5. NITROGEN FIXING SPECIES

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5.1 Introduction

A major feature of the present-day is the ever increasing degradation of the surface of the earth and the ecosystems upon it. This is no new process. Civilizations throughout time have been destroyed by loss of the soils of the croplands which allowed those civilizations to prosper as well by loss of the original vegetation on lands surrounding them. But the situation today is exacerbated by a combination of pressure of increased populations, the use of machinery and the particular demands of industry for more and more resources taken from the ground.

The first pressure leads initially only to removal of cover vegetation by grazing animals and by cropping. Carried out carefully, there need be no soil loss. But as population pressure builds up, good husbandry cannot be sustained, and inevitably soils are over-exploited, eroded and lost. Mechanisation only adds to this by allowing greater disturbance. The demands of industry lead to even more savage destruction of land as surface layers are removed to get at resources beneath.

We can see this as a progressive process. Firstly only the original vegetation may be destroyed, a loss which can easily be remedied if appropriate steps are taken. Nevertheless, all the nutrient capital held in that vegetation will be lost and will have to be replaced. Secondly, soon, because of the disappearance of its protective cover, the surface layers of the soil begin to be eroded. These contain all the capital of available plant nutrients, particularly nitrogen because this is held in organic matter. As the damage proceeds, so the whole of the soil disappears. Now, not only is the physical framework of the soil lost, but also the store of more tightly held nutrients contained within the matrix of soil particles. Only hard rock may remain. Where there has been industrial activity, the original soil is usually completely lost and replaced by some subsoil material which may even be toxic.

This scenario is familiar to everyone. It can be seen all over the world wherever human populations are concentrated. There is a critical need at the present time, not only to prevent the damage developing further, but also to restore those areas which have been destroyed. Obviously there are many steps which must be taken, involving proper management of plants, soils and animals. The techniques required are detailed in many textbooks and handbooks. But underlying the whole restoration and management process is one important principle which must be explored, because it has important implications for key species.

5.2 Nitrogen as a critical element in ecosystems

In all the tissues of living organisms, after carbon, oxygen and hydrogen, the commonest element is nitrogen. In plants it constitutes about 2% of the total dry

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matter. In ecosystems it is also one of the most critical elements. There is widespread evidence that it is the element most commonly holding the growth of terrestrial ecosystems in check.

Of course it occupies a special position in ecosystems, because although originally derived from air and not, like other elements, from soil minerals, it is stored mainly within the soil in organic form. Successful ecosystem functioning depends on there being not only the nitrogen in the vegetation itself, without which plants could not exist, but also a much larger capital within the soil, a small fraction of which is released annually by the decomposition of organic matter. The actual amounts vary from one ecosystem to another, but on average there is at least 100kg N ha^{-1}, representing 2.5% of the total soil capital.

The need for this soil capital can be verified not only by calculations based on known rates of organic matter decomposition in soil, but also on the growth of plant communities on degraded land. It can be shown that in temperate climates a soil capital of 1 000kg N ha^{-1} is the minimum necessary for proper ecosystem functioning. In tropical climates, where rates of organic matter breakdown are higher, the minimum capital will be less, but it will still be an appreciable amount.

5.3 Restoration of nitrogen capital in soils

The crucial point then is that, in all situations where land degradation is to be reversed, the over-riding need is to find a way in which the lost nitrogen capital can be replaced. Without its replacement, land and ecosystem restoration is impossible. The practical demonstration of this is in studies on the reclamation of land made derelict by industrial activity (Bradshaw & Chadwick 1980). Similarly, if land degradation is to be prevented in situations where exploitation is heavy, then an adequate nitrogen input, at least equal to the total of all losses, must be ensured.

In modern agriculture, nitrogen levels are now usually maintained by fertilizer inputs. This is perfectly possible in a high output system, where high inputs, in particular the high cost of a nitrogen input, can be paid for by the profits of the high output. But it is quite impossible to contemplate this for degraded land, since, because of the degradation, returns will inevitably be low. It will also be impossible in most cases where land is in the process of being degraded because the factors leading to a situation where degradation is occurring are likely to make fertilizer use impossible.

Wise use and recycling of organic materials, by minimising nitrogen losses, can go a long way to minimise degradation in progress. But it can do little to restore nitrogen capital that has been lost, except where special supplies can be brought in from other areas where they are in surplus. We are therefore left with the need to find a major source of nitrogen, which is readily available, easy to organise, and entails little or not extras in order to get it to operate.

The use of nitrogen-fixing species is the one obvious method which meets all these requirements. The species are mostly members of the family Leguminosae with their associated root-nodule organism, *Rhizobium*. But there are some notable species, such as *Casuarina equisetifolia*, which belong to other families and whose N-fixation is due to other micro-organisms. The levels of N-fixation that these species can achieve is remarkable. Even in the rather restricting conditions of totally skeletal materials produced by mining, in a cool temperate climate, annual nitrogen accumulation rates of 100-150kg N ha^{-1} can be produced by normal agricultural cultivars (Dancer *et al.* 1977). Wild established plants of *Lupinus arboreus* under the same conditions can achieve 185kg N ha^{-1}.

There is plenty is similar evidence. However, not all species can achieve these rates, and many have ecological requirements that either preclude them from certain soil where they would be valuable or require that the soil be ameliorated in some way, for instance by the addition of phosphorus. Other species, however, have surprising tolerance to special soil conditions, such as the aluminium and manganese toxicity found in acid soils.

A great deal of work has been done to find species with appropriate adaptations and effectiveness. The work of the Division of Tropical Pastures of CSIRO at Brisbane in Australia is outstanding, but it has been concerned with species suitable for pastures (Moore 1975). There is a good review of valuable tropical legumes (National Academy of Science 1979), but little about legumes for degraded land. A great deal of general knowledge has accumulated, from practical experience, about species suitable for the restoration of degraded land (Table 5.1) (Bradshaw & Chadwick 1980), but the information is really very limited.

In my experience of degraded land restoration in many different parts of the world, the usual position is that, firstly the importance of N-fixing plants is often only poorly understood, secondly where it is understood reliance is placed on one or two species only which have been found to be good elsewhere (such as *Leucaena leucocephala*), and thirdly little or no attempt has been made to find, or even assess the value of, other species. Yet the Leguminosae is an enormous family, and there are other groups of N-fixing species also. At the species level there is, therefore, room for a great deal more work. The experience of the CSIRO group shows that suitable species may come from anywhere in the world.

But there is also the need to work within species, at the level of ecological race and even population. The enormous diversity that can be found within species, much of it critical for ecological adaptation, is well documented. This diversity can certainly be found within members of the Leguminosae, for instance *Trifolium repens* (Snaydon & Bradshaw 1962).

5.4 Conclusions

All this argues that N-fixing species, particularly members of the Leguminosae, should be considered as one very important group of key species. There is considerable appreciation of their value as crop species already. Their importance as pasture plants is well understood. Recently their value in agroforestry has been realised. But their crucial importance in the restoration of all forms of degraded land is not fully appreciated, and certainly sufficient work to find and assess the most suitable species has not been carried out.

Degraded land provides a series of ecological and social constraints which species, to be used in restoration, must meet if they are to be successful. Some species are already known, and are being used successfully. But the problem of degraded land is so great and diverse, and the species and populations which might be useful so diverse and relatively unknown, that a great deal of work needs to be done.

It is the type of work which is best done as an international cooperative programme. The problem is shared by all countries. The suitable material may occur in any country. The expertise and experience of scientists from all parts of the world, especially those with good field knowledge of the species in their particular country, needs to be combined, if the best material is to be discovered and harnessed for the future of mankind.

Table 5.1 Perennial legumes suitable for the improvement of degraded land (from Bradshaw & Chadwick 1980)

Species	Soil preference*	Climate preference*
Amorpha fruticosa (indigo bush)	NC	W
Centrosema pubescens (centro)	AN	W
Coronilla varia (crown vetch)	AN	W
Desmodium uncinatum (silverleaf)	AN	W
Lathyrus sylvestris (mat peavine)	NC	W
Lespedeza bicolor (lespedeza)	AN	W
Lespedeza japonica (japan lespedeza)	AN	W
Lotus corniculatus (birdsfoot trefoil)	NC	CW
Lupinus arboreus (tree lupin)	ANC	CW
Macroptilium atropurpureum (siratro)	ANC	W
Medicago sativa (alfalfa)	NC	CW
Melilotus alba (white sweet clover)	ANC	CW
Melilotus officinalis (yellow sweet clover)	ANC	W
Stylosanthes humilis (townsville stylo)	AN	W
Trifolium hybridum (alsike clover)	ANC	C
Trifolium pratense (red clover)	NC	C
Trifolium repens (white clover)	NC	CW
Ulex europaeus (gorse)	ANC	C

* *For soil preference, A = acidic, C = calcareous and N = neutral.*
For climate preference, C = cool and W = warm.

5.5 References

Bradshaw, A. D. & Chadwick, M. J. (1980). *The Restoration of Land.* Blackwell Scientific Publications, Oxford.

Dancer, W. S., Handley, J. F. & Bradshaw, A. D. (1977). Nitrogen accumulation in kaolin mining wastes in Cornwall. II. Forage legumes. *Plant and Soil,* 48, 303-314.

Marrs, R. H., Roberts, R. D., Skeffington, R. A. & Bradshaw, A. D. (1983). In *Nitrogen as an Ecological Factor,* ed. J. A. Lee, S. McNeill & I. H. Rorison Blackwell Scientific Publications, Oxford.

Moore, R. M. (1975). *Australian Grasslands*. Australian National University Press, Canberra.
National Academy of Sciences (1975). *Tropical Legumes: Resources for the Future*. National Academy of Sciences, Washington.
Snaydon, R. W. & Bradshaw, A. D. (1962). Differences between natural populations of *Trifolium repens* L. in response to mineral nutrients. *Journal of Experimental Botany*, 13, 422-434.