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Reinstating soil microbial diversity in agroecosystems: The need of the hour for sustainability and health

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ABSTRACT

It has been reported that collapse of soil microbial diversity, mainly due chemical inputs leads to degradation of conventional agroecosystems. Indirect methods related to manipulation of plant and animal components in the ecosystems have been currently practised to reinstate the microbial diversity. However, those methods are laborious and time-consuming, and hence less efficient. Also, there are limits to those management methods due to ever increasing global food demand, particularly in tropics. Therefore, we have to look for methods that sustain productivity of large-scale conventional croplands even with continuous mono-cropping. This article reports that direct soil application of developed microbial communities in biofilm mode increases microbial diversity in the agroecosystems through breaking dormancy of microbial seed bank. That contributes to strengthen biodiversity–ecosystem functioning relationship, which leads to agroecosystem sustainability.

1. Introducing the problem

World food production is in jeopardy from conventional farming methods that have degraded soils and polluted water, and caused the loss of animal and plant biodiversity. Biodiversity loss frequently increases disease transmission (Keesing et al., 2010) and buildup of allelopathic compounds, resulting in gradual decline in crop productivity and ultimate dieback of plants (Papatheodorou et al., 2008). It is reported that 40% of global agricultural lands is already degraded, as reflected from greatly reduced yields, and a further 9% is degraded to the level that they cannot be reclaimed for productive use by farm level measures (Bossio et al., 2010). Sustainable land management methods such as land sharing/sparing, organic agriculture, crop rotation, and so on have been proposed as a unifying theme for current global efforts on combating the loss of biodiversity, desertification and climate change (Thomas, 2008; Phalan et al., 2011). However, there are limits to those management methods due to ever increasing global food demand, particularly in tropics. Therefore, we have to look for methods that sustain productivity of large-scale conventional croplands even with continuous mono-cropping.

It is apparent that we have not fully understood or considered the importance of microbes in sustainability of conventional agriculture. In sustaining the productivity of croplands, we have been manipulating frequently plant and animal components in the agroecosystems, as mentioned above, which are more laborious, time-consuming and less efficient. Although we have learned in theory that there are interactive controls between biodiversity (species identity in particular) and functionality, including productivity (Nadrowski et al., 2010; Isbell et al., 2011), which determine sustainability, we have not properly tested this for possible field applications. It has now been shown that the collapse of microbial communities, particularly N_2 fixers mainly due to chemical inputs leads to reduced plant diversity, as indicated by the study of van der Heijden et al. (2006), and agro-biodiversity in general (Hadgu et al., 2009). It has also been confirmed that even in natural ecosystems like forests, soil microbes play an important role in determining plant species diversity (Mangan et al., 2010). The N_2 fixers play a key role in the growth and persistence of effective soil microbial communities by supplying nitrogen through N_2 fixation (Singh and Amberger, 1998; Seneviratne et al., 2008). Disturbances to the ecosystem balance, caused by the stress factors promote negative environmental impacts on agriculture such as pests (Birkhofer et al., 2008) and pathogens, and also reduce internal biological actions and cycles, adversely affecting sustainability. This eventually leads to degradation of the agroecosystems.

2. Proposing remedial measures

It is obvious from the above facts that soil microbial communities play an important role in determining plant diversity, and hence other components in the ecosystem. Then, the question arises here is that since the ecosystem components are interrelated, can we manipulate the microbial communities, the easiest

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constituent to handle, in order to maintain biodiversity, productivity and sustainability of the agroecosystems? Evidences show that this can be done. So, why do not we apply directly developed microbial communities to the soil, rather than manipulating relatively less efficient plant and animal components to reinstate sustainability after reviving collapsed soil microbial communities, which may take few years?

Direct application of developed microbial communities in biofilm mode called biofilmed biofertilisers (BFBFs) has been shown recently to start restoring depleted tropical cropland soils, soon after their application, within 1–2 months, with better yields (Seneviratne et al., 2011). Interestingly, the BFBFs have shown that they can produce equal or even relatively high yields with only 50% of recommended chemical fertilisers of several crops, in comparison to 100% of the fertilisers, from the first year of their application. In addition, they contribute to increased soil carbon sequestration and reduced greenhouse gas emission, which lead to mitigate global warming. In fact, manipulating plant and animal components to get better agroecosystems in the long run can be done concomitantly, while the farmers can harvest a better crop with the BFBFs even from the onset of restoration of the deteriorated lands, without letting them to wait till the soil gets improved.

It is now proven that the BFBFs are more effective than conventional mono or mixed cultures of microbial biofertilizers. A major role of the BFBFs in the soil is the increase of microbial diversity, thus improving ecosystem functioning and sustainability. Interactions among microbes in the BFBFs have been observed to release diverse compounds (e.g. low molecular weight sugars, amino acids, etc., G. Seneviratne, unpublished), which induce to break dormancy of cyst, spores, akinete, conidia, etc. in the soil microbial seed bank (Saini et al., 1986; De Boer et al., 2005). When such compounds become increasingly available, it also allows resuscitating microbial cells to grow with a broader substrate spectrum (Lennon and Jones, 2011; Teeling et al., 2012). Thus, it is clear that the application of the BFBFs tends to break dormancy of microbial seeds, which causes emergence of a diverse microflora. On contrary, it is well known that chemical fertilizer application collapses microbial communities, leading to emergence of a community with a low diversity. In some cases, cell-to-cell communication via quorum sensing is reported to allow resuscitating cells to break dormancy of other dormant cells (Lennon and Jones, 2011). In biofilm formation, quorum sensing is a prerequisite, which helps establish the biofilm. Therefore, the role of BFBFs in breaking dormancy of the microbial seed bank in this manner is also obvious. These processes contribute to strengthen biodiversity–ecosystem functioning relationship (Langenheder et al., 2010), which leads to ecosystem sustainability (Tilman et al., 1996).

To promote quick and easy, novel biotechnologies like these in conventional agroecosystems for reinstating microbial diversity, scientists should take the lead, first to test, and then to adopt and popularize them among farming communities. This is the need of the hour in order to rapidly reversing speedy biodiversity loss and deterioration of agroecosystems, particularly in tropics.

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