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The creation of nitrogen cycles in derelict land

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Because of an almost total absence of N capital, nitrogen cycles in derelict land soils do not exist. If N fertilizer is added to newly established vegetation, growth will occur, but it ceases after a few months because of lack of any continued N supply from a mineralization cycle. A capital of N has to be built up in the soil. Studies of successional communities on china clay wastes suggest that the amount necessary to provide for the needs of a self-sustaining ecosystem is much less than the amounts found in well established ecosystems. Nevertheless, a minimum of approximately 1000 kg N ha^{-1} (with 700 kg ha^{-1} in the soil) is required in temperate climates. In land restoration programmes, if top soil is not replaced or an organic treatment such as sewage sludge used, this N capital must be built up, mainly by the use of legumes, which can readily accumulate 50–150 kg N ha^{-1} annually if provided with appropriate conditions. N cycling then will take place normally.

Introduction

Nitrogen deficiency is one of the most important factors limiting the growth of vegetation duri the reclamation of derelict land and mining spoils. Vegetation is often established on the materials, with the help of fertilizers, but after a few months becomes moribund and dies unless more N fertilizer is applied (Bradshaw & Chadwick 1980; Bloomfield *et al.* 1981). The main problem is that the raw soil material has a very low N content; in the extreme case of china clay wastes there is only between 10 and 30 kg N ha^{-1} (0–21 cm depth), and even in subsoil material there is very rarely more than 400 kg N ha^{-1}.

These values are much lower than those for soils in most well developed ecosystems (see the papers by Newbould and Batey, this symposium). In these there is a large pool of soil organic N from which soluble N is released very slowly for plant uptake by mineralization processes. This suggests that if adequate supplies of mineral N are to be available for plants there must be a large pool of soil N. This can be illustrated by considering that in a temperate climate a rather unproductive grassland might have a total annual productivity of 5000 kg ha^{-1}. Even if this contains only 1% N there will be an annual N requirement of 50 kg N ha^{-1}. To meet this requirement, if we assume an annual supply of 10 kg N ha^{-1} in precipitation, the N cycling processes must supply the deficit: 40 kg N ha^{-1} annually. If this were entirely supplied from soil mineralization, at an annual rate of 2% (Reuss & Innis 1977), a soil N capital of 2000 kg N ha^{-1} would be necessary. This capital could be smaller if cycling through alternative pathways (e.g. litter decomposition) were faster. It is significant that in most temperate systems the soil N capital is at least this order of magnitude.

Initially, in derelict land materials there can only be a low supply of plant available N, from cycling sources, as the soil capital is low, and cycling pathways have to be established. There is therefore a shortfall in the supply of N for plant uptake. To establish a self-sustaining ecosystem during reclamation some N must be supplied and accumulated, not only to satisfy the annual requirements of the vegetation initially, but also to establish the capital required for an adequate nitrogen cycle, which will satisfy the annual requirements of the vegetation subsequently without continued inputs of fertilizer N.

It is self-evident that the cycle must itself be working. In some derelict land materials, particularly those contaminated by heavy metals, mineralization can be almost completely inhibited (Williams *et al.* 1977). But in most situations a reasonable amount of mineralization does occur. In china clay wastes N turnover indices (amount of N mineralized per unit of total soil N) are equal or higher than those in agricultural soils (Marrs *et al.* 1982).

We therefore should turn our attention particularly to N capital. It must be developed until the internal supplies of N from cycling processes are sufficient to meet the requirements of the vegetation. But

(i) How much nitrogen must be accumulated to satisfy the minimum requirements of a self-sustaining ecosystem?

(ii) How can this be achieved most effectively?

In this paper these questions will be discussed in relation to studies on the reclamation of china clay sand spoils. The spoils are predominantly made of coarse sand and are extremely nutrient-deficient (Bradshaw *et al.* 1975). Although they are an extreme example of a N-deficient material, they exemplify a problem that is critical in almost all derelict land.

Assessment of minimum N requirements

The amount of N capital in the soil compartment of an ecosystem cannot be less than is necessary for the functioning of the ecosystem, but it could be more. We have derived estimates of minimum N capital required, for two types of ecosystem, from studies on the natural colonization of china clay wastes during primary succession (Dancer *et al.* 1977*a*; Roberts *et al.* 1981*a*; Marrs *et al.* 1981). A developmental series of four plant communities is found on a range of tips varying in age from 16 to 116 years. All major plant nutrients have accumulated with time, but N is the one element that shows the greatest accumulation (table 1).

The main source of N accumulation occurs during the phase of colonization when legumes (*Lupinus arboreus* or *Ulex europaeus*) dominate the vegetation. These two species make a substantial contribution to the N budget; from acetylene reduction studies it can be estimated that *Lupinus arboreus* can fix 72 kg N ha^{-1} annually and *Ulex europaeus* 26 kg (Skeffington & Bradshaw 1980).

By the time the intermediate scrub and mature woodland communities develop, the legume component is small. The amount of N found within them (table 1) can therefore be used as first approximations to the minimum amounts of N required to sustain these two ecosystems. The crucial evidence for this is that while woodland species do occur in the vegetation early in the succession, even as primary colonizers, they do not grow or contribute significantly either to the cover or the biomass until the N capital approaches these target values. A *Salix* scrub community therefore appears to have a minimum N capital of approximately 1000 kg N ha^{-1} with 700 kg ha^{-1} in the soil, and woodland 1800 kg N ha^{-1} with 1200 kg N ha^{-1} in the soil.

While we have no evidence from other plant communities, or for communities with different productivities, these values match those for ecosystems developing in more natural situations, e.g. glacial moraines (Crocker & Major 1955) and sand dunes (Olson 1958). It is clear that all these communities have a lower N capital than comparable well developed ecosystems. This suggests that further accumulation is not necessary for the existence of these ecosystems. If it occurs it presumably results in increased productivity or complexity. There is otherwise the intriguing possibility that well developed ecosystems have an excess of N that is not efficiently used (see Batey, this symposium).

Table 1. Dominant species, biomass and nutrient content of the main ecosystem types on naturally colonized china clay waste

(Biomass and nutrient contents are in kilograms per hectare.)

ecosystem type	dominant species	age of site (years)	biomass	N	P	K	Ca	Mg	
primary	*Lupinus arboreus*	17	10888	110	45	103	46	19	(plant)
				181	107	614	99	38	(soil)
primary	*Calluna vulgaris*, *Ulex europaeus*, *Sarothamnus scoparius*,	50	21445	151	15	84	29	20	(plant)
				672	152	1478	66	94	(soil)
intermediate	*Salix atrocinerea*	53	30292	259	11	344	56	31	(plant)
				722	119	1439	75	83	(soil)
mature	*Rhododendron ponticum*, *Betula pendula*, *Quercus robur*	92	157182	581	71	358	606	122	(plant)
				1189	126	704	155	130	(soil)

Acceleration of N accumulation and cycling

As we have seen, ecosystems and nitrogen cycles can develop naturally on china clay wastes, but this takes a long time. At least 50 years is required before a total of 1000 kg N ha^{-1} is accumulated naturally. This timescale is clearly unacceptable for restoration work. But the principles for the establishment of nitrogen cycles, and hence new ecosystems, remain the same. During restoration the accumulation process that occurs during primary succession must be mimicked, but at a much faster rate.

There are basically three ways in which the rate of N accumulation can be speeded up. These are:

(i) addition of N in a stored form, e.g. topsoil, sewage sludge, slurry;

(ii) use of nitrogenous fertilizers;

(iii) sowing of species that can fix N_2 biologically at a high rate.

In many areas of derelict land, topsoil can be removed and replaced as part of the mining or extractive operation (Bradshaw & Chadwick 1980). If the topsoil, which contains almost all the soil N, is removed and replaced without any storage period, little of the original soil N is lost. However, on many sites, including china clay wastes, the topsoil has been lost and would be expensive to import from elsewhere, or cannot easily be applied to wastes because of problems of instability. A possible alternative, which is being investigated, is the use of sewage sludge or farm slurry. A 50 mm layer of sewage sludge, with 5% dry solids, containing 4% N on a d.s. basis, would result in the application of 1000 kg N ha^{-1} in an organic form.

However, the two other techniques are normally used on china clay wastes, in combination; this achieves an accumulation of N in restored sites much faster than under natural conditions: 108 kg N ha^{-1} annually (Marrs *et al.* 1980*a*). This means that to establish a self-sustaining

Salix scrub or woodland system with a N capital of 1000 and 1800 kg N ha^{-1}, the timescale can be reduced to less than 10 and 18 years respectively.

The legume contribution to this enhanced accumulation rate is very important. In field plots on china clay sand, agricultural legumes can accumulate more than 100 kg N ha^{-1} annually (Dancer *et al.* 1977*b*). In practice, in revegetated areas acetylene reduction studies indicate that fixation is rather less. But white clover (*Trifolium repens*), for example, fixes 49 kg N ha^{-1} annually, and up to 50 kg N ha^{-1} of N fertilizer can be added annually without reducing this fixation rate (Skeffington & Bradshaw 1980). To achieve a healthy clover component in the vegetation, three management practices are essential. First, on these sterile materials addition of a *Rhizobium* inoculum at seeding is beneficial. Secondly, some N fertilizer is required initially to obtain good establishment of the clover plants, and thereafter the lime and phosphate status of the soil must be carefully maintained (Bradshaw *et al.* 1978; Roberts *et al.* 1981*b*). Thirdly, a controlled grazing régime reduces competition from grass species, and also transfers N locked up in the above-ground standing vegetation to the soil–root system in a form suitable for plant uptake (Marrs *et al.* 1980*b*). This increases the efficiency of the cycling of the accumulated N capital.

Conclusions

The N status of skeletal soil material, whether formed by natural processes or man's activities, will always be very low compared with normal soils. As a result, an effective nitrogen cycle, which provides sufficient mineral N to satisfy the needs of normal vegetation is not present. N is clearly a critical factor in vegetation development in both natural and artificial situations. In the restoration of derelict land, the establishment of an effective nitrogen cycle by the accumulation of a sufficient capital of soil N is a crucial, but often overlooked, part of the restoration strategy.

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