

# New-generative agriculture – based on science, informed by research and honed by New Zealand farmers

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## Highlights

- Regenerative agriculture is being promoted as a way to produce food sustainably while building soil carbon under high residual rotational grazing with minimal environmental impact. This article focuses on two of the principles frequently promoted as part of regenerative agriculture: species-rich pasture swards and high-residual (aka ‘long-grass’ or ‘lax’) grazing systems. We also consider the impact on nutrient density and soil organic matter.
- Research indicates that the environmental impact of conventional agricultural systems is generally lower than for alternative systems per unit of food production and sometimes per hectare. Soil carbon is higher under well-managed intensive grazing than under extensively managed systems. Adopting non-optimal grazing management decreases pasture quality and increases GHG and N losses.
- New Zealand has developed optimal rotational grazing and has soils with high organic-matter contents. Rather than adopting a concept developed overseas which has a fluid definition, New Zealand could promote ‘New-generative’ agriculture, encapsulating what is already being done, in the knowledge that New Zealand farmers will continue to adopt improvements as science advances and knowledge increases.

**Keywords:** Biodiversity, Production, Resilience, Soil Carbon, Soil Organic Matter

## Background

Regenerative agriculture is being promoted by various groups (including some farmers) as a better way of farming. Claimed benefits include improved soil health, building soil carbon (with the potential added advantage of offsetting climate change), restoration of landscapes and ecosystem multifunctionality, and improved well-being of farmers / farming communities. These benefits appeal to some people but others are looking for scientific rigour and economic analysis to back these claims.

\* A Perspective is a qualitative and balanced overview of a topic supported by relevant published literature

This paper highlights scientific research, within the New Zealand context where available, that examines some of the goals of regenerative agriculture against the Vision for New Zealand that the Ministry for Primary Industries published in September this year: to be the world’s most sustainable provider of high value food and primary products ([www.mpi.govt.nz](http://www.mpi.govt.nz) 12.09.2020). It examines whether a move to regenerative agriculture will assist with achieving the vision.

## What is Regenerative Agriculture?

There is no simple definition of ‘regenerative agriculture’ and various descriptions are available e.g. “a system of farming principles and practices that increases biodiversity, enriches soils, improves watersheds, and enhances ecosystem services” (Terra Genesis International n.d.), “farming and grazing practices that, among other benefits, reverse climate change by rebuilding soil organic matter and restoring degraded soil biodiversity – resulting in both carbon drawdown and improving the water cycle” (CSU & Carbon Underground 2017) and “a system of principles and practices that generates agricultural products, sequesters carbon, and enhances biodiversity at the farm scale” (Burgess et al. 2019). Similarities are apparent with definitions for organic agriculture: “a production management system which promotes and enhances agroecosystem health, including biodiversity, biological cycles, and soil biological activity” (FAO & WHO 1999). The inclusion of ‘mitigating against climate change through carbon drawdown’ is not in the organic definition, but the mechanism of drawdown through building organic matter is in both approaches. Greenpeace NZ has linked regenerative and organic farming in its request that the Government invest a billion dollars to reset New Zealand agriculture, stating that:

‘... Regenerative organic farming is not currently the dominant production system in New Zealand. However, it is currently practiced by a small number of farmers and growers. It is also known as “agroecology”, “ecological” and “biological” and includes farms operating with the market certifications of biodynamic and organic’ (Toop 2020). Similarly, ‘extensive,

regenerative and organic' are linked by Sir Jonathon Porritt (inaugural chair of the UK's Sustainable Development Commission) in 'Hope in Hell' (Porritt 2020). The key difference between regenerative and organic agriculture is that whereas regenerative agriculture minimises the use of synthetic fertilisers, pesticides and antibiotics, organic agriculture prohibits their use. The difference is important because research into regenerative agriculture is still developing, but the regenerative approach has been welcomed by Organics Aotearoa New Zealand as a 'stepping stone' to organic farming...' (OANZ n.d.). Research on organic agriculture is available and can inform the evaluation of regenerative agriculture (Terra Genesis International n.d.).

Landcare Research's website links to the following description and indication of challenges: *Regenerative agriculture seeks to enhance synergetic relationships that build organic matter and increase soil carbon, using a range of practices including no-tillage, cover crops, crop rotations, intercropping, integrated livestock management, increased biodiversity and diversification, reduced inputs of synthetic fertilisers and biocides, addition of biological products such as compost, seaweed extracts, fish hydrolysates and vermicast. These practices are aimed at optimising soil carbon functionality, with the ultimate result being an increase in plant and animal performance.*

*The effects of individual practices have sometimes been studied in isolation, but regenerative farmers adopt a whole-system approach that has been mostly overlooked by research scientists.*

*The lack of engagement between scientists and regenerative farmers is partly due to (i) the variety of practices are difficult to classify; (ii) the knowledge being context-specific and scattered amongst practitioners; (iii) regenerative management strategies (holistic) being viewed as too complex and time consuming to become mainstream. ([https://soilcra.com.au/current-projects/#project\\_4\\_1\\_004](https://soilcra.com.au/current-projects/#project_4_1_004))*

Despite the lack of holistic research in New Zealand, there is a body of pre-existing science through organic and traditional (reductionist) research that can inform our thinking on the likely impacts of these practices on New Zealand's current approach to food production. This is especially true with respect to two of the practices that are frequently promoted as part of regenerative agriculture: species-rich pasture swards and high-residual grazing systems (aka 'long-grass, 'lax' or 'long-rotation' grazing).

## Regenerative Agricultural practices Pasture sward species richness<sup>1</sup>

History explains the consequences of large-scale monocropping. The dustbowl in the USA is a warning not always heeded. The Cornbelt still involves rotation of soybean and maize with large areas of continuous cropping unbroken by fences or hedges. New Zealand is very different. Nevertheless, regenerative agricultural principles suggest that more diverse pasture swards (20-60 species) contribute to more productive, resilient pasture production, greater agricultural system biodiversity and improves the quality (more nutrient-dense) of animal products.

Current pasture mixes in New Zealand are typically based on perennial ryegrass and white clover, although forbs such as chicory and plantain are sometimes included. The variety of pasture plants used in New Zealand and their establishment is covered in Stewart et al. (2014). Over time, these pasture swards become more species rich as the sward is invaded from a range of sources (e.g. seedbank).

Multi-species pastures are generally considered to be more difficult to graze optimally (a balance between pasture quality and production) since any chosen grazing management will be sub-optimal for some species. Further, under the less frequent defoliation commonly used in regenerative agricultural systems, erect species such as grasses are able to grow taller and thus shade and suppress more prostrate species such as clovers (Burggraaf et al. 2018). This interspecies competition can result in weed ingress which decreases pasture quality (Tozer et al. 2011). The pasture composition some years after sowing will be quite different from the composition of the seed mix initially sown and will be at least partly determined by site and management factors.

Research at Lincoln University under irrigated sheep management (Black et al. 2017) examined pasture species mixes (19 combinations of four species); species were chosen based on considerable earlier research cited within the paper. The authors concluded that a balance of three species was optimal for pasture production. They acknowledged that other researchers have come to different conclusions about optimal species number but suggested that without pairwise monoculture comparisons, as in their research, it is difficult to assess results with respect to diversity effects. This supports research findings that pairwise interaction effects among species explain virtually all of the effects of biodiversity on ecosystem function (Connolly et al. 2011).

Resilience of pastures was a factor investigated in the

1 For the purposes of this discussion, "species richness" and "biodiversity" are considered synonymous

Jena experiment in Germany. Resistance (the degree of change after perturbation) and resilience (time until pre-perturbation state is regained) of aboveground biomass production against drought were highly dependent on management intensity and only partly on species richness (Weisser et al. 2017). This has implications for grazing management which is an important factor in pasture persistence (Tozer et al. 2011).

### System biodiversity

Biodiversity is enhanced under organic production systems when compared with conventional systems on a per hectare basis, at least in part because of mixed pasture species (Weisser et al. 2017). Biodiversity was higher above ground than below ground in the Jena experiment, which was managed without production animals (Weisser et al. 2017). Reduction in pesticide use in organic systems means that food sources (some of which might be competing with the crop i.e. ‘weeds’) as well as insect variety (some of which might be using the crop as food) are increased (Mondelaers et al. 2009). Although IPM is assisting with reducing the need for chemicals on conventional farms, competition from weeds, pests and diseases is still identified as needing research to improve yields in organic systems (Rööß et al. 2018).

The biggest negative impact on wider-scale biodiversity has been identified as expansion of agriculture (Sanchez-Bayo & Wyckhus 2019) not the type of agriculture being undertaken. This means that the regenerative/organic approach can achieve the goal of on-farm biodiversity but cannot protect biodiversity from agricultural expansion because of yield expectations to feed a growing population.

### Nutrient density

A key factor in food production is ‘nutrient density’ (the ratio of nutrient content to the total energy content of food). The nutrient-dense concern stems from the suggestion that conventional farming has depleted the soil of nutrients and that high yields have come at the expense of phytochemical richness ‘which has declined 5 to 40% in 43 fruits, vegetables and grains’ (Provenza 2018). The USDA research for the 43 vegetables concluded that any real declines are generally most easily explained by changes in cultivated varieties between 1950 and 1999, in which there may be trade-offs between yield and nutrient content (Davies et al. 2004). Marles (2017) reviewed research on archived soil samples and matching current soils and concluded that soil mineral composition had not declined ‘in locations cultivated intensively with various fertilizer treatments’. The author also concluded that the effect of production system on nutrient content of food is not as great as that of the environment (including elevated

carbon dioxide in the atmosphere which has created a ‘dilution effect’ in that carbon has increased whereas mineral uptake has not) and various other factors in choice of cultivar, growing, harvesting (particularly the stage of ripeness at harvest), processing and storage (Smith-Spangler et al. 2012; Marles 2017). Human health evidence does not suggest a marked benefit from consuming organic versus conventional foods (Smith-Spangler et al. 2012); increasing fruit and vegetable consumption has been suggested to be more important for health than mode of production of the fruit and vegetables (Winter & Katz 2011).

This concern about horticulture has spilled to pastoral agriculture. An example of system effects and resulting confusion is grass versus grain fed production. Conjugated linoleic acids (CLAs) are found mostly in grass-fed meat and dairy products and are marketed as a dietary supplement on the basis of their supposed health benefits such as helping to control the onset of cancer and arteriosclerosis (Hansen et al. 2002). There are significantly more CLAs in organic compared with conventional milk, which can be interpreted as a reason for using organic practices (Jahreis et al. 1997 cited in Hansen et al. 2002). It is, however, the grass diet, rather than the organic production system *per se*, that results in the CLA (Dhiman et al. 1999; Hansen et al. 2002); organics requires access to forage 120 days a year (USDA n.d.; in the UK, supermarkets such as Morrisons and Waitrose stipulate it CiWF n.d.). Most New Zealand cows have access to pasture 365 days a year. A further confusion is that grain-fed cows tend to be Holstein Friesian, whereas cows in organic systems are generally not; breed (i.e. genetics) has a considerable effect on milk composition (Schwendel et al. 2015). Significant differences in fatty acid milk composition have been recorded with pasture composition in some comparisons (Schwendel et al. 2015) but the significance within human health has not been evaluated in comparison with the overall boost in CLA with pasture-fed milk. (NB the debate about health and dietary CLA is the quantity required for efficacy.)

### ‘Long-grass’ grazing systems

Regenerative Agricultural principles suggest that allowing the pasture to grow longer pre-grazing and leaving higher residuals than New Zealand research currently recommends results in more leaf litter being incorporated into the soil, increasing soil organic matter (SOM) content.

Inevitably, leaving pastures to grow beyond ~2500 kg DM/ha (3 leaf stage, at least in dairy systems) results in decreases in pasture quality (Burggraaf et al. 2018 and refs therein). Although increased litter will increase SOM initially, the decrease in N inputs associated with regenerative agriculture will lead to SOM loss

with time. This is because grass growth (providing the organic matter inputs) is likely to be decreased, and animal numbers will be decreased as a consequence. Of importance is that the initial change in the carbon and nitrogen dynamic equilibrium in the SOM is not indicative of final state (Parsons et al. 2016; Weisser et al. 2017).

Methane is also affected, increasing per unit of production if animals are not performing at their genetic potential (as an increased proportion of energy goes to maintenance and time to reach weight is increased). N loss and GHG per unit of milk or meat produced will be increased under this scenario in comparison with the current New Zealand system; this means more impact on the environment for a given amount of production (Parsons et al. 2016).

### Soil carbon/organic matter

Increasing soil C has been promoted as a way of offsetting climate change, and potentially earning C credits, but has been a focus of soil health for much longer. Although 'health' is a value-laden term (Sadras et al. 2020), it includes aspects with which few farmers would disagree – drainage, aeration, organic matter and the soil organisms it supports, aggregate stability and water retention. Sometimes overlooked is that the requirement for, and cost of, nutrients to build SOM is considerable. One tonne of C in organic matter is associated with approximately 80-100 kg N, 20 kg P, 14 kg S and lesser quantities of other nutrients (Kirkby et al. 2011). Increases in soil C of 8t/ha/yr are claimed, for instance, without acknowledgement of the source of the extra nutrients required (e.g. <https://agfundernews.com/dr-richard-teague-regenerative-organic-practices-clean-up-the-act-of-agriculture.html> and discussed in Rowarth et al. 2020).

New Zealand researchers have been investigating the relationship between soil C and pasture management, including the effects of rotational grazing in comparison with set stocking, since the 1940s. Pasture production and soil C in New Zealand have increased over time due to research informing management strategies such as application of fertiliser and lime and optimisation of grazing regimes (Schipper et al. 2017). Soil total C is now within the target range (which is different for different soil types) for 95% of tested sites in 11 different regions of New Zealand; no information was given on the 5% not meeting target but a link to Landcare Soil Horizons 26 indicated that more sampling of native land cover would fill gaps (Ministry for the Environment & StatsNZ 2018). Soil C stocks have been estimated as high as 138tC/ha and average approximately 100t C/ha to 30cm depth across New Zealand (Mudge 2019). Once these soils reach higher soil organic C quantities, they can become susceptible to C loss if management

and/or climate changes (Schipper et al. 2014).

Pastures that are fertilised and intensively grazed are able to sequester more soil C than non-fertilised extensively grazed systems, while also producing more food (Allard et al. 2007). Sanderman et al. (2017) showed a linear relationship between productivity, soil C stocks and C turnover (from 40 to 13 years) due to soil organism activity reflecting increased quantity and quality of inputs: N inputs stimulated the increased activity. Optimum productivity and sustainability is context dependent (Trewavas 2008; Garnett et al. 2013), but C accrual on optimally grazed land is often greater than on ungrazed or over-grazed land (Smith et al. 2008). Managing agriculture for optimum productivity and sustainable land use is still 'our best option for conserving natural resources and mitigating and adapting to climate change' (Gaffney et al. 2019), but when systems are already being managed optimally, increasing soil C is difficult (e.g. Schipper et al. 2014; Smith 2014; van Groenigen et al. 2017; Poulton et al. 2018; Schlesinger & Amundsen 2018).

Some confusion about the role of N in managing SOM stems from a report that fertiliser N promotes the decomposition of crop residues and SOM. The fact that soil C content was often greater for fertilised than unfertilised subplots was considered 'erroneous' by the authors (Khan et al. 2007). A different conclusion is that added fertiliser increased soil C (because of increased production). This is supported by a meta-analysis by Lu et al. (2011) who reported a minor N-induced increase of 2.20% in soil C storage across all ecosystems ( $P < 0.001$ ), with a 3.48% increase in agricultural ecosystems ( $P < 0.001$ ).

Conflicting interpretations of the role of fertiliser often reflect a difference in starting point and the balance between inputs and outputs. Factors that increase flows of C to the soil and potential for sequestration include soil fertility, higher grazing residuals, increased residues (litter), and greater biomass. Factors that decrease the potential for C sequestration include an increase in stocking rate (and increased grazing pressure/utilisation). 'Intensification' of land use is a term that confounds these two opposing trends (Parsons et al. 2009) and regenerative agriculture argues for these factors without considering either the starting point or the confounding of the trends. An additional complication is that it takes time for the effect of management to become apparent. Long-term trials undertaken in New Zealand hill country support the fact that SOM can be increased with fertiliser application (Lambert et al. 1996; Parfitt et al. 2003). When the plots were grazed hard, however, SOM was lost – more from the high-fertiliser plots than the low-fertiliser plots due to increased activity of soil decomposers, but SOM was still higher on the high-fertiliser plots (Lambert et al.

1998), as found in the Khan et al. (2007) research.

Preventing loss of organic matter and soil degradation is easier in well-managed, conventional, high-input agricultural systems than low-yielding systems with low inputs (Allard et al. 2007). High-input systems, which also produce more food per hectare, are therefore generally considered to be more sustainable (Gaffney et al. 2019) as they prevent soil degradation and produce lower greenhouse gas (GHG) emissions per unit of food (Rosegrant et al. 2014; Clark & Tilman 2017; Balmford et al. 2018). Although GHGs increase with fertiliser production and application per hectare, the net effect of higher yields avoids emissions (Burney et al. 2010). Improved production per hectare also contributes to land sparing which provides the opportunity for leaving more area for natural habitat and wildlife (Tilman et al. 2011).

## Other Issues

### Environmental footprint comparisons

A recent report (Burgess et al. 2019 and references therein) on different approaches to food production in comparison with a conventional approach indicated that increasing soil carbon and biodiversity is generally possible under organic or regenerative approaches but that associated yields are decreased. This means that environmental impact might be decreased per hectare but is increased per unit of food. This outcome has also been reported by Clark and Tilman (2017) in their meta-analysis of organic and conventional systems. They concluded that increasing agricultural input efficiency (the amount of food produced per input of fertilizer or feed) would have environmental benefits for both crop and livestock systems. They also suggested that dietary shifts towards low-impact foods and increases in agricultural input use efficiency would offer larger environmental benefits than would switches from conventional agricultural systems to alternatives such as organic agriculture.

### Soil testing

Soil testing is under debate because some advocates of regenerative agriculture support the approach of Albrecht-Kinsey, which involves adjusting the ratio of calcium, magnesium and potassium to 'feed the soil and let the soil feed the plants'. Lack of research evidence to support this approach has led to the suggestion that 'continued promotion of the basic cation saturation ratio (BCSR) will result in inefficient use of resources in agriculture and horticulture' (Kopittke & Menzies 2007). In New Zealand considerable research by various iterations of MAF has developed a soil-testing system suited to our relatively recent soils and confirmed the 'overcoming limitations' approach (Liebig's Law of the Minimum) for plant yield which formed the foundation

of the MAF Soil Advisory Service.

Recent research comparing the Albrecht-Kinsey approach with nutrient management advice based on conventional (New Zealand) soil testing over a 6-year period in Canterbury (Bryant et al. 2019) reported that the Albrecht-Kinsey approach resulted in no significant differences in yield or nitrate leaching on paired dairy farms but resulted in a more expensive fertiliser regime and a decrease in soil phosphorus. Reviews of the Albrecht Kinsey system and appropriateness to New Zealand are available (Edmeades 2011, 2015).

### Food security, economics and farmer well-being

Food security is not a focus of regenerative agricultural literature but is a concern for the world. Food production is associated with GHG emissions, and so has featured in calls for change. However, concerns have been expressed that limiting global warming to 1.5°C would decrease food availability and increase undernourishment of 80–300 million people by 2050 (Frank et al. 2017). Process-based models can be used to seek the optimum trade-off between food, GHG, C sequestration and N loss. This allows consideration of how 'alternative' agricultural systems compare with 'conventional' intensity-driven ones (Parsons et al. 2016). As discussed earlier, Parsons et al. (2016) suggested that the New Zealand optimised system is associated with lower impact on the environment for a given amount of production.

Of concern in food security (for the farmer) is farm economics. Australian analysis for sheep stations over a decade has reported Return on Assets Managed of 1.66% for regeneratively-managed stations in comparison with 4.22% for conventionally-managed stations and an average station income difference of A\$2.46 million over the decade (Francis 2020).

Finally, farmer wellbeing is believed to increase when regenerative agriculture is adopted. Again, the starting point is important. If increased SOM decreases soil erosion and increases production and income, increased wellbeing is likely. Australian research (Ogilvy et al. 2018) involving 14 best practice regenerative producers indicated that they experienced a meaningful and significant wellbeing advantage compared with conventional NSW farmers matched for gender and age (51 males between 40 and 60). Factors in the increased wellbeing and resilience were health, higher 'farming self-efficacy' – confidence in being able to successfully manage different aspects of their farm and financial stability. However, they also reported higher financial stress. Francis (2020) interpreted the cost of stability of income as 'foregone profits'. Ogilvy et al. (2018) acknowledged that the sample of graziers was small and confounding factors might have influenced the result, hence the relationship between regenerative agriculture

and wellbeing could not be described as causal. However, the point about improved understanding – farming self-efficacy – might be the clue to improved wellbeing in all operations.

### Farm Systems

Farm systems can be described as an ecosystem managed to deliver food and other products for human consumption. The elements in that ecosystem are numerous and include physical and biological assets, and human/cultural management inputs. Farm systems are not discrete entities – they have inputs from beyond the farm gate (e.g. fuel, fertiliser) and connections with remote markets for farm products as well as environmental externalities (e.g. GHG). Farm systems are therefore complex and understanding the many direct and indirect interactions between the constituent elements is a key requisite for competent management. Changes in one element of the farm system can often lead to unexpected changes in other elements.

The impacts of changes in farm management may be felt over both the short and long term. Some of these impacts may be predictable but they may also be highly context-dependent. Other impacts may be entirely unpredictable. In addition, there are some key elements within farm systems that are incompletely understood, such as soil biology and its impact on nutrient cycling. Farm systems operating according to regenerative agricultural principles have a deliberate focus on effecting significant changes to soil biology. This adds further uncertainty to the predictability of the long-term performance of these farms.

Regenerative agriculture is often described as ‘holistic’, which is an explicit recognition of the connectedness of the elements in a farm system. There is certainly a need to consider the performance of the system as a whole in addition to understanding the more immediate impacts of individual management practices that are promoted as part of regenerative agriculture. Definitive studies of pastoral farms run according to regenerative agricultural principles are lacking. This means that it is not yet possible to conduct a critical ‘holistic’ assessment, although research based on organic systems does give some information, as does analysis of recent research overseas. The scientific evidence of the impacts of some of the key practices promoted by regenerative agriculture suggests that it is unlikely that farms in New Zealand operating according to regenerative agricultural principles can deliver all of the benefits claimed.

### The Future

There is increasing SOCIETAL pressure on pastoral agricultural systems in New Zealand. The community’s increasing sensitivity to the environmental externalities

of pastoral farming has produced a desire for significant change. Regenerative agriculture has been suggested as a potential solution. However, there is a risk that decades of research and development will be ignored in any change process. The challenge is to develop new systems that leverage existing knowledge and draw upon new research into identified gaps, thereby creating a ‘generative’ approach – generating food while minimising impact.

The Ministry for Primary Industries launched Fit for a Better World in July (MPI 2020), which included a vision of designing modern regenerative production systems. “In doing so, there is an expectation that regenerative farming systems will improve the profitability of farming while leaving behind a smaller environmental footprint.”

The research discussed here demonstrates that some relevant work has already been done, and some of it quite recently. The results of the research indicate that some of the approaches being promoted in regenerative agriculture (e.g. multi-species pastures, lax grazing,) will not necessarily achieve in New Zealand what has been seen elsewhere. Of concern is that even in countries where success has been suggested, doubts have been expressed: Australian research over a decade in dryland areas indicates profitability is not improved.

The long-term superphosphate trials in New Zealand show that effects of change are not seen immediately, and predictive modelling indicates that what occurs in the first few years is not indicative of final state.

New Zealand’s Generative Agriculture concept could be:

*Mixed pastures maintained at optimal quality allowing maintenance of high soil organic matter content and the soil ecosystem it supports by managing grazing animals in a rotation programme which recognises rapid pasture growth in good growing conditions while creating the world’s most efficiently produced milk and meat from animals in a natural environment.*

This fits with the MPI vision for New Zealand. New Zealand farmers are highly adaptive and constantly look for improvements, following market signals. The dairy boom, spread of kiwifruit, uptake of irrigation and of precision agriculture are examples. It is the New Zealand farmers’ positive approach to innovation, unbuffered/supported by government subsidies (a redirection from tax payers, common in other countries e.g. OECD average to farm businesses is above 20% of gross farm receipts), that has led to productivity gains in the industry.

The contents of this paper are presented as a foundation for progress so that New Zealand’s limited research funds can be targeted at developing further improvements for innovative and efficient food

production systems appropriate for the New Zealand ecosystems we have inherited. Continued adaptation of farming systems and education and support will achieve the MPI vision of being the world's most sustainable provider of high value food and primary products through New-generative agriculture – based on science, informed by research and honed by farmers.

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