4.2.1 Soil biodiversity as affected by no-till versus conventional tillage

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Tillage systems and global trends

The plough has always been a strong symbol of modern agriculture (Fig 1a). However, adoption of no-till farming has gradually increased since the 1970's as a way to deal with problems of soil erosion. The availability of herbicides as an alternative to ploughing for weed control played an important role. Starting in South and North America, no-till farming has spread to Australia, parts of Asia, and to a lesser extent, Europe and Africa (Table 1). The area of no-till arable land is estimated at 11 million ha globally, and covers a wide range of climates, soil types and crops. No-till systems minimize mechanical soil disturbance by using direct seeders (Fig 1b) and allow for the maintenance of a permanent soil cover in the form of crop residues or cover crops. These practices include appropriate crop rotations to prevent the building up of pests and diseases. Systems that combine these three principles are known as Conservation Agriculture (Fig 2).

Fig 1. The mouldboard plough (a) is a strong symbol of modern agriculture. Alternatively direct seeders are used in no-till agricultural systems (b). Photos: M.Pulleman (left) and CIMMYT (right).

Besides erosion control and water conservation, reduction of production costs is an important driver of no-till adoption. No-till, when combined with crop residue retention and/or cover crops, can have important benefits for soil life. On the other hand, the soil organisms are considered even more important for soil functioning and crop production in no-till soils, where they take over some of the functions otherwise initiated by regular ploughing, such as breaking of soil compaction, organic matter incorporation and nutrient mineralization.

Table 1. Area under no-till per continent (Derpsch et al 2010)

Continent	Area (hectares)	Percent of total/%
South America	49,579,000	46.8
North America	40,074,000	37.8
Australia & New Zealand	17,162,000	11.5
Asia	2,530,000	2.3
Europe	1,150,000	1.1
Africa	368,000	0.3
World total	115,863,000	100

Fig 2. A typical no till system with crop rotation and residue retention. Photo: CIMMYT

How does soil tillage impact on soil biodiversity?

Tillage can have detrimental effects on soil life. However, some organisms are more affected than others, depending on feeding strategies, habitat preferences and reproductive capacity. Harmful impacts can be direct (e.g. body damage or increased predation; Fig 3). In the longer term the indirect effect of habitat disturbance is probably more important. Soil tillage, especially when the soil is inverted, results in the incorporation of crop residues and destroys pre-existing burrows or nest structures. This strongly affects epigeic soil organisms (feeding on plant litter at the soil surface) and soil ecosystem engineers (see below). A third mechanism is the change in soil moisture and temperature, with bare, ploughed soil being more prone to fluctuations and extremes.

As a general pattern it has been shown that soil fauna with larger body sizes and slower reproduction/longer generation times are most sensitive to the impact of ploughing.

Fig 3. Seagulls feeding on earthworms and other soil fauna during ploughing (Photo Christopher Furlong-Getty Images)

No-tillage management also increases the importance of fungi relative to bacteria as primary decomposers, while ploughing creates conditions favourable to bacteria that are more disturbance-adapted and have higher metabolic rates. These changes can have important consequences for the structure of the soil food web in no-till versus ploughed soil and subsequently for organic matter decomposition and nutrient dynamics. (Fig 4).

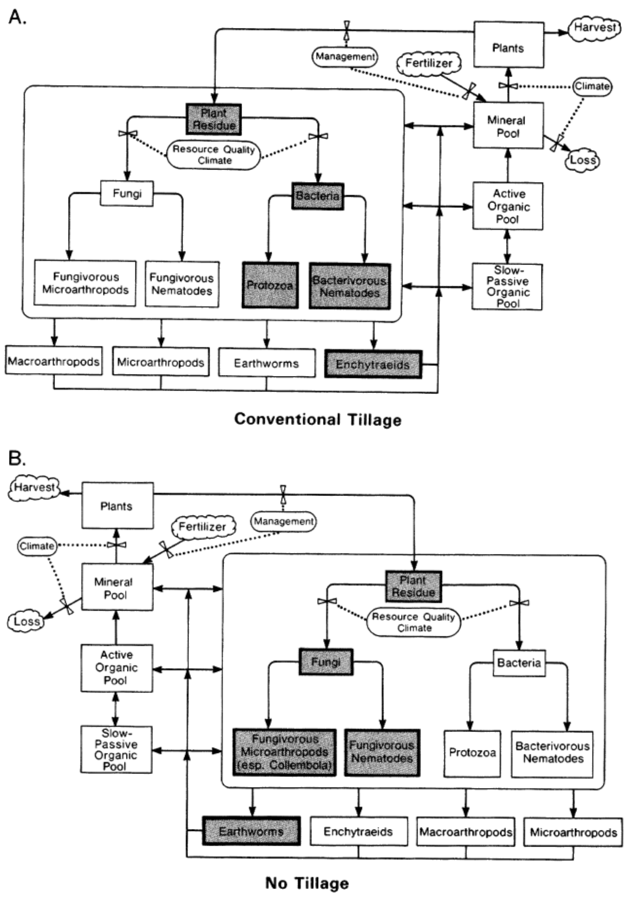

Fig 4. Two conceptual models of detritus food webs in conventional-tillage (A) and no-tillage (B) agroecosystems, based on soil community data from a long term field experiment. Boxes = nutrient storages, clouds = nutrient sources or sinks, and arrows = nutrient transfer pathways. Valves on arrows indicate that nutrient transfers are influenced by factors connected with dotted lines (Hendrix et al. 1986).

The incorporation of crop residues and manure in conventional tillage systems is associated with fast turnover of decomposer biomass, resulting in rapid organic matter decomposition and nutrient mineralization. Conversely, no-till systems are characterized by accumulation of crop residues at the soil surface and concentration of soil organic matter in the upper cms of the soil. Fungi and fungal grazers are comparatively more important and nutrient mineralization is often delayed due to higher nutrient immobilization. This will change the synchrony between nutrient availability and crop needs and can result in crop nutrient deficiencies, or, on the positive side, reduce nutrient emissions from the system. In practice the outcome in terms of nutrient use efficiency will depend on interactions between crop type, organic matter quality, soil type and climatic conditions. Changes in nutrient dynamics should therefore be accounted for when optimizing management of a no-till system.

No-tillage and soil ecosystem engineers

Termites (Fig 5) and earthworms are called soil ecosystem engineers. Their feeding, burrowing and nest building activities strongly affect the soil structure and they can incorporate large amounts of organic matter into the mineral soil. By modifying the habitat of other organisms they indirectly affect flows of energy and nutrients. Their impact on soil physical conditions can be impressive. Earthworms contribute to stable soil aggregation and both earthworms and termites can break soil crusting and greatly improve rainfall infiltration. Soil ecosystem engineers can thus have a key role in (agro)ecosystem functioning.

Fig 5. Termites (left) are the dominant ecosystem engineers arid to sub-humid tropical climates (Photo: P. Renoux)

It has been found that no-till systems generally support larger and/or more diverse earthworm communities. A shift in relative abundance of different ecotypes is also observed. Especially epigeic and anecic species that feed at the soil surface benefit from no-till, whereas endogeic species that live and feed inside the mineral soil do well in ploughed systems where crop residues are incorporated (Fig 6).

	Plough	Disc harrow	Mulch sowing	Direct sowing
Anecic	4.7 ± 5.3 a	18.7 ± 10.6 ab	21.3 ± 10.3 b	19.3 ± 9.9 ab
Endogeic	26.7 ± 8.3 c	20.0 ± 10.1 bc	21.3 ± 9.7 bc	2.7 ± 4.1 a
Epigeic	1.3 ± 2.1 a	7.3 ± 4.7 a	5.3 ± 4.8 a	6.7 ± 7.0 a
Juvenile	86.7 ± 20.9 a	114.0 ± 46.4 a	84.7 ± 33.2 a	128.7 ± 53.3 a
Total	119.3 ± 23.2 a	160.0 ± 53.2 a	132.7 ± 29.9 a	157.3 ± 62.9 a

Fig 6. Effects of different tillage systems (duration 10 yrs) on earthworm densities (ind m^{-2}) and community composition in Germany (Ernst and Emmerling, 2009).

Less is known about the impact of tillage on termites, although it is generally assumed that soil disturbance negatively affects species that build subterranean nests. Foraging on crop residues by termites can be a challenge to maintaining an organic soil cover in tropical no-till systems (Fig. 7).

Fig 7. Crop residue cover in no-till plots in Western Kenya with termite activity (left) and plots in which termite have largely been eliminated with targeted pesticides (right). Photo: M. Pulleman.

No-tillage and arbuscular mycorrhizal fungi

Arbuscular mycorrhizal fungi (AMF) are an integral component of terrestrial ecosystems, and form symbioses with most plant families, including agricultural crops. In this symbiosis plants supply sugars to AMF and in return receive nutrients, such as phosphorus and nitrogen. AMF can also increase drought tolerance, suppress diseases while their extraradical hyphae can bind soil particles mechanically and chemically to form stable aggregates. AMF are mostly negatively affected by soil tillage via different mechanisms that affect the propagation structure of AMF, i.e. spores, extraradical hyphae and colonized root segments.

Fig 8. Mycorrhizal fungal filaments around a plant root

One of those mechanisms is the dilution of spore numbers due to soil mixing. More importantly, tillage destroys the mycelial network and reduces mycorrhizal infectivity, thereby affecting nutrition acquisition especially at the early stages of crop growth. Tillage reduces both AMF densities and species richness. Drastic shifts in community composition indicate that different AMF species vary in their tolerance to tillage. Indirectly, modifications in physical soil properties or soil nutrient contents in response to soil tillage, as well as changes in weed populations that act as host plants, can influence soil microbial numbers, diversity and activity, including AMF communities. On the other hand, long-term no till farming can also result in soil surface hardening which is unfavorable for AMF propagules distribution.

References and further reading

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