Supporting Soil Fungi To Rebuild Soils in Agriculture

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Taking up Judith Wright's call to "make a new choice"[2] I argue that, if we are to reverse soil degradation and its contribution to climate change, we need to relate to soil fungi differently, becoming allies of certain fungi through recognising and enabling their life-supporting roles in ecosystems. This stance involves using different tools, materials and technologies, as well as becoming receptive and imaginative, seeing soils not merely as surfaces but as complex three-dimensional communities and meshworks[3]: worlds in themselves. The first section of the paper looks at how mainstream agriculture involves numerous practices that have banished soil fungi to the downtrodden margins of agricultural land. The second section explores a vision of agriculture as an intimate craft. I discuss how some innovative farmers and scientists are learning to support the flourishing of soil fungi through tools and methods that help soil life to become more interdependent.

In 2009, the residents of Sydney woke to a dust storm that enveloped the city in a surreal orange light. Social media and online news outlets were ablaze with images of the "apocalyptic" dawn. Scientists quoted in newspaper articles reassured the public that such an event was "natural"; that it was unlikely to be related to global warming, and that farmers' land management practices had improved markedly since the regular dust storms of seventy years ago.[4] The origin of the dust was said to be the Lake Eyre Basin, an arid region in South Australia that has been desert since before European settlement. A later research paper published in 2011 by Lim and others analysed the dust (including bacterial DNA) and traced it to Australia's agricultural food bowl: "the highly erodible and drought-stricken Mallee and Riverina regions of Victoria and central NSW".[5] These regions lie within the Murray-Darling Basin, some of the most intensively cultivated and degraded land in Australia.

The dust storm has served as an image of the breakdown of human relationships with the land since ancient times. In numerous works of literature, the dust storm is a portent of ecological and social breakdown, and certain technologies are framed as its cause. In Steinbeck's *The Grapes of Wrath* (1939), the soil loses its binding qualities to the landscape and becomes "an emulsion of dust and air". For the farming communities portrayed, "the dawn came, but no day".[6] The erosion prefigures the unbinding of the people to the land as the "dust bowl" conditions and economic restructuring force farmers to migrate to California to become landless labourers at the beginning of the Great Depression. As the tractors take over, there is a corresponding loss of loyalty and care given by people to the landscape. The tractor demolishes carefully-built homes and fills in water wells in pursuit of the straight line furrow of progress.

Timothy Morton points to the plough as the ultimate image of the Anthropocene in his analysis of Sophocles' play *Antigone*, written around 441 BCE. According to the translation Morton uses, this tool "grinds the unastonishable earth with horse and shatter"[7], leading to elemental chaos. A dust storm forms not only the backdrop to the human turmoil but also a parallel drama of the play in its own right:

SENTRY: Suddenly, a whirlwind!
Twisting a great dust storm up from the earth,
a black plague of the heavens, filling the plain,
ripping the leaves off every tree in sight,
choking the air and sky. We squinted hard
and took our whipping from the gods.[8]

According to Morton, agriculture "turn[s] reality into domination-ready chunks of parcelled-out space waiting to be filled and ploughed by humans".[9] Judith Wright's 1946 poem "Dust" similarly draws connections between sickness, misfortune, ploughing and dust:

This sick dust, spiralling with the wind,
is harsh as grief's taste in our mouths
and has eclipsed the small sun.
The remnant earth turns evil,
the steel-shocked earth has turned against the plough
and runs with wind all day, and all night
sighs in our sleep against the windowpane.[10]

While for Sophocles, the earth is "unastonishable", for Wright the earth is "steel-shocked". Both imply the question: Can the earth express a discernible reaction while encountering destructive activities? If so, are we capable of noticing and heeding it? In Wright's poem, the soil rises up, turning against the plough and eroding in the wind. Wright urges us to act differently towards the land, to "make a new choice", that is, to go on in a new way.

Business as usual agriculture

If we subtract the concept "dirt" from "soil" we are left with what is known as humus, the carbon-based components, both living and non-living. Subtracting "dust" from "dirt" leaves moisture and the heavier compound particles. Implicit in the different meanings of the words "dust", "dirt" and "soil" is knowledge about the importance of soil aggregation processes. Yet while this language reveals some understanding about healthy soil structures, our understanding is limited when it comes to the microbes that are the architects of such structures, and the impact of tilling on soil structure.

The words "culture", "cult" and "cultivate"derive from the Latin *colere*, meaning "to till" or "toil over" [the soil].[11] Massimo Angelini beautifully analyses the etymology of "culture" in the last edition of *Philosophy, Activism, Nature*.[12] These terms are imbued with associations of care, with the Latin *cultus* also meaning "care, worship, reverence".[13] "Cultivation" today is both a synonym for *ploughing* and also a synecdoche for associated practices of farming: *growing, tending*. It also is a verb of deliberate self and group actualisation. Such long-standing positive associations reveal and reproduce an assumption that tilling the soil is necessary for agricultural landscapes to bear an abundant harvest.

In large scale, capitalist agriculture, soil is often objectified and treated as an inert growing medium. Like hydroponics, such farming understands soil more in terms of its anchoring functions than the interactive capacities of its biological inhabitants. According to advocacy group Healthy Soils Australia, "in the view of traditional soil scientists, soil is merely a porous medium for holding water and keeping plants upright. The role of micro-organisms is seen as little understood, and certainly not as important as climate, geography and soil chemistry".[14]

Figure 1. Pumpkin at the Blue Mountains Food Co-op, New South Wales, Australia

Conventional plough usage upturns and crushes clods of soil, breaking apart the networks of beneficial microbes, especially fungi, leaving the newly opened-up surfaces exposed to the sun, which dehydrates the organic matter contained within. Carbon bound up in the soil particles can then become unbound, and can be consumed as food by certain creatures, and respired into the atmosphere, increasing the greenhouse effect. The burning of crop residues and of grassland further destroys the fungal networks in soils, and releases carbon that could have been incorporated into the soil. The wheels of a tractor or hooves of an ox can also compact the soil, reducing oxygen and promoting anaerobic microbes. These produce alcohols that inhibit the growth of plant roots and fungi, the primary dispensers of energy in the underground "economy", reducing the overall biomass in the soil. Similarly, herbicides and fungicides eliminate much soil biodiversity, while artificial fertilisers allow plants to obtain nutrients "the easy way", reducing incentives to develop relationships with microorganisms[15].

Certain species, vocabularies, ideal images, accounting systems, understandings of time and hygiene routines reinforce each other in assemblages to promote a "clean slate" surface as the goal at the end of each season. Annual plants, bred for a short lifecycle, are pulled out, roots and branches taken away or burned rather than allowed to be decomposed, and new seeds sown in the crumbly topsoil. There is a break in life-cycles, which is understood to be a good thing: in order to reduce the danger of disease. Anna Tsing calls this "the grain model", applied to broad acre agriculture, based on the skewed experiences of monocultural grain and potato-growing that encountered fungi mainly as threats, in the form of devastating diseases such as rust and blight[16]. In a recent public lecture in Sydney, American farmer Joel Salatin proposed a different typology: he called this the "germ model" of disease. Instead he advocates for a more complex "terrain model" that takes into account biodiversity and competition[17]. When plants are demolished each year with a plough and herbicides and the soil left to dry out, new microbial communities must laboriously establish each season in response to the new crop. With each harvest, each new removal of dead biomass, the soil life, especially the fungi, declines in abundance and diversity, thus creating greater potential for diseases to spread, and slowing crucial soil-building processes.

Tsing's critique of "the grain model" shows how assumptions from one context can become rigidly incorporated into templates for action, habits and technologies. When considering fungi, a large part of the problem is that their invisibility makes it difficult to perceive feedback that may inform farmers to change their actions. Michael Carolan claims that tensions between the visible and the non-visible play out in the debate between sustainable and conventional agriculture. He argues that a large part of achieving sustainable agriculture, involves working "to nurture certain ways of 'seeing', which "can only be accomplished by institutional changes and new social network formations".[18] Problems of scale can be compounded by the broadacre size of many farms, with mechanical work delegated to machinery, minimising direct contact with the soil surface by the hands and feet of farmers. Such machinery can frame the perspective from which soils are viewed (e.g., from a cockpit). In *The Grapes of Wrath*, Steinbeck's narrator critiques the atomism that became dominant with the rise of the tractor:

> in the tractor man there grows the contempt that comes only to a stranger who has no understanding and no relation. For nitrates are not the land, nor phosphates; and the length of fibre in the cotton is not the land. Carbon is not a man, nor salt nor water nor calcium. He is all these, but he is much more, much more; and the land is so much more than its analysis.[19]

Here is a double-alienation: The farmer suffers in losing wonder for and connection with the land and enjoyment of the work. Wonder implies a deeper understanding than mechanistic and atomistic science can impart, and a relationship that comes with embodied, respectful contact, "kneeling in the earth to eat his lunch"[20]. The land, in the paradigm ushered in by the technology of the tractor, is conceived of as a mere surface, and an amalgam of different chemical components. Steinbeck is lambasting the alienation of capitalist agriculture and of its attendant strains of reductionist science. Such ideologies are reproduced by the technological-social assemblages in which we participate. As Ivan Illich says, "a technology [can] incorporate the values of the society for which it was invented to such a degree that these values become dominant in every society which applies that technology".[21] Just as oppressive ideologies can be unwittingly re-performed by language, so too, technologies are performative; a critical outlook would problematise the worldviews that technologies sometimes presuppose.

Tim Ingold critiques the spatial imaginary that Western ontologies encourage: that of moving "across a pre-formed surface", rather than "through a nascent world".[22] He seeks to "re-animate" thought through engaging with the phenomenological method of Merleau-Ponty. He sees the indigenous "animistic" awareness of "the aerial flux of weather" to promote an ontology of interrelatedness in contrast to an outlook constituted by "the grounded fixities of landscape". Ingold advocates for a "meshwork" image of the fungal mycelium as preferable to the rhizome image of Deleuze and Guattari, to illustrate our entangled existences with other life in a relational field. Organisms extend along the multiple pathways of their "involvement in the world"[23]. The mycelium has a high surface area for the purpose of extending its capacity to interact with the world and the soil, to transport messages, to secrete sugars, to obtain water and nutrients. Its form is porous, receptive, sensitive. Not only do fungal mycelia grow outwards in order to grasp, but also in order to accept other outstretched limbs; to be nourished and to nourish others. They physically manifest an ecological existence.

The special role of soil fungi

Between 700-420 million years ago, a special kind of fungal partnership[24] enabled plants to step out of the great swimming pool of life and on to dry land.[25] Soil fungi still play many similar roles in ecosystems to those they had back then: protecting, hydrating, feeding, creating the basis for ever-more complex forms of life. Certain species prevent erosion, decompose dead matter, filter and store water (helping outlast droughts), redistribute resources, and in doing so they support the flourishing of other biodiversity.

In his fascinating book, *Mycelium Running: How Mushrooms Can Help Save the World*, Paul Stamets introduces readers to a complex and generous underground world of fungal relationships:

> the mycorrhizal, saprophytic, and endophytic mushrooms...benefit [plants] in 3 ways. These complementary mycological systems help plants survive starvation, dehydration, and parasitization. The richer the fungus-plant partnerships, the more the organisms the habitat can support.[26]

Mycorrhizal fungi extend from tree roots and through soils like blood vessels, joining plants together, linking them to other parts of the soil food web, and feeding numerous organisms throughout the soil. They unite the land into a body, in dendritic patterns of sensitive, sensate and even perhaps sentient membranes. These membranes detect and redistribute minerals, sugars and water – even responding to disturbance by allocating resources to that area, and giving extra sugars to trees under canopies that are starved of sunlight and thus energy.[27] Thus, as Paul Stamets says, "the mycelium guards the forest's overall health, budgeting and multi-directionally allocating nutrients".[28]Most plants allocate more than 40 percent of their food from photosynthesis through the roots, feeding a multitude of soil organisms.[29] Mycorrhizal fungi are prime among these microbial allies, with almost 80 percent of plants able to associate with them.[30] Mycorrhizal fungi build the architecture that holds healthy soil communities together, preventing erosion by binding particles together in aggregates. This aggregate formation is the most reliable biological pathway of sequestering carbon in soils. In this aggregation process mycorrhizal fungi convert carbon into more stable forms such as humates and glomalin.[31] A recent study of boreal forest in the journal *Science* indicates that 50 to 70 percent of the carbon bound in soil is from tree roots and the fungi that grow on them.[32] Given that soils globally hold twice the amount of carbon than the atmosphere,[33] the amount of carbon stabilised by fungi and roots and their potential to hold still more is mind-boggling.

Central to Stamets' argument is the life-giving impact of saprophytes (decomposer fungi). A former forester, Stamets worked daily in the presence of forest fungi, and witnessed their generative activities in enriching, even creating the enabling conditions for certain forest ecosystems. Each time a tree lies rotting on a forest floor, he claims, it contributes far more to the ecosystem than it ever did while living. (And that is no mean feat!) He describes an instance in Oregon in which a single underground fungal mycelium covered a horizontal area of 1,665 American football fields before the construction of logging roads restricted its extent through compaction and clearing. Throughout its life, the organism occasionally manifested pathogenic properties, "kill[ing] the forest above it several times over, and in so doing it has built deeper soil layers that allow the growth of ever-larger stands of trees"[34]. Stamets harnesses the qualities of saprophytes to prompt ecological restoration models, using inoculated wood chips to grow fibrous mats to improve soil structure and stabilise disused and eroded logging roads. He sees a special role for humans in this era:

> Under ordinary circumstances, nature self-prescribes fungi for its own healing. But since we have accelerated the forests' natural destruction and renewal cycles, thereby creating massive debris fields, for instance, through clear-cutting, we ought to help the forests accelerate the decomposition cycles by introducing mycelium in key areas – in essence by running mycelium.[35]

In this era of the Anthropocene, humans regularly curtail the self-propagating, reproducing, proliferating and recycling capacities of soil fungi. We would do better to help soil fungi live and reproduce. This could help fungi to deepen agricultural soils, building long-term stores of soil carbon rather than allowing most of it to be released to the atmosphere.

Paying attention to soil microbes

I peer down into the lens of the microscope and turn the fine focus knob. Suddenly a world comes into view. Long translucent filamentous threads extend from a black sphere. Tiny creatures scurry around, with larger ones occasionally entering the field of light. With the help of our teacher, the mass of dots and threads begins to differentiate. I learn to distinguish bodies and functional features. An energetically moving dot becomes a ciliate. Smaller dots are protozoa. A double line becomes a sprouted fungal mycelium. It extends across a quarter of the field of view. I scroll across and follow it until I see the spore it has sprouted from.

It is the second day of the "Soil Food Web" course held in a cottage beside the facilities management sheds at Southern Cross University Lismore, Australia. I and my classmates are observing samples of the aerated compost teas that we have left overnight bubbling away. Each is a sign of a certain biochemistry that has expressed itself in the 18 hour period of the brewing, allowing some potentialities to become actual. Some organisms have multiplied, others have not. Some samples are healthy, diverse and aerobic, containing fungi, protozoa and adequate bacteria. Others are more sparse – and full of ciliates – a sign of anaerobic conditions, enabled by a broken down motor that left the compost tea to stew. If the brew is anaerobic, bacteria and yeasts will produce alcohol that is so detrimental to plant growth that roots will bypass the patch of soil on which the compost tea has been applied. This is the danger of creating anaerobic conditions (e.g., through compaction) in soils: while some bacteria and invertebrates will thrive, plant roots and fungi will not, and thus the patch of soil will lose its connectivity to fungal hyphae and plant roots.

For many of us, this workshop is an initiation to another world. It opens the "black box" of soil microbiology for continued engagement and learning. Some have gained permanent access to microscopes, buying them as businesses or farmer groups (such as the Mudgee Microscope group and the Hawkesbury Microscope Group). I, perhaps unwisely, borrowed my late grandfather's super-heavy microscope and lugged it around in a backpack, copping a bodily beating in the process. Others engage with the microscope for this workshop only: to reconstitute their "black boxes", changing their everyday practices accordingly. Whether microbes remain in view or not, things will never be the same again. Our imaginations have been broadened. Plant species selection, machinery and tool use, planting methods, water provision, fertilising, composting, pest control, harvesting and dealing with vegetative remains of crops now are considered in the light of impact on the soil food web.

Convivial assemblages

For farmers concerned about the wellbeing of beneficial soil fungi, alternatives to conventional soil management are becoming more widespread. Alternatives such as Holistic Management, developed by Allan Savory, mimics African savannah herd migration and avoids the problem of overgrazing, erosion and compaction by animal hooves. This technique often uses electric fences to direct movement of large herds around the land, and encourages fungal growth through abandonment of trampled (and urinated on) grass fibres for extended periods, allowing grasses to grow much higher, and the roots much deeper, than in ordinary paddocks.[36] Other alternatives include Yeomans' "Keyline Plough", which makes an incision in the soil without dramatically disturbing its structure. In the picture below, the modified plough is attached to a hose that applies compost tea, another way to regenerate soil biodiversity. Compost tea is also being used as a substitute to chemical "sheep dips" and cattle drenches: the increased microbes on animal skins can then out-compete diseases.[37]

Figure 2. Keyline plough at Taranaki Farm, Victoria, Australia[38]

The keyline plough, the compost pile, the compost tea, the microscope and the cell grazing fences can be understood as part of "convivial assemblages"[39] from a microbial point of view. Such assemblages promote biodiversity and represent clear alternatives to those assemblages structured to fit the paradigm of the conventional plough or the overgrazed paddock. Rather than technologies of control that disentangle and simplify relationships, convivial tools at their best strengthen interdependence. In his book, *Tools for Conviviality*, Ivan Illich clarifies what he means by conviviality: "I intend it to mean the autonomous and creative intercourse among persons, and the intercourse of persons with their environment; and this in contrast with the conditioned response of persons to the demands made upon them by others, and by a man-made environment".[40] In other words, it is responsiveness and receptivity between humans and with earth-others. The technologies listed above do not promote full freedom for the organisms harnessed for agriculture, but they do allow them to express their ordinary inclinations more freely.

In the same grain-growing Western district of Victoria from which the dust storm arose, some farmers are learning to use technologies to support the flourishing of soil microbes. Quoted in the recent *Soils for Life* report commissioned by Outcomes Australia, Brian and Sandra Wilson of Briandra in Mingay "realised that we did not know how the basalt plains functioned as an ecosystem and why it was in such poor condition. We lacked detailed technical information. It was not until we went and talked to a wide range of experts that we began to understand why the soil condition and the water logging problems were related".[41] They then changed their use of vehicles: "Since moving to raised-bed farming we no longer drive machinery or vehicles on the beds. Our own tests have shown that this compacts the soil and reduces biological activity. To overcome this problem in the long term we have moved to control track farming where the tractors and harvesters only move in the furrows. To ensure this happens, machinery is fitted with high spatial precision tracking systems." Furthermore they initiated no-till practices, with a stubble digestion program applying brewed cellulose-digesting bacteria and saprophytic fungi through leaving cereal stubbles in the ground. They now incorporate wheat stubble into the soil. Sandra and Brian emphasised the importance of experimentation in this effort: "My business model has the philosophy to use ten per cent of farm gross income in experimentation, starting over small areas, and the encouraging results are expanded, and may develop into standard practice". This experimental orientation allows Brian to be receptive and responsive – to notice how certain interventions are received by soil ecosystems, and modify practice accordingly. In this example, and in many more of the case studies assembled by Outcomes Australia, we can see strategies adopted by farmers that allow for more "convivial assemblages" of technologies, substances and human modes of perception and action. These increase economic wellbeing, not through increased exploitation, but by scaling back inputs. Such changes also allow farmers to attend to the wellbeing of other species on the farm, and share some of the photosynthetic "surplus" of the system with soil biodiversity.

Reconstructing agriculture: Towards intimate crafts

Twenty-two years ago, Jack Kloppenburg Jr. argued for a deconstructive and a reconstructive project to move "agricultural technoscience" on to "new trajectories". He affirmed a role for science in more "grassroots" frameworks of knowledge production:

> Material resources for a 'successor science' are to be found in the 'local knowledge' that is continually produced and reproduced by farmers and agricultural workers.[42]

Colin Tudge likewise suggests a similar way forward, with science a "helpmeet" or helpful partner:

> Agriculture is, fundamentally, a craft industry, and the craft must prevail again, with science relegated to its proper role as helpmeet, and the devices of modern accountancy employed simply to keep score.[43]

In such a relationship, scientists concede some of their privileged "expert" statuses, and position themselves as partners to the practical wisdom of farmers. The educators at the Soil Food Web Institute modelled expert humility, speaking in plain English, helping students develop their craft and become more sensitive. Scientists have particular skills for representation that they can bring to this process, which they can share with hybrid groups. Latour imagines this relationship in a particularly interesting way:

> The sciences are going to put into the common basket their skills, their ability to provide instruments and equipment, their capacity to record and listen to the swarming of different imperceptible propositions that demand to be taken into account. They will also

> contribute to the work of consultation...through a competency that has allowed them to get ahead of all the other callings – that of controversy and experimental testing.[44]

Scientists regularly debate with each other the reliability of different interpretations of evidence – and Latour sees this as translating the difficult languages of the non-human. In this way science can help strive towards a "right relationship" with the species involved.

The work of caring for soil biodiversity can be understood as part of an economy of reproduction, like bearing and caring for children and the elderly. In a recent essay, Kathryn Norlock perceptively brings together Nel Noddings' "feminist ethic of care" and Leopold's "land ethic". She argues for the importance of receptivity, direct and personal experience, joy and play as sources of moral motivation in agriculture.[45] In a similar way, Maria Puig de la Bellacasa argues for non-mastery in technoscience, and the assembling of neglected things:

> Taking responsibility for what and whom we care for doesn't mean being in charge. Adequate care requires knowledge and curiosity regarding the needs of an 'other' – human or not – and these become possible through relating, through refusing objectification. Such a process inevitably transforms the entangled beings...From this affective perspective, transforming things into matters of care is a way of relating to them, of inevitably becoming affected by them, and of modifying their potential to affect others.[46]

This work differs from the ordinary agricultural work of planting, maintaining and harvesting crops or raising livestock in the way that resources are distributed. The needs of collaborator species are considered in decisions regarding allocation of surplus energy, water and other forms of sustenance.[47]These practices of being attentive to the needs of animals, plants and soil life can enhance agricultural wisdom or *phronesis*. As Stamets says:

> With every "failure", if I have paid attention, I hone my skills and sensitivity to the mycelium's needs. Every failure is the price of tuition I have paid to learn a new lesson...I have learned to make the wisest choices by listening to the mycelium.[48]

When Stamets writes of "listening to the mycelium", he implies a contrast with speaking, a subject position that assumes mastery, often imposing a ready-made system of knowledge on the world. "Listening" involves openness. It helps us "learn to be affected"[49] by unfamiliar new concerns. This allows for ordinary practices to be revised after observing the way the fungi participates in the world and interacts with its surroundings. This helps us form new body-worlds that are more sensitive.[50]

Choosing our tools more carefully, reconfiguring them, redesigning them and learning to use them sensitively can help us move from atomistic to ecological understandings of farming. These practices can help to "immerse" ourselves imaginatively in the "world" of the microbes, identifying with them, in the process of learning how to recognise and respond to their needs. To become more proficient at this ecological craft we need awareness of the impacts of certain movements and certain machine processes on the invisible bodies beneath us. Practicing these movements and viewing their impacts afterwards with tools such as microscopes can help develop a bodily-felt familiarity with the kinetics and the sensitive parts of these organisms that we interact with.

"Making a new choice" to support the flourishing of beneficial soil fungi in agriculture requires imagination, receptivity and experimental flexibility, as well as willingness to consult and understand "the science" regarding the needs of other species. Tools such as compost, keyline ploughs and microscopes can add to repertoires of perception and understanding so that the microbial world can emerge beyond ordinary vision to figure in our "mind's eye". These convivial technologies help to reconfigure power relationships from a paradigm of mastery to apprenticeship, working attentively and caringly with the materials and the organisms involved in the crafts of agriculture. In this way, environmental concerns about land degradation, biodiversity and climate change can be addressed simultaneously with efforts to produce an adequate harvest and a surplus for human consumers.

Notes

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2 J. Wright (1973), "Dust", *The Moving Image*. Folios of Australian Poetry. The Meanjin Press, Melbourne, p. 34.

3 T. Ingold (2006), "Rethinking the Animate, Reanimating Thought", *Ethnos*, 71(1), pp. 9-20.

4 G. Robinson (2009), "Dust Storm: Unclear If Climate Change to Blame", *Sydney Morning Herald*. September 23. Website: www.smh.com.au/environment/dust-storm-unclear-if-climate-change-to-blame-20090923-g28g.html (Accessed 14 April 2013).

5 N. Lim, C. Munday, G. Allison, T. O'Loingsigh, P. De Deckker and N. Tapper (2011), "Microbiological and Meteorological Analysis of Two Australian Dust Storms in April 2009", in *Science of the Total Environment [P]*, vol 412-413, Elsevier BV, Netherlands, pp. 223-231.

6 J. Steinbeck (1995), *The Grapes of Wrath.* Minerva, Australia, pp. 3-4

7 A. Carson and B. Stone (trans.) (2012), *Antigonick*, New Directions, New York, p. 20.

8 Sophocles (1982), *Antigone*, R. Fagles (trans.), Penguin Books, New York, pp. 463-468.

9 T. Morton (2012), "The Oedipal Logic of Ecological Awareness", *Environmental Humanities* 1, p. 16.

10 J. Wright (1973), p. 33.

11 Collins English Dictionary Online (n.d.), "Definition of Cultivate." Website: www.collinsdictionary.com/dictionary/english/cultivate (Accessed 23 June 2013).

12 M. Angelini (2012), "Down to the Roots of the Word 'Culture'", E. Addey (trans.), *Philosophy, Activism, Nature* 9, pp. 90-94.

13 Online Etymology Dictionary (n.d.), "Cult." Website: www.etymonline.com/index.php?allowed_in_frame=0&search=cult&searchmode=none (Accessed 23 June 2013).

14 Healthy Soils Australia (2010), "Soil." Website: http://www.healthysoils.com.au/soil.html (Accessed 15 April 2013).

15 J. Lowenfels, and W. Lewis (2010), *Teaming with Microbes: The Organic Gardener's Guide to the Soil Food Web*, Timber Press, Portland, p. 26.

16 A. Tsing (2012), "Unruly Edges: Mushrooms as Companion Species", in *Environmental Humanities* 1, pp. 141-154.

17 J.Salatin, whose free range forms of agriculture have been demonstrated in documentaries such as *Food, Inc.* gave a public lecture entitled "Real Food Forum" at the Sydney Town Hall on 16 February 2013.

18 M. Carolan (2006), "Do You See What I See? Examining the Epistemic Barriers to Sustainable Agriculture", *Rural Sociology* 71(2), pp. 232-260.

19 J. Steinbeck (1995), p. 132.

20 J. Steinbeck (1995), p. 133.

21 I. Illich (1978), "Energy and Equity", in *Toward a History of Needs*. Heyday Books, Berkeley, p. 110.

22 T. Ingold (2006), p. 17.

23 T. Ingold (2006), p. 18.

24 This partnership was a lichen.

25 ABC (2001), "First Land Plants Paved Way For Humans." Website: www.abc.net.au/science/articles/2001/08/10/344214.htm (Accessed 30 July 2013).

[26] T. Ingold (2006), p. 34.

[27] S. Simard *et al.* (1997), cited in P. Stamets (2005), *Mycelium Running: How Mushrooms Can Help Save the World*, Ten Speed Press, Berkeley, p. 26.

[28] P. Stamets (2005), p. 26.

[29] M. Amaranthus, L. Simpson, J. Lowenfels (2012), "Making the Most of Microbes." Website: www.mycorrhizae.com/wpcontent/uploads/2012/09/Oct12_Amaranthusetal.pdf 6 May 2013 (Accessed 30 July 2013).

[30] P.V. Sengbusch (n.d.), "Mycorrhizas." Website: www.biologie.uni-hamburg.de/b-online/e33/33b.htm (Accessed 23 June 2013).

[31] M. Rillig, S.Wright, V. Eviner (2002), "The Role of Arbuscular Mycorrhizal Fungi and Glomalin in Soil Aggregation: Comparing Effects of Five Plant Species", *Plant and Soil*, 238, pp. 325-333.

[32] M. Fischetti (2013), "Root Fungus Stores a Surprising Amount of the Carbon Sequestered in Soil", *Scientific American*. Website: www.scientificamerican.com/article.cfm?id=root-fungus-stores-a-surprising (Accessed 15 April 2013).

[33] J.I. Hedges, G. Eglinton, P.G. Hatcher, D.L. Kirchman, C. Arnosti, S. Derenne, R.P. Evershed, I. Kogel-Knabner, J.W. de Leeuw, R. Littke, W. Michaelis, J. Rullkotter (2000), "The Molecularly Uncharacterized Component of Nonliving Organic Matter in Natural Environments", *Organic Geochemistry* 31, pp. 945-958.

[34] P. Stamets (2005), p. 49.

[35] P. Stamets (2005), p. 51.

[36] A very interesting TED talk given by Allan Savory is available here: A. Savory (2013), "How to Fight Desertification and Reverse Climate Change." Website: www.ted.com/talks/allan_savory_how_to_green_the_world_s_deserts_and_reverse_climate_change.html (Accessed 30 July 2013).

[37] There is anecdotal evidence to support the practice of spraying compost tea on livestock to reduce skin infection. This was mentioned at the Soil Food Web Institute training course that I attended in March 2013. See E. Ingham (2010) "Spraying Livestock with Compost Tea." Website: http://tech.groups.yahoo.com/group/compost_tea/message/7159 (Accessed 30 July 2013). Also a company in the UK is selling probiotic animal skin sprays here: Emvelo (2013), "Emvelo Natural Products for Livestock." Website: www.emvelo.co.uk/livestock.php (Accessed 30 July 2013). I further checked this with W. Jehne, of Healthy Soils Australia, who said the scientific basis of this practice is sound (23 June 2013 pers.comm.).

[38] Photo is from Fusion Farms: http://www.fusionfarms.com/comingup/compost-may2010/ (Accessed October 2011). [No longer on internet]

[39] I theorise the notion of the "convivial assemblage" in other papers for my PhD thesis, drawing from Latour (2004) and Illich (1973).

[40] Illich, I. (1973), *Tools for Conviviality*, Calder and Boyars, London.

[41] Outcomes Australia (2012), "Soils for Life Case Study 15: Using Raised Beds and Beneficial Fungi to Restore Soil Health", in *Innovations for Regenerative Landscape Management: Case Studies of Regenerative Landscape Management in Practice*, pp. 166-171. Website: www.soilsforlife.org.au (Accessed 30 July 2013).

[42] J. Kloppenburg Jr. (1991), "Social Theory and the De/Reconstruction of Agricultural Science: Local Knowledge for an Alternative Agriculture", *Rural Sociology* 56(4), pp. 519-548.

[43] C. Tudge (2005), "Feeding People is Easy: But We Have To Re-Think the World From First Principles", *Public Health Nutrition* 8(6A), pp. 716-723 (p. 722).

[44] B. Latour (2004), *Politics of Nature: How To Bring the Sciences into Democracy*, Harvard University Press, Cambridge, pp. 138-139.

[45] K. Norlock (2011), "Building Receptivity: Leopold's Land Ethic and Critical Feminist Interpretation", *Journal For the Study of Religion, Nature and Culture*, 5(4), pp. 491-509.

[46] M. de la Bellacasa (2011), "Matters of Care in Technoscience: Assembling Neglected Things", *Social Studies of Science*, 41, pp. 99-100.

47 See the "ethical coordinates" of J.K. Gibson-Graham (2006), *A Postcapitalist Politics*, University of Minnesota Press, Minneapolis, p. 88.

48 P. Stamets (2005), p. 126.

49 B. Latour (2004), "How to Talk About the Body? The Normative Dimension of Science Studies", *Body & Society* 10(2-3), pp. 205-229.

50 J.K. Gibson-Graham and G. Roelvink (2009), "An Economic Ethics for the Anthropocene", *Antipode* 41(S1), pp. 320–346.