Appendix One

This an appendix to the briefing paper: The case for the New Zealand Government to invest in Regenerative Agriculture as part of its Covid 19 economic recovery package. Prepared by Genevieve Toop on behalf of Greenpeace NZ - April 2020

The following appendix provides a summary of common regenerative organic farming practices as well as a summary of each study referred to in the briefing document (in order of appearance) along with their full references.

Common regenerative organic farming practices

- **Diversification** also known as polycultures: The growing of multiple species of plant, forage, crop and animals.
- **Agroforestry,** also known as alley cropping, silvopasture, silvoarable: The integration of trees, into livestock and/or cropping farms, usually in rows.[1] The trees are usually high-value timber, fruit, nut or forage.
- **Cover-cropping** also known as green manures: Cover crops or green manures are plants grown for the purpose of enhancing the quality of soil, rather than for harvest.
- **Intercropping**: cultivation of two or more crop rows simultaneously on the same field.
- **Adaptive/holistic grazing;** significantly smaller areas of diverse pasture are grazed, over a shorter time and with a longer pasture recovery period than conventional grazing.
- **Conservation tillage** including direct drilling, low or zero till: A reduction in the intensity and frequency of soil tillage, and the retention of plant matter on the soil surface.

Resilience to drought, floods, and pest incursions

Introduction

Healthy soils create greater resilience by acting as a sponge, storing water during rainfall events and releasing it slowly over time. The USDA estimates that 1 percent of organic matter in the top 15cm of soil holds approximately 102,000 litres of water per acre.[2] Soils managed with regenerative organic methods have shown better water holding capacity, water infiltration rates, higher organic matter and lower erosion rates and as a result have **produced higher yields** than high-input monocultures in drought and flood. Mycorrhizae increase water and nutrient uptake in plants by attaching to the roots and developing a network of filaments that explores the soil and accesses more nutrients and water to transfer to the plant and have also been found at higher levels on regenerative farms.[3] Diversification has also shown to reduce the risk of crop failure during drought and flood, providing higher yields than high-input monocultures under these conditions.

Pest populations are more likely to grow and spread when they face a genetically uniform crop or animal species. Maintaining genetic diversity has been found to reduce the spread of pest populations which otherwise thrive in genetically uniform monocultures. Additionally, diversification and other regenerative methods have shown to support a higher level of natural predators that can deal with pests, as well as create a healthy soil biology that discourages breakouts of bacterial, fungicidal and viral infections.

Summary of Studies

- **Bulluck et al 2002**[4] - USA - field experiments at three organic and three conventional vegetable farms conducted to examine the effects of organic and synthetic soil fertility amendments on soil microbial communities, physical and chemical properties it found:
    - The organic fertilisers led to enhanced beneficial soil microorganisms and decreased numbers of plant-pathogenic microorganisms, such as Phytophthora and Pythium species in the soil.
    - They also increased soil organic matter, total carbon, and cation exchange capacity (CEC), and lowered bulk density thus improving soil quality
    - By the second year of the study yields were higher on organic farms
- **Lotter et al 2003** [5] - A 22 year Farming Systems Trial in USA - compared a regenerative crop and livestock, a regenerative crop and a high input monoculture crop system. It found:
    - On the regenerative farms water capture was significantly higher during high rainfall, leading to reduced flooding.

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[2] United States Department of Agriculture Natural Resources Conservation Service, 2013. Soil Health Key Points. Accessed here.
[3] Khalvati, M.A., Hu, Y., Mozafar, A. and Schmidhalter, U., 2005. Quantification of water uptake by arbuscular mycorrhizal hyphae and its significance for leaf growth, water relations, and gas exchange of barley subjected to drought stress. *Plant Biology*, *7*(06), pp.706-712.
[4] Bulluck Iii, L.R., Brosius, M., Evanylo, G.K. and Ristaino, J.B., 2002. Organic and synthetic fertility amendments influence soil microbial, physical and chemical properties on organic and conventional farms. *Applied Soil Ecology*, *19*(2), pp.147-160. Link here
[5] Lotter, D.W., Seidel, R. and Liebhardt, W., 2003. The performance of organic and conventional cropping systems in an extreme climate year. *American Journal of Alternative Agriculture*, *18*(3), pp.146-154.

    - In 4 out of the 5 drought years the organic maize and soybean out yielded the monoculture by significant margins. 38% - 137% higher for maize and 152%-196% higher for soybean this was attributed to;
    - Soil on the regenerative organic farms had improved soil carbon, water-holding capacity, infiltration rate and water capture efficiency. This meant soils that regenerative organic plots captured more water and retained more of it in the crop root zone than in the conventional monoculture.
- **Holt-Gimenez, 2002**[6] - In Central America over 800 farms using organic and sustainable methods were the subject of a comparison study, using paired conventional neighbor farms, of the effects of Hurricane Mitch.
    - On average, agroecological plots lost 18% less arable land to landslides than conventional plots and had a 49% lower incidence of landslides.
    - On average, agroecological plots on sustainable farms had more topsoil, higher field moisture, more vegetation, less erosion and lower economic losses after the hurricane than control plots on conventional farms
    - The farming practices commonly used on the agroecological farms included; agroforestry, intercropping, cover cropping, living fences, crop rotation, stubble incorporation, 0-tillage.
- **Mader et al 2000**[7] Switzerland - 15 year field study. Arbuscular mycorrhizal (AM) root colonization was compared on two low-input farm systems (organic and bio-dynamic) and two high-input farm systems using chemical fertilisers and pesticides. It found:
    - The percentage of root length colonized by AM fungi was 30–60% higher in plants grown on the low-input farming systems than in those grown in conventionally farmed soils.
- **Lockeretz et al. 1981**[8] - A 5-year comparison study of midwest USA organic farms and conventionally managed farms found:
    - That there was 30% less erosion on the organic farms.
- **Di Falco and Chavas, 2008**[9] - Italy used regional data for the period 1970–1993 to study the effects of genetic diversity in rainfed wheat fields and found:
    - High genetic diversity within fields reduced rates of crop failure during dry conditions when compared with monoculture wheat fields.
    - And conclude that ”under climatic changes, enhancing the biodiversity of an agroecosystem can help maintain its long term productivity and its ability to produce food”
- **Drinkwater et al 1995**[10] compared productivity on organic and conventional tomato farms in California and found that:
    - Greater microbial activity on organic farms contributed to suppression of root pathogens.

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[6] Holt-Giménez, E., 2002. Measuring farmers' agroecological resistance after Hurricane Mitch in Nicaragua: a case study in participatory, sustainable land management impact monitoring. *Agriculture, Ecosystems & Environment*, *93*(1-3), pp.87-105.
[7] Mäder, P., Edenhofer, S., Boller, T., Wiemken, A. and Niggli, U., 2000. Arbuscular mycorrhizae in a long-term field trial comparing low-input (organic, biological) and high-input (conventional) farming systems in a crop rotation. *Biology and fertility of Soils*, *31*(2), pp.150-156. here
[8] Lockeretz, W., Shearer, G. and Kohl, D.H., 1981. Organic farming in the corn belt. *Science*, *211*(4482), pp.540-547. link.
[9] Di Falco, S. and Chavas, J.P., 2008. Rainfall shocks, resilience, and the effects of crop biodiversity on agroecosystem productivity. *Land Economics*, *84*(1), pp.83-96. Link
[10] Drinkwater, L.E., Letourneau, D.K., Workneh, F.A.C.H., Van Bruggen, A.H.C. and Shennan, C., 1995. Fundamental differences between conventional and organic tomato agroecosystems in California. *Ecological Applications*, *5*(4), pp.1098-1112. Link here

    - "Differences between the agroecosystems were sufficiently robust to be distinguished from environmental variation and suggest that biological processes compensated for the reductions in the sue of fertiliser and pesticides"
- **Zhu et al., 2000.**[11]- China Field study comparing genetically diversified rice crops in 15 different areas with monoculture rice crops to calculate the effect of diversity on the severity of rice blast, a major fungal disease of rice they found:
    - Disease-susceptible rice varieties planted in diverse systems with resistant varieties had 89% greater yield and a 94% lower disease incidence – compared to when they were grown in a monoculture.
- **Krauss et al., 2011**[12] Germany - Assessed 15 organic vs. 15 conventional cereal fields and recorded vascular plants, pollinators, aphids and their predators. As well as compared, five conventional fields treated with insecticides with 10 non-treated conventional fields. They found:
    - In organic fields the abundance of cereal aphids was 5 times lower, predator abundances were 3 times higher and predator-prey ratios 20 times higher, indicating a significantly higher potential for biological pest control.
    - Insecticide treatment in conventional fields had only a short-term effect on aphid densities while later in the season aphid abundances were even higher and predator abundances lower in treated compared to untreated conventional fields.
    - The concluded "organic farming increases biodiversity, including important functional groups like plants, pollinators and predators which enhance natural pest control."
- **Hassanali et al., 2008**,- In Africa, scientists have developed what's called a "push-pull system" to fight a maize pest called stemborer and striga weed without the use of chemicals. They planted certain grasses on the borders of maize fields which attracted or "pulled" stemborer away from maize. Then they intercropped by planting two other plants within the maize rows which repelled or "pushed" the insect pests from the crop Maize. This 3 year long field study in Kenya compared 20 sets of 'push–pull' maize cropping with 20 maize monocrops and found:
    - Stemborer damage and striga counts to maize plants were significantly lower in the 'push–pull' plots than in the maize monocrop plots.
    - Maize height and grain yields were significantly higher in the push-pull system

Reduction in water pollution

Eliminating chemical fertiliser use and lowering stocking rates is a well documented method of reducing nitrate losses to waterways. Many of the regenerative organic practices listed at the beginning of the appendix have shown additional reductions in nitrate, phosphorus and sediment losses to waterways, which also provides better nutrient uptake by plants and reduced loss of topsoil. This is generally due to diversification and healthier soil practices notably agroforestry, cover-cropping and conservation tillage.

[11] Zhu, Y., Chen, H., Fan, J., Wang, Y., Li, Y., Chen, J., Fan, J., Yang, S., Hu, L., Leung, H. and Mew, T.W., 2000. Genetic diversity and disease control in rice. *Nature*, *406*(6797), pp.718-722.

[12] Krauss, J., Gallenberger, I. and Steffan-Dewenter, I., 2011. Decreased functional diversity and biological pest control in conventional compared to organic crop fields. *PloS one*, *6*(5). Link

Summary of Studies

- **Mondelaers et al. (2009)** [13] a meta-analysis comparing nitrate leaching on organic agriculture with conventional agriculture, found:
    - Significantly lower nitrate leaching for organic farming systems
- **Gardner and Drinkwater 2009**[14] A meta-analysis of global research on nitrogen uptake by crops found that:
    - Crop rotation and organic fertilizers enhance the uptake of nitrogen by the crop and reduce its losses as pollution.
- **Thapa et al. 2018**[15] - a meta-analysis using 238 observations from 28 studies to assess the overall effect of cover crops in cropping systems on nitrate leaching found:
    - There is a clear indication that non-leguminous cover crops can substantially reduce nitrate leaching into freshwater systems, on average by 56%
- **Kuyah et al. 2019** [16]An agroforestry meta-analysis of 1106 observations from 126 peer-reviewed publications that compared agroforestry and non-agroforestry practices. Across ecological conditions it found agroforestry:
    - significantly increased crop yield, total soil nitrogen, soil organic carbon, and available phosphorus compared to the control.
    - reduced runoff and soil loss and improved infiltration rates and soil moisture content.
- **Landcare Trust 2019**[17] - NZ modelling study - compared farms with varying stocking rates, fertiliser use and imported feed. It found that:
    - The farm with the lowest synthetic fertiliser use and the second smallest herd had the largest increase in profitability (29%) and the lowest environmental footprint, a 13% reduction in nitrate leaching and an 18% reduction in GHG emissions.
- **AgResearch 2009**[18] . Compared different dairy systems on farmlets in Waikato over three years. Farmlets compared varied in their intensity. A low input system (no N fertiliser, no brought-in feed, stocking rate of 2.3 cows/ha). An average Waikato system (114kg fertiliser-N/ha/year. An N-fertilised farm system (170 kg fertiliser-N/ha/year, 3 cows/ha). An N-fertilised and maize silage supplemented system (170 kg fertiliser-N/ha/year, 13 t DM maize silage/ha/year, 5.2 cows/ha) and found the low-input system had :

[13] Mondelaers, K., Aertsens, J., Van Huylenbroeck, G. (2009). A meta-analysis of the differences in environmental impacts between organic and conventional farming. British Food Journal 111 (10), (link)
[14] Gardner, J.B. and Drinkwater, L.E., 2009. The fate of nitrogen in grain cropping systems: a meta-analysis of 15N field experiments. *Ecological Applications*, *19*(8), pp.2167-2184. (link)
[15] Thapa, R., Mirsky, S.B. and Tully, K.L., 2018. Cover crops reduce nitrate leaching in agroecosystems: A global meta-analysis. *Journal of environmental quality*, *47*(6), pp.1400-1411. (Link)
[16] Kuyah, S., Whitney, C.W., Jonsson, M., Sileshi, G.W., Öborn, I., Muthuri, C.W., Luedeling, E., 2019. Agroforestry delivers a win-win solution for ecosystem services in sub-Saharan Africa. A meta-analysis. (Link)
[17] A.J. Litherland (NZ Landcare Trust), B. Riddler (E2M modelling), M. Langford (Fonterra), M Shadwick (DairyNZ) Finding a win-win for the farmer and the environment.
[18] Basset-Mens, C., Ledgard, S. and Boyes, M., 2009. Eco-efficiency of intensification scenarios for milk production in New Zealand. *Ecological economics*, *68*(6), pp.1615-1625.

    - The lowest greenhouse gas emissions, lowest nitrate leaching rates and the highest energy efficiency.
    - The highest milk production per cow.
    - The highest profitability when milk prices were low and maize prices were high.
    - The least financially risky in terms of profit due to fluctuating input prices.
- **Selbie et al 2017**[19] A dairy farmlet study was set up in the Waikato to compare a conventional system with a lower input system with lower N inputs and a lower stocking rate, and standing cows off pasture for 5-15 hours/day during March-July it found:
    - N leaching losses were consistently lower in the low-input farmlet. On average, N leaching losses were reduced by 43%, from 54 kg N/ha to 31 kg N/ha.
- **Kramer et al. 2006**[20] USA, compared organic and conventional apple orchards, found:
    - Annual nitrate leaching was 4.4–5.6 times lower in organic plots than in conventional plots
    - As well as increased amounts of carbon stored in the soil and increased diversity and activity of soil microbes in the organic plot.
- **Thevathasan et al 2004** [21]Canada - In field 15 year agroforestry study, researchers planted trees in between rows (3-15m sow spacings) of agricultural crops; soybean, corn, and either winter wheat or barley. They estimated:
    - That intercropping with trees has reduced nitrate loading to adjacent waterways by 50%, due to interception by tree roots.
- **Allen et. al 2004**[22] - USA in field agroforestry study which used a pecan tree –cotton alley cropping system to test the hypothesis that nitrogen leaching on agroforesry systems would reduce because deep roots of trees serve as a "safety net" for capturing the N that is leached below the root zone of crops.The scientists concluded:
    - "It is likely that tree roots were able to capture N in the non-barrier treatment, resulting in lower rates of leaching below the root zone.: It appears that tree roots play a significant role in alleviating groundwater nitrate leaching through their safety-net role in temperate alley cropping systems."
- Studies also finding reduced water pollution already covered in other sections:
    - **Lockeretz et al. 1981 (**resilience section)
    - **Davis et al 2012** (yield section)

Increased levels of biodiversity

Introduction

[19] Selbie, D.R. et al. 2017. Following the nitrogen: explaining the reasons for decreased N leaching in the Waikato P21 farmlets. In: Science and policy: nutrient management challenges for the next generation. (Eds L. D. Currie and M. J. Hedley). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 30. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 5 pages.

[20] Kramer, S.B., Reganold, J.P., Glover, J.D., Bohannan, B.J. and Mooney, H.A., 2006. Reduced nitrate leaching and enhanced denitrifier activity and efficiency in organically fertilized soils. *Proceedings of the National Academy of Sciences*, *103*(12), pp.4522-4527.

[21] Thevathasan, N.V., Gordon, A.M., Simpson, J.A., Reynolds, P.E., Price, G. and Zhang, P., 2004. Biophysical and ecological interactions in a temperate tree-based intercropping system. *Journal of Crop Improvement*, *12*(1-2), pp.339-363. (link)

[22] Allen, S.C., Jose, S., Nair, P.K.R., Brecke, B.J., Nkedi-Kizza, P. and Ramsey, C.L., 2004. Safety-net role of tree roots: evidence from a pecan –cotton alley cropping system in the southern United States. *Forest ecology and management*, *192*(2-3), pp.395-407. (link)

Regenerative organic farms' have been found to provide benefits to biodiversity by supporting more plant, insect and animal species including a higher number of pollinators.

- **Tuck et al 2014** [23]- A meta-analysis of studies over the last 30 years that compared biodiversity (measured as species richness) under organic and conventional farming methods using 184 observations garnered from 94 studies found:
    - On average, organic farming increased 'species richness' by about 30%.
    - The number of different pollinator species was 50% higher on organic farms
    - Most functional groups – herbivores, pollinators, predators and producers – were more diverse in organic farming

Increased carbon sequestration

The increased carbon sequestration occurring on regenerative organic farms is primarily due to the incorporation of agroforestry, and the increase in soil carbon stocks. While agroforestry systems contain less carbon than primary or managed forests, they sequester carbon over and beyond what would occur under other agricultural activities. Soils fertilised organically and using regenerative methods have shown to increase the amount of carbon stored in the soil, as well as have better soil stability, enhanced soil fertility, higher soil biodiversity and activity of microbes and earthworms.

Summary of Studies

- **IPCC 2000**[24] - The IPCC cites agroforestry as having an important role to play in mitigation of climate change
- **De Stefano et al 2018**[25]**.** A meta-analysis of 53 published studies was carried out to investigate changes in soil organic carbon (SOC) after land conversion to agroforestry. They found:
    - The conversion from agriculture to agroforestry significantly increased soil organic carbon stocks at all levels (26% at 0–15cm, 40% at 0–30cm and 34% at 0–100cm.)
    - The conversion from pasture/grassland to agroforestry produced soil carbon stock by 9% at 0–30 cm and 10% 0–30 cm.
- **Liebig et al 1999.**[26]- An evaluation of the impact of organic production practices on soil quality indicators in Nebraska and North Dakota. Five organic and five conventional farms, matched by soil type, were compared. Averaged across locations, they found that on organic farms:
    - There was 22% more organic C. in the surface 30.5 cm
    - 20% more total N in the surface 30.5 cm.

[23] Tuck, S.L., Winqvist, C., Mota, F., Ahnström, J., Turnbull, L.A. and Bengtsson, J., 2014. Land-use intensity and the effects of organic farming on biodiversity: a hierarchical meta-analysis. *Journal of applied ecology*, *51*(3), pp.746-755. Link here
[24] IPCC (2000) Land-use, land-use change and forestry. Special report of the intergovernmental panel on climate change. Cambridge University Press, UK, p 375
[25] De Stefano, A. and Jacobson, M.G., 2018. Soil carbon sequestration in agroforestry systems: a meta-analysis. *Agroforestry systems*, *92*(2), pp.285-299.(Link)
[26] Liebig, M.A. and Doran, J.W., 1999. Impact of organic production practices on soil quality indicators. *Journal of environmental quality*, *28*(5), pp.1601-1609. link

    - At four of five locations, organic farms had soil pH closer to neutral, lower bulk density, and higher available-water holding capacity, microbial biomass C and N, and soil respiration as compared with conventional farms.
    - Organic production practices cited to improve soil quality were more diverse crop sequences, application of organic amendments, and less frequent tillage.
- **Palma et al 2007**[27] Modelling study on 19 different locations in Europe modeled the adoption of silvoarable agroforestry systems - integrating trees and arable crops on the same land against a range of environmental indicators and found that agroforestry could:
    - Significantly reduced erosion, up to 65% when combined with contouring practices.
    - Nitrogen leaching could be reduced by up to 28% in areas where leaching is currently estimated high.
- Studies also finding increased carbon sequestration in soil covered in other sections
    - **Kramer et al., 2006**, (Water quality section)
    - **Bulluck et al 2002** (Resilience section)

Increased soil health

Soils fertilised organically and using regenerative methods have shown to have better soil stability, enhanced soil fertility, higher soil biodiversity and activity of microbes and earthworms.

Summary of Studies

- **Reganold et al., 1993**[28] - New Zealand field study over a four year period in the North Island examined the physical, biological, and chemical soil properties and economic profitability/financial performance of biodynamic and conventional farms (16 total) were compared. The biodynamic farms
    - Just as financially viable on a per hectare basis.
    - had better soil quality than the neighboring conventional farms
    - The biodynamic farms proved in most enterprises to have soils of higher biological and physical quality: significantly greater organic matter content and microbial activity, more earthworms, better soil structure, lower bulk density, easier penetrability, and thicker topsoil.
    - By mass, the biodynamic farmed soil had 86.3 g per square meter of earthworms, vs 3.4 g square meter on conventional famrs
- **Isbell et al., 2013**,[29] USA - used results from long-term grassland field experiments to test for direct effects of effects of long-term use of synthetic nitrogen fertiliser, at various levels on productivity. It found that long-term chemical fertilisation caused:
    - Adding synthetic nitrogen fertiliser initially increased productivity, but because it resulted in species loss it eventually led to a decline in productivity, especially in the plots receiving the most fertiliser.

[27] Palma, J.H., Graves, A.R., Bunce, R.G.H., Burgess, P.J., De Filippi, R., Keesman, K.J., van Keulen, H., Liagre, F., Mayus, M., Moreno, G. and Reisner, Y., 2007. Modeling environmental benefits of silvoarable agroforestry in Europe. *Agriculture, ecosystems & environment*, *119*(3-4), pp.320-334. (link)

[28] Reganold, J.P., A.S. Palmer, J.C. Lockhart, and A.N. Macgregor. 1993. Soil quality and ®nancial performance of biodynamic and conventional farms in New Zealand. Science 260(5106):344±349. https://www.demeter-usa.org/downloads/Demeter-Science-Soil-Quality-and-Financial.pdf

[29] Isbell, F., Reich, P.B., Tilman, D., Hobbie, S.E., Polasky, S. and Binder, S., 2013. Nutrient enrichment, biodiversity loss, and consequent declines in ecosystem productivity. *Proceedings of the National Academy of Sciences*, *110*(29), pp.11911-11916.(link)

    - They concluded that nutrient enrichment resulted in more species losses than species gains, especially in later years.
- **Mäder et al., 2002[30],** A 21-year-long study on European farms comparing two regenerative systems with one conventional system, It found:
    - Soils on the regenerative systems showed better stability, enhanced fertility and higher biodiversity, including activity of microbes and earthworms, than soils fertilised synthetically on the conventional system.
    - Biomass and abundance of earthworms were higher by a factor of 1.3 to 3.2 in the organic plots as compared with conventional
    - Root length colonized by mycorrhizae in organic farming systems was 40% higher than in conventional systems
- Studies that found also improved soil health already covered in other sections
    - **Liebig et al 1999.** (Soil health section)
    - **Kramer et al. 2006** (Water quality section)
    - **Bulluck et al 2002, Lotter et al 2003, Holt-Gimenez, 2002** (Resilience section)

Higher profitability

Many incorrectly attribute higher profitability on regenerative organic farms solely to their ability to access higher premiums for their products through organic, biodynamic or other similar certifications. In fact, many studies have shown that even without these premiums farms using regenerative organic practices can be more profitable. Higher profitability on regenerative organic farms is often a result of lower costs of production from the reduction in input use, access to multiple income streams through diversification and in *some* cases access to market premiums.

Summary of Studies

- **Dairy NZ 2013**[31] - a 10 year in-field study compared a farm with no synthetic nitrogen application and a farm using 181/kg/ha/yr of urea. It found that:
    - In a system using no synthetic n at all: a. ”profitable milk production systems can be achieved without N fertiliser applications”
    - At lower milk price ($4.60 kg/MS) the farm using no synthetic N was more profitable than the one using 181 kgs. 29
- **Crowder and Reagonold 2015**[32] - a meta-analysis using the financial performance of organic and conventional agriculture from 40 years of studies covering 55 crops grown on five continents. found that:
    - Organic agriculture was significantly more profitable than conventional agriculture

[30] Mäder, P., Fliessbach, A., Dubois, D., Gunst, L., Fried, P. and Niggli, U., 2002. Soil fertility and biodiversity in organic farming. *Science*, *296*(5573), pp.1694-1697. (link)
[31] Glassey, C.B., Roach, C.G., Lee, J.M. and Clark, D.A., 2013. The impact of farming without nitrogen fertiliser for ten years on pasture yield and composition, milksolids production and profitability; a research farmlet comparison. In Proceedings of the New Zealand Grasslands Association (Vol. 75, pp. 71-78)
[32] Crowder, D.W. and Reganold, J.P., 2015. Financial competitiveness of organic agriculture on a global scale. *Proceedings of the National Academy of Sciences*, *112*(24), pp.7611-7616. (Link)

- **Chavas et al., 2009,** [33]- USA - compared the profitability of conventional cropping systems and organic cropping systems which had high diversity and no pesticides or chemical fertilisers
    - The organic system was found to be more profitable than farming with monocultures and chemicals
- Studies showing increased profitability already covering in other sections:
    - **AgResearch 2009, Landcare Trust 2019** (Water quality section)
    - **Reagonold et al 1993** (Soil health section)

Comparable yields

It is important to preface any discussion on yields, that current global caloric production currently greatly exceeds that needed to supply the world's population. It is only social, political and economic factors that prevent many people from accessing sufficient food for a healthy life[34]

However, there are many studies showing greater or equivalent yield on regenerative organic farms when compared to high-input monocultures. This is often due to natural systems successfully replacing synthetic inputs, diversification and increased soil health. Greater or equivalent yields on regenerative organic systems occur primarily through increases in soil health and diversification. Historically, there have been many studies comparing organic to conventional systems showing lower yields on organic farms. However, a recent meta-analysis using an updated dataset with over three times more yield comparisons than previous studies, has found that the use of diversification practices on organic farms is significantly decreasing this yield gap and as the below studies show often yielding more than conventional systems.

Summary of Studies

Note: These studies do not include the greater yields found in drought, flood and storm conditions, which are already given above.

- **Reganold et al 2001**[35] - USA - Compared organic, conventional and integrated (ie. mix organic and conventional) apple production systems over five years and found:
    - All three systems had similar apple yields.
    - The organic system had higher soil quality, higher profitability and greater energy efficiency.

[33] Chavas, J.P., Posner, J.L. and Hedtcke, J.L., 2009. Organic and conventional production systems in the Wisconsin Integrated Cropping Systems Trial: II. Economic and risk analysis 1993–2006. *Agronomy Journal*, *101*(2), pp.288-295. (Link)
[34] Holt-Giménez, E., Shattuck, A., Altieri, M., Herren, H. and Gliessman, S., 2012. We already grow enough food for 10 billion people… and still can't end hunger.
[35] Reganold, J.P., Glover, J.D., Andrews, P.K. and Hinman, H.R., 2001. Sustainability of three apple production systems. *Nature*, *410*(6831), pp.926-930.

- **Tilman et al., 2012[36],** Long-term field study on pasture in Minnesota, using >7,000 productivity measurements from 11 long-term experiments between 5-28 years, found that:[37]
    - An increase in diversity from one to 16 species caused a greater biomass increase than 95 kg fertilizer N/ha.yr
    - An increase in plant diversity from four to 16 species caused as large an increase in productivity as addition of 54 kg/fertilizer N/ha.yr,
- **Davis et al 2012**[38] USA - 8 year field study from 2003–2011 compared three contrasting cropping systems varying in length of crop sequence and inputs. A conventionally managed monoculture with one crop rotation that received fertilizers and herbicides at rates with two more diverse cropping systems with lower synthetic N fertilizer and herbicide inputs and periodic applications of cattle manure and found the more diverse systems has:
    - Similar or greater grain yields, mass of harvested products, and profit than those in the conventional system.
    - Weeds were suppressed as effectively as in in the conventional system, despite using 6 to 10 times lower rates of herbicides.
    - Freshwater toxicity of the more diverse systems was 200 lower than in the conventional system**.**
    - They concluded; "Our results support the hypothesis that the development of ecosystem services over time in more diverse cropping rotations increasingly displaces the need for external synthetic inputs to maintain crop productivity."
- **Ponisio et al 2015** [39]- a meta analysis using a dataset three times larger than previously used (115 studies containing more than 1000 observations) comparing organic and conventional yields found:
    - Two agricultural diversification practices, multi-cropping and crop rotations, substantially reduced yield gap between conventional organic systems.
    - They concluded that these promising results, based on robust analysis of a larger meta-dataset, suggest that appropriate investment in agroecological research to improve organic management systems could greatly reduce or eliminate the yield gap for some crops or regions.
- **Badgley et al., 2007[40]** Modelling using data on from temperate and tropical agroecosystems found:
    - Nitrogen fixing plants could provide enough biologically fixed nitrogen to replace the entire amount of synthetic nitrogen fertiliser currently in use.

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