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ARE PERENNIAL CROPS MORE ADAPTED TO MAINTAIN LONG-TERM RELATIONSHIPS WITH SOILS AND, THEREFORE, TO SUSTAINABLE PRODUCTION SYSTEMS, SOIL RESTORATION AND CONSERVATION?

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ABSTRACT

Developing perennial crops involves many challenges, such as combining perenniality with high yield. However, attention also needs to be given to the sensitivity of perennial crops to tolerance for or resistance against pests and pathogens. Here, I discuss why it is important to consider soil-borne enemies and propose three avenues for further research.

Keywords: learning from nature, succession, plant traits, soil food webs, pathogens, ecosystem processes

Most major food and feed crops in the world have been derived from annual early successional plant species (Diamond, 1997). Traits that characterize early successional plant species are ephemeralism, preference for disturbed sites, low nutrient use efficiency, and pathogen sensitivity, however, such trait combinations in crops require crop rotation, land tillage, fertilization, and biocide use to control belowground and aboveground pests and pathogens. These requirements are a major constraint for sustainable agriculture, as they result in production of greenhouse gasses, loss of organic matter, nutrient leaching to ground- and surface water, and pollution of the environment with toxic biocides. Developing perennial crops could be a solution for circumventing intensive soil disturbance. However, early successional perennials also have adverse trait combinations that require intensive management practices. The question is what may be learned from nature when aiming at producing sustainable perennial crop production systems. I will discuss some research highlights on secondary succession following land abandonment in order to elucidate how soil food webs and soil ecosystem processes may respond to both changes in management and plant trait characteristics of early, mid, and late successional annual and perennial plant species.

Reducing land tillage and fertilization results in a development of the soil biodiversity and soil food web composition, which affects the mineralization and cycling of nutrients in ecosystems (De Vries *et al.* 2013). Such ecosystems could also be more resistant to extreme events, such as drought stress during the growing season (De Vries *et al.* 2012). Changes in soil food web composition and functioning are to some extent related to the presence of plant species with specific traits (Bezemer *et al.* 2010), whereas in part they are due to successional developments that are the result of reduced intensity of land use practices (Holtkamp *et al.* 2011). Insights from (semi-) natural ecosystems may stimulate thinking about how perennial crops could be developed in such a way that they will further enhance the sustainability of agriculture.

In a series of studies on the contribution of soil biota to vegetation development on abandoned ex-arable land, it was shown that early successional plant species had negative feedback interactions with the soil biota, both with soil fauna (De Deyn *et al.* 2003) and soil microbes (Kardol *et al.* 2006). Negative plant-soil feedback means that plants stimulate pathogenic components in the soil community more than symbiotic or mutualistic components, such as arbuscular mycorrhizal fungi (Bever *et al.* 1997). These negative feedback effects were not only evident in annual plant species, but also in (short-lived) perennials (Van de Voorde *et al.* 2011). Some plant species had positive feedback with the soil community, but those effects were more confined to later successional, slow growing plant species (Kardol *et al.* 2006). These species appeared to be promoted by the soil biota that were developing in their rhizosphere. However, this trait turned out to be combined with slow growth, which will be less desirable for plant species that are targeted for primary production.

Whereas these results are based on studies on non-cultivated (wild) plant species and mostly limited to temperate habitats, an increasing amount of studies is showing that negative plant-soil feedbacks occur in many early successional plant communities, independent of climate and soil type (van der Putten *et al.* 2013). Therefore, if annual crops are being developed into perennial crops, the advantage of perenniality, which will undoubtedly benefit the sustainability of soils, soil biodiversity, and counteract soil erosion due to reduced soil tillage, might be counteracted by the fact that crop ageing may go hand in hand with yield declines due to increasing exposure to soil-borne enemies, such as pathogens, root-feeding nematodes and herbivorous insect larvae.

There are several possibilities for counteracting these unwanted side effects of perenniality in crops, which may be accounted for in crop developing programmes. Thus far, there is little attention for these aspects and the question is how they may be accounted for. Here, I will provide three suggestions, which may need to be explored in subsequent studies. First, perennial crop varieties may vary in their susceptibility for negative plant-soil feedback development. Testing this would require screening of potential crop varieties in soils while allowing negative plant-soil feedback to occur. Recording effects of ongoing growth on temporal yield development and repetitive sowing in these soils may provide insight in the development of growth reducing soil biota. Second, the rhizosphere microbiome (Mendes *et al.* 2011) may be examined in order to test effects of perennial crop varieties on the development of a microbial community that may be antagonistic to major soil-borne pathogens and herbivores. Third, perennial crops may need to be grown in rotation, just as is being done with annual crops, in order to reduce the potential of soil-borne enemies between subsequent growth cycles. The main difference with current agriculture would be that crop rotations take many years, as each crop will be grown for several years in a row.

In conclusion, I wish to emphasize that the development of perennial crops may require prevention of negative side effects, such as the development of soil-borne pathogens. Perennial crops still have characteristics of early successional plant species, which make them sensitive to soil-borne enemies and, possibly, also aboveground pests and pathogens. Perennial crop development programmes, therefore, need to account for these unwanted side effects and I have proposed three avenues, but there will be clearly more possibilities to explore. The main point is that perennial crop development not only has to pass the hurdle of developing perennial varieties, but also of testing these varieties for resistance against, or tolerance of belowground and aboveground pests and pathogens. When accounting for these additional requirements, screening programmes may avoid future problems with e.g. yield declines in later years of perennial crop growth cycles.

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