FERTILIZERS AND THE DRY MATTER, PROTEIN AND MINERAL REQUIREMENTS OF FARM ANIMALS

(Met opsomming in Afrikaans)

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Abstract

The primary function of fertilizers in agriculture is to increase the total amount of food production. The effects of fertilizer applications on the chemical composition of plants is usually small, and it is often difficult to detect differences in animal performance that are ascribable to crop fertilization practices. Problems which might arise can be expected to require the combined efforts of soil, plant and animal scientists for their solution.

Introduction

During the last thirty years or so there has been a large increase in the use of fertilizers, not only in South Africa, but also in the world. Previously, man concentrated his cropping practices on the most fertile soils available, moving on to new lands as the fertility of old lands declined. This is no longer possible, and man has had to learn the proper use of fertilizer for producing crops from areas of relatively depleted fertility. Modern information on the rational use of fertilizers has made it possible for man to select and cultivate crops best suited to his needs, virtually independently of soil considerations, and has contributed a major share to the success achieved in meeting the nutritional needs of the world for both animals and humans.

The main function of fertilizers, then, is to promote food production. Animal production has the same objective and it is not difficult to visualise the connection between animals and fertilizers, a connection existing by virtue of the intermediate link, the plant. Ultimately, both animals and man satisfy their nutrient requirements by consuming foods derived from plants.

The question of the relationship between fertilizers and animals involves two main aspects. Firstly, we need to consider the link between fertilizers and the plant, and secondly the connection between the plant and the animal. The literature on the subject is widely scattered and it is my intention to present a short selection from this field, setting out thoughts and ideas which have been voiced. Time does not permit of an exhaustive treatment and this is not intended to be a comprehensive review. Most of what I shall say will refer particularly to the ruminant, and only passing reference will be made to other farm animals and feeds other than roughages.

Fertilizers and the plant

Although the response of plants to fertilizers has been widely studied, the effects of fertilizer application on the chemical composition of the plant are not well understood. The literature abounds with contradictions, making it difficult to reach acceptable conclusions. It appears that environmental factors, including those of soil moisture, light intensity and duration, temperature and soil type, play a major role in determining the composition of the plant. An example of this is the report that subterranean clover does not take up molybdenum when grown under warm conditions (Dick, 1969). Environmental factors serve to obscure the effect of a fertilizer application and can serve to explain many of the contradictory findings which have been reported.

The view has been expressed that poor soils produce plants of poor nutritive value, and that the remedy for this is to raise soil fertility by the application of fertilizers. The chemical composition of plants is however not readily changed. With only few exceptions, reported changes in plant composition due to fertilizers have been small. In their experiments, Widdowson, Penny & Williams (1966) found that nitrogenous fertilizer increased the percentage of nitrogen in grass by only 0,3 to 0,4 per cent, but potash increased the potassium content of grass quite considerably, both in the absence and presence of nitrogenous fertilizer. Malherbe (1969) achieved changes of some magnitude from fertilized *Setaria*, including a doubling of the crude protein content. The amount of any soluble or available element present in the soil is not necessarily directly related to the amount which the plant will absorb. It is difficult, for example, to define the amount of phosphorus in the soil which is available to the plant (Bache & Rogers, 1970).

The plant response is much more a matter of increased yield than of altered chemical composition. This seems to hold particularly for the seeds of plants. The primary function of plant seeds is concerned with the propagation of the species and not with the feeding of animals. As such, the composition is probably determined more by genetic constitution than by environment. The successes of plant breeders can be viewed in this light.

Even though fertilizers may not change plant composition to any significant degree, small increments in certain elements can be of importance in practice. Thus, the application of cobalt to pasture can combat a cobalt deficiency in stock.

Excessive nutrient accumulation in plants, on the other hand, is also not desirable. This can occur from overenthusiastic application of fertilizer, resulting in plant toxicity, such that the plant fails to thrive. Or the plant may accumulate elements which occur abundantly in the soil. Under these circumstances, the plant itself may still thrive, but it becomes toxic to the animal. Plants may accumulate copper (Todd, 1969) to levels which are toxic to animals. The same is known to occur for selenium. In practice, arsenic finds some use in protecting animals from selenium poisoning and it is interesting to speculate about the possibility of finding an antagonist to selenium which, applied to the soil, would prevent excessive selenium uptake by the plant. A similar example is that of molybdenum, which is toxic to animals in low levels. Here, the tolerance can be improved by increasing the copper intake of the animal. Interestingly, lime applications tend to raise the molybdenum content of plants (Conway, 1968) while superphosphate tends to decrease it (Fleming, 1965).

On the other extreme, plants cannot be expected to contain minerals which are absent from the soil. An example of this is the claim that certain ranges in the United States produce grazing which is deficient in selenium (Carter, Robbins & Brown, 1970).

A considerable amount of work has been done on plant responses to individual fertilizers. The findings usually vary with the crop in question. Applications of lime can increase the protein content and lower the phosphorus content of soya-bean hay, but the same treatment has no effect on these constituents if the crop is oat hay. Phosphatic fertilizer tends to increase the protein content of the soya-bean plant, but tends to have the opposite effect on the oat plant Mudd (1970) reports that potash lowers the calcium and phosphorus content of grass, and Alston (1966) found that KCl fertilizer decreased the magnesium uptake by oats and barley.

Applications of nitrogenous fertilizer are usually associated with some increase in the nitrogen content of the plant, including the seeds. An example of this is found in maize. It should be noted, however, that part of the increase in nitrogen reflects the storage in the plant of non-protein materials. In the case of the maize kernel, the zein content is increased (Quicke, von Finkel & Meulenaere, 1964) a protein which is nutritionally not as valuable as the other proteins of the grain which are hardly affected by the fertilizer treatment. The important principle is that an analysis of total nitrogen of plant material is unlikely to be sufficient for an appreciation of the significance of any change in plant composition. Other data suggests that nitrogenous fertilizers may lower the content of soluble carbohydrates of plants (Hodgson & Spedding, 1966; Reid, Young & Kinsey, 1967; Waite, 1970) or cause a decrease in the levels of silica (Jones & Handreck, 1967).

Complications which require mention include the form in which the fertilizer is applied and combinations of fertilizers applied simultaneously. Fleming (1965) has shown that phosphate applied as basic slag increases the uptake of molybdenum, but that superphosphate depresses uptake. While treatment of a ryegrass sward with nitrogen alone, or with potassium alone, did not render the pasture more prone to a lowering of the serum magnesium levels of dairy cows, treatment with a combined dressing of both nitrogen and potassium brought about a rapid decline in serum magnesium values (Smith, Conway & Walsh, 1958).

The problems associated with the fertilization of veld also merit mention here, not so much because of the effect on the plant as such, but because of the danger that such treatment may cause undesirable changes in the botanical composition of the plant community. That nitrogenous fertilizer tends to suppress clovers in swards has long been known (Hodgson & Spedding, 1966; Low & Armitage, 1970). Again, the response of a plant community may vary with such factors as site, season, climate and plant species. The only certainty in the matter seems to be that this practice needs to be approached with great circumspection.

Another aspect deserving attention is the possibility that fertilizer practice may affect the storage properties of feeds. It is disturbing to read that grass from fertilized fields may give rise to a silage with poor fermentation (Fox & Brown, 1969; Jones, 1970) and that silage with a lower nitrogen content may be a better feed for cows than one with a higher nitrogen content, when both derive from the same feed (Castle & Watson, 1969).

A word of caution will be in order with respect to the use of fertilizers generally. The guiding principle should be not to apply fertilizers indiscriminately, but only to supply those elements which are lacking for a balanced plant nutrition. A recent lament from the United States is that it took only thirty years to go from a copper deficiency to a state of copper toxicity in citrus. Some soils reportedly now carry 670 kilograms of copper per ha, resulting in a copper-induced iron deficiency. It is as well to remember that chemicals are easily applied to soils, but once incorporated, they can hardly be eliminated again.

Looked at in perspective, the main conclusions would seem to be that each problem needs to be investigated in its own context, and that the prediction of fertilizer effects is hardly possible. The complex interactions between plant nutrients themselves and between the nutrients and environmental factors combine to defeat predictions of plant response. At the present time, the main objective to fertilizer practice should be to increase overall plant productivity, with sufficient attention paid to the aspect of avoiding undesirable characteristics in the resulting product.

The plant and the animal

We all accept that the animal, particularly the ruminant, is dependent upon the plant for its nourishment. Unless deficits in the intake are provided for by man, the average farm ruminant has little opportunity to make good ration deficiencies. It is desirable that crop plants and grazing provide for the nutrient needs of the animal to the greatest possible extent.

The argument that animals in South Africa are prone to suffer from a phosphorus deficiency because of the generally low phosphate content of the soil is familiar to all of us. Improvement of the diet via soil improvement is often suggested as the ideal way of alleviating the difficulty, but we have seen that the chemical composition of plants is not very amenable to change in this way. Nevertheless, the use of fertilizers has contributed significantly to improved livestock production by increasing the amounts of available stock feeds.

Ironically, the lack of a sufficient total amount of daily feed intake is one of the most urgent problems in animal production. Since all other nutrients — apart from supplements fed — are contained in the dry matter of the feed consumed, an insufficient intake of feed can result in an inadequate intake of other dietary essentials, including proteins and minerals. The importance of high voluntary intake by the animal is not usually stressed sufficiently nor is it appreciated that the percentage of individual nutrients in the feed can safely fall to relatively low levels provided that the voluntary dry matter intake remains high. It is important therefore to pay attention to those plant factors which promote feed acceptabiliy. At the present time we have but an imperfect understanding of the feed characteristics associated with animal preferences for particular feeds.

Many authors have mentioned the effects of fertilizer treatment on forage acceptability. It is maintained, for example, that nitrogen improves the palatability of grasses via an effect on the chemical composition of the plant. Grass fertilized with nitro-chalk was eaten more readily than unfertilized herbage (Ivins, 1952). But it is difficult to establish clear, causal relationships between chemical composition and animal preference. For example, nitrogen has been reported to decrease the silica content of plants (Jones & Handreck, 1968), and it may be assumed that this will tend to increase palatability. But improved palatability is also claimed to occur with increases in the soluble carbohydrate content of grass (Reid *et al*, 1967). The latter plant components, however, tend to be depressed by the application of nitrogenous fertilizer, so that a decreased palatability should become evident. The same treatment, therefore, can generate opposing trends, and the final effect on palatability may well depend upon the balance arrived at between a variety of relatively independent factors.

It is clear that palatability requires much more study, if the factors involved are to be fully elucidated.

Although voluntary dry matter intake by the animal is of prime importance, a high intake alone does not guarantee success in animal feeding. For the animal to benefit from its feed intake, the food should be capable of adequate digestion. This aspect is closely related to the microbial population in the rumen of the ruminant, a population properly adapted to the food consumed and supplied with all nutritional factors for optimal function.

Supplying the nutrient requirements of micro-organisms with respect to nitrogen, energy and minerals, is the first essential for satisfactory ruminant nutrition. The animal requirement for cobalt is, in the first instance, a requirement of micro-organisms for this mineral. In the same way, the micro-organisms require energy and nitrogen in order to thrive. If plant sources fail to meet these needs, the consequences to animal health and performance can be dramatic. In many circumstances the nutrient content of forages is sufficient to meet the requirements of the micro-organisms, so that fertilization has only a negligible effect on the digestibility of such feeds. However, Hodgson & Spedding (1966) and Waite (1970) report that applications of nitrogenous fertilizer increased the digestibility of ryegrass. As an aside it might be mentioned that the lush plant growth resulting from proper fertilizer applications may necessitate adjustments in production methods. It may be preferable to harvest such forage at a much younger stage of growth than normal in order to avoid coarseness and stemmyness in the final product.

The presence of rumen micro-organisms is of advantage to the ruminant in many ways, particularly with respect to its nitrogen metabolism. They permit the animal to utilize non-protein nitrogenous compounds present in their food, and the bacterial protein synthesised makes the ruminant largely independent of dietary protein quality. But they are also a liability in that they bring about energy losses due to feed fermentation and, in some cases, as in nitrate poisoning or in bloat, may contribute to the death of the animal.

The nutritional requirements of rumen micro-organisms are not identical to those of the host animal, particularly in the quantitative sense. While the plant material consumed may meet the needs of the microbial population, it may be inadequate in total to satisfy the requirements of the animal body. The animal requirements for sodium, phosphorus and calcium come to mind in this context.

Animal nutrition is not only a matter of intake and digestibility, but is also a function of nutrient utilization. Only passing reference will be made to this aspect.

The presence of an element or nutrient in the feed does not necesarily mean that it is available to the animal, even if it is apparently digested in the sense that it is freed for absorption. Interactions between nutrients may easily complicate the picture. High dietary intakes of phosphorus are inhibitory to calcium absorption, and high intakes of iron, aluminium or magnesium interfere with phosphorus absorption (Maynard & Loosli, 1962). Mineral absorption is often a matter of proper balance between individual elements. It is important in fertilizer practice that the normal ratio of elements in the plant not be altered to any considerable extent. Mudd (1970) found that potash resulted in a lowering of the calcium and phosphorus levels in pasture and, at the same time, reduced the availability of the calcium to the animal. Forage high in potassium content increased urinary losses of potassium by the animal, and induced a magnesium drain via the urine. Stillings, Bratzler, Marriott & Miller (1964) report that the utilization of magnesium in herbage was decreased by applications of nitrogenous fertilizer.

Like the plant, an animal will not always accumulate a nutrient which occurs abundantly in its feed. The absorption of iron, for example, is regulated in accordance with body requirements. Usually, accumulations are associated with undesired conditions, as are seen in selenium or fluorine toxicities, but in some cases storage in the body is desirable. An example of the latter is the storage of vitamin A in the liver of the animal.

In view of the preceding considerations then, it seems to be a moot point whether a fertilizer regime aimed at the increase in the plant of certain nutrients is likely to be an effective means of promoting animal nutrition. This seems to hold true particularly with respect to the trace minerals. These nutrients are taken up by the plant only in small amounts, and the animal, in turn, utilises only a small fraction of the minerals present in its feed. The main virtue of fertilizer practice is the production of more feed in total amount, so making available to the animal increased amounts of all nutrients contained therein. The obvious consideration that fertilizer practice should not result in the production of feeds with properties that detrimentally affect their keeping quality needs no further elaboration here. It behoves us to adapt our pace of progress in fertilizer practice to keep in pace with advances in our understanding of the often complex biological relationships which exist between the animal and its feed.

Opsomming

BEMESTING EN DIE PLAASDIER SE BENODIGHEDE AAN DROË MATERIAAL, PROTEÏENE, ENERGIE EN MINERALE

Die invloed van bemesting op die samestelling van die plant, en die effekte daarvan op die dier word in breë trekke bespreek. Die chemiese samestelling van plante kan nie maklik deur bemestingspraktyke verander word nie, en die hoof voordeel van bemesting lê daarin dat die totale voeropbrengs verhoog word.

Op sy beurt is die dier afhanklik van plante om sy benodighede te voorsien. In hierdie verband is dit belangrik dat bemesting geen nadelige effek op voerinnames, verteerbaarheid of verbruik moet uitoefen nie, en dat 'n opbou van ongewensde bestanddele in plante vermy word.

Die oplossing van probleme wat met bemestingspraktyke mag ontstaan verg die samewerking van grondkundiges, plantkundiges en dierkundiges.

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Discussion

Mr H E Krumm

In the book "Concentrated incomplete fertilizers" by Blake, reference is made to the ionic balance in fertilizer application which is given the term the 'G' factor. Could Prof Stielau expand on this briefly?

Prof Stielau

I have not come across the book to which you refer. It is very difficult to define the availability of any plant nutrient in the soil. Even an analysis with respect to phosphorus for example may be very difficult ot interpret in terms of assigning that phosphorus into available and unavailable portions. If the ionic balance refers to the ratio of elements that are available then I think that this is probably correct because they must be available in certain proportions to each other for optimal utilization and absorption. If however it is a matter of total within that soil I think the figures would be completely different.

Prof E R Orchard

I think we must accept that electro-neutrality in the soil and in the plant must be observed. For every cation there must be a corresponding charge—for every negative charge there must be a corresponding positive charge — therefore there can be no excess of one over the other. If for example there is too much phosphorus and too little sulphur this could perhaps effect the plant adversely—this one must accept.

Prof J J Theron

I understood Prof Stielau to say that the composition of plants could not be changed by the application of fertilizer. Surely this is true only in respect of the seed? The seed is presumably produced for the next plant and not the animal, but that is not true as far as the vegetative part is concerned. I myself have often changed the protein content of grass hay from say three per cent to twelve per cent by the application of nitrogen.

Prof Stielau

What you say is correct. It is much more difficult to change the composition of seeds than to change the composition of the leaf portion. The seed is, as you say, designed for the next generation and not primarily as animal feed. However, the same argument can be turned around and said that the leaf portion is there not as animal feed but to produce the seed. I think we must accept that it is more amenable to change than the green plant. Breeding and selection do change the composition of crop plants. High protein maize is one example. If you peruse the literature you will find that the changes are not all that great, even in the leaf portion. The changes are not as impressive as one might expect.

Dr P J Möhr

Prof Stielau made mention of the possibility of highly-fertilized veld affecting the animal detrimentally. Are any results available on the possible effect of highly-fertilized maize on the animal?

Prof Stielau

I don't know that I put it exactly like that. When I was talking about the veld, I said one must be aware of the fact that the botanical composition may change. Better species regress and the poorer species remain. In that sense it is detrimental. I cannot recollect any work done specially on your question. The reference I have to poor fermentation properties of certain silages refers to work done with grass.

Prof B R Roberts

I think the poor fermentation that arises from highly-fertilized grass silage has to do with the balance between sugar and nitrogen in the final product. This can be solved in most cases quite simply by the addition of molasses at the time of ensilage.

Prof Stielau

Yes. High nitrogen usually brings about a reduction in soluble carbohydrates so that if you add carbohydrates to the silage you should be able to correct the silage.

Dr E V E Wolf

Some work done in California indicated that nitrogen at the rate of 448 kg to the hectare caused some loss in palatability but then it was found later that a split application of nitrogen overcomes this problem. You referred to the soluble animal nutrients within the plant as opposed to the nutrients left in the dry plant and so available to the animals. Could you expand on this point?

Prof Stielau

It is not even necessary to say that all fertilizer practice will come to nought if the cropping isn't up to standard — if the cropping isn't done in a proper way. It isn't any good at all to try to increase the nitrogen content of the forage or the hay if your haymaking and harvesting processes are going to lose you much of the benefit of the fertilizer.

Mr Krumm

Does Prof Stielau suggest that a more detailed analysis of our fodder crops should be done than is at present the case?

Prof Stielau

In the normal field analysis we get one figure for minerals for example, usually referred to as ash, which from the nutritional point of view is a figure which is hardly meaningful at all. Unless you know the individual components which make up that ash, you cannot even make any predictions. For example the ash of peanut hay is relatively high but the reason that it is high, is that in the making of the hay, soil contamination takes place. The ash figure thus reflects a lot of silica which from a nutritional point of view is of no value at all. There should be at least a calcium figure and a phosphorus figure in addition to the total ash.

Dr Möhr

Prof Stielau do you see any future for high lysine corn?

Prof Stielau

The question is a very leading one. As far as ruminants are concerned I don't think there is a particular future. In the feeding of pigs American data show that about 2 kg of a soya-bean oilcake can be saved per .45 kg of ration but the Americans have a soya bean surplus anyway. High lysine corn also presents other difficulties. For example the milling of lysine corn is very different from the milling of our ordinary dents and flints. I am told that it goes through a hammermill like water. It is very brittle and it has other undesirable handling qualities. In the bags the mealie pips themselves can break up and split. Another aspect is that the Americans are having difficulty encouraging farmers to grow this high lysine corn. The yield and income from high lysine corn is less than ordinary corn and there is no preferential price at the moment.