CHANGES IN SOIL NITROGEN DURING PASTURE-CROP SEQUENCES — A REVIEW

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ABSTRACT

The literature on nitrogen accumulation under pasture and decline under cropping falls into two basic groups:
1. Studies in which pasture and crop yields are used as index of "soil fertility".
2. Studies in which quantities of N in the soil are actually measured.

The first group indicates that both build-up and run-down are generally complete in 2-4 years while the second show that nitrogen accumulation can take very long times (t ½ = 25 years). This difference is reconciled by considering the types of organic nitrogen that can accumulate under pasture and their decomposition rates.

Recently added plant materials and the microbial nitrogen derived from its decomposition are quantitatively the most important fractions in the short term. Factors affecting rate of nitrogen input through these fractions are reviewed and management implications discussed in terms of nitrogen supply to subsequent crops.

Additional Keywords: organic matter pools, decomposition rates, nitrogen availability

INTRODUCTION

The benefits that crops express when they follow a period of pasture have been observed since agriculture was first practised. Over the past century the effects that grazed pastures have on the chemical, biological and physical characteristics of soils have been studied in various degrees of detail. Because the effects are complex, it is sometimes difficult to isolate single factors for study.

For soil nitrogen, there is a lack of good data that is unconfounded by the other soil factors that change under pasture. For this reason, the approach taken in this paper has been to examine prevalent points of view in light of recent work on soil organic matter (Jenkinson and Rayner, 1977). In some cases data refer to soil carbon rather than nitrogen. It is assumed that carbon and nitrogen are stablilised together in soil organic matter (McGill and Cole, 1981) and similar decomposition rates apply. A conceptual model has been developed which highlights the important processes and limitations and shows the areas where more hard data are needed.

The primary aim of this paper is to show the changes that have taken place in soil organic matter research lately. It should be of greatest interest to those Agronomists who have had little recent exposure to soil science. A comprehensive bibliography has not been compiled but papers have been quoted which show the development of concepts that are, or have been, thought to be important.

Two different pictures of nitrogen or "fertility" accumulation can be gained from the literature. The first is summarised by Jacks (1946) who wrote that: changes were effectively complete after two years in pasture and could be reversed in equal or shorter time. The work of Sears and his colleagues during the 1940's to 60's (Sears, 1953 a, b; Sears & Evans, 1953; Sears *et al.,* 1965 a, b) added weight to this view. With the exception of Sears & Evans (1953), these papers were addressed to "fertility" as indicated by pasture or crop growth.

The second view, summarised by Richardson (1938), showed that when old arable land was converted to pasture the nitrogen content of the soil continued to increase for many years. The time required for half the change to take place was estimated at 25 years. Similarly, Walker *et al.* (1959) showed a progressive average accumulation of over 100 kg N/ha/year (200 mm) over 25 years on a pumice soil.

The apparent difference between these views can be reconciled by considering the nature of soil organic matter. Jenkinson and Rayner (1977) based a classification of organic matter on the rates of turnover found in the Rothamsted classical experiments. While the turnover times (Table 1) may need modifying for other environments, the relationships between classes should remain intact. If the groups with short half times (1-3) are accumulated quickly under pasture, they could dominate organic nitrogen turnover in the short term. Movement of nitrogen into groups 4 and 5 could, however, continue for long periods without the effect on nitrogen availability being obvious in plant growth.

TABLE 1: Fractionation of soil organic matter after Jenkinson and Rayner (1977).

Group		t½ (years)
1	Decomposable plant material	0.165 (60 days)
2	Resistant plant material	2.31
3	Soil biomass	1.69
4	Physically protected O.M.	49.5
5	Chemically protected O.M.	1980

TABLE 2: Quantities of organic matter or nitrogen passing from herbage to the soil from grazed pastures.

Property	Quantity	System	Reference
N flux through leaf litter	Up to 140 kg N/ha	rotationally grazed	Hunt (1983)
Plant material between grazing height and	2-3.5 t/ha (DM)	set stocked ryegrass/white clover	Brock (unpublished)
5 cm soil depth	0.5-1.5 t/ha	rotationally grazed ryegrass/white clover	Brock (unpublished)

Groups 1 and 2 comprise plant materials added to the soil. The chemical composition of the material is probably the main factor determining decomposition rate. Clover leaf and grass stalk are obvious examples of decomposable and more resistant materials. The way in which groups 4 and 5 are formed is still controversial and not of crucial importance here.

The soil biomass nitrogen is that fraction of the total soil nitrogen that comprises living organisms. It occupies a key position in any discussion of soil organic matter dynamics as it acts both as a nutrient pool and as the agent of decomposition and change in other pools. Because it is a living entity the half time (Table 1) reflects the rate of turnover rather than decay, that is half the biomass will be replaced by new organisms every 1.7 years.

ORGANIC NITROGEN IN PASTURE SOILS

Heavy emphasis has been placed on grazing animals in "fertility" building (Sears, 1953 a; Sears *et al.*, 1965 b). Again it is hard to find documentary evidence for unconfounded effects of animal excreta on soil nitrogen levels. There is evidence that urine-nitrogen can enter the organic pools directly through microbial immobilisation (Holland and During, 1977) but this route is often quantitatively unimportant (Ball *et al.*, 1979; Carran *et al.*, 1982). Immobilised urine-nitrogen is unlikely to have an effect beyond the current season's production (Holland & During, 1977). Dung-nitrogen is not very important quantitatively. Where 10 tonnes of dry matter containing 350 kg of nitrogen are consumed by animals between 50 and 80 kg N/ha/year is likely to be returned as dung (calculated from data in During (1972)). Weeda (1977) found that a cattle dung nitrogen effect on pasture lasted about 9 months. The amount of dung-nitrogen on pasture that is either physically or chemically protected could be significant but is unknown.

While dung and urine-nitrogen have an important role in allowing high levels of pasture production (Sears, 1953 a, b) the direct effect on soil nitrogen is likely to be small and/or of short duration. Traditionally, models of nitrogen cycles have included a root death pathway (Walker, 1956) but current research shows that far more plant material (leaf stem and stolon as well as roots) senesces and enters the soil than was previously thought. Table 2 shows a variety of relevant data. These show substantial quantities of nitrogen or plant material entering the soil. Further support is given by measurements of the "light fraction" in soils (Table 3). This basically separates the light, unmodified and decomposing plant debris from the heavy, much modified organic matter which is largely associated with the sand, silt and clay particles. Table 3 shows both the quantity and type of organic nitrogen being influenced strongly by time in pasture.

TABLE 3: Nitrogen contents of whole soils and their light fractions under cropping and grassland. (From Whitehead *et al.*, 1975).

	Continuous arable 100 years	17 years pasture after 100 years arable	Pasture 200 yr
Total N (%)	0.102	0.163	0.476
N in light fraction as % of total N	4.1	11.4	17.8
C:N ratio of light fraction	19.3	18.5	12.9

The soil biomass derives its energy and nutrient supplies through the decomposition process. The size of the biomass pool thus reflects the amount of material available for decomposition. Ross *et al.* (1982) have shown that soil properties related to biomass increase rapidly when soils depleted in organic matter are pastured down. Between 2 and 6% of the total nitrogen in soils is associated with the soil biomass and this proportion varies with organic matter input (Ayanaba *et al.*, 1977).

In summary, pastures supply a considerable quantity of plant material of various kinds to the soil. The soil biomass decomposes much of this material easily, making nitrogen available. Some material is more resistant and decomposes only slowly. A smaller fraction as well as organic nitrogen compounds produced by the biomass are protected from further attack by organisms. During decomposition, the soil biomass itself comes into a balance with energy supply and acts as either a source or sink of nitrogen as energy supply fluctuates.

THE RATE OF NITROGEN DEPLETION UNDER CROPPING

In Fig. 1, the time course of decomposition of the various organic nitrogen pools is shown. It is clear that the amount of decomposable plant material has very little influence on the nitrogen availability for subsequent crops. The amount of crop residues entering the soil will dominate this fraction, even during the first crop.

Pasture residues of the more resistant kind will however, have an important effect and the size of this pool will largely determine the apparent fertility of the soil for crops 1-5.

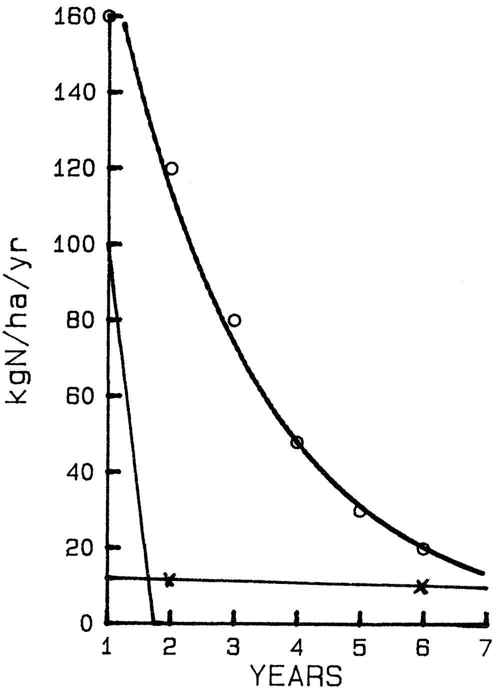

Figure 1: The annual release of nitrogen from a "Resistant" plant material pool of 700 kg N/ha (——o——o); a 500 kg N/ha pool of physically protected organic matter (——x——x——) and a 100 kg N/ha pool of "Decomposable" plant material (———).

The protected pools will have little effect from year to year but it is possible that the physically protected pools will deplete faster where aggregate stability declines rapidly. It is important to realise that these stable pools set the apparent basal or background level below which nitrogen availability will not fall over long time periods. Where soils have been under grass for very long periods, as in the case of the chernozems and black earths of the prairies, the protected fractions will be large and set at a relatively high base line. Where soils of low total nitrogen are converted to pasture for short periods, say up to 10 years, there is unlikely to be sufficient accumulation of relatively stable nitrogen forms to substantially increase the basal level of "fertility".

The work of Sears *et al.* (1965) on a subsoil confirms this. Although they returned 80% of all herbage harvested and doubled the total nitrogen content of soil, nitrogen deficiency limited growth in the first or second crop. Decline in "fertility" thereafter was progressive.

Studies with prairie soils converted to continuous, long term cropping suggest that the biomass pool declines relatively slowly, the rate being dependent on organic inputs (Voroney *et al.,* 1981).

Taken overall, these rates would suggest that an annual decline in nitrogen availability should be apparent from crops 1 through to 5 or 6.

In terms of crop yields the degree by which the annual change is noticeable will depend on:

(a) The amount of nitrogen accumulated in the plant material pools which defines the starting point;
(b) The amount in stable pools which defines the end point;
(c) The demand for nitrogen by the crop in relation to these;
(d) Losses from the inorganic nitrogen pools.

Good quantitative data to thoroughly test the conceptual model outlined here are not available.

THE INFLUENCE OF MANAGEMENT ON NITROGEN ACCUMULATION

The conceptual model used here lays heavy stress on the importance of decomposing plant materials. If this is correct, pasture management could influence the rate of nitrogen accumulation. Until the likely influences of management on net primary production of pastures, as opposed to yield measured above some rather arbitary "grazing height" is understood though, progress in this area is likely to be "hit and miss" rather than systematic.

SUMMARY

The rapid build-up of nitrogen-supplying power in pasture soils is considered to be the consequence of plant death and decomposition. The quantities of nitrogen involved and the effect of management are not known yet. Much of the material accumulated decomposes during the first few years of cropping.

The more resistant materials which accumulate in large quantities over long periods of time set the basal level of fertility and are probably not much altered by short periods of pasture. The principal effects of animals are considered to be indirect.

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