After the plough

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AGRICULTURE & CONSERVATION • JAMES MERRYWEATHER

SECRETS OF THE SOIL

The key to healthy soil is the vast web of complex symbiotic relationships.

THE GARDENER'S JOY is to straighten up after a day spent tilling the soil, to gently massage his or her aching back and heave a satisfied sigh, surveying the prepared land, now ready for planting. The weeds have all been composted and the seedbed is ready to nurture flowers or food. Equally satisfied, the farmer leans on the field gate confident of maximum yield from the crop. In both cases a fine yield can be assured by the addition of fertiliser and some well-directed pest control. Why is it necessary to add anything else? Because something is missing: the microbes that mediate in nutrition and biodiversity, and reduce the impact of pests and disease to levels an ecosystem can tolerate.

If, from earliest times, we had understood how soils worked and had developed agriculture in sympathy with soil organisms, we would never have chosen to use the intensive agricultural practices that have done so much harm to soils and landscapes. The plough makes life easy, but it doesn't account for the way plants really grow and living soils function, undisturbed. Tillage has created the necessity for continual intervention and chemical assistance. Before humans, who ploughed the land and added fertiliser and pesticides? Wild ecosystems are self-sustaining, with a social structure based on co-operative interaction and nutrient recycling.

SYMBIOSIS IS A major driving force for every living organism on the planet. All living creatures – animals and plants, bacteria, fungi and others – are involved in a worldwide, multi-layered web of co-operation. Symbiosis is not an occasional curiosity: it is absolutely everywhere. It is usually defined as two organisms combining for mutual benefit – a vast oversimplification. First, drop the idea of mutual benefit. Profit and loss in symbiosis can vary in any temporal and spatial dimension. Benefit to its components can be more or less equal, but it is frequently a one-sided affair, at least for a while, after which benefit may swing to another member of the association; a previous consumer might become net contributor. Also, forget about involvement of just two organisms. Symbiosis can occur between any number of organisms greater than one, at any scale from what we might consider to be an individual to continent-wide organisation. Symbiosis is infinitely variable.

The soil to which trees, shrubs and herbs are attached contains at least 50% of the biomass of any ecosystem and several times the number of species found above ground. Intact soil is the most diverse interactive web of interdependent organisms on Earth, but it is solid, dark and impenetrable. Since we cannot look into soil to see what is going on and understand it, we discount its importance and destroy its very life as we remove trees and clear away all the other nuisance vegetation so that we may "plough the fields and scatter the good seed on the land." Soil organisms, in mind-bogglingly complex interaction, support the above-ground flora and food webs upon which we rely for our existence, whilst the same above-ground flora support soil communities.

Mycorrhiza is a symbiotic association of a fungus and the roots of a plant. It is arguably the fundamental life process on land. Its most usual function is to facilitate plants' supply of phosphate. This essential nutrient generally occurs at low concentrations in natural soils and is mostly held tightly by soil particles, unavailable. Mycorrhiza provides the remedy. For instance, the roots of Britain's favourite wild flower, the bluebell (*Hyacinthoides non-scripta*) operate in an environment where phosphate is available in soil solution at less than 0.1 part per million. Bluebells cannot survive if non-mycorrhizal, for their short, thick roots are incapable of exploring the soil for inaccessible nutrients. Evolution and symbiosis have taken care of the problem. Bluebell roots are colonised by at least eleven different mycorrhizal fungi, most of which are unculturable, unidentifiable and new or unknown to science. They range out beyond the root system, some of them gathering otherwise inaccessible phosphate on behalf of their plant partners; in return they receive carbohydrate, a basic foodstuff they cannot produce themselves.

Around 500 million years ago, ancestral plants found phosphate acquisition uncomplicated in their primeval, aquatic habitat. It was not so easy when, rootless, they experimented with life on land. They collaborated with fungi as mycorrhiza, which enabled them both to live on land and diversify. From the start, co-operation with soil fungi was the normal way of life for land plants, and it still is for an estimated 90–95% of plants in all ecosystems on every continent.

From the outset, humanity's intervention set in motion a series of disasters for naturally self-sustaining, symbiotic communities. Yes, worms, rabbits and earthquakes all disturb the soil, but only in isolated patches that all the constituent species can rapidly recolonise. This sort of disturbance is built into soil ecological processes for it releases localised bursts of nutrients, which promote soil heterogeneity and ecosystem biodiversity. Intensive tillage affects vast areas, repeatedly exterminating soil organisms by exposure and also, in the case of the fungi, which form delicate, wide-ranging networks, causing fragmentation. Destroy mycorrhizal fungi and, though some can adjust, plants that are dependent upon them will die. The fungi themselves are not so adaptable: if separated from their plants, their only source of carbohydrate, they cannot survive. Therefore, if you remove the fungi, plant populations suffer, and if you remove the plants, you kill the fungi. Whether you take the viewpoint of the plants or the fungi, it is symbiosis that keeps them alive and symbiosis that is disrupted by humans, who must share the consequences.

MYCORRHIZAL PARTNERSHIPS CAN be highly specific and also very specialised. If components of a community are removed, community structure may soon be compromised. Remove a lot of them, and community structure will collapse. Ecosystem collapse is occurring with the progress of deforestation and intensive agriculture, and not just because wild plants are exterminated, but also because complicated webs of symbiotic partnership are disrupted.

Agricultural land, particularly in the 'developed' world, is probably a worse starting point for ecosystem restoration than bare rock thanks to contamination, and not just by pesticide residues. At low concentrations, soil phosphate is a nutrient in biological communities that can recycle it efficiently. In agricultural circumstances, where populations of mycorrhizal fungi are impoverished, we find we have to keep adding phosphate to soils so that crops will grow. Therefore, when it is added in large quantities as an artificial fertiliser and is not utilised or recycled, phosphate becomes a pollutant. Only phosphate in soil solution is available to roots unaided, and even then it does not flow in soil in the way that, say, nitrate solution does. Excess becomes attached to soil particles – stuck so that only specialist fungi can gather it – or is out of reach to the root system. Phosphate-rich soils favour non-mycorrhizal plants, and therefore ecosystems become permanently changed, usually not for the better.

> Few things matter more to human communities than their relations with the soil. The biology of soil is of fundamental importance to the sustainability of life on Earth – soil remains the least understood, and perhaps the most abused, habitat on Earth.
>
> – Richard Bardgett (*The Biology of Soil*, 2005)

COURTESY: CULTURE ARCHIVE

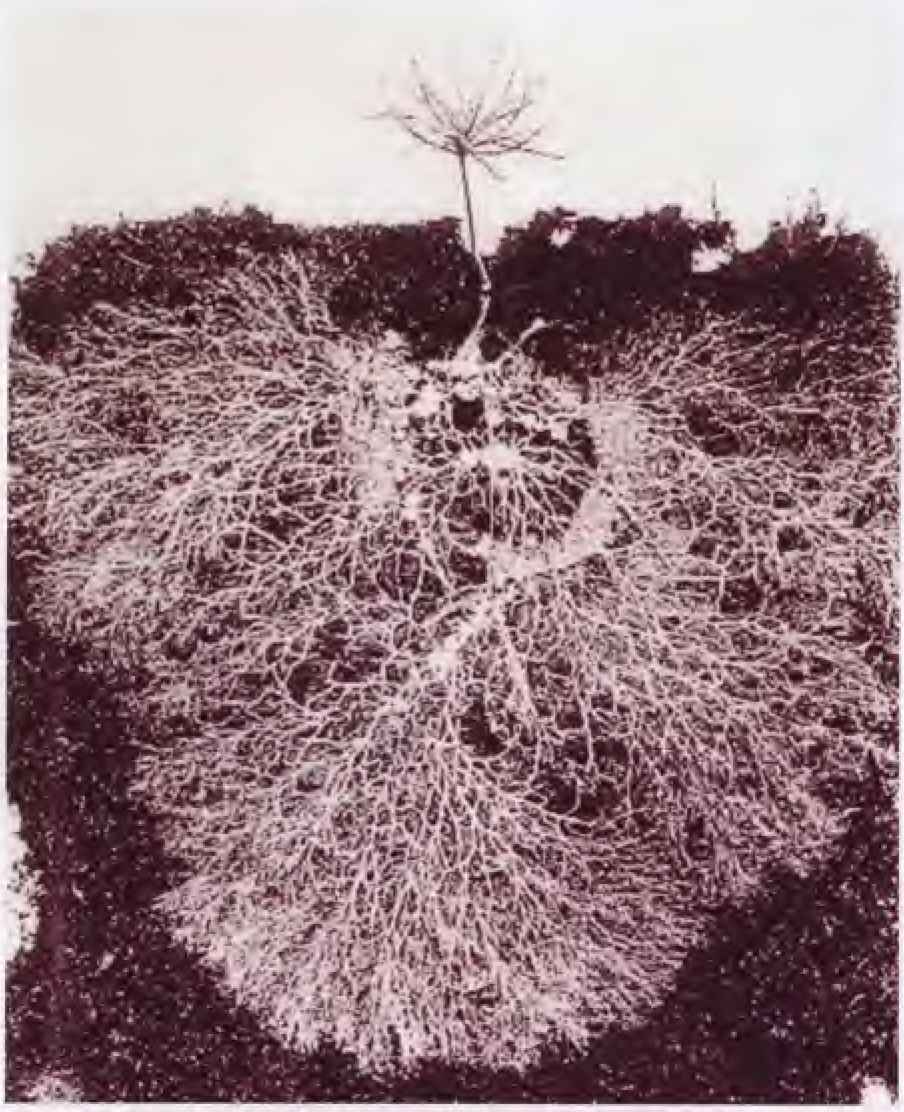
When we add phosphate to crops, even the few tough, generalist mycorrhizal fungi that have survived mechanical assault are physiologically excluded from roots by their plant hosts, cutting off the last remains of the phosphate acquisition service they would receive free of charge in an intact natural community. Thereafter, plants must gather their own phosphate. The majority cannot, but some can: pioneer, weed and crop species.

Grasses are perhaps the most successful plants in the world. They have refined the highly branched, fibrous root system so that a single plant might have kilometres of fine roots that can explore the soil for phosphate very efficiently. Grasses can gather phosphate unaided. That is what makes them such good crop plants. When humans exterminate plant-support microbes, just adding water and fertiliser to disfunctional soil enables a grass monoculture such as wheat, barley, rye, maize, sorghum or rice to thrive. For the same reason, other fibrous rooted crops, such as potato, sunflower, flax, alfalfa and soya, also seem to do well in monoculture as they too are able to gather phosphate unaided.

Many weeds and pioneer plants have to be non-mycorrhizal because their life cycle is necessarily unpredictable and they cannot rely on symbiotic fungi arriving at the same time as their seeds. They too have fibrous roots or alternative phosphate acquisition strategies. The most successful weeds are in the non-mycorrhizal cabbage, beet and goosefoot families, which also happen to include some of the most amenable crops -for example, rape/canola, cabbage and its many variants, sugar beet, quinoa, 'green manure'.

Imagine the consequences for soil organisms of non-mycorrhizal plant crops over an entire season or more. In the past, crop rotation and fallowing assisted soils to recover from unsympathetic crops, but nowadays farmers repeatedly plant rape or rape/wheat, for instance, without resting the soil. This effectively deprives mycorrhizal fungi of carbohydrate for a year or more, which is fatal for them. If we want biologically functional soils, we must strive to maintain diverse plant-microbe soil communities, returning biodiversity to agricultural land.

If we want to reconstruct naturalistic ecosystems, why not add mycorrhiza when we plant? If only it were that easy. Like plant seeds, mycorrhizal inoculants are available to purchase, but they contain only generalist, easily cultured fungi - essentially fungal 'weeds' - which might show benefit in simple cropping regimes, but do not represent the majority of mycorrhizal fungi found in the natural world, of which most are unknown and many that are known cannot be cultivated.



A pine seedling grown between glass plates, illustrating how the young root system is extended widely by the ectomycorrhizal fungus with which it has been inoculated COURTESY: <DoctorTed@mycorrhiza.net>

NATURE HAS PROVIDED us with food production processes proved over millions of years in collaboration with evolution. Yet we choose to ignore, interfere with and damage them, arrogantly making remediation - which is expensive in time, money, transport, raw materials, environmental distress and common sense - the basis of our agriculture, rather than co-operation. It seems that before we begin to grow food, we must first deliberately make the land unfit for that purpose. However, if we took just two measures we could eliminate the need for the toxic evils of modern agriculture. The first is to cease crop monoculture and follow the mixed cropping methods used in Eastern countries (which mimic nature). The second is to reduce tillage to a practicable, soil-conserving minimum.

It would be rather like 'co-opting' ourselves into existing symbioses, collaborating with and assisting the organisms that support the plants that provide us with food. When we cultivate the land, we can acknowledge the natural history and purpose of elegant natural mechanisms such as mycorrhiza, tailoring our methods to suit them rather than exterminate them and then have to devise crude alternatives to replace them. Symbiosis will prosper. Our environment will benefit. We will thrive. ●

To discover more about mycorrhiza please visit <www.merryweather.me.uk>.