SOME PRACTICAL CONSIDERATIONS IN DESIGNING A PROGRAMME OF FIELD TRIALS

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A notable feature of the agricultural policy of the South African Sugar Industry is that much of our plantation practice still derives from the arbitrary ordinance of tradition or custom, casual observation, and so-called experience. Sugar cane cultivation is an occupation requiring, for its success, the utmost precision both in conception and performance; and further that precision necessitates accurate and comprehensive observation of all relative factors, or values, followed by a carefully dedesigned plan of action for their most profitable exploitation.

Whether probing the unknown or exploiting the known factors of sugar cane cultivation, the agriculturist, in endeavouring to make the greatest use of all available resources, employs those principles of strategy which are commonly associated with military enterprise and defined by Agee (1) as, "a plan of action based on values". The keynote of strategy is that the whole picture must be carefully reviewed right down to every detail proximate or remote.

In our own sphere of action, the technician and the field man have widely divergent activities, but they are closely allied, like the obverse and reverse of a coin, though of different design, yet inseparable. The planter acts according to his assessment of the values in his case, and the technologist, or soil scientist, offers him assistance in the appraisal of such values.

During the long and complex process of bringing a crop of sugar cane to maturity a considerable number of occasions will arise when plantation man and research officer will be called upon, either individually, or in collaboration, to make selections between two or more alternative plans of action, to decide what resources are necessary and which of them are available, to discriminate as to their comparative values and how to use them in the best manner and at the correct time. At such times it is evident that the value of any collection of data, reference to which would localize one's selection, quickly, decisively, and unambiguously, and beyond question or argument, would incomparably exceed the value of inaccurate observation and half remembered experience.

No industry can be said to be in a flourishing condition - irrespective of its present profits - unless the idea of progress and improvement is found to be in the forefront of all strategic and tactical schemes. In our own case statutory limits have been imposed on the gross maximum outputs of our plantations, wherefore a jettisoning of most projects concerned with further exploitation of mass production economies are forced upon our attention. Nevertheless, increased yields per acre remain a matter of the greatest potential importance, for there is no doubt that through this medium we are still in a position to reduce considerably our operation costs, and by the same means we can bring about a liberation of surplus cane lands which will henceforth be available for other profitable uses.

With this in view we proceed to discuss some of the aspects of designing a programme of field trials.

Survey of Plantation Problems.

In designing a programme of field trials the attention of the plantation agriculturalist is primarily called to a careful, critical, and systematic survey of the unknowns with which his field work is concerned. Field experiments cost money and take up time and skilled attention. They should be sanctioned only on the basis of their potential value in determining the policy of the plantation for the greater gain of the plantation proprietors so far as it is possible to do so from available data. (4). If they hold no other possibilities than the disclosure of interesting, but unprofitable information, they should be erased from the programme, or deferred until a more suitable occasion.

The agriculturist will, therefore, attempt to classify his unknowns somewhat as follows: what is the possible extent of the economic gain per acre (increased yield or decreased production cost) to which the result of any given experiment may contribute? Over what percentage of the total area of the plantation will it be possible for the improvement to materialise? Concerning the choice of inaugurating one out of a number of alternative experiments, from which it is most likely that the proprietors will obtain increased profits? Answers to such questions as these can only be made by one who knows the plantation, and who is able to assess the possible value of each proposed experiment from an agronomic point of view.

The problems may be divided into the following main groups:

1. Cultural, such as:—
   - Long versus short fallowing.
   - Surface soil mulching.
   - Hilling-up ratoons.
   - Sub-soiling.

Growing and ploughing-in a leguminous crop.
Banking trash and cultivating versus hand weeding only, etc., etc.

2. Determination of the optimum conditions for cane varieties; time of planting; age to harvest the crop.

3. Those that involve the determination of the optimum from a large number of possibles, or from many variations of combinations of possibles. Irrigation and fertilizer trials comprise this group; and they also can be sub-divided:

Irrigation Trials.

Optimum quantity of water.

Optimum time of application.

Water in relation to fertilizer.

Water in relation to variety.

Fertilizer Trials.

Quantitative trials of nitrogen, phosphate and potash, and their interactions.

Qualitative trials of nitrogen, phosphate and potash, and their interactions.

Optimum time of application.

Positional availability—most advantageous placement of nutritive material.

Lime requirements.

Study of growth failure areas for possible deficiencies of one or more of the rarer elements.

Study of interaction of nutrients—physiological relationship—balance of plant food.

Some of these problems are of more pressing importance than others. For instance dealing with group 1, short fallowing versus long fallowing is probably the most important point at issue, but a decision will probably only be necessary under certain conditions. If one is allowed to postulate a thoroughly tilled seed-bed as a *sinequa non* of the establishment of a field of cane, it must be agreed that in the majority of cases the question may be dropped; for, under South African conditions of climate and time availability, and concerning most of our cane soils, a short fallow treatment will not result in a satisfactory seed-bed. In the cases not governed by the fore-going, it is of importance to put the matter quickly to field trial tests, because the whole of the agricultural policy of the plantation depends on the result.

Green manuring is as much an inexpensive method of improving the mechanical condition of the soil as anything else; the decision whether or not to include it in the plantation practice may rest with justification on its tilth-giving effect alone. For the rest, rather strong evidence has recently been led indicating that, provided that in the first place the field is ploughed well and thoroughly prepared to the normal plough depth, resulting in a good seed-bed, and thereafter weeds are kept under control, no definite gain, either from plant cane or ratoons can be expected from the less general cultivation operations. Even such radical processes as sub-soiling and other forms of deep tillage are but faintly praised by their results, while theoretical condemnation is not lacking (5).

Turning to Group 2, it is at once obvious that the time of planting is governed by so many factors besides the resultant comparative yields (generally speaking we plant in South Africa when climatic conditions allow) that, as a research project, the question may be put on one side for a time. Concerning optimum age at which to harvest the cane, we are of opinion that quite considerable progress may be made regarding the question of harvesting the crop at a time which will yield the best quality juice and the highest return of sugar per acre, by carrying out a comparative study of the harvest results of whole fields or blocks, co-ordinating the data with the analyses of periodic field samples - since certain of our commercial varieties are now harvested as less than two-year old the comparative yield per acre per month is not without importance - and thus it is perhaps neither necessary nor advantageous to study this problem through the medium of field trials (2). As for variety trials, though much can also be learned from a careful comparison of field results, noting the response on various soil types, all other variables being taken into consideration, properly designed replicated plot trials are a vital necessity if one would obtain the benefit from the perhaps extremely slight, but in the aggregate, important superiority of one variety over all others in any given environment.

Concept of Field Experimentation.

Before going any further, it is necessary to discuss, and later define, our concept of field experimentation. Primarily there is the soil. Nowhere is it found to be uniform; everywhere it is intensely heterogeneous. One notices first, due to variations in colour and structure, the approximate boundaries of the main agro-geological types. (9) The sketch-map shown in fig. 1 illustrates how complex the variation may be in an area of a few hundred acres. Again, each agro-geological type is heterogeneous; there are variations in structure, arrangement, depth, water-holding capacity and freedom of drainage, micro-organic activity, chemical composition, available plant food content. Some soil characteristics, that vary from type to type, are constant for a given type. On the other hand, many characteristics, including most of those that effect plant growth, vary from place to place within one type, and vary from time to time at any given place. In brief, most of the soil conditions affecting plant growth are dynamic, not static.

Secondly there is the plant. Each variety has characteristic growth habits and inherent growth powers, which cause it and its vegetative progeny to respond to a given treatment in a certain way. (15) However, apart from the intervention of disease, it is held by some that there may be a variation within a type—there definitely is in the case of a sport or bud mutation, but this may be said to constitute a new type—such as a gradual senescence, resulting finally in the variety concerned deteriorating to such an extent that it becomes unprofitable to grow it. Thus the results of any given variety trial cannot stand for all time, but must be subjected to periodic checks.

The effect of cultural operation, and of irrigation water, may vary according to the soil, possibly according to the variety, but not, it may be supposed, from time to time; though water bears watching for the possible introduction of some harmful or beneficial substance in solution or suspension, necessitating a change in the water supply, or potentializing a reduction in fertilizer purchases. (11).

This brief sketch of the variable factors affecting the growth of the cane plant is neither accurate nor comprehensive, but it comprises perhaps enough material observations to make it possible to extract from the discussion some sort of formula.

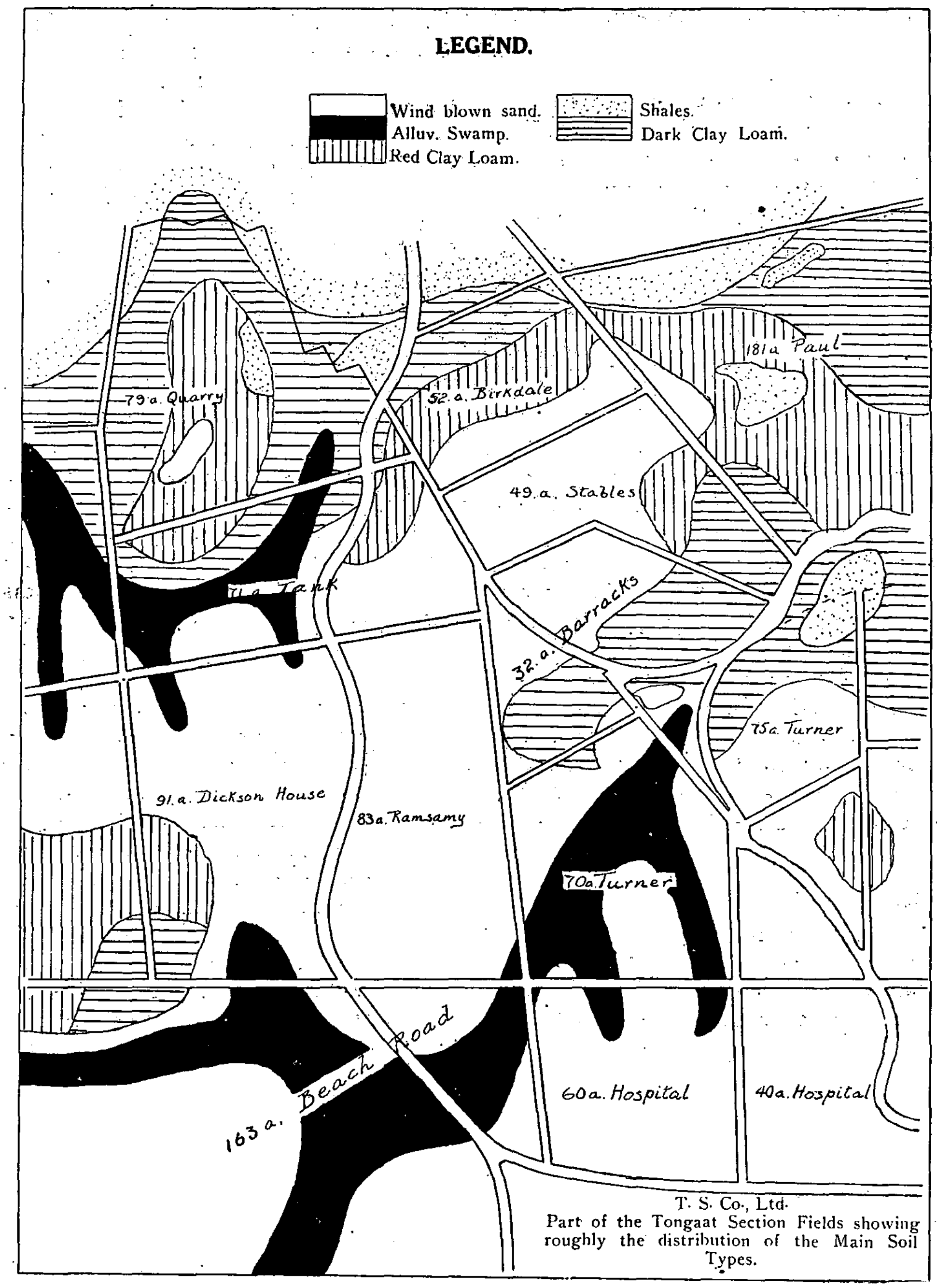

Fig. 1.

denoting the conception of field experimentation on which our programme is to be designed. We would express that formula as follows:

> A conception of field experimentation, which seems to conform to most local requirements and conditions, is a plurality of field trials, representing all important environmental conditions, co-ordinated and compared with other experiments of a similar nature, supported by all other obtainable correlative evidence, and maintained, where necessary indefinitely, for the purpose of noting trends, the period of existence of individual trials being partly determined by the tendency of the unknown factor to be dynamic or static.

Variety Trials.

The amount of work involved in variety trials depends largely on the number of new varieties being introduced from time to time, and also on the extent to which environmental conditions lack uniformity within the plantation. Even if the number is large, the work can probably be kept within reasonable limits by some kind of eliminating test, using small comparison plots. In South African cane lands there is not a very great variation in altitude for any single soil type, nor in exposure. The soil map looks as if it might be one's chief guide for determinating the programme of variety trials unless irrigation is a factor. It may be noted, before leaving this section, that it is really impossible to attribute any great importance to a variety trial, unless the canes on test have been grown under conditions, in which as far as possible all limiting growth factors, saving those inherent in the plants have been removed, or adequately guarded against. We refer especially to the need that there should be no possibility of a deficiency of any constituent of plant food; hence it follows that at least a rough reconnaissance of the quantitative status of available plant food in different parts of the plantation should precede a set programme of variety, irrigation, or cultural operation experiments.

Fertilizer Trials.

Fertilizing, in the present context, consists of adding to the soil extraneous substances, or materials - mineral or organic, simple or mixed - which contain one or more of the three principal plant foods, this process taking place when there is evidence; failing which grounds for suspicion, that such plant foods are not supplied or made available in sufficient quantities from natural sources.

It is generally accepted, in fact it has been demonstrated, - that, apart from rare cases, all the essential nutritive substances - including sulphur, boron, manganese, iron, magnesium - are usually found in the soil in adequate amounts, with the exception of nitrogen, phosphate, and potash. The amounts of one or more of these three principal plant foods present in the soil may be insufficient to meet the needs of the plant, in which case its growth will suffer restriction, no matter how favourable other growth factors may be. But the objects of fertilizer trials are not confined to determining the amounts required of the three principal plant foods. The form in which such deficiencies should be supplied, the time and position of the application, and the effect on availability of the interaction between nutritive components, also need studying; and an attempt at a comprehensive statement of the reasons for laying down fertilizer experiments might run somewhat as follows:--

> The object of a series of field fertilizer experiments is to obtain such knowledge as will enable one within economic limits to approximate the addition of artificial fertilizers to the actual plant and field requirements, that is to say: to determine as closely as possible the amounts of the three principal nutrients, nitrogen, phosphate and potash, that should be contained in a fertilizer treatment in order that such treatment will result in the optimum economic yield, for any given soil type, or field, or portion thereof, and for any given crop or variety; to show, moreover, how the requirements of the particular area are inclined to change, becoming larger or smaller, under the influence of climatic conditions, cultivation, soil and crop absorption, and chemical and biological activity in the soil including the interactions introduced by and between the fertilizing materials added to the field; and to determine the optimum form, time, and position or mode of application, of such treatment.

TABLE 1.

Some Simple Fertilizers showing Analysis and Cost.

Fertilizer	Plant Food Supplied per cent Fertilizer.			Lbs. Fertilizer to give 100 lbs. p.f.			Approx. cost of 100 lbs. of plant food.			
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	£	s.	d.	
Ammonium sulphate	20.5	—	—	500.0	—	—	2	0	0	
Sodium nitrate	15.5	—	—	666.6	—	—	3	1	8	
Superphosphate	—	20.0	—	—	500.0	—		17	6	
Basic slag	—	16.1	—	—	625.0	—	1	4	3	
Muriate of potash	—	—	60.0	—	—	166.6		13	4	
Sulphate of potash	—	—	48.5	—	—	206.2	1	0	7	
No. 1. Whale guano	10.5	1.5	—	952.0	—	—	3	1	2	(a)
	6.1	—	—	1640.0	—	—	2	11	2	(b)
No. 2. Whale guano	—	15.0	—	—	666.6	—	1	2	1	

(a) Less value of P_2O_5 at the rate of 17/6 per 100 lbs.
(b) Less value of N at the rate of 40/- per 100 lbs.

Obviously all cannot be achieved at once, and again there has to be a selection of those phases of investigation which are most likely to be worth while. Here it strikes one immediately that the quantity of plant food required is the first point for attention. To make a practical illustration, most planters have had experience of being suddenly unable - owing to a rise in price, etc. - to obtain their phosphatic fertilizer in the form they usually bought, say basic slag or bone meal. Compelled to purchase another form, they have used such quantities of it as would provide the same amount of P_2O_5 per acre as before, and their crops have not been materially affected. If no substitute had been on the market, and their cane had been deprived of phosphate altogether; they would have been exposed to the danger of very depressed yields.

According to Dr. Oswin Willcox: "In the early stages of development of the general law of growth factors (the "action" law) by Mitscherlich and others, attention was first arrested by the obvious constancy of **C** (proportionality factor) for a given agrotype in a given habitat. Later on, comparing the constants obtained under dissimilar circumstances with dissimilar agrotypes it began to appear that a definite constant factor of proportionality or "effect factor" tended to associate with a given growth factor, which means that a particular growth factor tends always to produce the same proportionate result, irrespective of external circumstances or of the kind of crop. Thus, in a long series of vegetation experiments in different years with sandy soils, and humus soils, of different original states of fertility and possessing alkaline, neutral or acid reactions, Mitscherlich found that the numerical values of **C** for the growth factor phosphoric acid in all these experiments ranged between the values 0.46 and 0.68, with an average value of 0.60, this average value being approached independently of the form in which phosphoric acid was offered to the crop - whether as Rhenania phosphate, superphosphate, Thomas meal - provided only that it was soluble or available." (15)

It is therefore evident not only that the greatest possibility of gain accruing to the plantation proprietors lies first of all in a study of the amounts of plant food required by the soil, but also that other phases of fertility studies cannot be tackled with much hope of success until a good deal of quantitative data has been compiled. In fact, since the crop produced is the ultimate measure of the success of our agricultural operations, a quantitative examination of soil fertility, and the means of its maintenance and amendment would appear to be necessary precedent to all other branches of field research.

Amounts required by the Plant.

Having discussed some of the evidence favouring the view that the primary function of fertilizer trials is a quantitative diagnosis of nitrogen, phosphate and potash, it is now in order to consider rather carefully what amounts of these three principal plant foods are likely to be required in the field. One takes notice first of the amounts absorbed by the plant; that is to say, removed from the soil in the stalks, tops, leaves and trash. It is very plain that the amounts absorbed by the tops, leaves and trash should be reckoned as removed from the soil as far as the next succeeding crop is concerned, because although the nutrients contained therein are, particularly where it is not the custom to burn the trash, such plant food will not be immediately available to nourish the young ratooning cane. On this subject R.J. Borden says:

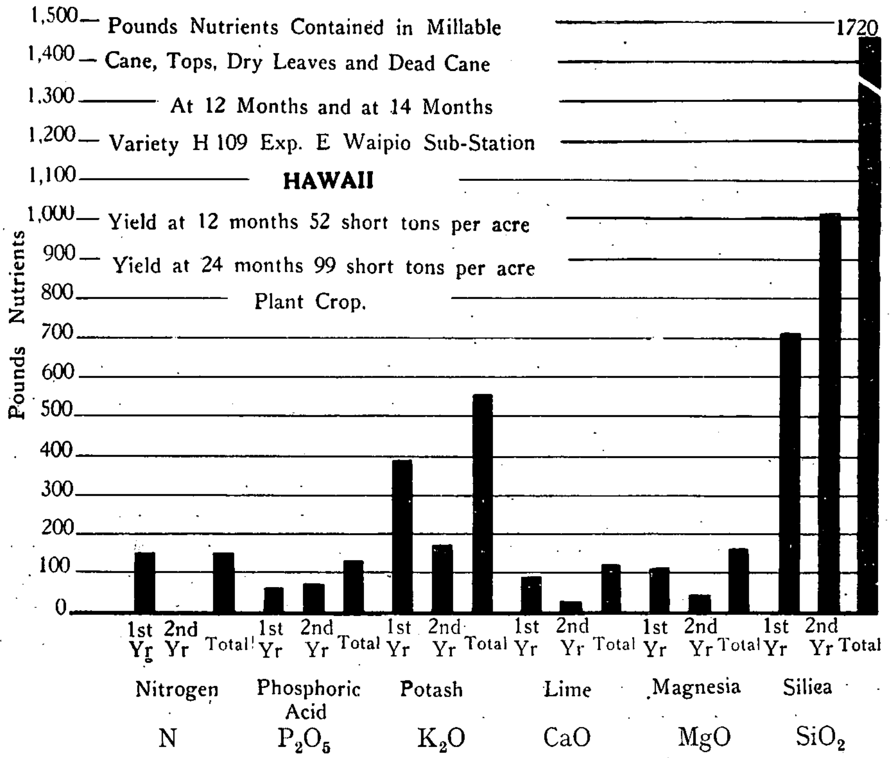

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Fig. 2.

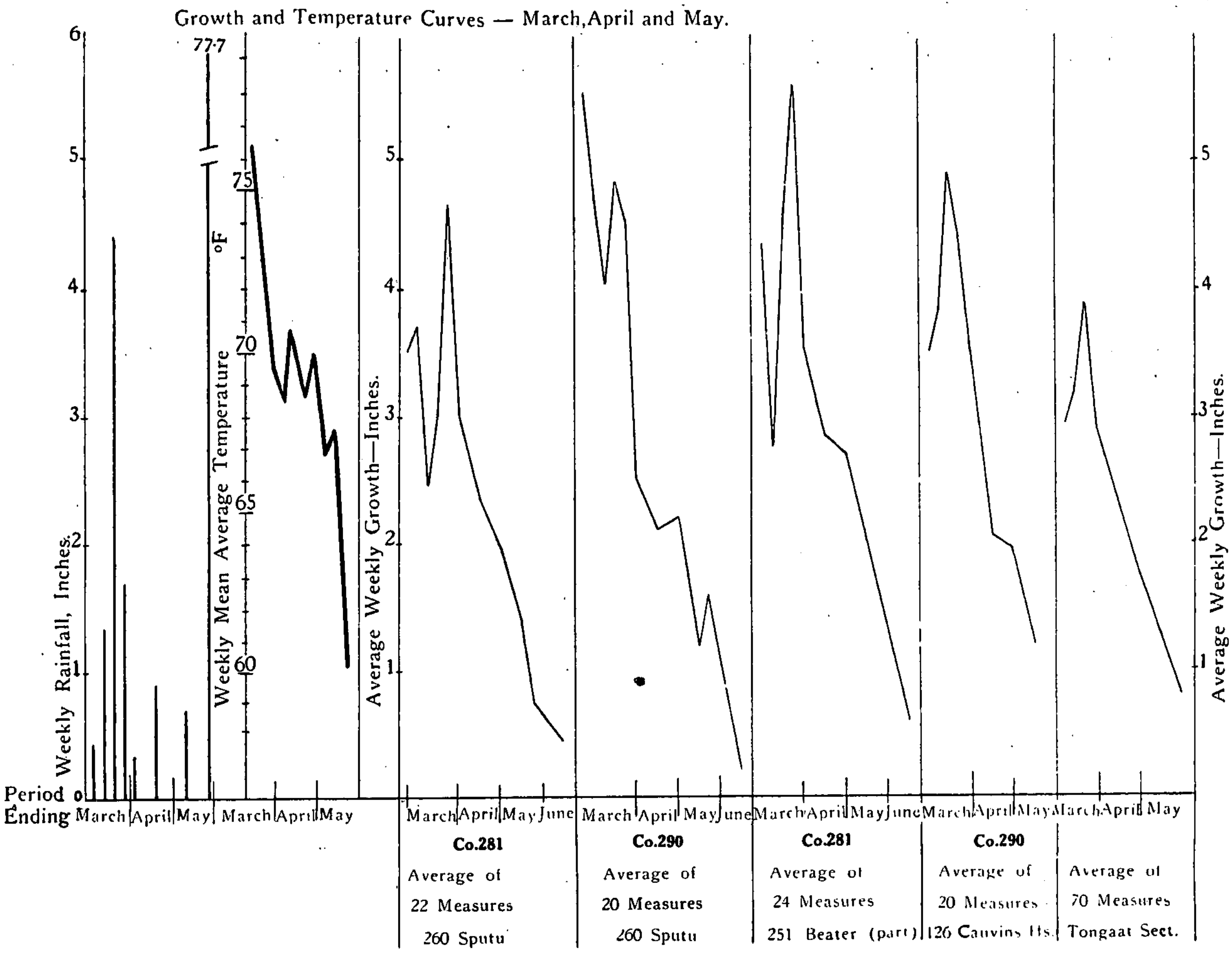

Fig. 3.

"Fertilizers are materials that are designed to supply deficiencies in the soil of nutrients that are essential to the growth of plants, in sufficient quantity, and at a rate sufficiently rapid to enable the plant to take the fullest advantage of its supplies of water, heat, sunlight. and other necessary factors, especially during the most critical periods of its development. The scientist has told us what elements are essential to plant growth, and he can analyse our soils and tell us how much of each plant food is there. But the amount of each element is not so important as its mode of combination; is it already available; can it be made so; or is it locked up in such a way that the plant cannot get at it, or gets it too slowly? If the latter case, then for all practical purposes it is unavailable for the immediate crop we want to grow; hence it is deficient and we shall need to apply fertilizers to remedy the deficiency." (12)

The diagram in figure 2 illustrates the uptake of plant food by a 50- and a 100- ton crop of H-109 cane. It is of special interest to note that practically all the nitrogen, and definitely the larger portion of the potash, is absorbed in the early part of the first year. (13)

The diagram (fig. 3) shows how the rate of cane growth parallels very closely a curve representing the average weekly temperature. In Natal it would appear that growth comes more or less to a standstill from the end of April to the beginning of October. From October the growth rate increases until about the end of February, when it starts to fall very rapidly in conformity with decreasing temperatures. As this period of rapid growth and high temperatures is usually one of good rainfall one can realise how important it is that the greatest advantage of these favourable conditions should be taken by affording the growing plant a sufficient ration of food.

On top of the plant absorption comes the soil demand and losses to the plant through leaching and the like. Thus fixation and colloidal absorption, as well as the loss of soluble fertilizer salts in drainage water must be brought in some way into the calculation. When this has been done an approximation of the plant's requirements, ignoring any plant food which may be contained in the soil, may be made. Field trials, together with laboratory analyses, will thereafter disclose the extent to which the first approximation may be reduced in respect of the amount of plant food contained in and provided by the soil.

In regard to actual amounts absorbed one can only get an idea of the probable state of affairs under field conditions. No doubt the literature is teeming with evidence on this point. Unfortunately we have only been able to make one or two references. In this country Hedley and Beater (8) in a limited number of tests, made the following determinations:

TABLE II.

	30 ton crop.			40 ton crop.		
	Uba A.	Uba D.	Uba B.	Uba C.	Co.290	Co.281
N	391	420	223	183	336	382
P_2O_5	112	130	70	82	95	164
K_2O	1,195	1,044	402	267	724	1,018
CaO	133	154	193	188	234	245
MgO	126	139	263	74	343	224

Uba A, D, Co.290, 281—leaves tops trash stalks roots.
Uba B, C. —no roots.

Eliminating the amount taken up by roots, and equating to 30 tons per acre, the above figures would give the following:

TABLE III.

	Uba A.	Uba D.	Uba B.	Uba C.	Co.290	Co.281	Average
N	246	224	223	183	223	249	225
P_2O_5	79	83	70	82	95	116	87
K_2O	986	813	402	467	508	788	660

As far as the writer knows the various lots of cane tested in this experiment were not grown under uniform conditions, nor was it ensured that a plentiful supply of all plant foods was available. Hence just about the only inference one is inclined to draw at this time is that under average Natal conditions a crop of sugar cane may possibly absorb amounts equivalent to the maximum figures shown in these tables, and that it is necessary to provide in some way for such a contingency. The indications thus offered are in agreement with the determinations of Kobus in Java, and with the results of the Hawaiian experiments, as shown diagramatically in figure 2. (13). Noel Deerr, referring to this aspect of cane work, says: "The very many analyses which have been made of the cane afford means to construct a balance sheet of the demands made on the soil by the cane and of the distribution of the plant food removed." (7) An abstract from this balance sheet, converted to the basis of a 50-ton per acre crop, would give 175 pounds nitrogen, 105 lbs. phosphate, and 525 pounds potash, absorbed by leaves, tops, roots and stalks.

From the foregoing it would appear to be in order to take as a basis for the future discussion the following figures, which would be roughly representative of the amounts of plant food absorbed by a 50-ton crop:

Nitrogen	150 lbs.
Phosphate	100 lbs.
Potash	400 lbs.

The "Safety" Policy.

An accurate statement regarding present day trends of fertilizer policies amongst planters of the South African sugar industry can only be obtained by co-ordinating the answers to a general questionnaire, in the absence of which we are limited to venturing the following opinion:

1. There is a tendency to use more artificial fertilizers, and to make a larger per acre application.
2. No material movement has been initiated towards differentiating between the requirements of specific soil types, or fields within such types.
3. The popularity of organic fertilizers persists notwithstanding that the cost is usually considerably higher than the equivalent amount of plant food in mineral form.
4. In regard to ratoons the generally accepted idea is that a good deal, if not all, of their plant food requirements is to be obtained; (a) residually, from the plant cane dressing; (b) from the decomposition products of plant residue; and (c) from the soil itself by means of inter-row tillage. In many cases ratoon treatments, if any, bear no resemblance whatever to plant cane applications.
5. The idea of soil deficiencies of phosphates dominates all fertilizer schedules to such an extent that large areas probably receive nothing but phosphates, chiefly in the form of super.
6. Nitrogen and potash, if applied at all, are usually placed in the furrow at the time of planting, and seldom side-dressed after the cane is established. Whatever is given is applied at one time, and not split up into periodical doses.
7. Although the idea of an exclusive phosphate deficiency for practically all soils is very strongly established, it is probably a fact that quite a large percentage of growers include small rations of nitrogen and potash in their treatments, as an insurance.

The analysis of a typical proprietary sugar cane mixture marketed locally, and as far as one knows quite extensively used is 3 - 17 - 5. If a planter should apply this mixture at the rate of 800 lbs. to the acre - this is probably higher than the average rate of application - the amounts of plant food supplied will be as follows:

Nitrogen	24 lbs. to the acre
Phosphate	136 lbs. to the acre
Potash	40 lbs. to the acre

But the three principal plant foods may be absorbed by a 50-ton crop in amounts of the order of:

Nitrogen	150 lbs. to the acre
Phosphate	100 lbs. to the acre
Potash	400 lbs. to the acre

Further there is the question of phosphate fixation about which there seems to be a great deal of indefinite speculation, though it seems to be agreed that much more phosphate is required than is shown to be absorbed by the plant. Concerning fixation of phosphates it has been demonstrated in a series of experiments at the Cedara School of Agriculture that the proportion of phosphate fixed for all the soils tested was of the order of 80 per cent. (16). In an examination of 12 soil samples taken from various descriptions of soil on the Natal coast Beater (3) makes determinations of the percentage of permanently fixable P_2O_5 which vary from 27% on yellow grey-brown sand to 94% in red lateritic clay. For the purposes of discussion it is therefore permissable to adopt 60% as a figure roughly representing the amount of phosphates which may be fixed, although obviously it is impossible to generalise.

Allowing for fixation, therefore, and bearing in mind other modes of encountering fertilizer losses or unavailability, the amounts might be restated thus:

Nitrogen	150 plus
Phosphate	250 plus (two-fifths of 250 reckoned available, i.e. 100).
Potash	400 plus

Hence it is clear that the "safety" policy fertilizer treatment cited as our example, which many an optimistic planter relies upon to supply the needs not only of plant cane but of one or two ratoon crops, actually only provides one-sixth of the total nitrogen, one-half of the total phosphate, and one-tenth of the total potash, **which may, under certain conditions, be absorbed by one crop of cane.** Thus such a treatment cannot be considered as a very effective insurance against plant food starvation.

We have remarked that ratoons probably receive considerably less attention as to their fertilizer requirements than plant cane. Practically all the results of experiments done in this country and placed on record have been the results of trials laid down and treated as plant cane only, the ratoon crop receiving no treatment in order to afford evidence of residual treatment; though it would appear that residual effect could be studied and demonstrated had the ratoons received the same treatment as the plant cane, by observing a decreasing or increasing response to the treatment under trial. The results are almost exclusively negative to nitrogen and potash, but does it follow that there would be no respose to such nutrients, if applications of significant amounts of nitrogen and potash materials were made to ratoons?

It should be remembered that ratoons start off on their career under very dissimilar conditions to those governing the early life of plant cane, and a very possible explanation of the apparent non-response, in the South African sugar industry experiments, to anything but phosphate is:

Phosphate carrying soil minerals are, in most soils, few in number and low in quantity. Cultivation activities during fallow periods cannot therefore be depended upon to increase materially the amount of available phosphates in the feeding zone of the plant's roots, though the use of buckwheat as a green manure crop is said to do so. Hence the quick response to chemical phosphates.

By contrast, potash-bearing soil minerals form an important group, and constitute a material percentage of many soils. Decomposition during fallowing tends to increase the amount of available potash in the surface soil.

Further, we know that during the fallow period several agencies are at work tending to augment the amount of available nitrogen:

(1) rainfall (atmospheric nitrogen in solution)

(2) bacterial fixation of atmospheric nitrogen;
 (a) independently of plants,
 (b) through the aid of leguminous plants

(3) decomposition of organic matter.

Thus a plant cane crop may have a modicum of available nitrogen and potash. But the start of the ratoon crop is not preceded by any natural or cultivation-induced activity which would tend to replenish the used up nitrogen and potash. Therefore it would seem reasonable to suppose - and our surmise is supported by the appearance of the crops - that ratoon crops are likely to respond to additions of these nutrients as well as to a further increment of phosphate.

In passing it may be noted that an improved general average of tons of cane, or sucrose, per acre is by no means the only advantage which may accrue from raising the quality of one's ratoon fields. Looking after the ratoons better, and giving them a plentiful supply of fertilizer, means acceleration in their growth rate; a rapidly growing crop means a material decrease in weeding and cultivation costs, for the faster it grows the sooner it is able to control weeds without assistance. Also the longer the ratoons are kept at an economic and profitable standard the more one will be able to reduce the area which has to be planted, with all the risks attendant upon that costly and precarious operation.

We come, therefore, to a point when it seems necessary to consider means of designing a fertilizer policy in such a way to afford an insurance against plant food starvation for both plant and ratoon fields. How may this be done without spending more money than we are likely to get back? It is clear that:

1. Any "blanket" policy (i.e. all areas treated the same) which is within economic limits cannot be relied upon to satisfy plant food requirements.
2. Any "blanket" policy designed to meet the maximum possible plant food requirements is quite beyond the economic limits; and therefore,
3. The only way of determining and supplying the actual requirements, as they vary from field to field, and as far as they can be afforded financially, is to inaugurate a comprehensive series of field trials, and co-ordinate their results with such comparative analytical data as can be obtained.

Range of Amounts in Quantitative Trials.

From the question of amounts of plant food absorbed by the plant and the soil, the discussion comes naturally to a contemplation of the range of amounts calling for field trial examination. In the complete absence of any contrary indications the range, in respect of each nutrient, would appear to run from zero to that amount which would satisfy both plant and soil demands without depending on any natural supply. At one end of the scale, in a soil which contained for all practical purposes, no available N (or P_2O_5 or K_2O) one would expect to find the optimum response near the maximum point on the range, representing the total amount absorbed by the plant and the soil. At the other end, given a soil with a surplus of available N (or P_2O_5 or K_2O) one would not expect any increase in yield from even the first increment of the plant food being tested, the optimum response in this case lying close to the zero point.

We are assuming that every soil type - or rather every field, or group of fields, as the case may be - on being tested by a correctly laid-out field trial, will show optimum response at one point within each of the nutrient ranges. There are generally some indications, with the help of which the agriculturist will decide in what sector of the scale of amounts he should place his experiment (6) (10) (14); but if no outside indications come to his assistance he is bound to investigate each nutrient range from one end to the other. That proportion of the complete range which may be included in a single experiment depends on the number of introduced variables, and also on the manner in which the nutrient range is graduated.

One feels that there must be some close relationship between the manner in which the plant food range is graduated and the maximum possible requirement for the nutrient concerned. When considering the increment of plant food, which shall represent, in a quantitative fertilizer experiment, a single graduation of the plant food range, it is surely necessary to compare such an amount with the total maximum possible amount which might be required, the concept in this case being that a single graduation must tend to be a significant proportion of the total maximum. What the minimum significant increment would be for any given plant food is impossible to state; but variables consisting of increments which are prima facie unlikely to alter the fertility status of the soil can be avoided.

Recapitulation.

In any general project of industrial agricultural research the investigator's opening move is to make notes of all the factors that may bear on the growth and welfare of his crop, making certain that not a single particle of relevant matter is overlooked, or falsely valued. Such factors will of necessity be grouped and classified in order of their agronomic importance. A survey of the groups will reveal that the chances of bringing profit to the plantation through field trials of cultural conditions, time of planting and harvesting, irrigation, allocation of cane varieties, are probably less than the scope for harvest yield improvements through the medium of refinement of fertilizer practices. From such a survey it will also be realised that, of the many phases of soil and plant food study, the importance of the quantitative aspect is likely to over-ride the others, not only in regard to its scope for economic crop improvement, but also because one must have a certain amount of knowledge of the quantities of nourishment needed by the plant before other field investigations can successfully be performed. Thus the agriculturalist in charge of the project will start by planning his preliminary quantitative tests; and when these are well under way, and a certain amount of data has been gathered which will act as pointers, the remainder of his programme, consisting of field trials of all other questions of worthwhile agronomic importance, may be gradually planned, decided upon, and laid down.

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NOTE:—Since this paper was not read during the Congress the following discussion has been communicated in writing.

Mr. B. CAMPBELL: Said first of all I should like to express my appreciation of this paper of Mr. Watson's, in which he reveals a very sound conception of the mode of approaching the problems confronting us at the present time. While his conception is essentially Hawaiian in outlook, it is none the less applicable to our local conditions.

There are one or two points in Mr. Watson's paper that I should like to endorse and enlarge upon. The first is in connection with the collecting and recording of accurate field data, as opposed to what Mr. Watson terms inaccurate observation, and half remembered experience. By field data I do not mean only the results of field trials, I refer to routine records in general. Such practice would be of benefit to both the small planter and the big concern.

By field records I mean the keeping of an individual field record sheet for each individual field, recording all relevant data from year to year, such as acreage, variety, time of planting, time of harvest, age in months at harvest, quantities of the three plant foods applied, when and how applied and the resulting juice analysis, cane ratios and yields. Such records are of infinitely more value, than the common practice of keeping what might be termed "yearly" records, in which all the fields planted, fertilised or harvested are listed. In endeavouring to ascertain a field's past history, i.e., agricultural treatment, yields, etc., it is necessary to refer to numerous ledgers to get the required information. As opposed to this, the field record sheet contains all this information on one sheet and one's attention is immediately localised to the particular yield in question. A good example of a yield sheet is given in the proceedings of the Hawaiian Sugar Technologists' Association, 1934, page 46. Such records as this will reveal information on a number of the major points brought out by Mr. Watson in his paper.

Another point on which I feel Mr. Watson might have laid more stress is the Hawaiian practice of expressing yields on the acre per month basis. This is important in connection with the keeping of accurate yield records. While it is a decided improvement on the local method of expressing yields, it has the disadvantage of not differentiating between winter and summer months. It is for that reason that the Hawaiian Industry has gone a step further, and most plantations are now recording their yields also on the 1,000 day degree basis, which takes into account both time and temperature. I feel this is a subject well worthy of investigation under Natal conditions.

In regard to Mr. Watson's reference to the lack of sufficient response to anything but phosphates in local experimental work in the past, I feel this will be overcome to a great extent by improvement in the technique and design of field experiments.

In regard to the author's references to phosphate fixation and the figures quoted for per cent fixed, it might not be out of place to offer a word of caution in regard to the interpretation of these figures. In the preliminary work carried out by Mr. Dixon at Natal Estates, it has been found that the per cent temporarily and permanently fixed phosphate, varies in a very complex manner with the amount of phosphate added to the soil. In general it has been found that the per cent permanently fixed increases with the amount added up to a critical point, after which it remains constant or in some cases drops. Whereas the per cent temporarily fixed seems to decrease with the amount added. When plotted on graph paper the resulting curves are such as to suggest a very complex transformation taking place, few of the curves being alike. In quoting per cent fixation therefore it is essential that the amount added be stated.

And lastly I should like to endorse Mr. Watson's references to what he terms a "Blanket" policy. I will not enlarge upon them as I feel he has said all that is necessary.

Mr. FOWLIE: Said I wish to compliment Mr. Watson on writing such a comprehensive survey of the agricultural problems which confront the cane grower. It is a formidable list and I notice he has omitted to say anything on our very variable and uncertain climate. Certainly we cannot alter our climate but we know for example that the average annual rainfall varies considerably from place to place in the cane belt and such variations so far as they are known ought to be taken into account in assessing the results of experiments. So also ought the nature of the seasons to be taken into account when considering the results of experiments and trying to decide how far these results are likely to be applicable.

Mr. Watson has passed over most of the problems he mentions in the first part of his paper as being of secondary importance and has devoted the major portion to the fertiliser problem. This is probably as it should be as the fertiliser problem is much the most difficult and intriguing factor in field husbandry, but I think he has passed over the question of variety trials with rather scant ceremony seeing we in this part of the world have increased our production very largely the last few years after preliminary trials to pick out these few varieties from amongst many others. Could we hope to increase our output by a similar amount as cheaply by a forward fertiliser policy. It is possible we might, but there are many reasons for thinking it will be difficult. Fertiliser experiments are highly necessary not only to assist us to grow the maximum economic crop under conditions where considerable applications of fertiliser are highly profitable but to prevent us from wasting money by applying the same amounts of fertiliser under conditions where they are unable to give an economic response.

There are many matters in connection with agriculture where the experience of the man who has proved himself a good farmer is of great value and though I fully agree with Mr. Watson that it is desirable to collect as much data as possible concerning every alternative method of doing things I still think there are things which are best decided by the man on the spot as varying conditions arise provided he is sufficiently trained and experienced. This is particularly the case in connection with the cultural operations where the weather plays such a large part in determining the best way of achieving the ends in view.

Dr. McMARTIN: It is indeed encouraging to find the value of experimental work for directing plantation practice being appreciated by one who, like the author of this paper, is concerned more directly with the production side of cane growing than with the investigation of its problem; and this to such an extent that he has ventured to record his views on the subject in a paper.

A paper on such a subject is bound to be of a controversial nature, as unfortunately the human mind is not great enough to avoid, even in research work, following out lines of investigation which attempt to prove further some point of view originally held, and to rather minimise the value of conducting experiments along other avenues of approach.

It is, moreover, unfortunately easy in agricultural research to be snared into one or other more or less dogmatic schools of opinion; and once more the nitrogen-phosphate-potash (plus minor elements) school has enlisted an adherent.

The opinion is expressed that only experiments should be conducted which are likely to show to the grower how to increase his profits—without doubt a very laudable project, but which yet nevertheless assumes from the start that the experimenter, by rejecting certain lines of study, and accepting others, knows to some extent what fruits his experiments are going to bear. Thus, the author states that: "A survey of the groups (i.e. different classes of experiments) will reveal that the chances of bringing profit to the plantation through field trials of cultural conditions, time of planting and harvesting, irrigation, allocation of cane varieties, are probably less than the scope for harvest yield experiments through the medium of refinement of fertiliser practices."

How far the relationship between type of experiment planted and profits gained can be seen by examining some figures for variety trials and fertiliser trials. The author in his paper on "Notes on Fertiliser Experiments Harvested at Tongaat During 1936 and 1937," page 33 this volume, shows that in one case £6/1/8 per acre was gained due to fertiliser application, and in another paper by Steward on "The Fertilisation of Ratoon Canes," page 72 this volume, a gain of £3/2/1 per acre is recorded. The highest gain due to fertiliser application which it has been possible to find records of is that given in "The Financial Aspect of Some Experiments Harvested During 1934 and 1935" by J. E. Colepeper (Proc. S.A.S.T.A. 1936), where at Wilton Park, Empangeni, a nett gain of £13/11/1 was shown over four crops. On the other hand in the "Fourth Progress Report on Experiments at Umfolozi," by the Experiment Station Staff, page 94 this volume, it is shown that in that district a nett gain of £80 per acre was gained over four crops by changing the variety grown. This may, it is agreed, be an outstanding case; it however serves to show that, if only those experiments which are most likely to show profit should be conducted, in this instance there is a very strong case for variety trials, and that the benefit from the superiority of one variety over another is **not** always "extremely slight," as the author states.

The case is also presented that fertiliser trials should precede variety trials, so that the latter can later on be carried out with optimum amounts of plant food in the soil; this, however, does not allow for any nutritional differences that may exist between varieties, which can only be investigated by carrying out a combined variety and fertiliser trial. Such a point of view also tends to emphasise perhaps a little too strongly the importance of the soil as the determining factor in the adaptability of variety to an environment, and to minimise the effects of other, climatic, factors.

Under the heading of "Amounts required by the Plant" (i.e. amounts of N.P. and K.), tables are given showing the amounts **taken out** of the soil by the sugar cane, and the difference between these amounts and that returned to the soil in a typical fertiliser mixture is taken to show that the latter is insufficient. This time-worn argument, which since the days of Liebig has already dominated the mental outlook of fertiliser specialists, does **not** seem however to have elucidated the rather elusive question of the optimum amount of plant food to apply to the soil, since according to the author the study of the latter must still take precedence over other questions relating to productivity.

Concerning irrigation, if the author were offered the choice of a free water supply for his crops, or a free supply of fertiliser, which would he rather have?

Having satisfied himself, then, that fertiliser studies are the prime necessity on an estate, the author with one sweep casts aside variety trails, cultural operation investigations, green manuring experiments, irrigation experiments, and other forms of enquiry which for a few generations have been dear to the heart of the agricultural experimenter. How simple scientific work will become!

These, however, are not to be shelved indefinitely, but only till the more pressing problem of the correct amount of NPK has been settled, and then their time will come.

The studying of fertilisers has been proceeding with increasing activity since the days of Liebig, and is still the most puzzling, most pressing problem facing the invesigator; when, does the author think, will the time come to embark on these other problems?

Mr. DODDS: We are again indebted to Mr. Watson for a suggestive and constructive paper covering much ground. A paper of this kind, however, cannot fail to excite some criticism dealing as it does with many subjects about which different opinions exist.

In column 2 of Mr. Watson's paper it is stated that experiments are to be sanctioned only on the basis of their potential value. This is often difficult to assess until the experiment has been done. These remarks seem to me to imply an antithesis between pure and applied science that I do not think really exists. Nearly all the applications of science such as in electricity, radio, and the utilisation of chemicals of every kind have originated in discoveries of which the material benefits could not be foreseen. It is said that Gladstone on one occasion visited Faraday's laboratory to see a demonstration of his pioneer and epoch-making electrical experiments; he said "Well Mr. Faraday this is all very interesting but what is the use of it?" Faraday very wisely replied that nobody could say, and that it was like asking the use of a new born babe. "At all events," he said "it is likely to develop into something you will be able to tax."

The discovery of aritficial fertilisers and their application to the soil during the last 50 years has saved the rapidly increasing world population from starvation, by vastly increasing the yields from crops and pastures, but most of these discoveries also originated in research without any definite economic object in view.

I agree, of course, that as far as our local sugar industry is concerned we are not in a position either as individuals or as an Association to undertake fundamental experiments, and have plenty to do in the selection of experiments likely to solve immediate economic problems, which is no doubt what Mr. Watson means.

The question of what Mr. Watson calls "plant senescence" has already been discussed at this Congress and the view expressed that there is no essential deterioration within any measurable period of time of plants propagated vegetatively, but that some disease factor supervenes eventually to cause the deterioration that is usually found in practice. If the plant could, however, be kept perfectly healthy and grown under favourable conditions there is no reason to suppose that any degeneration will occur.

In conclusion, I would like to congratulate Mr. Watson on his very comprehensive and constructive paper. I would be glad to see this example followed by the field management of other large estates.

Mr. LINTNER: I would like to congratulate Mr. Watson on his paper I particularly appreciate this contribution on account of the fact that it shows that members of the Staffs of the Estates are beginning to realise the importance of thorough investigation based on scientific lines. It is very gratifying to find that fertilisers are being valued from a price point of view in a sensible and correct manner because it is surprising how often one still comes across the most extraordinary ignorance in this connection in quarters where very often one would not expect it. I am also glad, to notice that great importance is attached to the available nutrient supply of the soil because so often on the Natal sugar belt one receives the impression that those engaged in cane production looked to the variety of cane grown to improve yields whilst maintenance of the soil fertility is considered of secondary importance. I think that if only more men engaged in cane growing would pay more attention to experiments carried out on the sugar belt very much more rapid progress could be made. A certain amount of information has been accumulated which could form the basis of trials run by the field staffs of the estates who are endeavouring to obtain more detailed information regarding the reactions to different treatments of the various soil types occuring in their area. If more people would adopt the same attitude as that taken up by the author of this very interesting paper results obtained from experiments at the Experiment Station which at times might appear of remote importance to the uninitiated could be tested out further and be put to practical use as soon as it is proved that the same results could be obtained under local conditions, thus eliminating a great deal of extension work required at the moment to convince those who are reluctant to believe in findings from experimental work largely because they lack the energy to devote a little time to finding out the reasons why much of the work is undertaken in the first place.

Mr. WATSON (communicated): I wish to thank those who have contributed to the discussion, both for the interest they have shown and the trouble they have taken, and for their appreciative remarks.

In his enthusiastic reference to Hawaii, Mr. Bruce Campbell sounds a note that might well be given more prominence in the agricultural affairs of the Industry. I have always been impressed by the radical differences in policy of the two countries. In the early records and history of Hawaii it is made very clear that the pioneers of agriculture in that territory realised—how I cannot say—that a good deal of their country was essentially low in fertility, that the heavy crops they planned to produce, and the tropical climate, acted together as a colossal drain on its inherent fertility, and that. therefore, they had to set about right from the start to maintain and improve the productivity of their soil. The pioneers of Natal relied upon the soil to yield what it was able, and the consideration of maintaining or improving fertility tended to be left to prospertiy.

I am glad that Mr. B. Campbell has filled in my omission and stressed the importance of keeping accurate field records, not only of experiments, but of crop scale operations. He refers to the Hawaiian concept of the 1,000 Day Degree as a basis of crop comparison. This is the latest evolution, the logical outcome of "Sugar per acre per Month" which, in its turn, has arisen from "Sugar per acre per Annum" and "Cane per acre per Annum." Another step backward, the basis of comparison was simply "Sugar or Cane—per acre," the time factor not yet included; and one cannot help reflecting in this connection that we in Natal have a very long way to go, for in Natal, of what percentage of fields may it be said that even the area is accurately known?

I accept Mr. Fowlie's rebuke concerning reference to varying climatic conditions, and their effect on experiment and field results. The 1,000 Day Degree, which takes in temperature but not moisture, has been mentioned. Would it be possible to evolve a day degree suitable to Natal, embracing moisture as well as temperature, to form a sound basis for comparisons of crop yields and climatic influence?

I admit that I am rather puzzled over formulating my reply to Dr. McMartin's comments. Despite some effort to avoid ambiguity a number of points seem to have missed their mark so far as he is concerned, and thus in some cases he appears to criticise opinions and ideas which do not in actual fact emerge from the text. It is pointed out that by the experimenter accepting some lines of investigation and rejecting others there is an implication that a certain amount of knowledge concerning the probable value of the experiment is possessed from the start. Is this implication really false? Is it not likely that even Faraday, notwithstanding his singularly discourteous reply to Mr. Gladstone's (no doubt irritating) enquiry, had some preconceived ideas, some intuitions, that helped to guide him to success? Industry is comparable to war. Time is of the essence of the campaign. Each objective must be decided upon and, in turn, each objective, in conformity with the general strategy, must be achieved with despatch. The industrial scientist, like the executive officer in war, has no opportunity to be delving into this or that hoping for something to turn up which will be taxable. The intuitive ability to see clearly into the future, to estimate requirements, to forecast the effects and to plan accordingly, is as necessary in agriculture as it is in battle. There must be discrimination. Even at a sacrifice to science, there must be a plan of action.