CODEN: IBBRAH (17-85) 1-24 (1985)
ISSN 0434-6793

INSTITUUT VOOR BODEMVRUCHTBAARHEID

RAPPORT 17-85

ESTABLISHMENT OF FERTILIZER RECOMMENDATIONS ON THE BASIS OF SOIL TESTS

by

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1985
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Inst. Bodemvruchtbaarheid, Rapp. 17-85 (1985) 24 pp.

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1. INTRODUCTION

The use of fertilizers has become a necessity in most cultivated areas to meet the growing demand for food for an expanding population.

Efficient fertilizer use is essential in preventing environmental pollution and saving (fossil) energy, and will contribute to increasing the individual farmer's profit. However, there is a lack of information on fertilizer performance as affected by climatic and soil conditions, time and method of application, and physical and chemical characteristics of the various formulations. In several countries even more surprising is the lack of a sound basis for fertilizer application rates, as assessed by soil tests or plant analyses and calibrated against crop responses in field experiments. This aspect of judicious fertilization practices will be discussed here. The various steps in establishing a basis for optimum fertilizer application rates, including plant and soil analyses, pot and field experiments, are outlined below. Stress factors affecting crop responses to applied nutrients will be taken into consideration. Due attention is paid to the economics of fertilizer inputs and net return of marketable product.

This paper was presented before the first National Congress of Soil Science of the Soil Science Society of Pakistan, Lahore, October 1985.

2. CHOICE OF SOIL EXTRACTANT

2.1. Relationship between soil nutrient and plant tissue concentration

Numerous soil extraction procedures for assessing "available" nutrient are known, but their effectiveness in reflecting plant uptake under various soil and climatic conditions requires further verification.

Testing soil nutrient concentration against plant uptake (tissue concentration) is often performed in pot experiments. Soils should vary widely in concentration of the nutrient studied, and also in relevant soil factors, e.g. pH, humus, clay, calcium carbonate, likely to affect plant uptake. Soils are selected in such a way that correlations between any soil factor and the soil nutrient in question, and also correlations among soil factors are largely eliminated (Van der Paauw, 1956). A specific plant tissue of a common crop plant is selected for analysis. As nutrient concentration changes with physiological age of the tissue a strict sampling procedure should be adhered to. The effect of physiological age is largely eliminated by adjusting nutrient concentration to a standard nitrogen concentration.

Plotting plant tissue against soil concentration may yield a curve of best fit like that in figure 1. Next, the deviations from the curve are plotted against relevant soil factors, an example of which is shown in figure 2. The regression line indicates deviation to be nil at soil pH a. Now the deviations from the curve in figure 1 may be corrected for pH, points with pH > a moving upward and those with pH < a downward. Figure 3 presents the plant x soil nutrient relationship, following elimination of pH effect, and valid for pH a. The same procedure is adopted for other relevant soil factors. Eventually, a plant x soil nutrient relationship is obtained that is valid for specific levels of relevant soil factors.

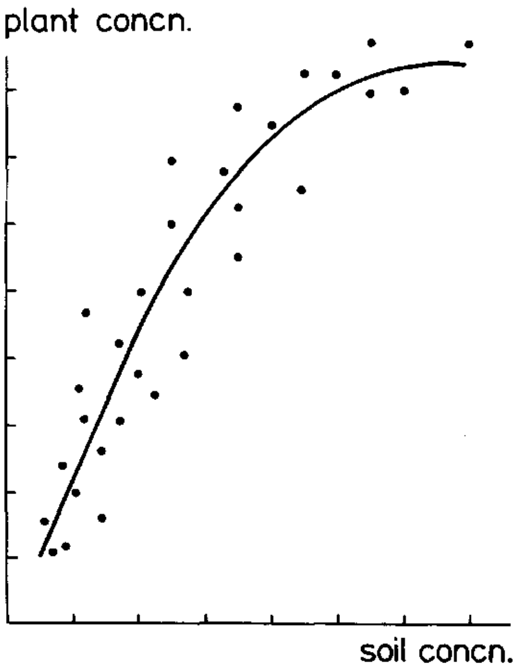

Figure 1. Relationship between soil and plant nutrient concentration.

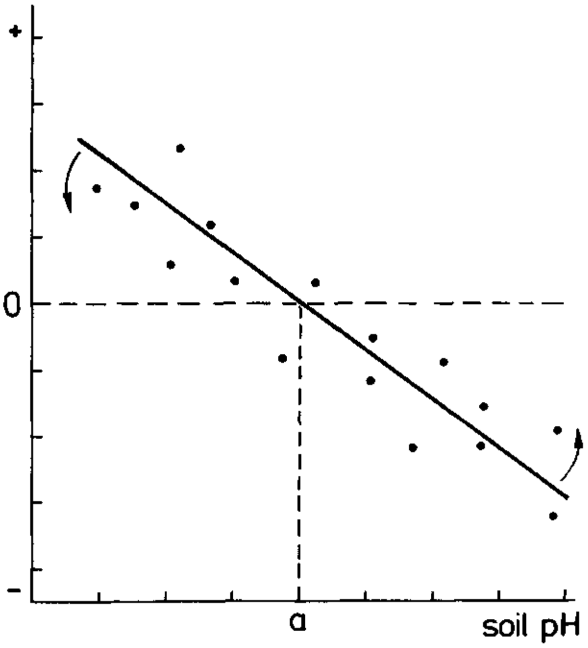

Figure 2. Deviations from the curve in figure 1 as plotted against a relevant soil factor (pH).

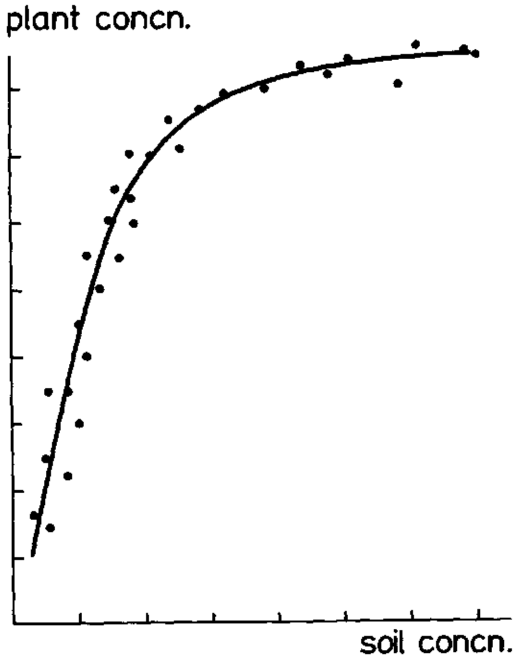

Figure 3. **Relationship between soil and plant nutrient concentration, as corrected for soil pH, and valid for pH = a (figure 2).**

2.2. Relationship between soil nutrient and relative yield of control (untreated) crop

Crop yield in the absence of applied nutrient is considered a useful criterion in testing the effectiveness of a soil extractant for that particular nutrient (Ris **et al.**, 1981). It is assessed in pot experiments with a test plant that responds strongly to the nutrient under study when deficient (Van der Paauw, 1980). Soils are selected according to the procedure described in the foregoing paragraph. Yield without applied nutrient (y_o) is expressed as a percentage of (maximum) yield (y_m) with applied nutrient. This is to eliminate yield differences resulting from soil characteristics other than the nutrient in question. Furthermore, it is a generally accepted principle that in studying plant response to a particular nutrient, deficiencies of all other nutrients should be avoided.

The procedure for plotting data is similar to that in paragraph 2.1. Curves obtained by plotting soil nutrient against relative, or adjusted relative yield (y_o/y_m) of the control crop, receiving no nutrient, may be similar to those in figures 1 and 3, respectively.

Sometimes (maximum) yield increase ($y_m - y_o$) is used, rather than relative yield (y_o/y_m), in evaluating soil test values (Van der Paauw, 1980).

3. CALIBRATION OF SOIL TEST AGAINST YIELD RESPONSE TO ADDED NUTRIENT

After having selected an effective soil extractant on the basis of pot experiments as shown above, the soil test value should be calibrated against yield response to the nutrient in question, so as to predict fertilizer requirement. This work is conducted in field experiments with various rates of applied nutrient. Experimental sites are selected, with sufficient variation in concentration of the particular nutrient, and in relevant soil factors possibly affecting plant response. Any correlations among these factors should be avoided. For reasons pointed out above, yields without (y_o) and with (y_x) applied nutrient are expressed as a percentage of yield maximum (y_m).

An example of curves showing the relationship between relative yield and soil nutrient concentration is presented in figure 4 (Smilde, 1970). Scatter about the curves may be reduced by eliminating effects of (soil) factors other than the nutrient in question as outlined in paragraph 2.1.

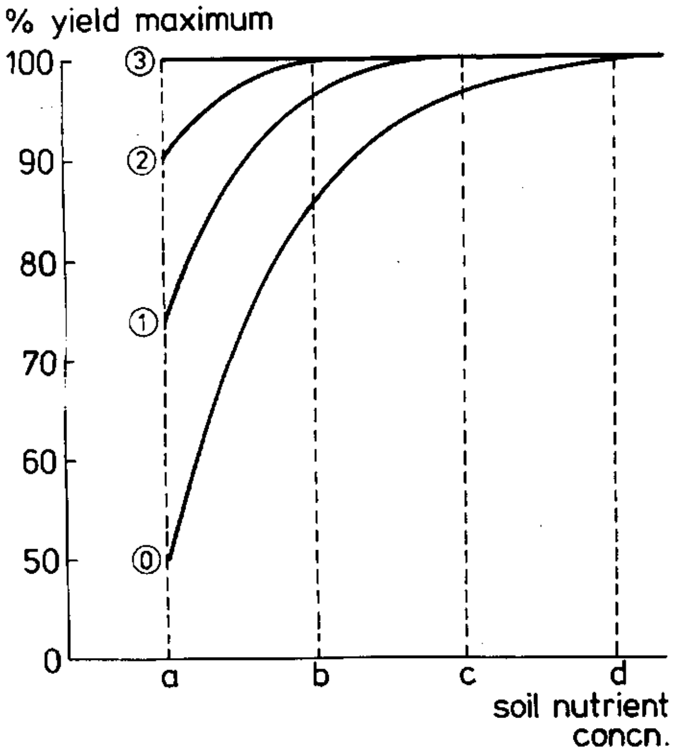

Figure 4. Percentages of yield maximum as affected by soil nutrient concentration and nutrient application.

Adjusted curves may be constructed for specific values of these factors. An example is given by Hauser (1973), showing how the relationship between cotton response to applied P and soil P can be adjusted for the number of irrigations.

In fact, figure 4 depicts nutrient recommendations, based on soil nutrient concentration, in a nutshell. With increasing levels of soil nutrient (a < b < c < d), rates of added nutrient needed to prevent yield losses decrease (3 > 2 > 1 > 0). Above level d application of nutrient is no more needed to attain maximum yield.

It is often argued that short-term experiments for establishing fertilizer recommendations on the basis of soil tests are less appropriate, as they do not account for variability in meteorological conditions. Still, duration should be restricted to one season only, and repeating a series of short-term trials is to be preferred to a continued trial. This is because of accumulation phenomena in long-term experiments, confounding the effects of residual and freshly applied nutrients.

4. CALIBRATION OF SOIL TEST AGAINST OPTIMUM RATE OF ADDED NUTRIENT

4.1. Economically optimum nutrient rates for various soil test classes

Sites for fertilizer experiments are selected as outlined in paragraph 3. There should be a sufficient range both in soil concentration of the nutrient studied and in other relevant soil factors, among them.

For each trial (each site) various nutrient rates are plotted against yield. If they are both expressed in monetary units, cost of nutrient is represented by a straight line from the origin. Optimum nutrient rate (o), producing maximum profit, is determined by constructing the point of tangency on the yield response (monetary return) curve for a line parallel to the nutrient cost line (figure 5).

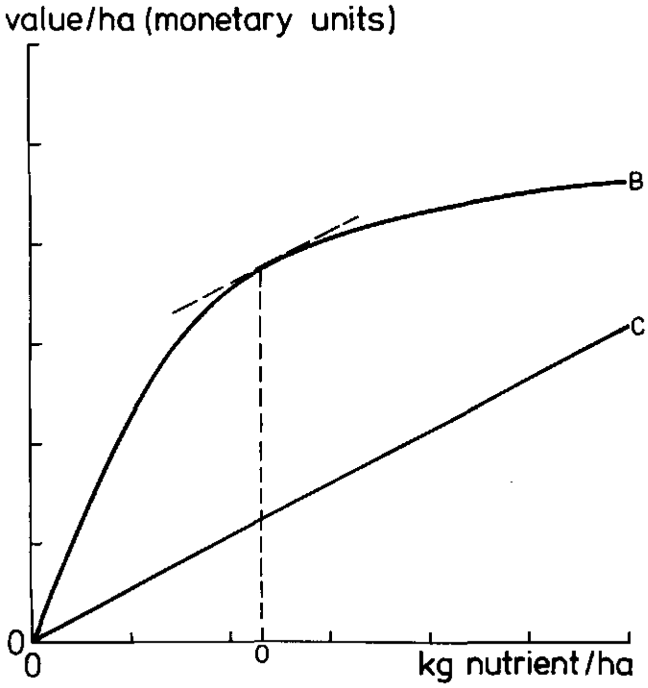

Figure 5. Assessing economically optimum nutrient rate (0), by constructing point of tangency on yield response (monetary return) curve B (benefit) and cost line C.

Optimum nutrient rates obtained from the various fertilizer experiments are now compared with the corresponding soil nutrient concentrations, pooled into fertility classes. For the various soil test classes, ranging from 'very low' to 'very high', stepwise decreasing nutrient (fertilizer) rates may be established (figure 6).

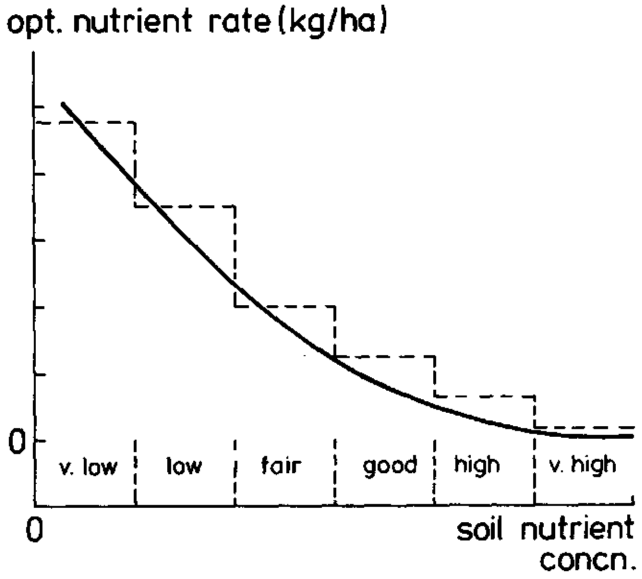

Figure 6. Economically optimum nutrient (fertilizer) rates for soils of various fertility classes (very low - very high).

4.2. Benefit/cost and price ratios affecting nutrient optima

Farmers may be reluctant in increasing inputs, because of poor credit facilities, high interest rates, obsolete tenure systems, and lack of storage capacity and marketing facilities for the extra output in the case of subsistence farming. Therefore, when adopting fertilizing practices, monetary return, i.e. value of yield increment, should be at least double the cost of fertilizer to obtain it, which means a benefit/cost (B/C) ratio of at least 2 (Vermaat, 1964). As illustrated in figure 7, for cost line C maximum net profit (B-C) is attained at 100 kg of nutrient per hectare, and B/C is 3. With higher rates of applied nutrient net profit decreases and B/C ratio as well. With lower rates net profit also decreases, but B/C ratio increases. In the case of the much steeper cost line C', only 60 kg of nutrient per hectare is needed for (a much lower) maximum net profit (B-C'), and B/C' is 1.5. Farmers may refrain from applying more than 20 kg of nutrient per hectare, where B/C' is 2.

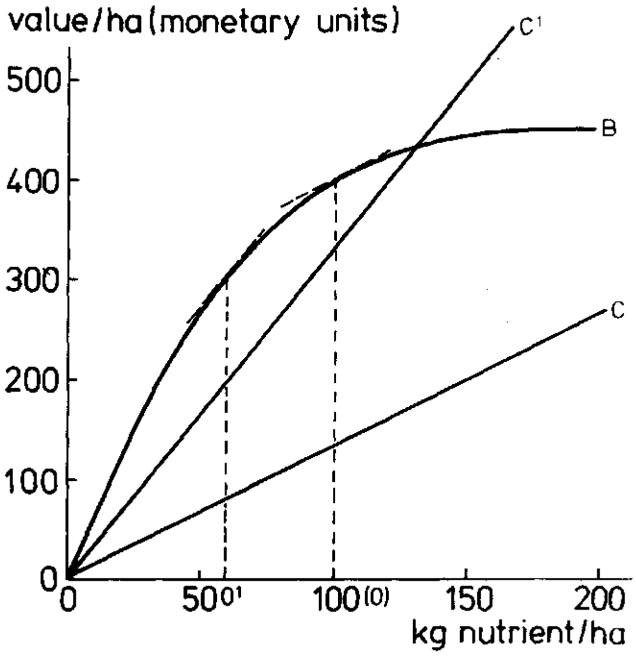

Figure 7. Economically optimum nutrient rates (0,0') for yield response (monetary return) curve B (benefit) and cost lines C and C', respectively.

Figure 8 (Ris et al., 1981) shows the effect of various price ratios, i.e. price of 1 kg nutrient (N) divided by that of 1 kg marketable product (wheat), on optimum nutrient rates. Yield increment in cash and cost of nitrogen (fertilizer) have been plotted against rates of applied nitrogen. Curves B_1, B_2 and B_3 represent average response curves for low, medium and high soil nitrogen classes, respectively. Cost lines are drawn from the origin representing price ratios of 10 and 1, respectively. Optimum nitrogen rates, producing maximum net profits, are found by constructing the points of tangency on the various yield response curves for lines parallel to the nitrogen (fertilizer) cost lines. The so defined 'economical' nutrient (fertilizer) optima decrease with an increase in soil test class, or an increase in price ratio by rising nutrient cost or declining product prices (Hauser, 1973; Ris and Van Luit, 1978; Van der Paauw, 1980; Ris et al., 1981). A relationship between price ratio and optimum nutrient rate may be established and interactions with soil test class assessed (figure 9).

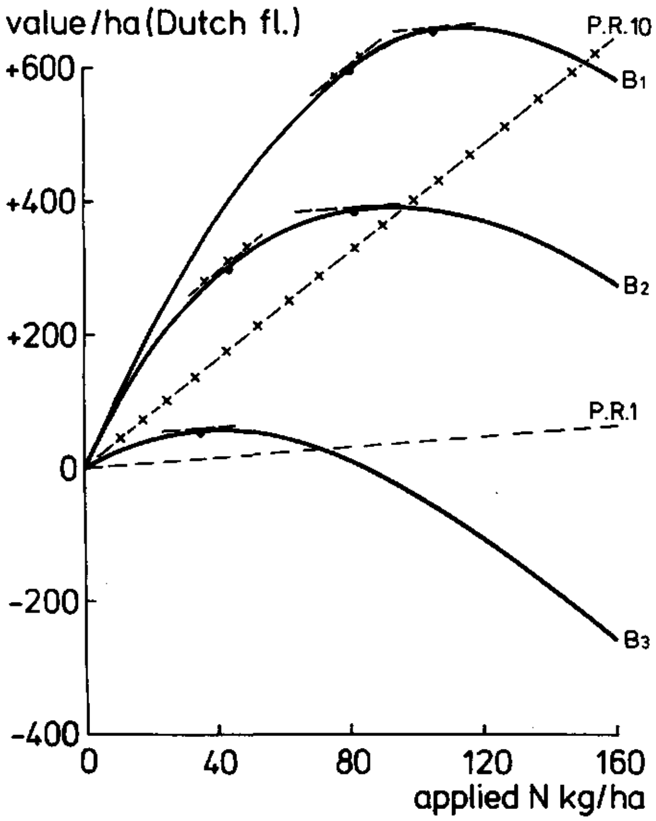

Figure 8. Economically optimum N rates (points of tangency) for various yield response curves (B_1, B_2, B_3: low, medium, high soil N) and cost lines (P.R. = price ratio 10 and 1). Experiments with winter wheat (Ris et al., 1981).

In general it is not feasible to establish nutrient (fertilizer) requirements on the basis of soil tests for more than one test crop in the region. An approximation for the requirements of other crops may be obtained by plotting relative yields of test crop and 'unknown' crop, both grown without applied nutrient in long-term field experiments, against each other. The relationship is supposed to be linear, and it is assumed that the yield ratio obtained in this way also holds for crops that receive nutrient. With calculated yields for the 'unknown' crop, graphs like those in figures 4 and 6 may be constructed and nutrient requirements assessed (Ris and Van Luit, 1978).

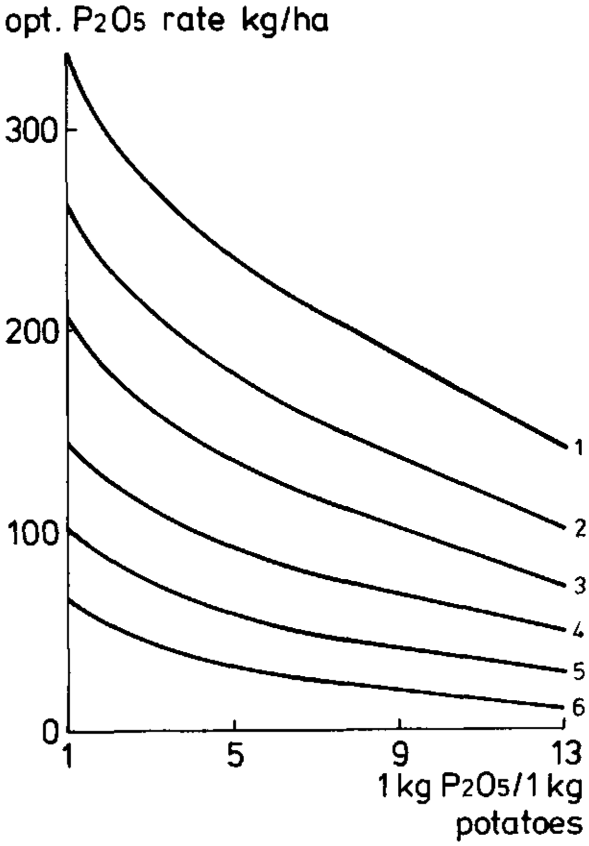

Figure 9. **Relationship between price ratio (1 kg P_2O_5/1 kg potatoes) and economically optimum P_2O_5 rates at various soil P classes (1 = low; 6 = high), after Ris and Van Luit (1978).**

With the above fertilization policy, based on 'direct' need of the crop, soil test class (e.g. P and K status) often declines, as recommended nutrient rates may not make up for losses by crop removal, erosion, leaching and fixation. In fact, responsive crops not only demand an optimum rate of added nutrient, but also ample 'soil' nutrient, i.e. soil test class 'fairly high', for maximum productivity. Such crops when grown in soil of low fertility class produce less, regardless of the amount of added nutrient (Smilde, 1972). Strictly speaking figure 4 is not correct under such conditions. When fertilizer use is not hampered by constraints in terms of cash, storage and marketing facilities, it is recommended to bring the soil up to a fairly high fertility level and to maintain this.

5. STRESS FACTORS IN SEMIARID AREAS AFFECTING NUTRIENT RESPONSE

5.1. Salinity

Salinity affects nutrient uptake and utilization by osmosis-imposed moisture stress, and nutrient imbalances induced by excess sodium and chloride. Interpretation of soil tests for plant-available nutrient may differ considerably from that under non-saline conditions (Hagin and Tucker, 1982).

Data on responses to added nutrient in saline soils are conflicting. According to Fine and Carson (1954) large amounts of phosphate fertilizer alleviated salt injury in cereals. This is in line with Ravikovitch and Porath (1967) stating that additional nitrogen and phosphate fertilizer on soils of slight to medium salinity (EC 4.3-7.0) in some instances could overcome adverse salinity effects, in crops like cow peas, maize, millet, tomatoes, clover. This evidence on a beneficial effect of high phosphate is further corroborated by Ravikovitch and Yoles (1971) for millet and clover, by Patel and Wallace (1976) for maize, tomatoes and Sudan grass, and by Malakondaiah and Rajeswararao (1979) for peanut. Khalil **et al.** (1967) suggest that high levels of phosphate fertilizer make up for the decline in phosphorus uptake by a salt-affected root system, rather than increasing salt tolerance. Also, more potassium may be needed in saline soils to counteract the competitive effects of other cations.

In their review on salinity/fertility interactions, Bernstein **et al.** (1974) state that salinity does not normally aggravate nitrogen and phosphorus deficiency in various cereal crops and vegetables. Conversely, low nitrogen and phosphorus did not consistently decrease salt tolerance of the crops studied. The authors recommend equal fertilizer applications for saline and non-saline soils, provided salinity is not so serious as to inhibit crop response to applied nutrient, by a direct limiting effect on growth or an inhibition of root growth.

When salinity is the dominant factor restricting yield, increasing fertility is rather ineffective as compared with reclamation. Conversely, when fertility is predominating yield, increasing nutrient supply has first priority.

5.2. Soil moisture

Soil water is a major factor governing nutrient uptake, whatever the transport mechanism of the nutrient ion: mass flow, diffusion or root interception.

Plant absorption of nutrients in dry soils is reduced, but more so for nutrients like phosphorus and potassium than for nitrogen. Nitrogen, as nitrate, moves readily in and with soil water and may be stored in deeper layers of the soil profile, during periods of heavy rainfall, for later use (Tisdale and Nelson, 1966). Phosphorus and potassium move by diffusion in water films between roots and soil particles. As soil moisture tension increases water films become thinner and path length to plant roots increases.

As illustated in figure 10 (Shimsi, 1969), crop response and optimum rate of applied nitrogen decrease with increasing soil moisture tension. Apparently the crop is unable to utilize high rates of applied nitrogen when soil moisture is limiting. Another example is shown in figure 11 (Stanberry **et al.**, 1955). Similar to figure 10, soil water stress is more pronounced at high than at low rates of applied nitrogen. For phosphorus no such interaction was found, water stress reducing yield to the same extent in the high and low treatments.

A more direct (negative) effect of soil moisture tension on nutrient uptake is presented in figure 12 (Watanabe **et al.**, 1960). Similar data on potassium were provided by Mederski **et al.** (1960).

As discussed above, water increases efficiency of applied nutrients. Although beyond the scope of this paper, it should be emphasized here that the reverse is also true: nutrient application increases water use efficiency, i.e. dry matter production per unit of water used (Tisdale and Nelson, 1966; Cooke, 1972; Mengel and Kirkby 1978; Hagin and Tucker, 1982).

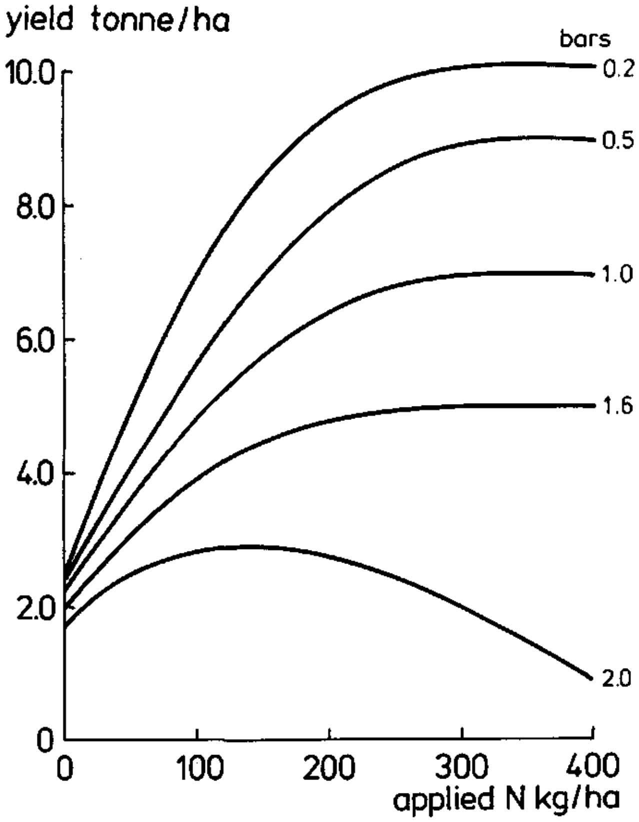

Figure 10. **Effect of N application on maize yields at various soil moisture tensions (Shimsi, 1969).**

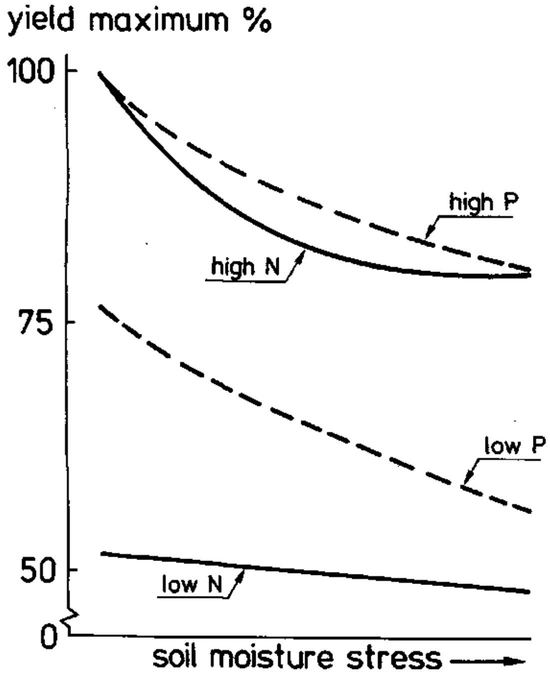

Figure 11. **Soil moisture-fertility relationship for lucerne (——) and cotton (---), after Stanberry et al. (1955).**

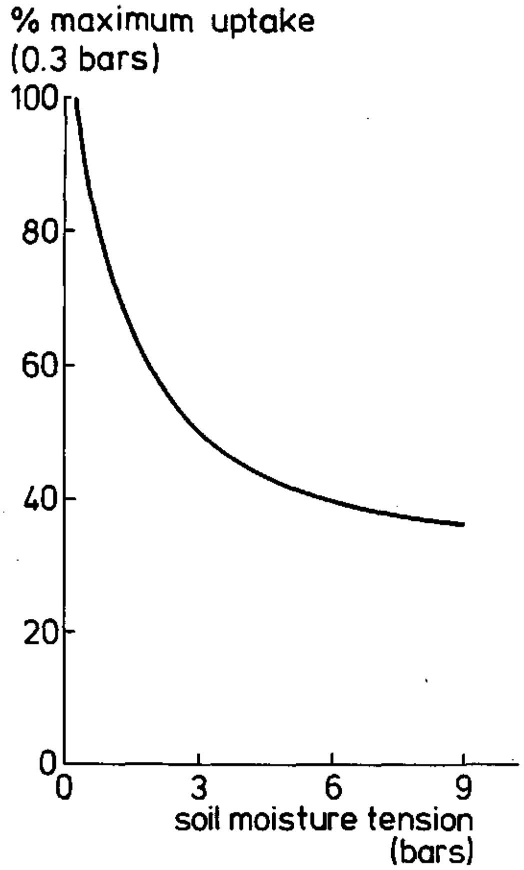

Figure 12. Relative uptake of P by maize as related to soil moisture tension (Watanabe et al., 1960).

6. PLANT ANALYSIS

Plant analysis is indispensable in calibrating soil tests, as pointed out in paragraph 2.1. Now the merits of plant analysis as the **sole** guide for defining nutrient needs will be discussed briefly. For more detail the reader is referred to the reviews by Chapman (1966) and Cottenie (1980).

Plant analysis is based on the concept that the concentration of a particular nutrient in a specific plant tissue reflects its availability in the soil. It is also assumed that growth is restricted when plant nutrient concentration drops below a certain 'critical' level. 'Critical' concentrations have been established for a number of crops, indicating the nutrient level below which a yield response to that nutrient is likely to occur (figure 13; Smith, 1962).

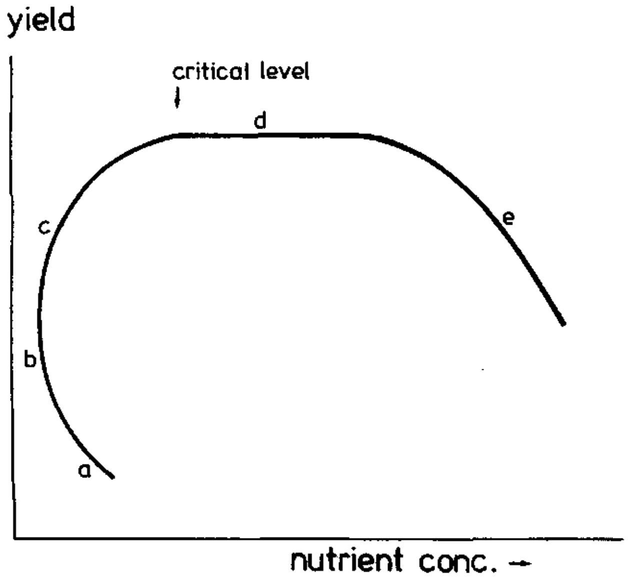

Figure 13. Relationship between yield and plant nutrient concentration (Smith, 1962). a–b = severe deficiency; b–c = medium deficiency; c–'critical' level = mild deficiency; d = luxury

For a more quantitative approach, plant nutrient concentrations have to be calibrated against crop yields and optimum rates of applied nutrient, according to the procedure developed for calibrating soil tests. This work is to be conducted in field experiments.

Nutrient concentrations in plant tissue vary with physiological age, nutrients like nitrogen, phosphorus and potassium decreasing, and calcium, magnesium, manganese and boron increasing with plant age. Therefore, a strict sampling procedure should be adhered to.

Interpretation of plant analysis is complicated, not only by physioloigcal characteristics but also by various soil and climatological factors. Generally, analysis for a single nutrient in the absence of other analyses is useless as it does not account for nutrient interactions. For these reasons the use of 'universal' critical levels, as single values, may be questioned, even for diagnostic purposes.

For annual crops, tissue (leaf) analyses may come too late to prevent yield losses. A notable exception is the estimation of tissue nitrate as a guide for topdressing nitrogen. In perennial crops (fruit crops, plantation crops), where correction of nutrient deficiencies is less time dependent, leaf analysis is widely accepted as a basis for fertilizer recommendations. In other cases plant analysis serves as a quality check, for instance in food crops and fodders.

In plant analyses, 'total' nutrient is normally determined. This is an obvious advantage over soil tests as it saves the complicated procedure of choosing an efficient extractant (paragraph 2). When soil tests fail to estimate plant-available nutrient, for instance iron or manganese, leaf analyses and/or deficiency symptoms may be used as a guide for fertilizer application, either by foliar spray or soil application.

7. A QUALITATIVE METHOD TO ASSESS SOIL NUTRIENT STATUS

Where facilities for a comprehensive soil testing programme are lacking and/or soil tests cannot be readily interpreted, a more qualitative method has to be resorted to, to assess soil nutrient status. This holds especially for micronutrients.

An elegant technique is the 'double pot' device by Bouma/Janssen (Janssen, 1974). Plants are grown in the soil under investigation, in a pot with a perforated bottom placed on top of a vessel with nutrient solution. Roots pass from the soil into the nutrient solution. If a particular nutrient, say nitrogen, is omitted from the nutrient solution, plants can absorb it only from the soil. The difference in growth between plants on the 'minus-N' and the 'complete' solution reflects the capacity of the soil to release nitrogen. It is expressed as the relative growth rate, i.e. the ratio of the increase in plant height (or dry weight) in a certain time interval on a minus-N solution to that on a complete nutrient solution. The higher the relative growth rate the more available the nutrient in the soil. At unity, the availability of the nutrient in question in the soil equals that in the nutrient solution.

Relative growth rates for various soils may be compared with soil tests for a semi-quantitative calibration. Janssen (1974) reports significant correlations between nitrate-N, and exchangeable potassium, and the respective relative growth rates (maize, wheat), for Turkish and Surinam soils. These results are confirmed by Muller **et al.** (1980) using cotton as the test plant on Nepal soils. For micronutrients results were less conclusive.

In general, the double pot technique is very useful in identifying nutrient deficiencies in various soils and as such it serves demonstration purposes. In addition it may provide a more quantitative estimation of availability of some nutrients in the soil.

8. SUMMARY

Developing a basis for fertilizer recommendations comprises choice of an effective soil extractant in pot experiments and calibration of soil tests against yield response to applied nutrient in field experiments. Soils used in pot and field experiments should have sufficient variation in concentration of the nutrient in question and in relevant factors affecting plant response among them. Optimum economical fertilizer rates for various soil test classes ranging from 'low' to 'high' are established, taking into consideration the price ratio of nutrient (fertilizer) to marketable product per unit of weight. When fertilizer is expensive and not generally used, the farmer may stop short of economically optimum rates, where benefit (economic return) to cost ratio is at least 2. When fertilizer use is common and its price moderate, a higher soil fertility status (P, K) should be aimed at, in addition to satisfying the crop's direct needs. The effects of stress factors, like salinity and soil moisture, in relation to fertilizer response are discussed. Plant analysis as a substitute for soil tests is briefly described, and the use of 'critical' tissue levels as a guideline to fertilizer application evaluated. Where facilities for soil testing are lacking or soil tests cannot be readily interpreted, the so-called 'double pot technique' may provide a useful tool in assessing soil nutrient availability, mainly on a qualitative basis however.

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