Challenges in Dryland Agriculture — A Global Perspective

Proceedings of the International Conference on Dryland Farming

August 15-19, 1988
Amarillo/Bushland, Texas U.S.A.

107 Enhancing Biological Activity in Dryland Soils

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Introduction

The biological components of agricultural soils, excluding roots, comprise soil microorganisms and soil invertebrates. The diversity of these organisms is great, as is the complexity of sites within soil as habitats for these organisms. The major limitation to the activity of soil microorganisms is the availability of carbon substrate. Plant residues and root-derived compounds are the major carbon source for heterotrophic soil organisms. Agricultural practices and climate will dictate which organisms are active at any time due to changes in the chemical and physical environment of soil. It is realistic to attempt to understand how agricultural practices change the level of activity of beneficial organisms in soil, with the intention of assessing the potential for management to attain maximum soil fertility. Such management may include inoculation if particular organisms (e.g., root nodule bacteria) are absent.

With a knowledge of the abundance and activity of potentially beneficial soil microorganisms and an understanding that varying the soil physical, chemical, and biological environment can change the level of activity of particular organisms, what are the options for management to gain greater benefits from them? Microorganisms may play an important role in dryland agriculture by affecting the infiltration of water and its uptake by plants. First, water-stable aggregates may be formed either by mechanical binding of soil particles by microorganisms or by the production of microbial polysaccharide gums (Lynch and Bragg, 1985). Second, mycorrhizal plants may have a greater capacity to tolerate water stress than non-mycorrhizal plants. This greater capacity may be related to both improved phosphorus (P) nutrition (Nelson and Safir, 1982) and to an ability to deplete soil water to a greater extent (Bethlenfalvay et al., 1987). However, in this review we will concentrate on the role of soil microorganisms in affecting nitrogen (N) and P availability for plants in dryland agricultural soils. We will present an approach to managing vesicular arbuscular (VA) mycorrhizal fungi as an example of the procedures necessary for assessing the potential for management of soil organisms.

Enhancing Nitrogen Supply

Nitrogen available for plant growth in soil, with the exclusion of applied fertilizer, is derived either from mineralization of organic material or from biological N fixation. The mineralization of organic matter is a function of heterotrophic microorganisms, with some interaction with certain soil invertebrates. Whether or not mineralization leads to increased N availability for plant growth will depend on the timing of mineralization and nitrification in relation to uptake by plants and conditions which are conducive to nutrient loss via leaching. An understanding of how agricultural practices such as stubble management affect mineralization could be used in deciding whether the stubble is burnt, retained on the surface, or incorporated into the soil.

Biological N fixation is a major source of N in dryland farming where fertilizer N is expensive or not readily available. Nitrogen fixation by bacteria occurs either symbiotically with plants or by bacteria living freely in soil or in the rhizosphere of plants. Inoculation with suitable non-symbiotic N-fixing bacteria associated with roots is a possibility, but research so far has had mixed success (Jagnow, 1987). Nonsymbiotic N fixation may be enhanced in some environments by stubble management to provide suitable supplies of carbon released from organic matter by certain microorganisms for both free-living and "associative" N fixers (Roper, 1985; Halsall and Gibson, 1986). The widespread exploitation of these interactions among microorganisms has yet to be demonstrated, but would depend on the agricultural practices used in management of stubble, the type of tillage used, and the climatic conditions.

The most successful management of soil microorganisms has been with legume root nodule bacteria. Symbiotic N fixation has been established in areas of dryland farming where neither the host plant nor the required rhizobia were previously present. Initially, the appropriate management strategy was inoculation with selected rhizobia suited to particular legume species and soils. More recently, inoculation with more effective rhizobia which are saprophytically competent has been required, leading to difficulties in introducing the new strains into soils containing similar rhizobia which may compete with the inoculant strains for nodulation.

Agricultural practices may affect the abundance of established populations of rhizobia in soils. The practices that could affect the success of symbiotic N fixation include: (i) rotation, including the length of time between legume crops or pastures; (ii) tillage, which may affect the distribution of rhizobia in the soil profile, with cultivation spreading the bacteria more evenly within the surface layers, thus reducing the numbers in the vicinity of the germinating seed and possibly leading to reduced nodulation (Coventry et al., 1985); (iii) soil amendments such as lime may enhance the abundance of rhizobia that are not tolerant of increasing acidity related to some agricultural practices (Coventry et al., 1985); and (iv) gypsum, which may reduce nodulation (French, unpublished data). Application of N fertilizer may also affect the establishment of an effective symbiosis. Decreasing mineral N in soil by incorporating residues of preceding cereal crops may increase N fixation by crop and pasture legumes.

Important areas for future research are the selection of root nodule bacteria which are: (i) effective symbionts for new pasture and grain legumes, (ii) competitive with naturalized strains, and (iii) tolerant of environmental stresses such as soil acidity and low temperature (Robson and Abbott, 1987).

Enhancing Phosphorus Uptake By Plants

The management of VA mycorrhizal fungi in agricultural soils has potential for improving the supply of phosphate for many plant species (Abbott and Robson, 1987). These potentially beneficial fungi occur naturally in all agricultural soils. The actual benefit that they provide is not known and is not easy to measure. Species of VA mycorrhizal fungi differ in their ability to increase plant growth (under controlled conditions) and species of plants differ in their responsiveness to mycorrhizal infection (Abbott and Robson, 1984).

Agricultural practices can alter the abundance of VA mycorrhizal fungi in soils used for dryland farming. Fallowing can markedly reduce the population of fungi available to colonize subsequent crops (Thompson, 1987). Rotation can change the number of infective propagules (e.g., *Brassica* species), and lupins (*Lupinus* sp.) and wheat (*Triticum aestivum* L.) may reduce the infectivity for later sown crops or pastures (Hayman et al., 1975; Scheltema et al., unpublished data). Mixtures of plant species in pastures are likely to affect the number of propagules of the fungi for subsequent plant growth either due to differences in total root length or susceptibility of roots to colonization by VA mycorrhizal fungi. Tillage can change the distribution and abundance of propagules of the fungi in the soil profile (Smith, 1978), and in the limited number of studies examining the effect of grazing, the level of colonization of roots may be altered (Bethlenfalvay et al., 1987). Applications of herbicides apparently do not have adverse effects on the populations of VA mycorrhizal fungi in soils provided they are applied at recommended rates (Trappe et al., 1984). Other agricultural practices requiring further attention in relation to the ecology of VA mycorrhizal fungi in dryland soils are fertilizer practice (particularly levels of P supply and induced changes in soil pH) and the use of rotations of particular plant species that will build up the abundance of propagules of these beneficial fungi in the soil (France et al., 1985).

To determine whether it would be practical to attempt to manage VA mycorrhizal fungi by changing agricultural practice (including the option of inoculation), it is necessary to be able to predict the likely benefits of any change from current practice. For benefits to be gained from these fungi in addition to those that may already have been received, P must be limiting for plant growth. It is also necessary to ensure that the indigenous fungi are not already providing the maximum benefit possible. Currently it is not possible to (i) identify sites where mycorrhizal fungi are operating suboptimally, (ii) quantify the benefits that would result from changing the rate of infection or the timing of infection in relation to the P requirements of the plant, or (iii) change the species of fungi present in the soil. With existing knowledge, the most cost-effective management practice for a particular site cannot be selected.

Research Approach

The following approach to managing VA mycorrhizal fungi (Abbott and Robson, 1987) is an appropriate model for research aimed at enhancing the activity of beneficial soil organisms. As VA mycorrhizal fungi occur in all soils, the current benefits they provide need to be known. Perhaps they are already contributing at their maximum level. First, it is necessary to predict the response of plant growth in a particular soil to P supply and to mycorrhizal infection. What is the likely level of infection that is needed for maximum benefit? Thus, the relationship between root colonization and enhancement of plant growth is required for different plant species in different soils. What is the likely level of infection that will develop in plants growing in the field? Here a procedure for predicting infection development in field soils is required. This could be based on an understanding of the effects of agricultural practices on the population of mycorrhizal fungi in field soils, as well as the development of a plant bioassay to measure the current infectivity of the mycorrhizal fungi in the soil. This information could then be used to predict the likely level of infection for a particular crop or pasture if relationships are first established between the bioassay and the actual colonization of roots of plants in the same soils in the field.

If soils prove to have limited potential for mycorrhiza formation, inoculation with selected strains of the fungi may be an option. The other possibility is to change agricultural practices to enhance the abundance of mycorrhizal fungi. At this stage, further research is necessary to develop the relationships described above before the potential for managing VA mycorrhizal fungi to enhance phosphate uptake by plants can be assessed.

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