THE FERTILISER ASSOCIATION OF IRELAND

OPTIMISING THE RETURNS FROM FERTILISER IN THE PERIOD OF TIGHT MARGINS AT FARM LEVEL

Gerry Cronin

SOME CURRENT CONCEPTS UNDERLYING NUTRIENT ACQUISITION AND UTILISATION BY CROPS

W.A. Jackson and M.A. Morgan

WINTER MEETING—NOVEMBER 23rd, 1984

Publication No. 25

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G. Gronin
Greenpark, Mallow
Co Cork

INTRODUCTION

Like all businesses today farmers must attempt to optimise returns from all inputs. Because of the price-cost squeeze and higher interest rates, tighter control of farm inputs and monitoring of fixed costs, is absolutely vital. Fixed costs have risen faster than variable costs over the past number of years — for example machinery, contractor charges, oil, electricity and permanent labour have all increased faster than variable inputs such as fertiliser and meals.

I look on the return from any investment in both the long and the short terms. Fertiliser has a quick return with the rewards being available within a year, often in a few weeks in the case of nitrogen (N). Machinery, on the other hand, is a much longer term investment and therefore has much higher risks associated with it because once the investment decision has been made the output price to repay on the machinery in future years is unknown. During the development phase of my farm, I therefore concentrated on short term investment rather than putting large amounts of money into buildings and sophisticated machinery.

BACKGROUND

I began my full-time farming career at the age of 18 having spent one year in an Agricultural College following my secondary education. I am the youngest of 8 children, my father died when I was 3 years old. My older brother inherited the home farm and an 84-acre farm was purchased for me in 1966. I was a farming enthusiast from the start and was anxious to introduce new ideas and methods. The experience gained in developing the home farm and my association with Macra na Feirme and numerous Agricultural Advisers, gave me the necessary confidence to progress. I did numerous night courses in everything from Economics to Woodwork and from Law to Ecology. I mention this, not because of any academic achievements on my part, but in recognition of the value of these courses.

TABLE 1
Farm Structure

	AREA	*PURCHASED*
Division No 1	84 map acres	1966
Division No 2	110 map acres	1972
Division No 3	75 map acres	1976
Total Owned	269 map acres (240 adjusted acres)	
Rented	170 acres	
Total Farmed	439 acres	

I am at present farming 240 adjusted acres in three blocks. All of this land has been purchased by me, the last division of 75 acres in 1976. In addition, I rent 170 acres including a slatted house for cattle. The farm on which I live comprises 110 acres and is entirely devoted to dairying. This was purchased in 1972 but there were no buildings. Initially we made silage on a concrete pad. I erected a 10 unit herringbone parlour and commenced milk production.

Most of the buildings were constructed by myself and the farm workers. There is nothing elaborate about them, yet we can easy-feed the cows. The buildings are reasonably adequate to cater for 120 cows and their new-born calves.

The 84-acre farm is serviced with sheds for about 100 cattle. These were built shortly after purchase, again using farm labour. The 75-acre farm, purchased in 1977 is 3 miles away and does not have any buildings. However, it needed an expenditure of around £12,000 for drainage, fence removal and a central roadway.

TYPE OF LAND

The type of land ranges from medium to heavy loam. Most is suitable for any enterprise though there are about 50 acres which tend to be heavy and are laid down in permanent grass. In wet years poaching can be a problem on most of the grassland.

LABOUR

There are three full-time labour units on the farm including myself. Part-time labour is also employed. I am a member of the Local Farm Relief Service and I can get part-time labour at short notice and at reasonable cost. I say reasonable because there is no PAYE or PRSI on this service while permanent labour attracts high rates of PAYE and PRSI.

MACHINERY

We have a full range of machinery for all operations. There are no contractors em-employed except for sowing and harvesting beet. I consider it important to carry out the various operations at the proper time. The use of contractors does not allow for this. There are four tractors on the farm including one four-wheel-drive. The grassland and tillage mix ensures that machinery is utilised throughout the year.

RENTED LAND

At present I have 170 acres of rented land. There is a slatted house for 100 cattle on one 60-acre lot. This made it possible to finish all the cattle reared on the farm. The target weight for the half-bred Simmenthals is 600kg and for Friesians 560kg. The Hereford heifer crosses are finished at about 14 months. These weigh around 325kg and are in demand from butchers in April. The remainder of the rented land is devoted to tillage.

REASON FOR RENTING

This has been a natural progression in my system. It reduces the unit fixed costs by spreading them over more acres. Labour and machinery are used more efficiently. Each enterprise is big enough to justify a fair degree of mechanisation. The by-products of the tillage e.g. straw, beet, pulp, etc, are utilised by the livestock.

The concentrates for the livestock can be purchased cheaper than in an all-livestock system. Catch crops can sometimes be of great benefit. At present we are feeding Typhon which was sown after peas. This land will be free in time for winter wheat, a crop with a high gross margin.

TABLE 2
Stock Numbers 1984

Cows	–	125
Simmenthal Bull	–	1
Hereford Bull	–	1
Calves	–	98
Cattle 1-2 years	–	110
Replacement Heifers	–	20
Total livestock units	=	258

These are carried on 228 acres giving a stocking rate of 1 livestock unit/0.88 ac.

TABLE 3
Crops 1984

Crop		*Acres*
Winter Wheat	–	82
Spring Barley	–	23
Oats	–	17
Sugar Beet	–	22
Peas	–	13 – Typhon
Oilseed Rape	–	25
Total Crops	–	182 acres

REASON FOR MIX

There are certain rotational restrictions in any cropping programme so within those restrictions one opts for the best financial returns. It is difficult to predict with accuracy the returns from any crop but winter wheat is one of my favourites. It gives a consistently high return on labour and capital. Spring barley is losing favour and is only grown because of its usefulness in making rations for the livestock on the farm. Oats acts as a break crop and can be followed with winter wheat. Sugar beet gives a high gross margin but is now subject to quota. Winter wheat follows beet but it must be taken out early and the tops ploughed in. Some years we feed the tops and follow with a spring crop.

Peas provide an excellent break, the returns are unpredictable but can be very good. They can only be grown every seven years on the same ground and can be followed with Typhon. This gets 100 units N plus a small amount of P and K. It matures in about 10 weeks providing about 10-12t of fresh green material/ac. The land is released in time for winter wheat.

I have had two years' experience with oilseed rape and am pleased with the returns.

The predominant crop in the 1970's was spring barley. Despite the fact that winter wheat and oilseed rape take twice the amount of fertiliser, the returns are far superior. From a labour point of view there are obvious advantages in getting some crops sown in autumn. The prudent use of the optimum amount of N has been a key feature in this development.

GRASSLAND MANAGEMENT

In order to optimise returns from fertiliser, grassland management must be good. There are 228 acres of grassland. This includes 30 acres of Lemtal. The remainder of the grassland is laid down to permanent mixtures, mostly medium late and late varieties.

TWO SWARD SYSTEM

The Two Sward System is practised on the dairy farm. There are 24 x 3ac paddocks. The reason for the 24 paddocks is to allow the calves to graze the paddocks ahead of the cows up to June when they are transferred to aftergrass. I find in practice that more grazing area is needed in April than in May. If growing conditions are good, we can close extra paddocks in late April, apply more fertiliser to the grazed paddocks and benefit from the extra silage produced in this period.

If the cutting date of this silage does not coincide with some other cut, then we allow it go to hay. This has the disadvantage of tying up the paddock for a longer period as well as the delay in saving the hay before fertiliser can be applied. The Two Sward System gives firm control and enables decisions taken as a result of the varying climatic conditions to be implemented. Each paddock is serviced with water and a roadway.

The remainder of the grassland is laid out in larger blocks of 6 to 10ac to facilitate silage cutting.

FERTILISER PROGRAMME

Each field is tested for soil nutrients every four years and any deficiency rectified. Lime is applied to the grassland mostly in late autumn or early winter and on silage ground after the last cut. Liming for tillage crops is done in spring. The latest soil test results for 1984 are given in Table 4.

TABLE 4
1984 Soil Test Results

	LIME REQUIREMENT	*P*	*K*
FIELD NAME	*T/AC*	*PPM*	*PPM*
Pond	2.5	4.0	150+
20 Acre	3.0	5.5	135
Old Pea	3.5	6.0	137
New Pea	2.5	4.0	96
Dry	3.5	3.5	150+
RvP	2.5	3.5	145
Railway	2.5	2.0	150+
Flat Railway	2.0	6.0	105
By Yard	3.0	4.0	150+
Bungalow	0	11.0	150+
Opposite Entrance	2.5	4.5	150+
Jeans Paddock	3.0	6.5	150+
Hill	0	8.0	137
Kiln	2.0	9.0	141
3 Corner	2.5	7.0	149
Front of Foleys	0	19.0	150+
Heifers	1.5	4.0	150+

Lime deficiency was corrected in Autumn 1984. The previous test in 1981 showed no need for lime.

The P status is low relative to K status, this is due to soil type. On the Railway Field, for example, 3cwt of 14.7.14 were applied plus 27.2½.5 as N source and grazed by dry stock, yet P level as per soil test is low.

GRASSLAND FERTILISER

We use a high N compound 'Pasture Sward' 27.2½.5. Before purchasing, the unit price is established. In the past I have found it comparable to other types of fertilisers available. The convenience of using one compound rather than involving two or more operations is important.

APPLICATION RATES

In early February we apply 2 bags/ac. We hope to have the whole area covered by mid-February. The next application of 1½ bags/ac is put on after the first grazing, i.e. beginning about 25th March. Over the years we have delayed cow turnout from about 15th March to 25th and have concentrated instead on making more and better silage. 1½ bags/ac is applied after every grazing cycle. Thereafter 1 bag is applied finishing about 10th September. Total for the year is about 12-14 bags/ac.

Moorepark figures show response to N as in Table 5.

TABLE 5

	Lb DM/Lb N	*COST PER Lb DM (P)*
Early March	5.3	4.3
Late March	4.0	5.7
Mid April	14.8	1.6
Early May	12.5	1.8
Mid June	14.1	1.6

We note that the best response is in mid-April to mid-June.

TABLE 6
Relative cost of feed

	GRASS	*SILAGE*	*MEALS*
Cost/tonne DM	£22	£70	£200
% of total cows diet	55%	29%	16%
Annual cost/cow	£75	£112	£140

Grass and silage provide over 80% of the cow's energy requirements yet meals are almost as expensive as their combined cost.

SILAGE PROGRAMME

30ac of Lemtal were cut four times — the first cut was taken at the end of April with subsequent cuts at five week intervals. The first cut was wilted as the weather was favourable, increasing the dry matter to about 22%.

FERTILISER/AC LEMTAL

First cut : 2½ bags urea split 40:60 plus 3 bags 0.7.30.
Second cut : 4 bags 'Cut Sward' 24.2½.10.
Subsequent cuts : 3 bags 'Cut Sward'.
Most slurry was applied before the first cut with some before the second cut and some after the last cut.

It is important to apply the fertiliser as soon as possible after cutting to take advantage of the full growing season.

MAIN CROP SILAGE

I aim for early cutting. The cutting date for the first cut is determined by growth stage and variety as well as calendar date. This year we started cutting the main crop on 21st May. We are conscious of the vital need to have good silage for the spring-calving herd especially. Of course there are also compelling reasons for having good silage to get good weight gains on cattle. The aim is to harvest the grass in dry conditions if possible.

The second cut is taken six weeks later and coincides with the third cut of Lemtal while the third cut is taken in early August from ground that has been cut early and grazed. I get better overall production by grazing some aftergrass and cutting ground that had been grazed rather than taking three cuts from the same area. This practice is of benefit where one is rearing calves and it provides fresh grass free of parasites.

The silage programme is geared for a 5½ month winter. We produce 8 tonnes per livestock unit. Molasses is used as an additive at the rate of 2—3 gal/t. This year we are doing an experiment by adding layers of dried beet pulp to our first cut silage. By doing this I hope to achieve a higher intake by improving the palatability of the silage. There was less effluent because the pulp absorbed the juices of the grass.

SILAGE FERTILISER

Cost is a factor in making out a fertiliser programme. I have tried various options. This year I opted for urea for early main crop silage. 120 units N/ac were applied in two splits — 1st March and 1st April.

3—4 bags 0.7.30 were applied/ac in late summer of the previous year plus slurry in Autumn or Spring to provide adequate P and K.

Second cut and third cut each received 3½ bags of 'Cut Sward'/ac.

HERD MANAGEMENT

The super levy restrictions do not adversely affect us. In 1983 I took a conscious decision to establish a good quota by artifically boosting cow numbers to 132. This was achieved by retaining cows due for culling and putting in a few extra heifers. This resulted in a milk output 13.5% higher than the previous year. With the announcement of the quotas these extra animals were sold off after calving this year.

RECORDING

The herd is recorded monthly and the data processed by computer at Ballyclough Co-op. Butterfat and protein tests are carried out during the three summer months. Individual yields are used for the purpose of selecting animals with the best genetic merit for breeding. The poor performers are culled from the herd.

BREEDING

The best 50 cows are bred to proven A1 sires. There is no Holstein breeding in the herd as I consider the advantage of their higher milk yields is outweighed by the poorer performance of their beef offspring. The remainder of the herd is bred to Simmenthal and Hereford bulls. The replacement heifers are heat synchronised. They are all inseminated on two consecutive days with AI sires of an easy calving strain. The conception rate is around 65%. A Hereford bull is then run with the heifers for six weeks. The mean calving date is February 14th. Meals are not fed before calving except to second calvers with a low body fat score.

After calving 16lb of a 16% protein ration is fed. This is home produced using barley, beet pulp, soya bean meal or ground nut plus minerals. The best silage is fed on an easy-feed system. Turnout date is about 25th March. At this stage there is adequate grass.

When cows go to grass meal levels are reduced to 8lb and gradually reduced to 2lb. They are phased out altogether shortly after cows reach peak yield. This year (1984) meals were introduced in July because of the drought. Milk yield is projected for each month in order to meet target yield. If the monthly target is not being reached action can be taken by supplementing feed. Cows are housed in early November. Prior to this supplementary feed is introduced.

YIELD

This year's yield will work out at about 1,050 gal/cow using 13.75 cwt. of meal and 340 units N.

CEREAL ENTERPRISE

To illustrate the role of fertilisers in the tillage system I will now select winter wheat and detail some of the main points.

Winter Wheat: This year we grew 82 acres of winter wheat; we have 100 acres sown for the coming year.

Varieties: Last year we sowed three varieties — Norma, Guardian, Armada. The yield from Norman and Guardian was 4t/ac and Armada was 3.5t/ac. This year Norman and Mission were sown.

Sowing time: We plough about 75% of the area in September and commence sowing the first week of October or as soon afterwards as weather permits. Headlands are sown last. The remaining 25% is ploughed and sown on the same day at the rate of 10ac/day.

Seeding rate: We commence sowing at 13 st/ac and increase to 14 st/ac as the season progresses.

Fertiliser: 3½ bags of 0.10.20/ac are drilled with the seed. This is followed in Spring with 130 to 150 units N which is applied as split dressings of CAN. The first 50—60 units were applied in late February at growth stage 3. The second application is made at growth stage 5.

Spraying programme: Roundup or Gramoxone is used before ploughing if there is grass in the field. Weed control is carried out by using 2 pts CMPP/ac about mid-March. An MBC fungicide is used for Eyespot control at growth stage 4. Growth regulators are applied when the first node is visible i.e. growth stage 6.

Mildew and Septoria are controlled by spraying Tilt, Radar or Sportak at growth stage 9—10, this is before ear emergence. The final spraying is done after ear emergence and when the flowers are falling. We include Metasystox with the fungicide to control aphids, the fungicide in this case is Bayleton CF. Diseases and pests are monitored throughout the growing season and corrective action is taken immediately.

SUMMARY

I have been fortunate that my development took place during a period of rapidly rising farm output prices.

In future I will aim to ensure that the major inputs are used so as to yield the optimum return.

I believe that P and K levels should be maintained as an investment in the future. Each field is tested every 4 years and any deficiency rectified.

The use of 340 units N/ac of grass will help ensure that forage contributes its true value in terms of feed for my cows.

The amount of fertiliser used in other enterprises will be directly related to the value of the produce of these enterprises.

The timeliness of all operations on the farm is very important in order to optimise the return from all inputs including fertiliser.

SOME CURRENT CONCEPTS UNDERLYING NUTRIENT ACQUISITION AND UTILISATION BY CROPS

W.A. Jackson
and
M.A. Morgan
Soil Science Department, North Carolina State University
Raleigh, North Carolina, U.S.A.
and
Department of Agriculture, Chemistry and Soil Science
University College, Dublin

INTRODUCTION

Plants absorb essential nutrients from the solution phase of the soil. The concentration of each nutrient in the soil solution is determined by various exchange and precipitation reactions, as well as by various biological transformations. The result of all these reactions, however, must be the maintenance in the soil solution of a concentration from which the roots can absorb the nutrient rapidly enough to meet the demands of the plant for optimal growth. Soil scientists have examined intensively the chemical, physical and biological properties of soils which influence soil solution concentrations. By relating these properties to nutrient acquisition and crop growth rates on various soils, they can reasonably well predict the soil conditions under which specific nutrients in the soil solution will be sustained at the necessary concentrations. Appropriate soil amendments and fertiliser treatments thus are based on reasonably well established soil characteristics.

But plants themselves play a role in the acquisition and efficient utilisation of nutrients. One way they do so is by altering the chemical, physical and biological attributes of the thin layer of soil immediately surrounding their root tissue (the rhizosphere), thereby altering the concentration of nutrients in the soil solution to which they are exposed. Plants also are able to adjust their capacity to absorb nutrients from a given soil solution concentration. Both alterations in root morphology and capacity for absorption by a given root mass can be brought about as the plants undergo nutrient stresses. Finally, plants differ substantially in the amount of a given nutrient which needs to be absorbed to produce optimal growth rates of specific plant parts such as forage, grain, tubers or roots. These plant attributes have not yet been characterised in the detail necessary to incorporate them into precise recommendations for specific soil conditions. But the magnitude of the effects are so substantial that it can be anticipated that they may be able to be utilised in future in ensuring maximal nutrient use efficiency. The hope is that ultimately they may be defined and manipulated precisely enough to be used for soil and fertiliser practices. It is the purpose of this paper to describe briefly some of these plant-related attributes which are involved in the efficient acquisition and utilisation of nutrients.

RHIZOSPHERE ACIDITY CHANGES

The hydrogen ion concentration in the soil (as measured by the soil pH) has a pronounced effect on the precipitation and exchange reactions which control the concentrations of various nutrients in the soil solution. As the soil acidity becomes greater (the pH decreases), the solubility of some trace elements tends to increase as does that of the toxic element aluminium. Within a certain range, the solubility of phosphorus (P) also tends to increase. Soil acidity also influences the microbial populations and the biological transformation which takes place and thereby greatly influences the amounts of nitrogen (N) and sulphur (S) available for absorption. Hence, a knowledge of the soil pH is fundamental in assessing the fertility and productivity of a given soil. However, it has been known for a long time that plants have the capacity to alter the acidity of their rhizosphere and that whether this was increased or decreased depended upon the source of N to which the plants were exposed (Jackson, 1967; Nye, 1981). The magnitude of these pH changes in the vicinity of roots and the marked diversity among plant species in response have only recently been demonstrated in soil systems. Likewise, concepts of how such changes in the hydrogen (H) ion concentration at root surfaces are brought about are only now commencing to emerge.

Rhizosphere pH changes have been clearly illustrated by Marschner and Romheld (1983) using a technique of embedding a dye onto the surface of a soil in which roots of plants were growing. The colour of the dye depended upon the acidity of the soil with which it came in contact. The effects were dramatic; when maize was grown in a soil at pH 6 with N supplied as ammonium (NH_4) a pronounced acidification (to pH 4.5 or below) was evident in the soil within a few mm of the root surface. When the soil was dressed with nitrate, (NO_3) precisely the opposite occurred, the thin soil zone near the roots became more alkaline than the bulk soil, increasing to greater than pH 7.0. Because the soil pH affects the solubility and mobility of many essential nutrients, such dramatic pH changes must have influenced greatly the concentration of these nutrients in soil solution of the narrow zone of soil surrounding the roots and at the absorbing surfaces of the root cells.

These experiments (Marschner and Romheld, 1983) and other studies indicate that the acidifying effect in the rhizosphere accompanying the supply of NH_4 occurs with all species so far examined. Moreover, leguminous plants relying on N fixation also tend to acidify their rhizosphere, although to a lesser extent than occurs with NH_4. When NO_3 is the N source, however, the rhizosphere pH change is highly dependent upon the plant species. So far as is known now, all cereals and grasses when exposed to high NO_3 supplies tend to cause the rhizosphere pH to increase. When the NO_3 supply is low the tendency is less marked and some decreases in rhizosphere pH can occur in certain parts of the root system. Many broad-leaved species tend to exhibit relatively little pH change with NO_3. But, even at high NO_3 supplies, one species (chickpea) has a markedly acidic rhizosphere whereas the rhizosphere of maize growing in the same container becomes alkaline relative to the bulk soil. Thus, it is clearly evident that plants, within limits, can modify the soil environment to which their root systems are exposed. The effect is highly dependent upon the N source and is, at least in the case of NO_3, also highly species dependent.

A few examples suffice to illustrate the importance of these rhizosphere changes in acquisition of nutrients. Increases in P uptake in the presence of NH_4 as compared to NO_3 have been associated with the differences in rhizosphere acidity developing from the two N sources (Riley and Barber, 1971) although other effects involving root development and capacity to absorb P may contribute to such observations (Soon and Miller, 1977). On sandy, low exchange-capacity soils of Western Australia, marked alterations in soluble manganese (Mn) and aluminium (Al) were shown to result from the differential N sources supplied to subterranean clover (Jarvis and Robson, 1983a; 1983b). The acidifying tendency in legumes dependent upon N fixation has been shown to enhance the solubility of rock phosphate (Aguilar and van Diest, 1981) and may contribute significantly to soil acidification under long-term leguminous pastures (Jarvis and Robson, 1983a; 1983b). The consequence of altered rhizosphere acidity on plants in monoculture compared to those in mixed culture where the rhizospheres of each species intermingle has not, to our knowledge, been examined as yet although the influence potentially can be profound. Differences among cultivars may be substantial (Olsen ***et al.,*** 1981), and the possibility of utilising this genetic diversity for developing cultivars for specific adverse soil conditions, such as in highly acid soils, is at present receiving considerable attention.

It is not yet known with certainty how metabolic events in plant root tissue are altered such that the marked rhizosphere pH changes occur. Nevertheless, physiological and biochemical evidence supports a model which can accommodate most of the observed responses (Israel and Jackson, 1982). This model (Fig 1) envisages a series of proteins embedded in the root cell membranes which facilitates transfer of the essential elements from the soil solution into the root cells. Another protein has the capacity to utilise energy to secrete H ions into the ambient solution, thus resulting in a pH gradient across the membrane, with the cell interior becoming alkaline relative to the surrounding soil solution. The action of this H ion secreting protein also results in an electrical gradient across the membrane, with the cell interior being negatively charged relative to the exterior solution. The electrical gradient serves as an attractive force for entry of positively-charged nutrients such as potassium (K), calcium (Ca), magnesium (Mg) and NH_4 across their specific protein carriers. Entry of negatively charged nutrients such as phosphate (PO_4), sulphate (SO_4) and NO_3 is viewed as occurring across their specific carriers in exchange for the hydroxyl (OH) ions generated in the root cells by the original outward secretion of H ions. Thus, for each H ion excreted, a positively charged nutrient can enter the tissue and a negatively charged nutrient can also enter as it exchanges with the internal OH ion. If this equivalent transfer occurs, there will be no change in pH of the rhizosphere because the outwardly-secreted H and the OH ions undergoing exchange for the anions neutralize each other. If, however, there are few negatively charged nutrients present in the soil solution, such as may occur when NH_4 and a nitrification inhibitor is added to the soil, or when the uptake systems for these particular nutrients are not fully active, then less OH ions leave the tissue, the secreted H ions are not fully neutralized, and the rhizosphere becomes acid. Under these conditions the internal OH ions are consumed in the synthesis of organic acid anions which serve to balance the entering positively charged nutrient. Because the carrier systems for PO_4 and SO_4 do not operate nearly as rapidly as those for NO_3, it is the inward movement of NO_3 which largely determines how much OH ion secretion takes place. Carrier systems for NH_4 also operate quickly so that when this positively charged nutrient is present it is absorbed rapidly and contributes to the large net H ion secretion.

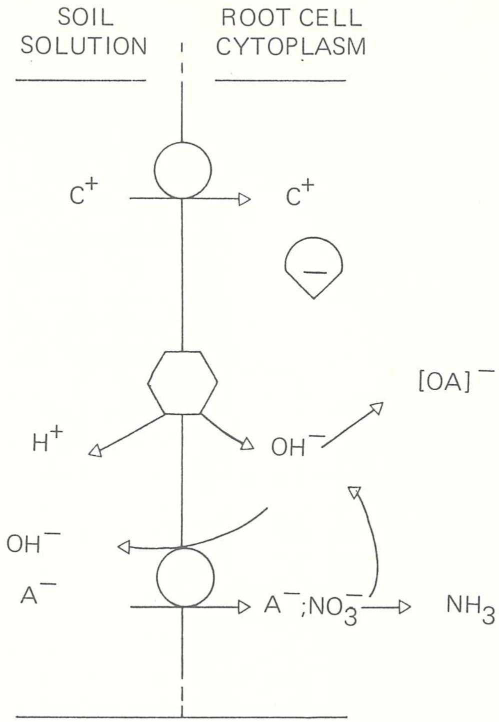
In order for the net inward movement of negatively charged nutrients to exceed that of positively charged nutrients, an additional way of generating OH ions in the root tissue has to occur. This is visualized to take place as a result of the reduction of NO_3, the OH ions so generated being used to supplement those generated by the H ion secreting mechanism. Under conditions where the soil mineral N supply is low and nodulate plants are relying largely on N fixation, the activity of the carrier systems for uptake of the positively charged nutrients exceeds that of the systems for uptake of negatively charged nutrients such that rhizosphere acidification takes place. Differences among plant species in their tendency for rhizosphere acidity-changes where NO_3 is present may be viewed as resulting from differences in the efficiency with which their uptake systems for NO_3 operate relative to those responsible for uptake of the positively charged nutrients. The evidence for this model will not be described here, but a number of the predictions to be made from it have been verified (e.g. Israel and Jackson, 1982), and it serves as a useful way to visualise the dramatic changes that plant roots can make in modifying the acidity to which they are exposed.

ADJUSTMENTS IN NUTRIENT TRANSPORT

Plants undergo a number of adaptive responses when the soil nutrient supply is too low to sustain good growth (Chapin, 1980; Clarkson and Hanson, 1980). The nature of these responses differs to some extent for the various nutrients but the general tendency is to increase both the surface area of the roots for absorption and the capacity of the tissue to absorb nutrients. With N and P deficiencies, for example, there is a marked increase in the growth of the roots relative to the growth of the shoots. With cereals, shortly after a N deficient condition is imposed, there may be an actual temporary increase in the root growth rate as that of the shoot slows down (Morgan and Jackson, 1984). As the deficiency becomes more severe, root growth declines but the roots still continue to grow relatively faster than the shoots. Similar observations have been made with plants undergoing P deficiency, and in both instances there can be significant changes in the morphology of the root system. The consequence of these changes is an increase in the root surface area relative to the mass of the shoot tissue i.e. relatively more soil mass per total plant mass is permeated by the root system. An additional increase in volume of soil exploited in the case of P deficiency is brought about by the development of mycorrhizal associations where the fungal hyphae permeate the soil and increase the surface area of absorption.

In addition to these growth and morphological adjustments, there is a marked change in the capacity of root tissue to absorb the nutrient. As noted in Figure 1, each nutrient is viewed as having a specific transport system or carrier which facilitates its movement into the root tissue from the soil solution. When a plant becomes P deficient, for example, the capability of the plant to absorb PO_4, if it becomes available, increases appreciably (Clarkson and Scattergood, 1982). This alteration in capability for absorption has been demonstrated with a number of plant species by growing them in nutrient solutions at PO_4 concentrations ranging from an inadequate to an excessive supply. The plants are then transferred to a standard concentration which is labelled with the radioisotope P-32, and the entry of the labelled PO_4 measured over a short time period. Such experiments consistently have shown that plants which are deficient in P have a much greater capacity to absorb P than plants which have been adequately nourished with P. This means that plants have a negative feedback control over the absorption mechanism for PO_4. A specific internal P compound, or a metabolic consequence of P nutrition, apparently exerts an influence over the PO_4 absorption mechanism.

It is not yet clear whether the differences in absorption rates are brought about by changes in the activity of the carrier systems or whether the control is exerted by altering the rate at which carrier systems are synthesised and degraded. Nevertheless, there is a significant, finely-tuned, internal control exerted over the absorption of a number of the essential nutrients. The pattern has been demonstrated with K, SO_4 and NO_3 as well as more recently with NH_4. In these instances the absorption systems for a given nutrient have the capacity to operate at a rapid rate when the root system of a plant deficient in that nutrient is exposed to an adequate soil solution concentration, or when a portion of the root system of a deficient plant strikes a



$C^+ = NH_4^+, K^+, Ca^{++}, Mg^{++}$

$A^- = NO_3^-, H_2PO_4^-, SO_4^=, C1^-$

Fig 1: Schematic of metabolic processes which result in differential acidification of the rhizosphere of plant roots. C^+ represents positively charged nutrients such as ammonium, potassium, calcium and magnesium. A^- represents negatively charged nutrients such as nitrate, phosphate, sulphate and chloride. Separate and specific transport systems are envisaged for each nutrient.

zone of soil enriched in that nutrient (Drew **et al.**, 1984). Precisely how this adaptation response to nutrient stresses can be used in fertilisation and management practices has not yet been worked out. It seems reasonable to expect, however, that appropriate genetic manipulations could result in plants that are highly efficient in absorbing nutrients from very low soil solution concentrations.

NUTRIENT USE EFFICIENCY

Plants differ in the amount of growth produced per unit of absorbed nutrient (Chapin, 1980; Clarkson and Hanson, 1980). This may result from differences in the concentration of the nutrient at functional sites required for optimal metabolic rates, or from differences in the effectiveness of redistribution within the plant for storage locations to regions where the nutrient participates in essential processes. Hence, overall efficiency in the use of a given nutrient involves considerations of both efficiency in acquisition (uptake from the soil) and efficiency in its utilisation for the production of dry matter or specific plant parts after it has been absorbed.

For a given genotype, the relative contributions of uptake efficiency and utilisation efficiency for a given nutrient can vary between soils or nutritional conditions. Relative contribution of each attribute to overall nutrient use efficiency can also differ among cultivars of a single species growing in the same soil. This concept has been illustrated by Moll **et al.** (1982) with eight experimental maize hybrids growing on a sandy loam soil at either low or high N supplies. Because grain was the plant part of interest, N use efficiency was defined as grain weight produced/unit N supplied (Nt/Ns), and N utilisation efficiency was defined as the amount of grain produced/unit N absorbed (Gw/Nt). Nitrogen use efficiency is thus the product of uptake and utilisation efficiency (Gw/Ns = Nt/Ns x Gw/Nt). Hence, by simple measurements of grain weight and total plant N, the two components of N use efficiency can be delineated.

A comparison of these two traits and their relative contribution to N use efficiency indicates the advantages of the approach. Data for four hybrids at two levels of fertiliser application are shown in Table 1. At the low N level, a significant range (from 120.2 to 72.8g grain/g N supplied) in N use efficiency occurred among the hybrids. The difference between the highest (No 7) and lowest (No 5) was totally a result of ineffective grain production/unit N absorbed (utilisation efficiency) by No 5; they did not differ significantly in their capacity to absorb N. On the other hand, hybrid No 8 was relatively ineffective in absorbing N although its utilisation efficiency was equal to that of hybrid No 7. Differences among the genotypes in N use efficiency were also evident at the high N supply, but the genotypic rankings were not the same as at the low N supply. Thus, at the high N supply, hybrid No 2 compensated for a low utilisation efficiency with a high uptake efficiency. Hybrid No 5 had a low N use efficiency at both levels of N but for different reasons. At low N supply it was ineffective in N utilisation whereas at high N supply it was ineffective in N uptake.

Both uptake efficiency and utilisation efficiency can be sub-divided into further components which tend to reflect specific plant processes. Uptake efficiency (Nt/Ns), for example, can be described as the product of total root mass/unit N supplied (Rm/Ns) and the amount of N absorbed/unit root mass (Nt/Rm). Thus, Nt/Ns = Rm/Ns x Nt/Rm. As noted in the previous section, both components of uptake efficiency may be altered as plants undergo nutrient stresses, and significant differences in each may occur among various genotypes. However, evaluating the relative contribution of each component to uptake efficiency under field conditions is very difficult. There is less difficulty in ascertaining experimentally the component traits of N utilisation efficiency (Gw/Nt) because measurements can be made on the above-ground part of the standing crop. Nitrogen utilisation efficiency can be described as the product of grain weight produced/unit N in the grain (Gw/Ng) and the fraction of the total plant N that is translocated to the grain (Ng/Nt). Thus, Gw/Ng x Ng/Nt. The first component is the inverse of the N concentration in the grain and the second reflects the ability of the plant to redistribute absorbed N from vegetative to reproductive growth. In the eight experimental hybrids examined by Moll **et al.**, 1982), significant independent variation in each component of N utilisation efficiency was observed, and the hybrids ranked differently at the different levels of N supply.

Overall, the data illustrates appreciable genetic variation in N use efficiency, in the two main traits whose produce results in N use efficiency (i.e. uptake and utilisation efficiency) and in the individual components which contribute to N utilisation efficiency. It is important that these various attributes tended to vary among the hybrids independently of one another. This implies that genotypes with specific desirable traits can be selected, or combined with material having other desirable traits, for significant improvement in N use efficiency in their progeny. It is equally important that there were distinct differential responses in each of the attributes to variations in N supply. Some hybrids, for example, were able to absorb N efficiently at a low supply but were not especially efficient at a high supply (Table 1). Moreover, one hybrid (No 5) actually had a higher utilisation efficiency at high N supply whereas the others all tended to be lower.

TABLE 1

Nitrogen use, uptake and utilisation efficiencies in four experimental maize hybrids at two fertilizer nitrogen applications (Moll et al., 1982)

	NITROGEN EFFICIENCY		
HYBRID	*USE (Gw/Ns)*	*UPTAKE (Nt/Ns)*	*UTILISATION (Gw/Nt)*
Ns = 2.47 g/plant			
7	120.2	2.04	58.9
8	103.0	1.75	58.7
2	88.4	2.12	41.6
5	72.8	2.08	35.0
Ns = 9.88 g/plant			
7	27.9	0.58	48.0
8	26.0	0.57	45.2
2	27.8	0.77	36.0
5	19.7	0.43	46.0

The differential responses in the component traits to variations in N supply implies that superior genotypes can be developed to meet specific soil and management practices. This possibility is further emphasised by recent information indicating a distinct difference among maize hybrids in their capacity to absorb N as NH_4 or as NO_3^- during the grain-filling period (Pan et al, 1985). Finally, it would seem possible to evaluate use efficiencies of other nutrients and with other crops using the concepts of Moll et al, (1982). The approach is relatively straight-forward and provides information which has a bearing on performance under varying soil conditions as well as the development of genetic materials specifically adapted to them.

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