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Nitrogen loss from a soil restored after surface mining

R.S.Davies
Soil Environment Services, Stocksfield, UK

A.Younger
Department of Agriculture, University of Newcastle upon Tyne, UK

R.Hodgkinson
ADAS Boxworth, Cambridge, UK

Ross Chapman
CSIRO, Perth, W.A., Australia

ABSTRACT: Anaerobic conditions develop below about 1 m depth in soil stockpiles and this can lead to an accumulation of ammonium and transformations of a normally relatively inert organic-N pool within the soil. After reinstatement of the soil from the stockpile, the ammonium may rapidly be transformed to nitrate and lost from the soil with the labile organic-N. The magnitude of nitrogen losses were measured from a soil that had been reinstated for agricultural use after being stored in a stockpile for 12 years. Over the two year monitoring period, 2449 kg ha^{-1} of nitrogen was lost from the soil profile; 90% of this was not accounted for either in the soil or in the runoff or drainage water as mineral-N and was presumed to have entered the atmosphere or aquatic environment as organic-N. The proportion entering the atmosphere as nitrogen and nitrous oxides or the aquatic environment as organic-N, needs further investigation.

1 INTRODUCTION

Soil stockpiling takes place for surface mining, road construction, pipeline installation and many other large development projects world wide. In the UK, some of the largest soil stockpiles are at opencast coal sites. Millions of tonnes of soil at these sites can be in stockpiles for over a decade after which the land is usually returned to agriculture. Low soil nitrogen levels have been found particularly in reinstated soils which had previously been stockpiled. This study investigated the causes and magnitude of nitrogen losses taking place in a soil that had been stockpiled for 12 years during open-cast mining for coal and then reinstated. Nitrogen in undisturbed soil and in soil stockpiles was examined and the nitrogen content of the reinstated soil, drainage water and surface runoff were measured over a 2 year period.

A series of changes in the soil are known to take place during movement, stockpiling and reinstatement. Transformations of nitrogen which take place within the stockpile were expected to be the first stage of a particular route for nitrogen loss. At depths below about 1 m in the stockpile, the numbers of anaerobic bacteria increase whereas those of aerobic bacteria decrease (Harris et al. 1989). This inhibits nitrification due to poor aeration within the stockpile leading to an accumulation of ammonium in the anaerobic zones. Once the soil is removed from the stockpile and reinstated, the aerobic microbial population rapidly re-establishes, usually at higher than normal levels (Williamson & Johnson 1991) and nitrification recommences at greater than normal rates. If high levels of ammonium are present in a reinstated soil, the amount of nitrate generated is likely to be much greater than normal and consequently there is a high potential for N loss to the environment via leaching and/or denitrification (Johnson & Williamson 1994). Nitrate leached to water courses is not only a threat to aquatic environments and drinking water supplies (Addiscott et al. 1991), but if nitrogen is lost from soil in the form of gaseous nitrous or nitrogen oxides, this will contribute to the degradation of ozone (Isermann 1994). Apart from any pollution potential, a loss of nitrogen is also the loss of a crucial agricultural resource.

2 MATERIALS AND METHODS

2.1 *Site and soils*

The site was located on the southern end of the Butterwell open-cast coal site in Northumberland, North East England (Grid. Ref. NZ201888). Four hydrologically isolated plots each of 0.6 ha. were established on soil that had been reinstated during

August 1991. The soil was a clay loam stagnogley of the Dunkeswick series which exists extensively in the region. The soils are recorded as wetness class III in the undisturbed state and class IV/V in the reinstated state (Jarvis et al., 1984).

Topsoil and subsoil had been stripped from the original site, and stored separately in stockpiles up to 5 m in height for 12 years during the coal extraction period. All soil handling was carried out by box-scraper earth movers Reinstatement consisted of replacing the overburden and levelling, replacing approximately 1 m (if available) of subsoil and finally replacing about 0.25 m of topsoil. Soil layers were evenly replaced to the final contour and generally of uniform depth. The soil profile which comprised two horizons overlying overburden material was a direct result of the reinstatement procedure .

After reinstatement, the drainage system was installed and the site subsoiled and disced before perennial ryegrass (*Lolium perenne*) was sown in September 1991.

2.2 *Soil sampling and analysis.*

Soil samples were taken using an auger at depths down to 0.75m from October 1991 to October 1993. This took place in October, March and May or June of each hydrological year. Soil analysis was carried out using methods described fully by MAFF (1981).

2.3 *Water sampling and analysis.*

Drainage pipes and surface collectors were connected by sealed plastic main drains to a chamber housing the discharge monitoring equipment. Data were collected automatically by a radio-telemetry link each night. Water samples were collected using EPIC automatic liquid samplers controlled by a programme on the data logger. The maximum numbers of samples were taken when the greatest changes in flow rate were taking place.

3 RESULTS AND DISCUSSION

3.1 *Nitrogen transformations, movement and loss.*

Soil samples taken at the start of the experimental period in October 1991, two months after the soil was replaced, indicated that over 325 kg ha^{-1} of the topsoil total-N was in the form of ammonium (Figure 1a) compared to the more normal 10-20 kg ha^{-1} at this time of the year in a similar undisturbed soil. This indicated that nitrification had indeed been inhibited during soil stockpiling. Topsoil nitrate content (Figure 1b) was also relatively high at 80 kg ha^{-1}, compared to that previously found in a similar undisturbed soil in the region (10 - 20 kg ha^{-1}). The total amount of mineral and organic nitrogen in the topsoil (Figure 1c) was initially similar to that previously found in an undisturbed soil of the same series in the region. Up until the time of soil restoration, nitrogen losses should have been minimal as during stockpiling the soil was not uncovered and leaching of accumulated ammonium would have been minimal. Subsoil ammonium and nitrate contents were less than those in the topsoil and similar to those in an undisturbed subsoil at this time of the year.

The accumulation of ammonium in the topsoil was rapidly removed within six months over the period October 1991[month 1] to February 1992[month 6] (Figure 1a) and the proportion of the total nitrogen present as ammonium in the soil decreased from 4.4% to 0.9% whereas the proportion present as nitrate increased from 1.1% to 2.7% (Figure 1b) some of which entered the drainage system. Johnson & Williamson (1994), found approximately the same pattern of ammonium reduction and nitrate increase over a similar time period from a soil reinstated after stockpiling. In this study however, losses through the drainage system were relatively small, compared to the total amount of N lost from the topsoil. This can be attributed to much lower rainfall (91 mm) than the long term average (235 mm), (Smith & Trafford 1976) which resulted in less than 1 mm of surface runoff and only 46 mm of drainage being recorded during this period.

Surprisingly, from the end of October 1991 to the end of February 1992[month 6], total-N in the topsoil (0-0.25 cm) decreased more rapidly than expected (Figure 1c). This was thought to be either due to mineralisation and nitrification with subsequent leaching and/or due to leaching of soluble/particulate organic-N. In total, 1.5 tonnes ha^{-1} ($P<0.01$) of mineral and organic-N was lost from the topsoil between October 1991 and February 1992. A large labile pool of organic-N was possibly created as a result of anaerobic conditions during soil stockpiling (Harris, J., Environment and Industry Research Unit, University of East London, personal communication) and the precise mechanisms which led to the release of much of this nitrogen, and the transformations it underwent once released from its usually relatively inert state in an undisturbed soil were not investigated.

Data collected for the subsoil at 0.25 to 0.5 m

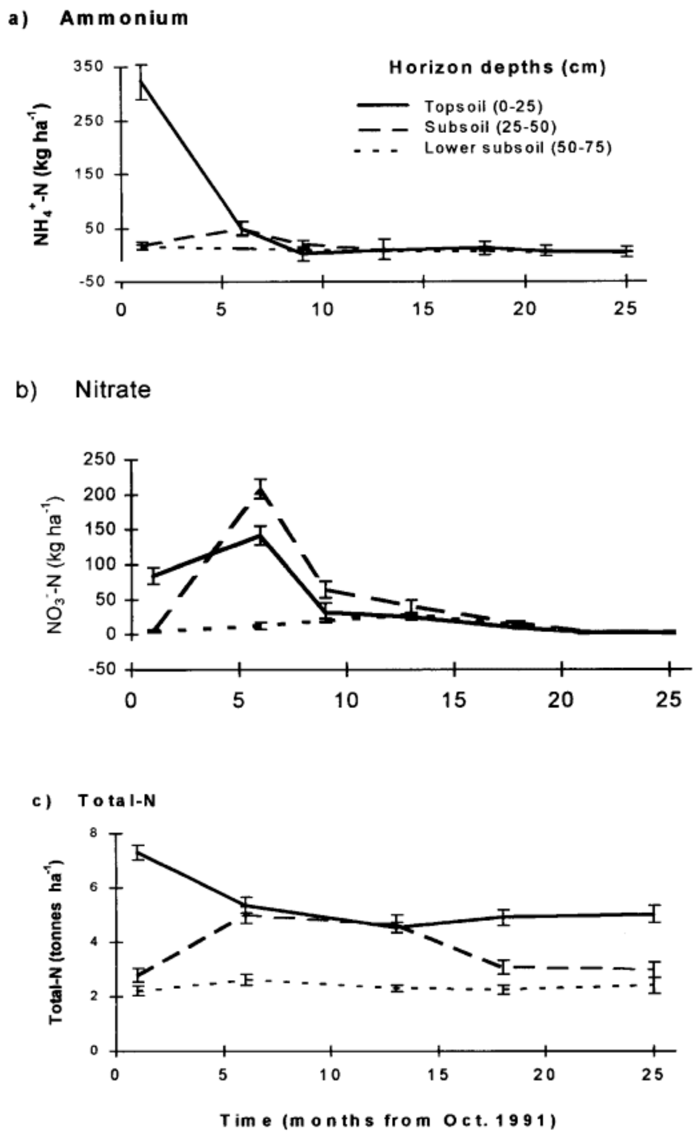

Figure 1 Soil nitrogen transformations at Butterwell

gave a strong indication that the 1.5 tonnes of nitrogen per ha. that had been lost from the topsoil, and which had not reached the watercourses, had in fact entered the subsoil (Figure 1c). The relatively small amount of the nitrogen in the subsoil occurring as mineral-N at this time (Figures 1a and 1b) suggested that a large quantity of soluble/particulate organic-N originating from the topsoil had been leached into the subsoil. Immobilisation of nitrogen which was transported from the topsoil as nitrate and then assimilated into the microbial population could account for a proportion of this large amount of organic N moving into the subsoil. The poor artificial soil structure may have resulted in this large amount of organic and mineral N remaining in the subsoil in man made "dead-end fissures".

From February 1992[month 6] to October 1992[month 13], 1 tonne of N was lost from the topsoil and 0.4 tonne from the subsoil. This nitrogen was lost from the soil profile. From October 1992[month 13] to February 1993[month 18], a further 1.5 tonnes per ha of N was lost from the subsoil horizon (0.25 to 0.5 m), this is shown in Figure 2c. Only 30 kg of this was accounted for as mineral-N in the drainage and again only minimal crop uptake occurred with none moving to greater depth. Over the entire study period, there was no increase in the total-N content of the lower subsoil (Figure 1c); which confirms that the final destination of this nitrogen was to the atmosphere or the aquatic environment. Both were undetected during this study.

The compaction that takes place during soil handling of reinstated soils tends to result in a greater number of small pores than undisturbed soils. These may have remained saturated for extended periods creating anaerobic zones between the larger fissures through which drainage took place. There were also periods when temperature and moisture could have allowed high rates of denitrification resulting in gaseous losses to the atmosphere.
Eighteen months after reinstateent, little further change was detected. Thirty percent of all soil nitrogen had been lost.

3.2 *Nitrogen measured in the drainage water*

Concentrations of nitrate-N observed in drainage water (Figure 2) were well in excess of levels defined in the EC drinking water directive (11.3 mg l^{-1}).

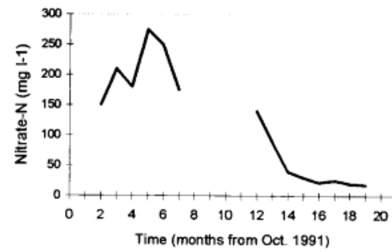

Figure 2. Drain discharge nitrate-N concentration, 1991-1993

Initial samples of drainage water were generally less than 150 mg l^{-1} but increased rapidly. Peak N concentration increased in each subsequent drainage event reaching a maximum of 270 mg l^{-1} in February 1992. Concentrations of ammonium-N in drain water typically remained around 0.2 mg l^{-1} rising to a maximum of 6.3 mg l^{-1} on occasions of peak drainflow. These concentrations are high in relation to the EC directive on drinking water that suggests a Maximum Acceptable Concentration of 0.5 mg l^{-1} with an average of 0.05 mg l^{-1}. This is also much higher than has been observed in other studies undertaken on undisturbed soils. At Brimstone Farm (Rothamstead Experimental Station) a value of 0.5 mg l^{-1} was rarely exceeded with 90% of values being less than 0.1 mg l^{-1}. When higher concentrations, in the range 0.9 to 1.2 mg l^{-1} were observed these were associated with the movement of soil particles (Dowdell 1984). In a study at Cockle Park on similar, but undisturbed, soil to that at Butterwell (Hodgkinson et.al. 1992), over 90% of samples contained less than 0.1 mg l^{-1} under both arable and grassland cultivation.

4 CONCLUSIONS AND RECOMMENDATIONS

The consequences of stockpiling and reinstatement were to cause unusually large nitrogen transformations and movements with eventually substantial loss (Figure. 3). The magnitude of this loss was unexpectedly large and via an unexpected route. In total, over the an 18 month period, 30% of the total nitrogen was lost from the soil profile (2.8 tonnes per ha.).

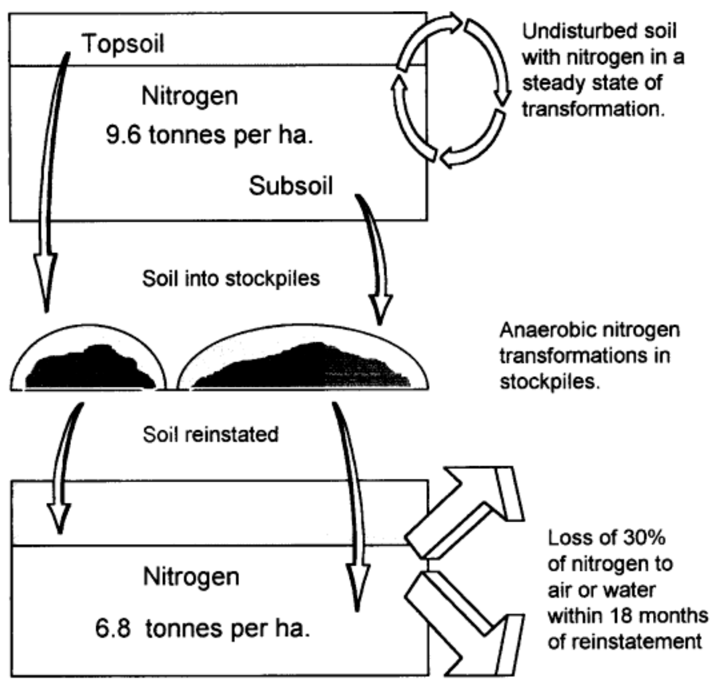

Figure 3. The process of soil nitrogen depletion.

Loss was either to the atmosphere, possibly via denitrification as a combination of nitrous and nitrogen oxides and molecular nitrogen, or to the aquatic environment as mineral and soluble/particulate organic-N. It was unknown whether the atmosphere or aquatic environment was receiving most of this nitrogen.

Consequently the final fate of this nitrogen in the atmosphere or in the aquatic environment is also unknown. This study served to indicate that apart from the depletion of a major soil nutrient there exists the potential for significant environmental pollution over a period of some months following reinstatement of stockpiled soil.

Nationally and world wide, the pollution potential and resource loss could be considerable. The soils reinstated for this experiment are common in Northern England (Jarvis et al. 1984) and have been and are continuing to be widely disturbed for mining operations. Also the techniques used for reinstatement reported here are typical and commonly used. It would not therefore be unreasonable to expect similar rates of nitrogen loss to those found in this study to occur from most similar soils that are stored for periods of over 2 years and then reinstated. This would represent from a sample of 20 sites currently in operation for the next 12 years in England, Wales and Scotland (British Coal Opencast 1993), 1000 tonnes of nitrogen lost to the atmosphere and/or water courses per year.

Further research is required to determine the precise mechanisms and routes of nitrogen loss and the effects of soluble/particulate organic-N entering the aquatic environment. Ultimately methods to prevent this nitrogen loss need to be devised. These may be very simple procedures such as careful soil stockpiling during the phasing of mineral extraction or the use of nitrification inhibitors after restoration.

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