The Microbial revolution

Reviewing evidence for the use of microbial fertilisers in agriculture

“Modern agriculture has altered the face of the planet, more than any other human activity. We need to urgently rethink our global food systems, which are responsible for 80% of deforestation, 70% of freshwater use and the single greatest cause of terrestrial biodiversity loss.”

“Land degradation is affecting food, water, carbon and biodiversity. It is reducing GDP, affecting people’s health, reducing access to clean water and worsening drought.”

“Every single farmer, big and small, can practice regenerative agriculture. There are a panoply of techniques and you don’t need hi-tech or a PhD to use them.”

Ibrahim Thiaw, Executive Secretary, UNCCD

[The Guardian, April 2022]

This report has been prepared by Lifeworks, a UK-based international charity that provides training to equip farming communities with low-cost, sustainable agricultural techniques that improve soil quality and boost crop yields.

Summary

A quiet revolution is taking place in developed and developing countries around the world. This revolution is about the growing use of microbes – microorganisms such as bacteria, fungi, archaea and protists – to replace products containing inorganic chemical compounds.

This short report focuses mainly on agriculture, where 'biofertilizers' and microbial inputs are increasingly being used to replace or complement the use of chemical fertilisers. This report reviews evidence that **microbial inputs can be produced cheaply and have a range of proven benefits**: increasing crop yields and improving plants' resistance to pests, pathogens and abiotic stresses. There is also strong evidence that natural fertilisers containing microorganisms can improve or restore soil fertility, enhance soil structure and increase soil's capacity to sequester carbon.

The use of 'natural' fertilisers is as old as agriculture and fertilizing soil using manure and compost are practiced in every region of the world today. Since the 1980s, the use of prepared microbial inputs and 'biofertilisers' to stimulate the soil microbiome and boost crop health have become widespread. Researchers such as microbiologist Dr Elaine Ingham have pioneered the study of soil microbiology and what she has called the 'soil food web' – the interconnected interaction of a large number of soil microorganisms that determine the nutrients available, soil pH and structure, and ultimately the health of plants and crops and their ability to resist pests and pathogens.

The growing acceptance of microbial approaches in agriculture comes at a time of crisis in soil fertility**. Intensive agriculture and the widespread overuse of chemical fertilisers have led to a global soil degradation crisis**. In its most 2022 report, the UNCCD's Global Land Outlook estimated that up to 40% of the world's land is degraded. At the Global Forum for Food and Agriculture where the report was launched, agricultural ministers agreed that "healthy soils are key to the production of sufficient nutritious and safe food, adaptation to and mitigation of climate change, and the halting and reversal of biodiversity loss."

This report showcases some of the **growing body of research evidence into the benefits of microbial fertilisers in agriculture**. We have selected 17 papers published in peer-reviewed journals – all are meta-analyses, systematic research reviews or long-term studies.

Together, these provide a 'horizon scan' of recent research into the use of microbial inputs such as biofertilisers, biochar and manure – and the comparative performance in terms of crop yields of those inputs compared with other approaches. Some of the studies also investigate the mechanisms by which micro-organisms operate to regulate soil fertility, soil composition (including levels of soil organic carbon sequestered), and plants' abilities to resist pest and pathogens.

We also summarise some of the **evidence from small scale trials** carried out by agronomists and others trained by Lifeworks; we also provide a selection of **farmer case studies** to provide examples of the benefits that families and communities gain from use of microbial approaches.

Finally, this report also looks beyond agriculture, and briefly surveys the ever-growing range of **microbial products for domestic and commercial applications**. Household cleaning products of different kinds are available to buy in many developed countries. In commercial settings, bioremediation products are being used to remove or neutralize contaminants – such as ocean oil spills.

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About Lifeworks

This report has been produced by Lifeworks, with the aim of bringing some of the powerful evidence for use of microbial inputs in agriculture to the attention of government decision makers in developing countries and organisations delivering programmes supporting agriculture in those countries.

The aims of this report are:

1) to make the case for further research into microbials specific to developing country settings and subsistence and small-scale farming;

2) to propose the inclusion of appropriate training in use of microbial inputs into existing or future programmes designed to support farmers and agriculture; and

3) to encourage commercial production of microbial inputs for agriculture to support farmers in developing countries.

Lifeworks mission is to empower communities with low-cost, sustainable agricultural techniques that improve soil quality and boost crop yields. Lifeworks provides training for small-scale and subsistence farmers, equipping them with simple techniques for making and using four different microbial fertilisers from widely available ingredients.

Our training includes sessions on ‘agribusiness’ skills, such as planning and record keeping. We encourage farmers to set up trial plots, which enables them to compare different approaches over more than one growing season and to see what works best in their fields. Typically, farmers would use the plots to compare yields from a control plot with no inputs, a plot treated with microbial inputs and a plot treated with commercial fertilisers.

Many of the Lifeworks trained farmers reports that using microbial inputs results in very significant increases in crop yields (up to 150% in some cases), often meaning there is surplus to sell, as well as savings to be made on fertilisers. Many farmers tell us the training has transformed their lives for the better.

1. Research evidence on the impact of microbial fertilisers in agriculture

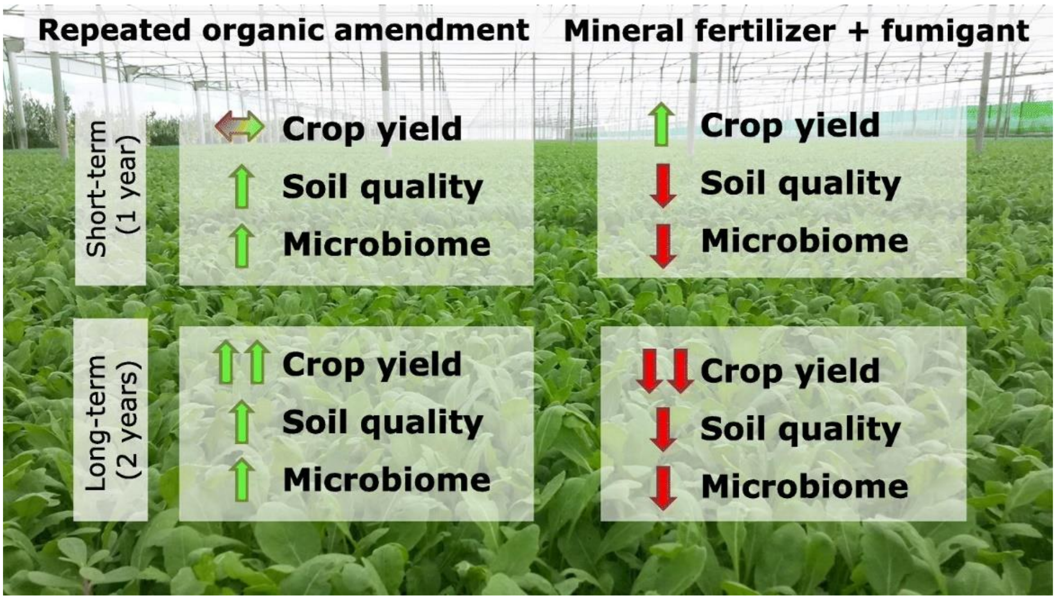
1.1 Summary of findings

We have selected 17 papers published in peer-reviewed journals – all are meta-analyses, systematic research reviews or long-term studies into the use of microbial inputs such as biofertilisers, biochar and manure – and the comparative performance of these inputs in terms of crop yields compared with other approaches.

Some of the studies also investigate the mechanisms by which micro-organisms operate to regulate soil fertility, soil composition (including levels of soil organic carbon sequestered), and plants' abilities to resist pest and pathogens.

Surveying the selected research papers**, a clear picture emerges of the potential of microbial inputs to replace or complement chemical fertilisers and pesticides in agriculture**. Notable findings include:

- When used alone or alongside chemical fertilizers, microbial inputs can improve crop yields when compared to use of no inputs or chemical fertilisers alone.
- Crop yield gains tend to increase when microbials are used over the course of several seasons.
- Microbial inputs can improve soil fertility and the levels of available nutrients in the soil that plants require.
- Soil fertility is strongly linked to soil's capacity to sequester carbon.
- Fertile soil has better capacity to withstand periods of drought and flooding.
- Microbials can improve the capacity of crops to withstand pests, pathogens and abiotic stresses.



Graphic source: "Repeated applications of organic amendments promote beneficial microbiota, improve soil fertility and increase crop yield", Bonanomi et al, Applied Soil Ecology, Vol 156, Dec 2020, 103714

1.2 Selected research on the use of microbial inputs in agriculture

Title of research	Date	Journal	Type of research	Key findings
Reviews / meta-analyses				
Potential Use of Beneficial Microorganisms for Soil Amelioration, Phytopathogen Biocontrol, and Sustainable Crop Production in Smallholder Agroecosystems	2021	Frontiers in Sustainable Food Systems, Crop Biology and Sustainability, 29 April 2021	Review of 176 research studies	The use of plant growth promoting microorganisms by smallholder farmers has substantially grown owing to their impressive performance, economic benefits, and environmental safety. Benefits include: soil nutrient amelioration, crop nutrient, and yield improvement, plant tolerance to biotic and abiotic stresses, biocontrol of pests and diseases, and water uptake.
Microbes as Biofertilizers, a Potential Approach for Sustainable Crop Production	2021	Sustainability, 2021, 13(4), p 1868	Review of 178 research studies	Biofertilizers are a promising alternative to hazardous chemical fertilizers – and play a key role in increasing crop yield and maintaining long-term soil fertility, which is essential for meeting global food demand. Microbes interact with crop plants and enhance their immunity, growth, and development.
Effects of manure fertilizer on crop yield and soil properties in China: A meta-analysis	2020	CATENA, Vol 193, Oct 2020, 104617	Meta-analysis, 774 comparisons from 141 published studies	Increased crop yields; long-term increase in soil fertility and productivity.

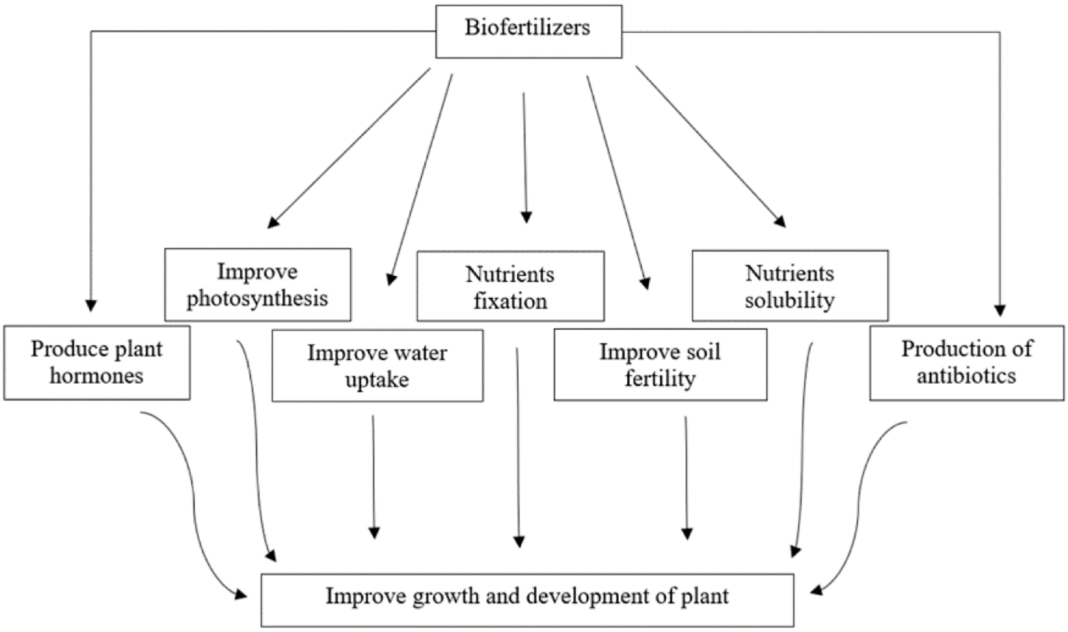
Organic amendments increase crop yields by improving microbe-mediated soil functioning of agroecosystems: A meta-analysis	2018	Soil Biology and Biochemistry Vol. 124, Sept 2018, pp 105-115	Meta-analysis of 690 experiments on organic amendments	Crop yields were on average 27% higher with organic amendment than mineral fertilizer; organic amendment had 22-48% higher C-, N-and P-cycling enzymes than mineral fertilizer; soil enzyme activity strongly linked to soil fertility.
Microbial fertilizers: A comprehensive review of current findings and future perspectives	2018	Spanish Journal of Agricultural Research 16 (1), e09R01, 18 pages (2018)	Review of 109 research studies	There is a considerable body of research presenting evidence of the positive impact of microbial fertilizers, though widespread take up is hampered by various issues.
Bio-fertilizers as key player in enhancing soil fertility and crop productivity: A Review	2018	Direct Research Journal of Agriculture and Food Science, Vol. 6, 3; pp 73-83	Review of 43 research studies	The use of bio-fertilizers leads to improved nutrient and water uptake, plant growth and plant tolerance to abiotic and biotic factors – and they could play a key role in productivity and sustainability of soil as eco-friendly and cost-effective inputs for farmers.
Tiny Microbes, Big Yields: enhancing food crop production with biological solutions	2017	Microbial Biotechnology, 2017 Sep; v 10(5): pp 999–1003.	Thematic review of 18 research papers	Increasing evidence that biological technologies that use microbes can enhance nutrient uptake and crop yield, control pests and mitigate plant stress
Impact of Crop Production Inputs on Soil Health: A Review	2017	Asian Journal of Plant Sciences, June 2017, DOI: 10.3923/ajps.2017.109.131	Review of 154 research studies	Organic amendments such as manure, compost, biosolids and humic substances provide a direct source of C for soil organisms as well as an indirect C source via increased

				plant growth and plant residue returns.
Potential of Biofertilizers to Replace Chemical Fertilizers	2016	International Advanced Research Journal in Science, Engineering and Technology, Vol. 3, Issue 5, May 2016	Review of 53 research studies	Biofertilizers naturally activate the microorganisms found in the soil - and being cheaper, effective and environmentally friendly they are gaining importance for use in crop production, restoring the soil's natural fertility and protecting it against drought, soil diseases and stimulating plant growth.
Comparative analysis of the microbial communities in agricultural soil amended with enhanced biochars or traditional fertilisers	2014	Agriculture, Ecosystems & Environment Vol 191, 15 June 2014, pp 73-82	Comparative analysis	Application of enhanced biochar provides similar sweet corn yields to standard fertilisers – but have a higher impact on microbial communities in the soil.
Long term studies				
Repeated applications of organic amendments promote beneficial microbiota, improve soil fertility and increase crop yield	2020	Applied Soil Ecology Volume 156, December 2020, 103714	Two-year mesocosm study comparing conventional fertiliser and eight organic treatments	Long-term application of organic amendments effectively improved soil fertility and promoted the development of a beneficial soil microbiota capable of supporting high plant yields under intensive agricultural system.
Microbial formulation and growth of cereals, pulses, oilseeds and vegetable crops	2020	Sustainable Environment Research volume 30, Article number: 10 (2020)	Review of 114 research studies	Application of effective microbials improves productivity, biomass accumulation, photosynthesis efficiency and drought tolerance in cereals. In beans, pulses and vegetable crops, microbials increase the

				biomass, yield and other characteristics. In sunflower and groundnut, drought tolerance, virus and fungal disease resistance are improved.
[Long-term benefits of combining chemical fertilizer and manure applications on crop yields and soil carbon and nitrogen stocks in North China Plain]()	2018	Agricultural Water Management Vol 208, 30 Sept 2018, pp 384-392	Long-term (1991–2012) effects of various fertilization regimes on crop yield, and soil organic carbon and total nitrogen and TN in the topsoil of a fluvo-aquic soil in wheat and maize	Long-term application of organic manure in combination with conventional chemical fertilization significantly increased crop yields and levels of soil carbon and nitrogen, with caveats over excess use of manure.
[Effects of fertilization regimes on tea yields, soil fertility, and soil microbial diversity]()	2014	Chilean Journal of Agricultural Research, Vol.74, 2014	Long-term field experiment (2006-2011) to investigate the effects of fertilization regimes in tea crops	Organic manure amendment was a key factor in improving soil properties and productivity. Based on soil quality and tea yields, organic manure is recommended either alone or mixed with chemical fertiliser.
[Long-Term Effects of Organic Amendments on Soil Fertility]()	2011	Sustainable Agriculture Volume 2 pp 761–786	Review long-term experiments (3–60 years) on the effects of organic amendments used both for organic matter replenishment and to avoid use of high levels of chemical fertilizers.	Long-lasting application of organic amendments increased organic carbon by up to 90% versus unfertilized soil, and up to 100% versus chemical fertilizer treatments. Crop yield increased by up to 250% by long-term applications of high rates of solid waste compost.
[The long-term effects of manures and fertilisers on soil productivity and quality: a review]()	2003	Nutrient Cycling in Agroecosystems volume 66, pp 165–180 (2003)	Review of 14 field trials comparing the long-term (20+ years) effects of fertilisers and manures	Soil productivity (crop) from manured soils matches performance of fertilisers, with caveats

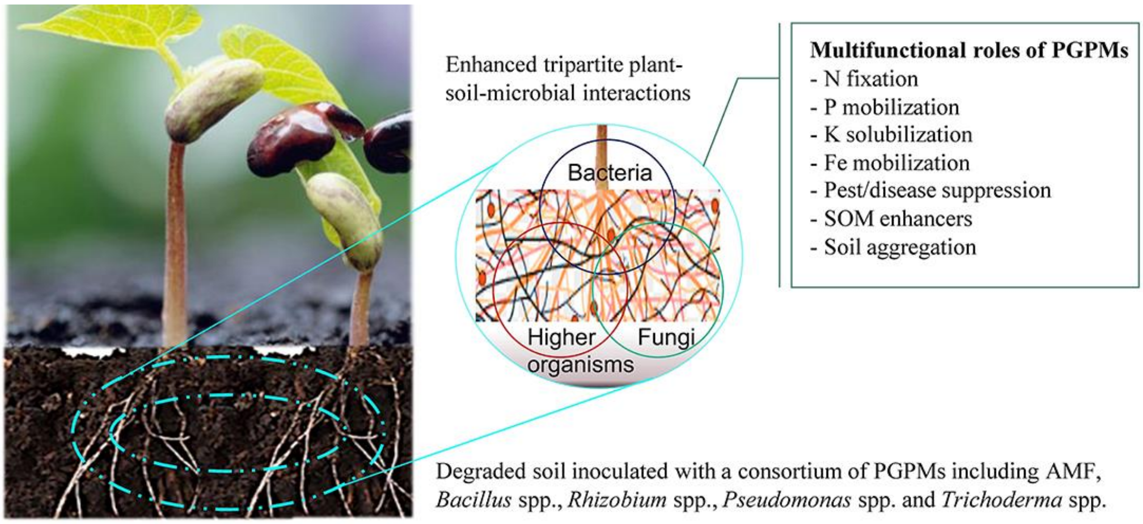
1.3 Mechanisms by which microbial fertilisers improve plant growth

Biofertilisers containing microrganisms impact plant growth and development through a number of mechanisms: improved nutrient fixation and solubility; improved photosynthesis, water uptake and soil fertility; and through production of plant hormones and antibiotics.



Source: Microbes as Biofertilizers, a Potential Approach for Sustainable Crop Production, Nosheen et al, Sustainability 2021, 13(4), p. 1868.

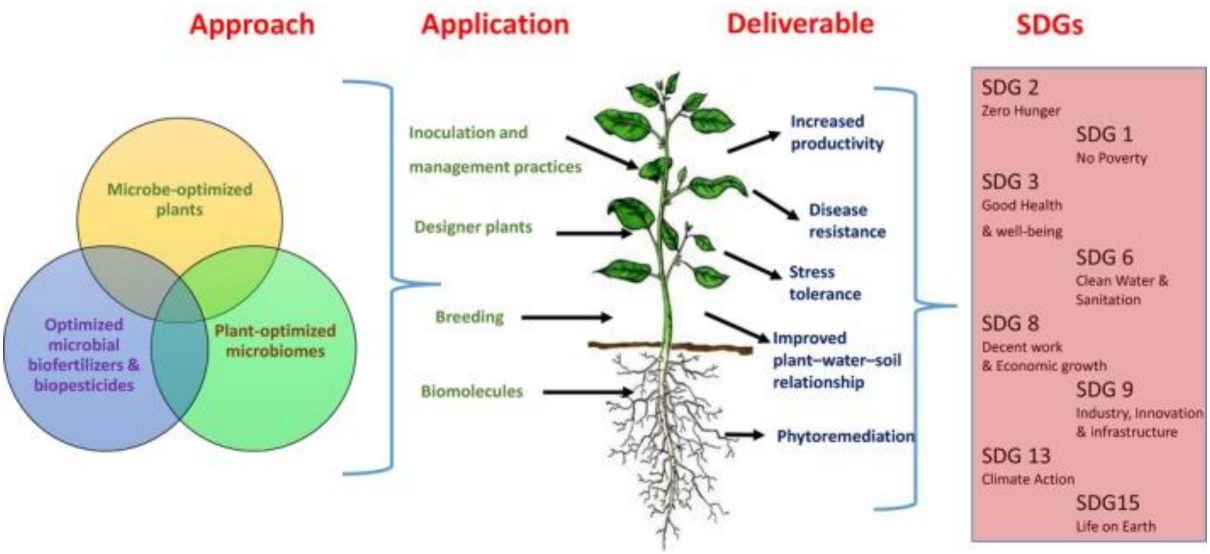
Soil microorganisms' also play a role in soil fertility – which also impacts crop yields. Plant growth promoting microorganisms (PGPMs) form multifunctional interactions that enhance nutrient availability and uptake, pest and disease suppression, soil organic matter (SOM) accumulation and formation of soil aggregates, that collectively increase crop productivity.



Source: Potential Use of Beneficial Microorganisms for Soil Amelioration, Phytopathogen Biocontrol, and Sustainable Crop Production in Smallholder Agroecosystems, Koskey et al, Frontiers in Sustainable Food Systems, 29 April 2021

Microbial technologies can increase productivity of small holdings, improve disease resistance and stress tolerance, and improve the plant-water-soil relationship.

Sustainable increase in farm productivity by harnessing microbial technologies is critical for delivery of multiple **Sustainable Development Goals** (SDGs).



Source: Tiny Microbes, Big Yields: enhancing food crop production with biological solutions, Microbial Biotechnology, 2017 Sep; 10(5), pp 999–1003.

2. Evidence from field trials of Lifeworks' approach

Agronomists / researchers trained as trainers by Lifeworks have conducted their own small-scale field trials. Below are summaries of their findings.

Western Kenya, 2020

Trial comparing crop yields and other characteristics achieved when using: Lifeworks compost alone: a combination of two microbial inputs and the compost; different synthetic fertilisers and commercial inputs; and using no inputs at all. Three crops were tested – maize, kale and tomatoes.

In all three crops, the best results were achieved using a combination of the Lifeworks compost and microbials with some synthetic fertiliser – though this only slightly out-performed the plots treated with just the Lifeworks inputs.

For maize, the yields achieved using the Lifeworks inputs alone were five times (by weight) the yield from no input plots; for kale it was more than double (by weight); for tomatoes it was nearly three and a half times. In all the test plots, the Lifeworks microbials significantly outperformed the synthetic fertilisers when applied alone. (See appendix 1 for full test data).

Weight of Kale leaf using Life LaB, Life FH+ and Berkeley Compost
5.7 grams

Weight of Kale leaf using chemical fertilisers
3.2 grams

Weight of Kale leaf without any inputs
2.6 grams

Maize cultivated with Life Lab, Life FH+ and Berkeley Compost

Weight 447 grams

Maize cultivated with blended chemical fertiliser, lime and trace elements
Weight 306 grams

Maize cultivated with nitrogen / phosphorus pentoxide fertiliser without lime and trace elements
Weight 197 grams

Rwanda, 2020
Trial involving five farmers working with a range of crops African beans, Maize, Irish Potatoes, Soya Beans, Tomatoes and Cassava. Using the same plots, all the farmers increased their yields in the first harvest after applying the microbials. The increases ranged from 50% to 146%, with the average increase in yield of 100%. The average increase in income per farmer was more than U$200. The farmer who experienced the highest yields in the first round, continued the microbial trial for a second harvest and saw larger increases for both crops planted.

Eastern Kenya, 2020
Trial involving 215 farmers in eastern Kenya planting test plots of Kunde, an African leafy vegetable. The farmers had an average germination rate of 95% when using a combination three Lifeworks microbial inputs: 'milk' and 'fish' fertilisers and compost – compared to 39% in plots where no microbials were used and 42% where synthetic fertiliser was used. The plants in the microbial combination plot were the healthiest looking (dark green leaves), tallest, thickest stemmed and reached maturity fastest.

In addition, a number of **long-term, institution-led trials of Lifeworks' approach** are underway on a range of crops across four countries, with early results confirming Lifeworks' own findings about improvements to yields. The trials include the following:

PABRA research trial (beans) in Kenya
A three-site trial of microbial inputs on bean crops compared to synthetic fertilisers is being conducted by Pan-Africa Bean Research Alliance (PABRA) Head office in Kenya.

IITA research trial (maize) in Zambia, Zimbabwe and Malawi
Three-country trial in Zambia, Zimbabwe and Malawi. The data is being collated and analysed and two scientific papers will be submitted to scientific journals.

Microbials and soil carbon sequestration trial, Kenya
Dr Michael Mokhoka, a carbon sequestration scientist, is currently running a trial in western Kenya to ascertain the efficacy of the inputs in sequestering carbon. This would scientifically validate the inputs as a climate smart input and open the door to dialogue around small scale farmers being paid for the carbon credit that they are able to scientifically prove.

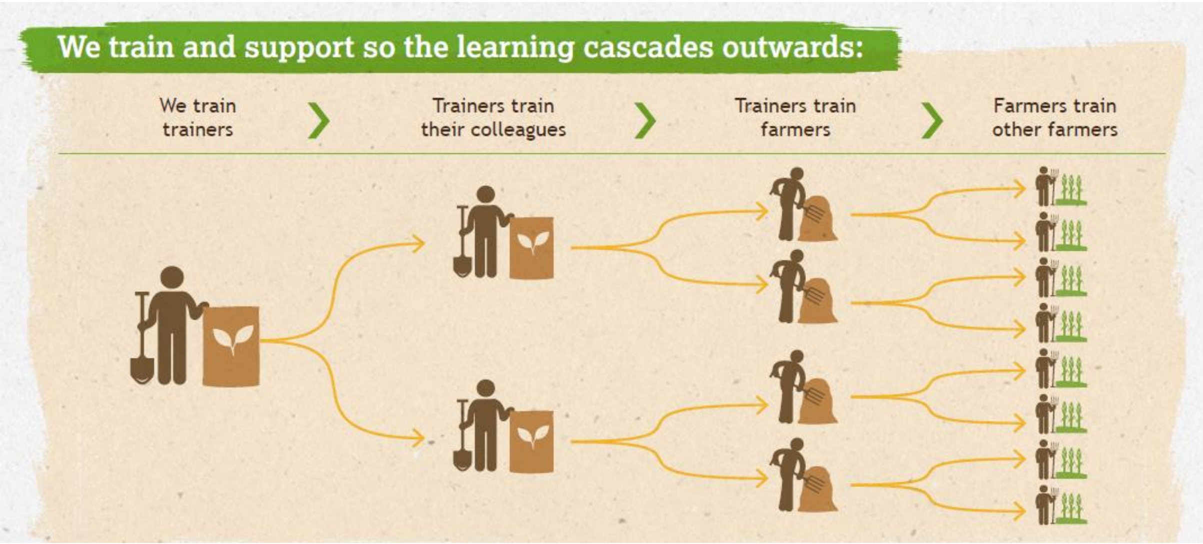
Soil fertility trial, Malawi
Dr Keston Njira, of the Lilongwe University of Agriculture and Natural Resources, Malawi, is a specialist in microbes affecting soil fertility. He has agreed to co design a trail protocol with Lifeworks Global to ascertain the efficacy of the inputs on soil fertility.

3. Case studies: the impact of Lifeworks' training

Lifeworks uses a cascade training model in a number of sub-Saharan countries. We initially train a group of trainers in each country, people who typically work for national or regional governments, or organisations and programmes that support farmers.

We sometimes train groups of farmers directly. We teach them how to produce and apply organic microbial fertilisers and compost made from locally available, low-cost materials.

Often the farmers we train go on to train others in their community and surrounding districts – and Lifeworks supports those farmers, paying travel and other expenses.



3.1 Farmer case studies

Rwanda

<u>*Patrick,*</u> a 28-year-old genocide survivor in Rwanda, was a small-scale subsistence farmer renting a piece of land 40m x 50m. In 2019 he harvested 89Kg of beans. He attended the training in January 2020. He made and applied the microbial fertilisers and in June 2020 he harvested 219kg of beans and in 2021, he called us quite emotionally to tell us he harvested 450kg of beans. His beans harvest had increased fivefold. He has made the leap from being a subsistence farmer to a small-scale commercial farmer. He has started a piggery, bought land and built a house and he is getting married this year.

<u>*Clementine*</u> couldn't pay here rent of $30 a month and struggled to grow enough food for her family before attending the Lifeworks Global training in Kayonza in Eastern Rwanda. She had adopted 3 children in her neighbourhood as their parents could provide for them. Her family struggled. She was on the village list of parents who couldn't pay school fees, a socially embarrassing mechanism design to urge parents to pay. The family used to eat meat, fish or chicken once a year at Christmas. Now they eat meat, fish or chicken twice a week. They have bought a small piece of land and built a large chicken-house and she is starting a chicken rearing business. She is off the school fees list and hold her head up high in her village.

Zambia

Christopher Chiluba is Regional Commander Western Zambia's prison service. He and seven colleagues attended our training in September 2020. He was so inspired that he committed to rolling out the Lifeworks method to inmates across the six correctional facilities he oversees, and to support them after their release. So far more than 100 inmates have learned how to make and apply the compost and microbial inputs, and how to set up demonstration plots to test them. At one prison, inmates have set up a demo garden overseen by an officer who attended our training. Christopher now has plans to scale up and to reach more than 300 prisoners. Lifeworks is collaborating to create a 'Release Package' which will include all the training materials translated into the local language, together with a selection of seeds. Christopher hopes that this project can be replicated in other regions across the country.

Kenya

Augustus lives in the village of Mudindi, near Lake Victoria, where he plants maize to feed his family and to take to market. His fields are flourishing and his neighbours are asking what he has done. Augustus is now passing on what he learned at a Lifeworks training about building resilience to torrential rains. In this part of western Kenya, the rains used to be reliable, but now the rains are so intense the soil is often washed away and crops destroyed. This did not happen to Augustus' maize plants or the soil, which can withstand the heavier rains. Now, armed with resources from Lifeworks, Augustus has learned how to pass on the training to his neighbours.

Christopher is a farmer in western Kenya, a recent new member of a consortium for scaling organic agriculture agroecology, supported by training by Lifeworks. Christopher was not able to grow enough food for his own family, but now using microbial inputs such as fish hydrolysate he has a surplus for the first time. Today he no longer has to buy food for his family and he is able to sell his surplus and pay school fees for his children. Christopher has trained 10 farming families in his village and plans to continue and play a role in eliminating hunger in his community.

3.2 Trainer case studies

George Mwima, Kenya
George is a university lecturer and project manager for the Anglican Development Service in the Kakamega province of Western Kenya. For the last 12 years he has worked in community development, particularly on programmes focusing on agriculture, food security and environmental sustainability. In 2019, George was trained by Lifeworks. He went on to test the use of microbial inputs on his own farm and, after seeing the results, he started to train five groups of farmers, part of a Soil Rehabilitation and Fertility Management group he supports. In 2022, George joined Lifeworks as a trainer.

> "Soils treated with microbes are better at sustaining a crop for two weeks in the absence of rain. Regenerative agriculture is a key mechanism to help us cope with the vagaries of climate change.

"We must avoid herbicides and pesticides, as they are killing our soils by reducing the diversity of the microbes within the soil eco-system. Microbes are a lifeline for our degraded soils.

"The farmers who have learnt these skills are excited and they feel part of the growing movement for regenerative agriculture. These approaches don't need technical knowledge, just knowledge of a simple fermentation process that anyone can do. They feel confident and like the fact they can control the process.

"Farmers are looking for alternatives, and knowledge of soil health is changing. There are so many counterfeit fertilisers and other products on sale in this country, you can never tell if they are real or not. On the other hand, soil micro-organisms are available to all and are a single bullet that can help all farmers.

"If you have got a low-cost formula for unleashing the potential of the soil it will transform the future for many families and many communities. With microbial and regenerative practices we can build a better soil and pull many people out of poverty. Micro-organisms are what bring about all this magic."

Fred Anami, Kenya
Fred is an agronomist based in Western Kenya. He works for the Kakamega County Widows Empowerment Project, which was founded in 2016 and which helps thousands of women across the county. Fred was trained by Lifeworks in 2019 and has since trained nearly 3,000 women farmers in how to use and microbial preparations to improve their soils and their crops. Fred is involved in field trials for the Pan-Africa Bean Research Alliance (PABRA) on the use of microbials on bean crops and other legumes without use of synthetic fertiliser.

"The women we have trained are seeing good results: The first thing that is obvious to them is the quality of the produce: the taste is sweet and the plants look healthy. They get better yields and then, as the soil fertility regains, many of them find they are producing a surplus which they can take to market and sell.

"The Lifeworks microbial preparations can be produced using materials that are locally available at an affordable rate. For example, to produce 5 litres of fish hydrolysate, which can last an entire planting season, it costs less than half what the farmers usually spend on synthetic fertiliser and other inputs for just a single crop.

"In the tests we have done, we find the crops last longer, the rate of infestation of pests is lower, and the rate of germination is higher, so using microbials saves on seeds too. Climate change is causing unusually heavy rainfall and also periods of prolonged drought. Microbials help crops resist periods where there is no water.

"Microbials can make a lot of difference, particularly when seen over three or four seasons, the soil fertility will improve, they will be more nutrients and farmers will increase the surplus they have that they can sell.

"There are environmental benefits too, farming with microbials reduces the impact on health from contamination with chemicals and synthetic fertilisers."

4. Commercial applications of microbial products

The commercialization if microbial products has a long history and was led by two international pioneers of microbial research – Dr Elaine Ingham and Professor Teruo Higa.

In the US, leading soil fertility researcher **Dr Elaine Ingham** founded the Soil Food Web School to train farmers and others how to restore soil fertility using microorganisms. As well as developing multi-level commercial training courses, Dr Ingham has created a range of proprietary microbial fertiliser called Biocomplete. In March 2022, the Soil Food Web School hosted Soil Regen Summit 2022, an international online conference on soil regeneration.

In Japan, **Professor Teruo Higa** has commercialized a range of microbial products since the 1980s under the brand name of EM, which stands for Effective Microorganisms. He founded the EM Research Organization Inc. (EMRO) in 1994. The early EM products were developed following a decade of research and today there is a range of EM applications, including agriculture, animal husbandry, aquaculture, health care, water treatment, waste treatment and construction. Proprietary EM technology is available in many countries around the world through a network of distributors and affiliates.

Austria's Multikraft was founded in 1977 selling antibiotic-free animal feed and other agricultural products. This long-established company later began selling EM products from EMRO, as well as its own range of microbial products. Applications include: plants and garden, animal husbandry, agriculture and farming, ponds and water, household cleaning products, cosmetics, composting and sewage, among others.

Founded in 2007, the UK's Microbz sells a range of its own microbial products for health, home, garden and animals. In 2021, the company expanded into agricultural products.

Microbial technology is developing fast and specific bacteria have been discovered that can help clean up after ocean oil spills and to deal with the growing issue of plastic waste.

In agriculture, the global biofertilizer market is expected to grow by 13% per year over the period 2020-30. The market is expected to grow in value from U$ 1.4 billion in 2020 to U$ 4.71 billion by 2030, according to the research firm The Brainy Insights.

Appendix 1: Field trial results from Kenya, 2020

Researcher: George Mwima

MAIZE	No. of plants	Germination rate %	Deficiency symptoms	Pest burden	Weight (g)
Compost	100	89	Severe yellowing	Fall armyworm, stalk borer, ants	373
Compost, LaB	100	98	Mild yellowing	NIL	n/a
Compost, LaB, Fish	100	97	Dark green	NIL	**447**
Synthetic fertilizer (blended)	100	75	Yellowing	Fall armyworm, stalk borer, ants	306
Synthetic fertilize (acidifying ones)	100	82	Yellowing	Fall armyworm, stalk borer, ants	197
Synthetic fertilizer, compost	100	84	Dark green	Fall armyworm, stalk borer, ants	412
Synthetic fertilizer, compost, LaB, Fish	100	94	Dark green	NIL	**459**
Without any input	100	89	Yellowing, stunted growth	Fall armyworm, stalk borer, ants	89

KALE	Number of plants	Germination rate % at nursery	Deficiency symptoms in the field	Pest burden	Disease burden	Weight (g)
Compost	100	98	Yellowing, brown	Aphids, Diamond Buck Moth, caterpillars	Mild Stem rot, wilting	4.9
Compost, LaB	100	99	Yellowing	Aphids absent	NIL	5.5
Compost, LaB, Fish	100	98	Dark green	Aphids absent	NIL	**5.7**
Synthetic fertilizer(blended)	100	72	Yellowing, stunted, grayish	Aphids, Diamond Buck Moth, caterpillars	Severe stem rot, wilting	5.2
Synthetic fertilizer (acidifying ones)	100	79	Yellowing, stunted, grayish	Aphids, Diamond Buck Moth, caterpillars	Severe stem rot , wilting	4.6
Synthetic fertilizer, compost	100	94	Dark green	Aphids, Diamond Buck Moth, caterpillars	Mild stem rot, wilting	5.4
Synthetic fertilizer, compost, LaB, Fish	100	98	Dark green	NIL	NIL	**6.3**
Without any input	100	96	Yellowing, brown, grayish stunted growth	Aphids, Diamond Buck Moth, caterpillars	Severe stem rot, wilting	2.6

TOMATOES	Number of plants	Germination% at nursery	Deficiency symptoms in field	Pest burden	Disease burden	No. of plants surviving to harvest	Weight (g)
Compost	100	89	Leaves and stem burn, yellowing	Aphids, bollworms, caterpillars	Blight, Bacterial and fusarium wilt, blossom end rot, rust	56 tomatoes	52.5
Compost, LaB	100	98	Yellowing of leaves margin	NIL	Bacterial wilt	67 tomatoes	n/a
Compost, LaB, Fish	100	97	Dark green	NIL	Bacterial wilt	**89 tomatoes**	**56.3**
Synthetic fertilizer(blended)	100	75	Yellowing, brownish, leaves burn	Aphids, bollworms, caterpillars	Blight, blossom end rot, fusarium wilt, rust, bacterial wilt	41 tomatoes	29.9
Synthetic fertiliser (acidifying ones)	100	82	Severe leaves and stem burn, Yellowing	Aphids, bollworms, caterpillars,	Blight, bacterial wilt, fusarium wilt, blossom end rot, rust	29 tomatoes	22.7
Synthetic fertilizer, compost	100	84	Dark green	Aphids, bollworms, caterpillars	Bacterial wilt, blight, rust	51 tomatoes	53.9
Synthetic fertilizer, compost, LaB, Fish	100	94	Dark green	NIL	Bacterial wilt	**83 tomatoes**	**61.6**
Without any input	100	89	Yellowing, severe leaves and stem burn, stunted growth	Aphids, bollworms, caterpillars	Bacterial wilt, blight, rust blossom end rot, fusarium wilt	14 tomatoes	16.4

Annexe 2: Further information and useful links

How microbial life transforms soil and plant fertility

Dr Elaine Ingham's Soil Food Web School website features a number of short videos that explain how soil microorganisms interact with each other and with the plants that grow in the soil. The 'How it works' videos cover the following topics:

- The soil food web – an introduction to the soil microbiome
- Nutrient cycling – how microorganisms harvest beneficial nutrients
- The formation of structure – how microorganisms influence soil structure
- Weed suppression – the role of beneficial fungi
- Inhibiting pests and diseases – how microorganisms help plants' immunity
- Soil carbon sequestration – the role of microorganisms in soil's carbon capacity

Lifeworks: how we work, how to make microbial fertilisers

The resources section of our website features an introductory video and a two-page leaflet that tells you all the key facts about Lifeworks and how we spread life-changing knowledge to farmers in sub-Saharan Africa. In addition, there are a series of 'how to videos' that show you how to make four different fermented microbial fertilisers from readily available ingredients: lactobacillus 'milk fertiliser, fish hydrolysate fertiliser, cow dung / urine fertiliser, and 18-day compost (Berkley hot compost method).