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Review paper

Challenges and opportunities in harnessing soil disease suppressiveness for sustainable pasture production

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ABSTRACT

Grasslands are an important source of biodiversity, providing a range of essential ecosystem services such as ensuring water quality and soil carbon storage. An increasing proportion of grasslands are used for pastoral agriculture, supporting production of domestic livestock. Pasture productivity is significantly affected by soil-borne microbial pathogens. Reducing the impact of soil-borne diseases in pastures is challenging given the complexity of interactions within the soil/rhizosphere microbiome and the diverse impacts of vegetation, land management, soil conditions and climate. Furthermore, there are fewer opportunities to control plant pathogens in pastures compared to arable cropping systems. The greater diversity of vegetation leads to the development of more diverse and less well characterized pathogen complexes, and the application of agrochemicals for control of soil-borne diseases is economically prohibitive and ecologically undesirable. Soil-borne plant pathogens can be suppressed through the general activity of the total soil microbiota acting in competition with the pathogenic microbiota, or by increases in the abundance and activity of specific microbes or microbial consortia that are antagonistic against selected pathogens. The development of strategies that enhance disease suppressiveness in pastures will depend not only on phylogenetic assessment of microbial communities, but also on a mechanistic understanding of the functional potential and properties (i.e. disease suppressive traits) of the soil microbiome. Collectively, this fundamental knowledge will be essential to identify the factors driving the emergence of desired disease suppressive microorganisms and traits. To understand and predict disease suppressive functionality, the spatial and temporal variability of the soil and plant-associated microbial populations and their activities must be taken into account. A systems-based approach is therefore required to identify the obstacles and opportunities related to controlling plant pathogens in pasture systems. Such an integrated approach should incorporate a "microbial" perspective to examine traits, drivers and activities of soil-borne microbes, while utilizing emerging tools in ecological genomics, as well as computational, statistical and modelling approaches that also accommodate the chemical and physical complexity of soil ecosystems.

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1. Introduction

Grassland ecosystems represent one of the most extensive types of land cover globally, representing approximately 40% of the Earth's ice-free land surface (White et al., 2000). Grasslands are important sources of biodiversity, support production of grazing animals, provide essential ecosystem services such as ensuring water quality and soil carbon storage and, in many areas, have considerable touristic and recreational value. An increasing proportion of grasslands are used to support production of domestic livestock, and the sustainability of pastoral-based agriculture is of great economic importance to many countries reliant on pasture-derived production for both domestic and export purposes.

In New Zealand, for example, approximately 30% of the total land area is used for high-producing pastoral agriculture (Statistics New Zealand, 2012). As the foundation of the dairy, meat and fibre industries, pasture is the country's most important agricultural system (Harvey and Harvey, 2009) and thus, it's protection and development is imperative for sustainable economic growth. As the pastoral sector undergoes increasing intensification globally, changes in soil fertility, botanical composition, and grazing management are occurring at a rapid rate. These changes provide new abiotic and biotic contexts within which pasture diseases may emerge.

Although often not recognized, soil-borne plant diseases result in significant production losses (Janvier et al., 2007), and they are known to drastically reduce the efficiency (plant production per unit use) of water and nutrients (Baligar et al., 2001). As the symptoms of soil-borne diseases primarily manifest belowground, production losses are difficult to quantify and are consequently greatly underestimated. Although production losses quantified in monoculture systems may not be directly indicative of losses in multispecies grasslands, an array of transferable knowledge regarding plant disease, and suppression thereof, has been acquired from grass-based agricultural systems of importance for food production. Comprehensive studies on well characterised agricultural systems of wheat and other cereals report highly variable yield increases in response to soil pathogen eradication of up to 113% (average ≈ 43%), with the variation reflecting differences in crop type, pathogen virulence and levels, and the specific disease mitigation strategies used (Raaijmakers et al., 2009).

The control of soil-borne diseases remains an intractable challenge. In intensive agronomic systems, cultivation practices such as crop rotation, breeding for resistant cultivars and the application of synthetic fungicides provide, at best, only partial control of some diseases (Haas and Défago, 2005; Bonanomi et al., 2010). Furthermore, the use of soil fumigation with certain broad spectrum chemicals, such as methyl bromide, has been phased-out globally (United Nations Environment Programme, 2012). The inconsistent control provided by conventional techniques, in addition to increasing public concern about the effect of agrichemicals on environmental and human health, is driving renewed research interest in environmentally benign methods for the control of plant pathogens (Raaijmakers et al., 2002).

Disease suppressive soils, through the competitive activity of the resident total soil microbiota (general suppression) or the antagonistic capabilities of specific groups of microorganisms (specific suppression), are able to reduce the occurrence or severity of disease caused by soil-borne phytopathogens (Weller et al., 2002). The management of soil ecosystems towards a state of increased disease suppressiveness represents one of the methods by which sustainable disease control may be achievable. In contrast to the black-box approaches of previous decades, the availability of high throughput community characterisation techniques provides new possibilities for the ecological assessment of disease suppressive components in complex agricultural systems. Here, we examine the challenges and opportunities of harnessing the microbial basis of naturally occurring disease suppressive soils for sustainable pasture production. As a model system, we focus on the pastoral sector of New Zealand, as this provides a diverse mosaic of high- and low-input grassland systems, which are highly representative of grasslands across a wide range of global regions.

2. Pasture pathology: pathogens and associated production losses

Pastoral agroecosystems differ in a number of important ways from other forms of agricultural production. Pastures are typified by having a mixed botanical composition often including grasses, legumes, and herb species and may also include forage brassicas used in rotations. These mixed swards may include annual and/or perennial species, with the botanical composition usually selected for its suitability within wider agroecological conditions such as climate, soil fertility, drainage and pest, weed and grazing pressures, as well as required growth rates and timing to meet livestock needs. Belowground, the structure and composition of the soil microbial community in pastures continually changes through plant-based selection. This selection is driven by seasonal changes in plant growth and the characteristics of dominant plant species (Kennedy et al., 2005), as well as the impacts imposed by fertiliser inputs, grazing and other management characteristics (Wakelin et al., 2009). Plant species-dependent responses to high plant diversity have further implications for soil microbial communities. For example, increased root biomass, by vertical niche differentiation (Mueller et al., 2013) or interspecific growth stimulation (Mommer et al., 2010), increases the potential for plant root-driven