Soil Health: The Role of Microbes in Crop Productivity

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Microorganisms in soil regulate a wide range of processes that are critical for plant growth and crop productivity. A large, diverse and active soil biota could help provide soil conditions for sustainable cotton production through (i) crop residue decomposition and improvement of nutrient supplying potential of soils, (ii) preventing aggressive plant pathogens taking hold and improve plants ability to withstand disease effects, (iii) reducing the loss of inorganic fertilizers through erosion and leaching by short-term immobilization (iv) stabilizing soil structure and (v) reducing the reliance for agrochemicals and reduced persistence of pesticides in soil and thus less off-site impacts. In a high input cropping systems such as cotton, it is essential to maintain activities of key microbial groups to maximize input efficiency and to reduce non-target environmental negative effects.

Management practices and Soil microorganisms

Management practices used in cotton production affect soil microorganisms either through direct effects on populations and activity or indirectly through the modification of soil environment. They can be both beneficial and / or detrimental to the soil biota. The various management practices that influence microbial populations and their activities include: (1) tillage, (2) stubble retention, and (3) crop rotations, (4) application of fertilizers and pesticides, (5) irrigation and (6) soil compaction. Herbicide use is a vital component of modern agriculture; in particular under reduced till systems. With increased adoption of stubble retention and reduced till practices and the introduction of new herbicides, herbicide use will remain as an essential practice in the near future. More than one million kg active ingredients of herbicides are applied annually in order to obtain weed-free cotton fields in Australia (Charles, 1991). Non-target effects of herbicides on soil biological activities may (i) cause undesirable effects on essential nutrient cycling processes (e.g. reduced nitrification and nitrogen mineralization, nitrogen fixation) or (ii) promote the growth of deleterious microorganisms (plant pathogens) resulting in unexpected damage to crops through increased diseased incidence.

Non-target effects of herbicides could be either positive or negative. Figure 1 illustrates two basic types of inhibitions caused by herbicide application i.e. irreversible and reversible against the base line of a given population / activity remains constant (untreated control). If a specific herbicide has been shown to cause irreversible inhibition of key groups of microorganisms then avoiding its use is the simple and best option. The two reversible inhibitions shown in Figure 1 differ in the magnitude of maximum depression (the greatest difference between treated and untreated/control soil samples) and the duration of the herbicide effect (recovery period for the microbial function in treated samples to reach that in control soil samples). This information is essential for developing management options that either reduce the negative effects or compensate for the loss of a biological function. Management of the use of herbicides that cause reversible inhibitions is difficult, as reaching a balance between high herbicide efficiency and minimum non-target effects requires a better understanding of herbicide-microorganism-environment interactions.

Methods and Results of Our Research and Implications

Traditionally, pesticide effects on microorganisms are tested on individual organism populations or a specific biological activity. Population changes are difficult to interpret without knowing the effects on function. We used an integrated approach and measured the effects of herbicides on populations of key groups of soil biota and the associated processes they regulate (Gupta and Neate, 1998). In field experiments conducted at Narrabri, during 1998 and 1999 seasons, we investigated the effects of single application of pre- and post- emergence herbicides that are commonly used in cotton production (e.g. Fluometuron, Prometryn, Pendimethalin, Pyrithiobac, Diuron and Metolachlor) on a number of key microbial groups and the biological processes they regulate. Field experiments were conducted at sites in Auscott and ACRI farms, soil type was at both sites was self-mulching grey clay. Organic carbon levels in the surface soils ranged between 0.75 to 1.1% with a C:N ratio of ≥10:1, % clay >35% and moisture levels at field capacity were 35% and 29% (w/w) for Auscott and ACRI farms respectively. Each year surface soil samples (0-10 cm) were collected, using either a core sampler or troul, from field experiments within the first 8-10 days and 8-10 weeks after herbicide application. These sampling dates were chosen based on the results observed by VVSR Gupta in glasshouse and field experiments in other parts of Australia. Care was taken, during collection and transport (in Eski with ice) of soil samples to Adelaide laboratories, to reduce moisture loss and alterations to microbiological properties.

The biological parameters measured included: microbial activity, populations of cellulolytic bacteria and fungi, nitrifying bacteria, functional groups of decomposing microorganisms (BIOLOG plate method), and associated processes such as rate of nitrification, mineralization of nitrogen, mineralization of carbon (and activities of enzymes involved in cellulose decomposition) and the size and metabolic status of microbial biomass. Litterbag experiments were conducted to determine the effect of selected herbicides on cotton stubble decomposition (Cotoran, Gesagard, Staple, Stomp and Endosulfan). In this paper we present a brief discussion of the results and their implications.

In general, the levels of microbial biomass (<500 μg C / gram soil) and microbial activity observed for these soils (i.e. soils under cotton cultivation) are lower than that reported for soils of similar texture in this region. For example, microbial biomass carbon levels in clay soils (northern NSW and southern Queensland soils) under wheat or legume crops have been reported to be >750 μg C per gram soil. The effect of all herbicides was not negative, for example herbicides such as Prometryn had a negative effect on microbial biomass, the herbicide Fluometuron showed no negative effect in the short-term. In general the negative effect of herbicides on microbial biomass ranged from 10 to 50% compared to that in no herbicide treatment. Herbicide effects on microbial activity, cellulolytic populations were reversible and different for different herbicides e.g. not all herbicides had a significant negative impact (Figure 2A and B). Negative effects of some herbicides (e.g. Diuron, Pendimethalin) on cellulolytic bacteria disappeared within 10 weeks after herbicide application (Figure 2A). Recovery periods for cellulolytic bacteria and fungi were different for the same herbicide (e.g. Prometryn, Pyrithiobac) resulting in a significant shift in bacteria: fungi ratio. All these changes in the microbial biomass, microbial activity and populations of cellulolytic microorganisms resulted in significant impacts on the decomposition of cotton stubble. Results in litterbag experiments indicated that application of herbicides Pendimethalin, Pyrithiobac and Prometryn caused a significant reduction in the rate of stubble decomposition compared to the untreated cotton stubble. The significance of the observed changes in microbial populations and microbial activities including a period of microbial stress (i.e. inability of microorganisms to grow) involved in decomposition is that it may result in proliferation of opportunistic plant pathogenic fungi. Evidence for this has been reported by Gupta et al. (1998) for dryland wheat systems.

Single application of herbicides also caused a significant negative impact on the populations of nitrifying microorganisms, rates of nitrification and the mineralization of nitrogen. Once again most of the negative effects were reversible partly or fully within the study period.

We also determined the impact of herbicides used in cotton and in rotation crops (Imazethapyr, Prometryn, Diuron, Cyanazine, Imazethapyr + Simazine, Fluometuron, Diuron + Prometryn and Metribuzin) on the symbiotic nitrogen fixation by legume crops such as Vetch and

Fababeans. Our results indicated that herbicides such as Prometryn, Cyanazine, Diuron+Prometryn and Imazethapyr+Simazine significantly reduced the nitrogen contribution through symbiotic nitrogen fixation by fababeans. Whereas for the Vetch crop the effect of herbicides such as Fluometuron and Metribuzin was significant. Overall this work suggests that a careful consideration need to be given to the herbicide regime used in cotton and rotation crops in order to gain maximum benefits from legume-rhizobium symbiosis.

Summary & Future

A brief summary of our results is as follows:

1) A number of herbicides currently used in cotton soils have negative impact on key groups of microorganisms, for example Fluometuron and Pyrihiobac reduced microbial activity and populations of cellulose degrading microorganisms during a 10 week period following herbicide application.
2) Most of the negative effects were reversible partly or fully within 10-weeks after herbicide application.
3) Some herbicide caused a significant shift in bacteria:fungi ratio and reduced decomposition of stubble
4) Not all herbicides applied in cotton had negative impact on symbiotic nitrogen fixation by legumes in rotation

Our results are based on a single application of individual herbicides where as multiple applications of a wide array of herbicides in a single season is a common practice. Even though the effects of single application were reversible, the impact of additional herbicides applied prior to the full recovery may result is currently not known. This information is critical for an effective management of herbicide use in cotton with minimal non-target effects on soil microorganisms and microbial processes.

Intensive cultivation, stubble burning and judicious use of pesticides have been an integral part of cotton growing in Australia. Recently different levels of reduced cultivation practices and a more prudent use of agrochemicals are being investigated and incorporated in to cotton production in order to develop a more sustainable cotton farming systems. Our research provides one set of information on soil microorganisms and microbial processes that will help achieve this goal. Research from other farming systems suggest that retention of crop residues, reduced tillage, legumes in crop rotations, moderate use of agrochemicals are some of the management practices that could enhance biological activity and result in a balanced detritus food web which would help achieve a sustainable cotton production system.

In this talk we propose to discuss the implications of our findings in relation to getting maximum benefits from soil microorganisms and the development of sustainable cotton production systems.

References

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