at both 5% and 1% levels.

(Sample No. 578)

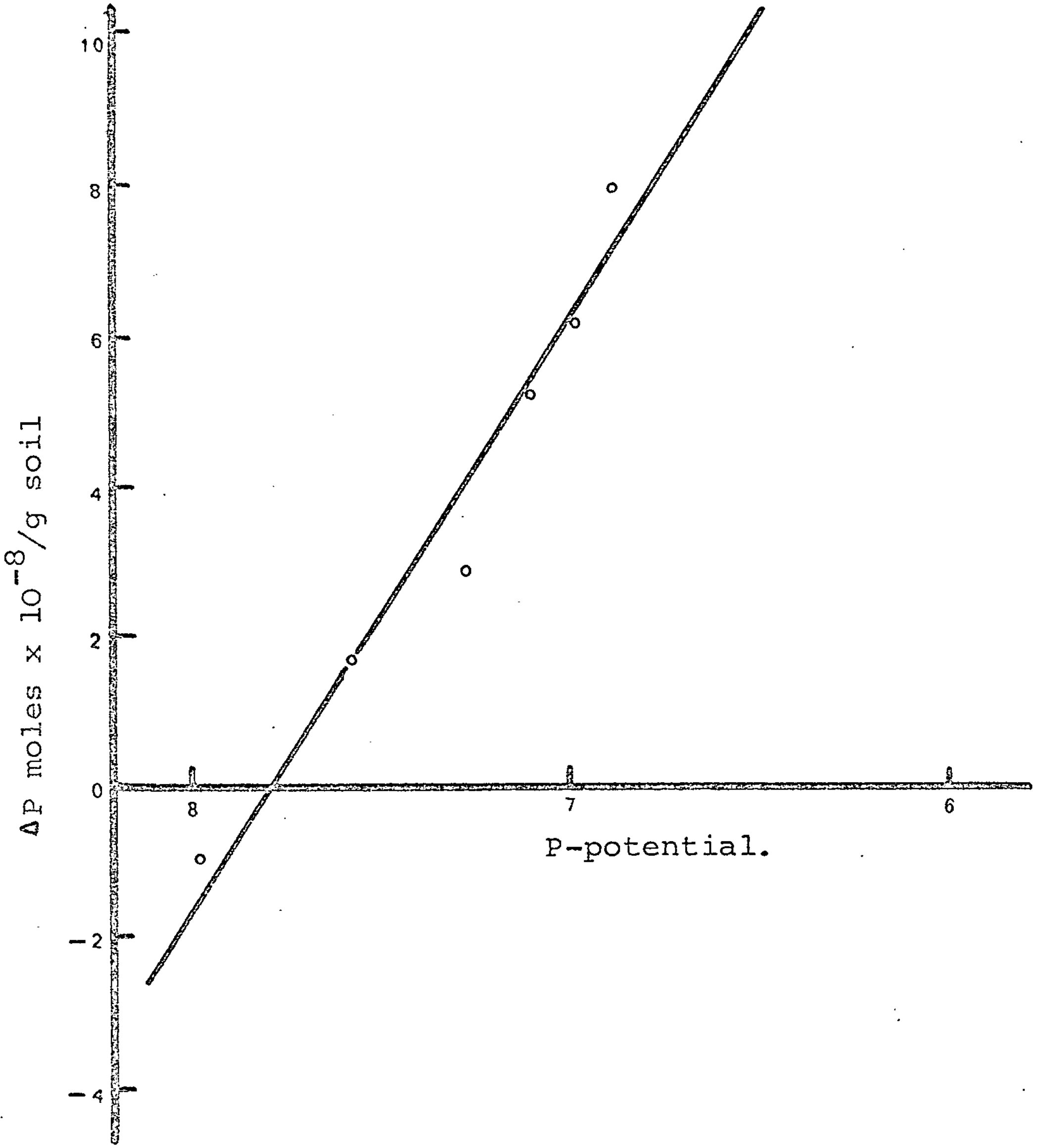

Fig. 7 Relationship between P and P-potential

(Sample No. 582)

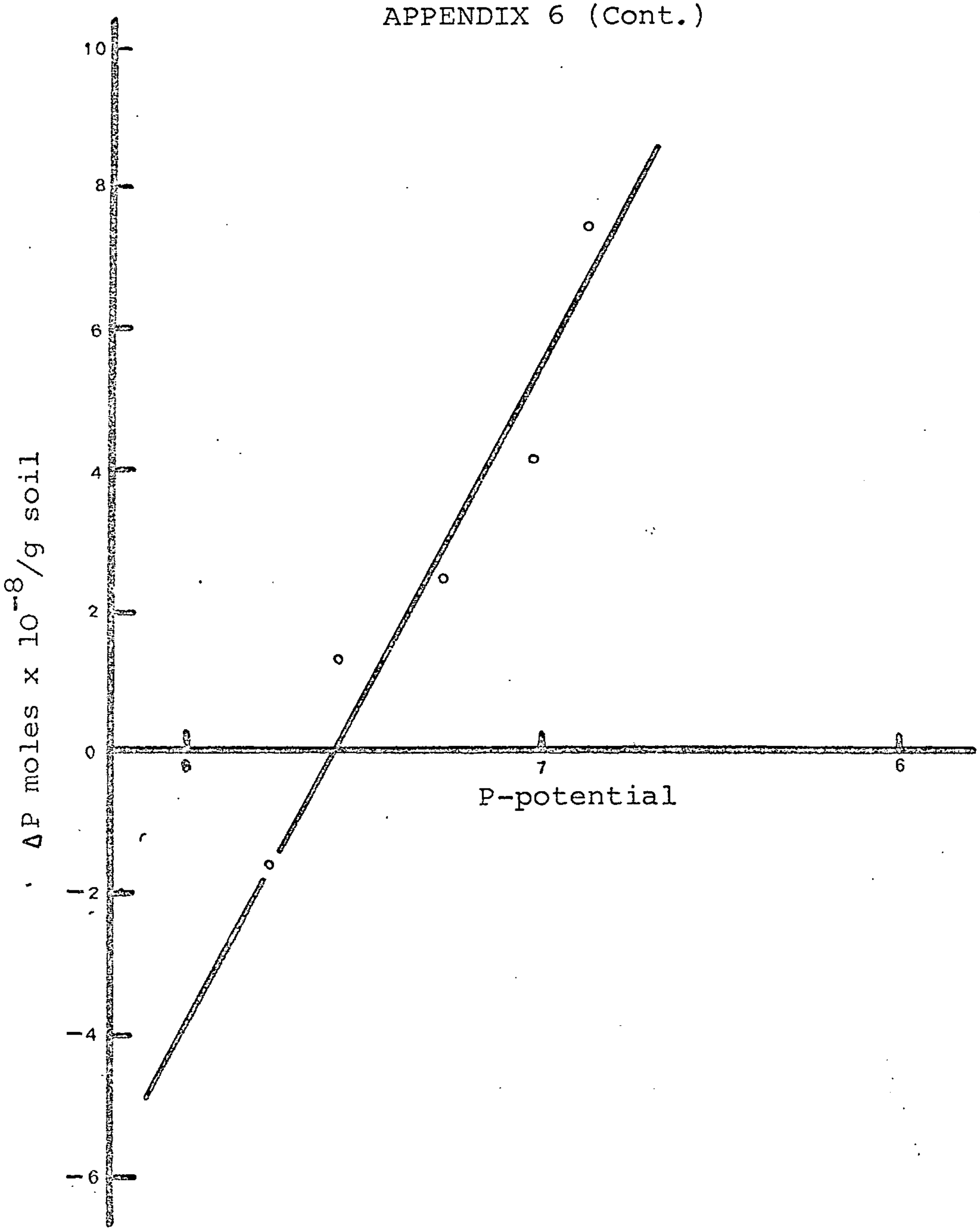

Fig. 8 Relationship between P and P-potential

(Sample No. 574)

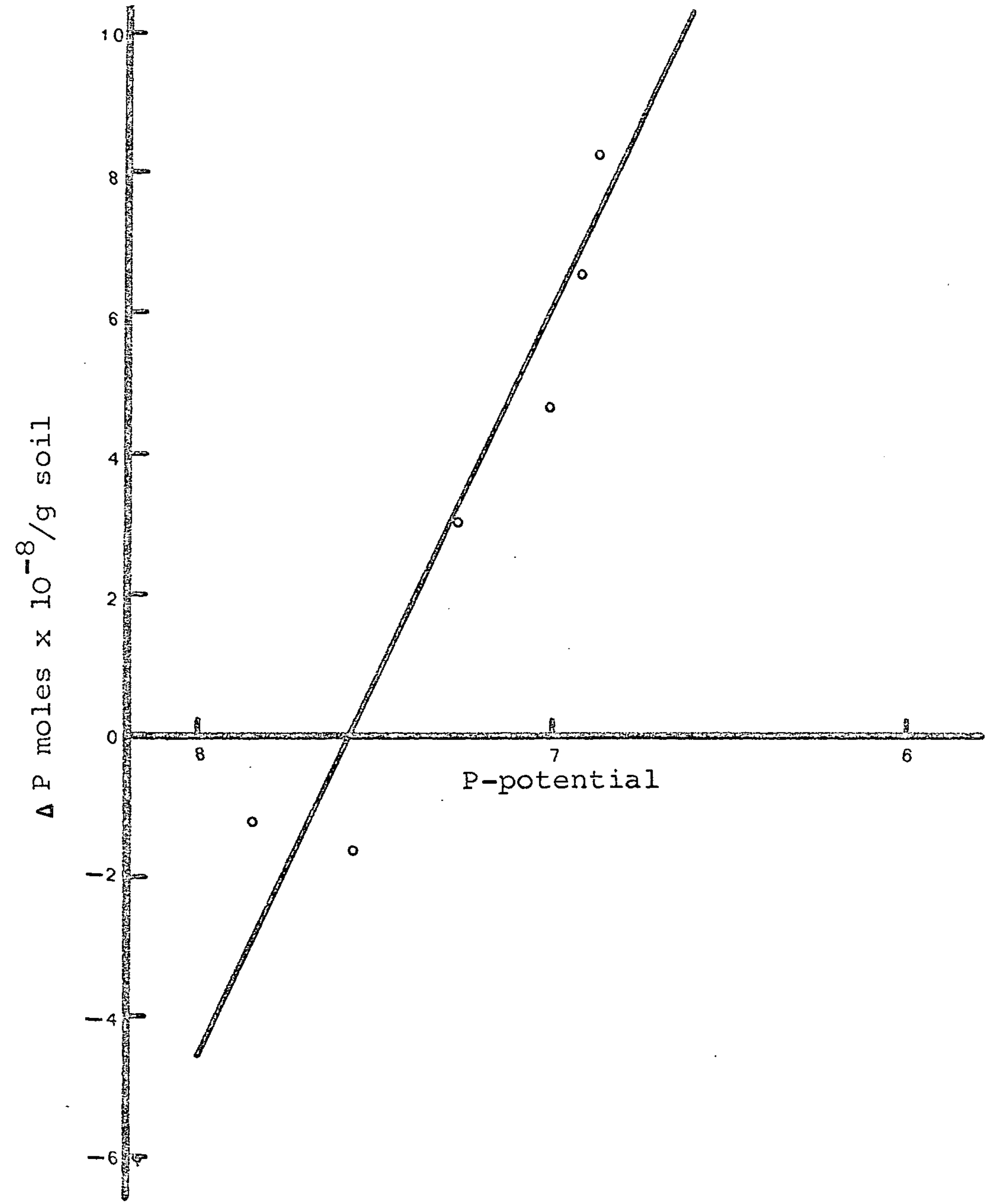

Fig. 9 Relationship between P and P-potential

(Sample No. P)

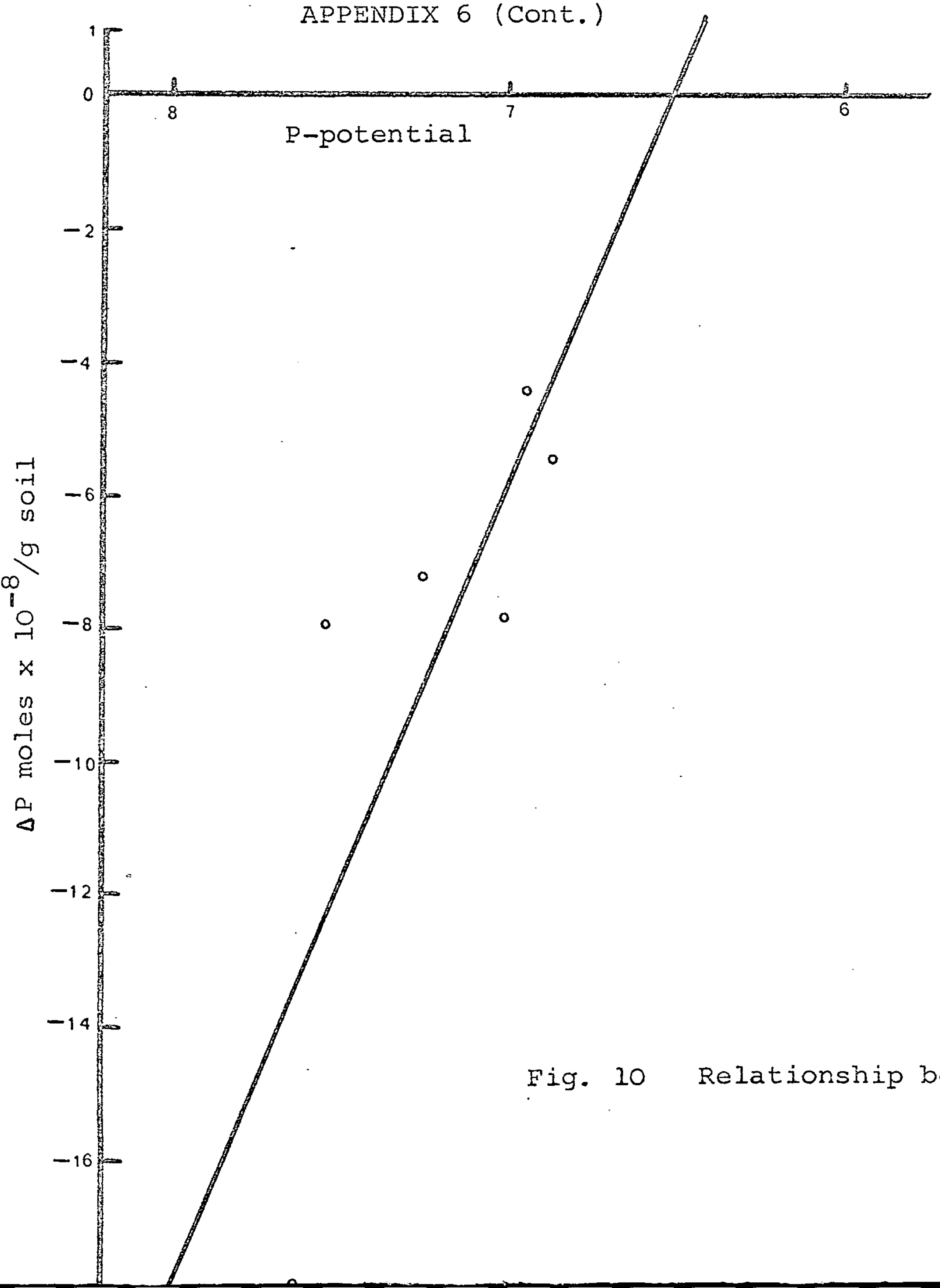

Fig. 10 Relationship between P and P-potential

(Sample No. 55)

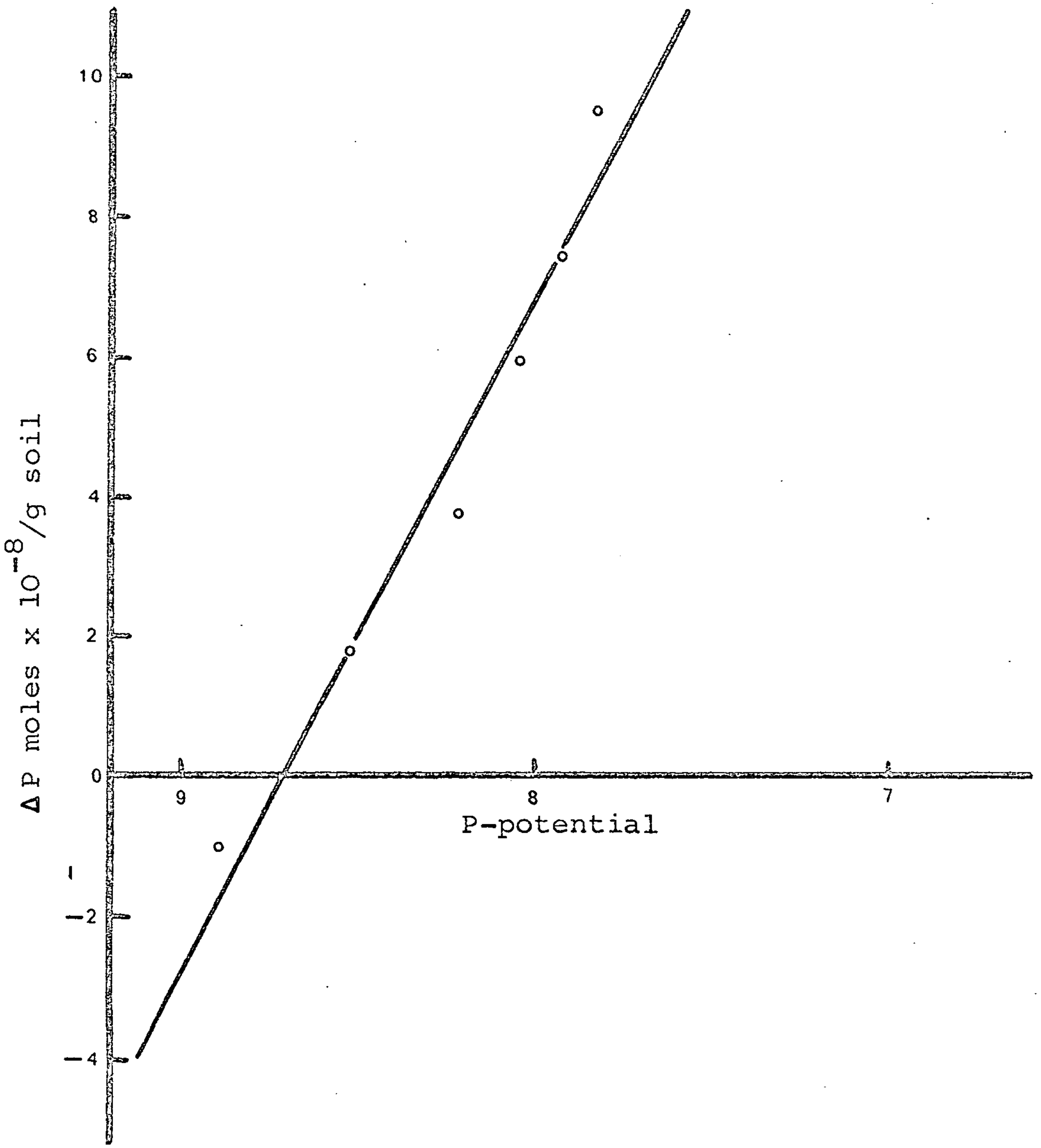

Fig. 11 Relationship between P and P-potential

(Sample No. 559)

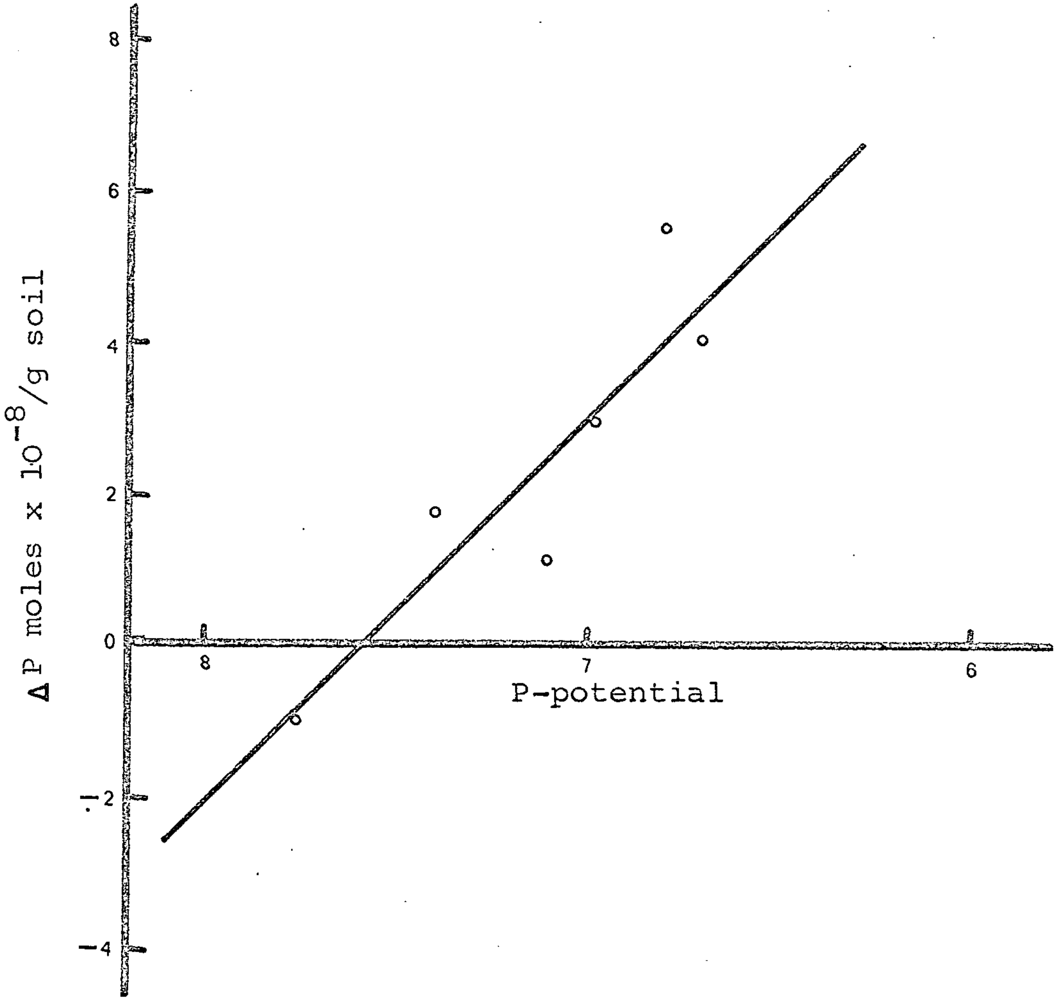

Fig. 12 Relationship between P and P-potential

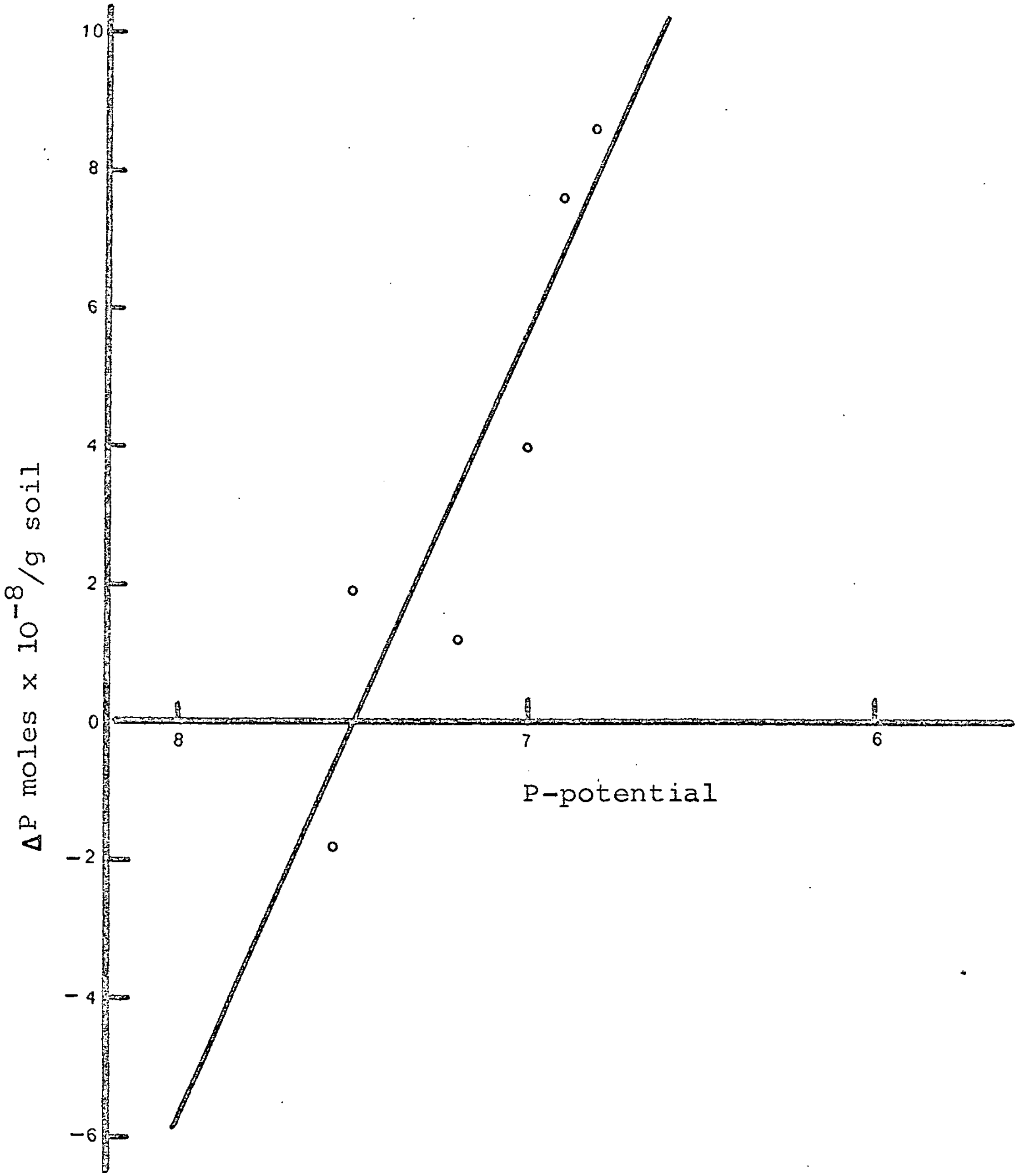

Fig. 13 Relationship between P and P-potential