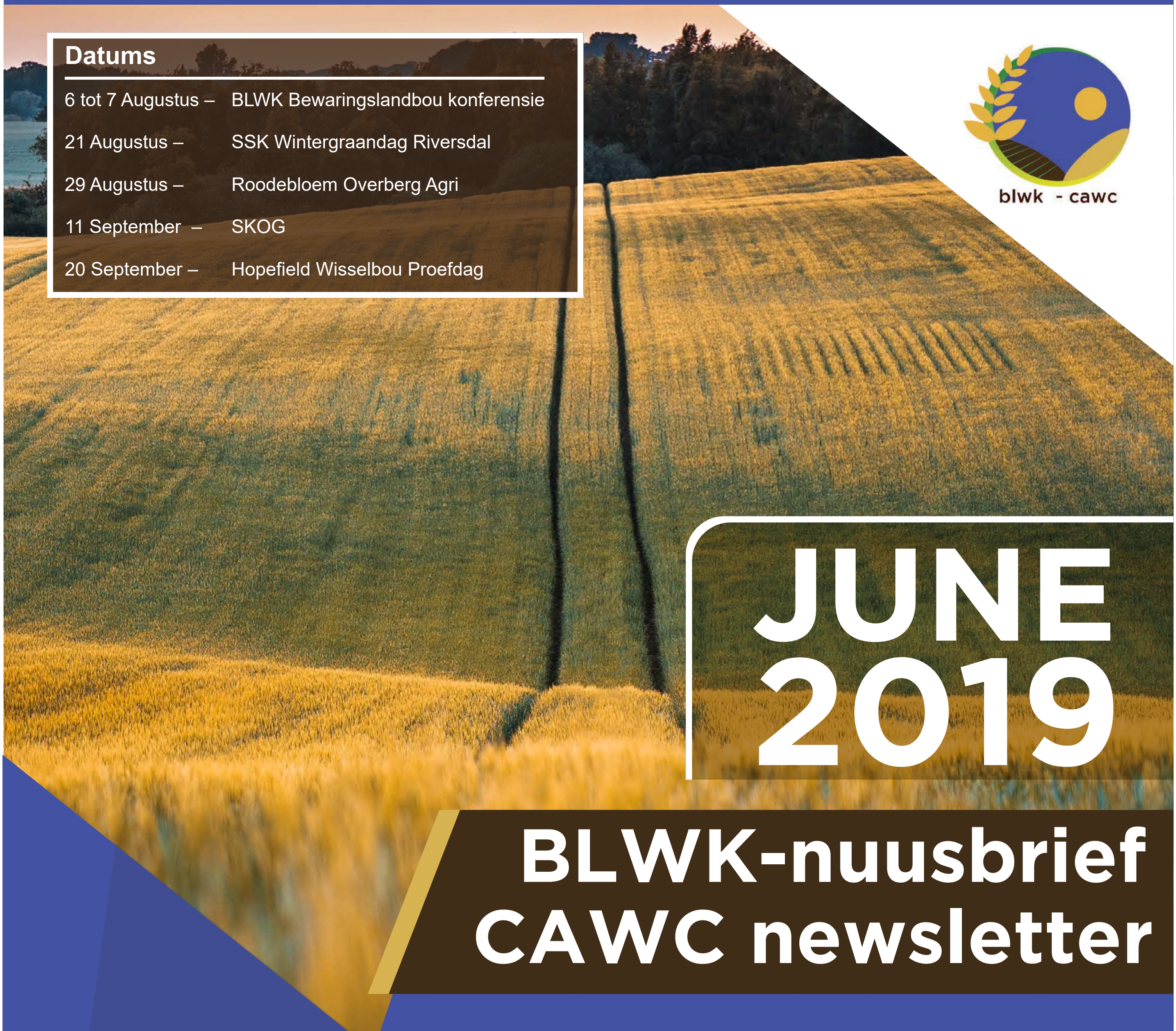
Issue/Uitgawe 75



Datums

6 tot 7 Augustus –	BLWK Bewaringslandbou konferensie
21 Augustus –	SSK Wintergraandag Riversdal
29 Augustus –	Roodebloem Overberg Agri
11 September –	SKOG
20 September –	Hopefield Wisselbou Proefdag

blwk - cawc

JUNE 2019

BLWK-nuusbrief CAWC newsletter

Inhoud / Contents

Dit is alweer Junie en die reën kom so bietjie-bietjie, maar ten spyte van dit is die meeste gewasse al baie mooi aan die groei. Die advertensies vir ons BLWK is ook al verlede maand uit en is weer ingesluit in hieride nuusbrief. Ons hoop en vertrou julle sal inskryf, want die twee dae se programme gaan baie interessant wees. Geniet die nuwe nuusbrief.

Redakteur

We are nearing the middle of the year again. June has arrived and most crops are well established with the little rainfall that has fallen. The adverts for the CAWC week has gone out in the May newsletter and again in this one. We hope that you will be able to attend. We believe that the programmes for the two days will be valuable to all. Enjoy the June newsletter.

Editor

What No-Till is All About

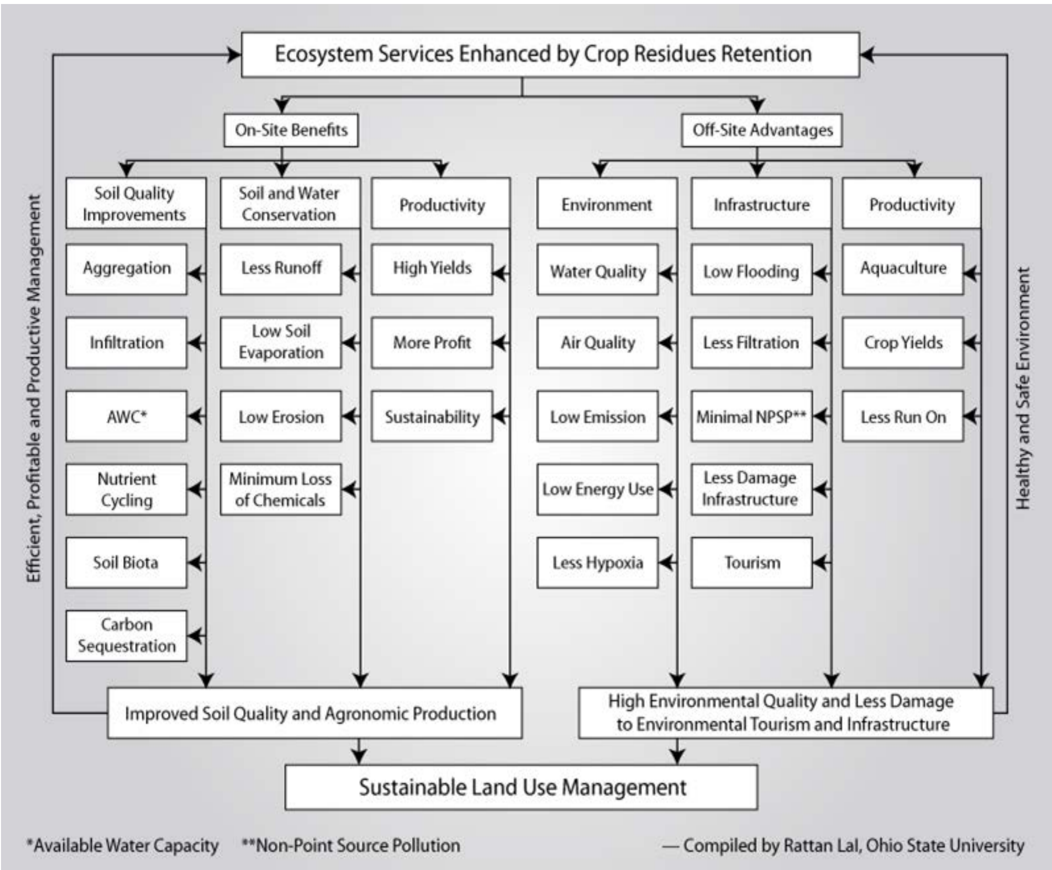
By Frank Lessiter posted on May 22, 2019 |
Posted in Residue Management, Soil Health

The resulting crop residue with no-till has a major impact on soil quality, productivity and the environment.

While the headline "Ecosystem Services Enhanced by Crop Residue Retention" sounds academic, this chart effectively illustrates the many benefits that no-till brings to protecting the environment. Pulled together by Ohio State University soil and carbon scientist Rattan Lal, this data highlights more than 2 dozen on-site and off-site benefits and advantages of no-till.

On-site benefits include soil quality improvement, soil and water conservation and productivity. No-till's off-site advantages fall into the areas of environment, infrastructure and productivity. These 26 no-till benefits and advantages lead to improved soil quality and health, improved crop production and higher environmental quality rankings when compared with more intensive tillage systems.

When you look at the benefits that can be gained with effective management of soil organic matter, clay content, soil depth and water retention, they all favor no-till. The move to no-till also improves carbon sequestration, biodiversity, elemental cycling and resilience to a number of naturally-occurring environmental concerns that affect food security.



Different Approach Needed

Lal recognized that agricultural ideas inherited from the “Green Revolution” that got started in the 1950s and 1960s — which emphasized farm mechanization and relied heavily on high fertilizer, pesticide and herbicide inputs — were too expensive and out of reach for many of the world’s poorer farmers.

By nurturing the soil through no-till, crop rotations and consistently covering soil with cover crops or mulch, he’s demonstrated that growers throughout the world can farm sustainably and eliminate many of the negative impacts of intensive agriculture.

A leading researcher on carbon sequestration, Lal has demonstrated how soil can provide a long-term storage site for carbon regardless of the number of years intensive tillage has destroyed soil carbon. His research has shown that with no-till, soil carbon can be restored over many years, turning these soils into carbon sinks and thereby helping reduce troublesome atmospheric carbon dioxide concentration.

Lal maintains further worldwide adoption of no-till will lead to more effective management and sustainable land use. Since no-till today has been adopted on only 9% of the world’s 3.3 billion acres of arable land, there’s plenty of room for further adoption of this highly valuable reduced tillage system.

Links of the month

Click on the button to visit the website.

Please note you will need an Internet connection

Dr. Christine Jones - Building New Topsoil Through The Liquid Carbon Pathway

No-tillers must think about C-N ratio

HOLD WATER IN THE SOIL

Under Cover Farmers - Feature Length

No-tillers must think about C-N ratio

Cover crop weed suppression

The bacterial solution to plastic pollution | Morgan Vague | TEDxMtHood

The Nitrogen Balancing Act: Tracking the Environmental Performance of Food Production

David R. Montgomery on Symbioses in the Soil

BEWARINGSLANDBOU WES-KAAP – JACK HUMAN-WEEK

Lesingsdag – 6 Augustus 2019

Nooitgedacht-wynlandgoed, Stellenbosch

07:30-08:15
Registrasie en koffie met aankoms

08:20-08:30
Opening – Chris Burgess, *Landbouweekblad*-redakteur

08:30-08:35
Skriflesing – Hopkins Uys, voorsitter van BLWK

08:40-09:20 (40 minute)
Beatrice Conradie – Landbou-ekonoom
Lupiene en plaasproduktiwiteit

09:25-09:55 (30 minute)
Johan Reyneke – Reyneke Wines, Stellenbosch
Hoe ek my koolstof gebou het

10:00-10:30 (30 minute)
Johniby Rabie – Oorkant Boerdery, De Wet, Worcester
Bewaringslandboubeginsels in wingerdbou

10:30-11:00 – Koffie/tee en verversings

11:05-11:45 (40 minute)
Egon Zunckel – Bewaringsboer van KwaZulu-Natal
My pad van bewaringslandbou

11:50-12:50 (60 minute)
Chris Gazey – Navorsingswetenskaplike
Bestuur van grondversuring en strategiese bewerking

13:00-14:00 – Middagete

14:10-14:40 (30 minute)
Casper Brink – Bestuurder van Sporatec
Die effek van wisselboustelsels op mikrobes

14:45-15:15 (30 minute)
Rens Smit – MSc-student
Dekgewasbenutting

15:20-16:20 (60 minute)
Groepbespreking oor dekgewasse – werklike ervarings

16:30
Afsluiting

Praktiese dag – 7 Augustus 2019

Langgewens-navorsingsplaas, Moorreesburg

08:00-08:45
Registrasie en koffie met aankoms

08:50-09:00
Opening – Johann Strauss, Elsenburg

09:00-10:00
Plantergesprek – plaaslike maatskappye
Wat wag op ons in die toekoms?

10:00-10:30
Beweeg na proewe;
drinkwater word uitgedeel

10:30-13:00
- Besigtiging van proewe
- Stikstofbemesting in bewaringslandbou
- Beweiding van dekgewasse met skape
- Dekgewas-saaidigthede
- Bemesting met 'n skyfplanter tydens plant
- Met of sonder – topbemesting in 'n koring-medic-stelsel
- Uitwerking van kunsmistipe op kanolaproduksie
- Profielgate met volledige chemiese en biologiese ontledings
- "Intercropping" – voorbeelde

13:00
Middagete

BORGE
Wintergraantrust
Advance Seed

NAVRAE
Johann Strauss
E-pos: JohannSt@elsenburg.com

KAARTJIES – bespreek aanlyn
https://www.quicket.co.za/events/65960-blwk-jack-human-bewaringslandbouweek-2019-cawc-jack-human-conservation-agricult/#/

blwk - cawc

Western Cape Government
Agriculture

Landbou weekblad 100 JAAR

CONSERVATION AGRICULTURE WESTERN CAPE
JACK HUMAN WEEK

Lecture Day – 6 August 2019

Nooitgedacht Wine Estate, Stellenbosch

07:30-08:15
Registration and coffee on arrival

08:20-08:30
Opening – Chris Burgess, editor of *Landbouweekblad*

08:30-08:35
Scripture reading – Hopkins Uys, chairman of CAWC

08:40-09:20 (40 minutes)
Beatrice Conradie – Agriculture economist
Lupines and farm productivity

09:25-09:55 (30 minutes)
Johan Reyneke – Reyneke Wines, Stellenbosch
How did I build my soil carbon levels?

10:00-10:30 (30 minutes)
Johniby Rabie – Oorkant Boerdery, De Wet, Worcester
Conservation agriculture principles in viticulture

10:30-11:00 – Coffee/tea and snacks

11:05-11:45 (40 minutes)
Egon Zunckel – Conservation farmer from KZN
My conservation agriculture journey

11:50-12:50 (60 minutes)
Chris Gazey – Research scientist
Soil acidity management and strategic tillage

13:00-14:00 – Lunch

14:10-14:40 (30 minute)
Casper Brink – Manager of Sporatec
Effect of crop rotation systems on microbes

14:45-15:15 (30 minute)
Rens Smit – MSc student – *Cover crop utilisation*

15:20-16:20 (60 minutes)
Group discussion on cover crops – real experiences

16:30 – Closing

Practical Day – 7 August 2019

Langgewens Research Farm, Moorreesburg

08:00-08:45
Registration and coffee on arrival

08:50-09:00
Opening – Johann Strauss, Elsenburg

09:00-10:00
Seeder discussion – local manufacturers
What can we expect from the future?

10:00-10:30
Move to trial sites;
drinking water will be handed out

10:30-13:00

- Trial viewing and discussion
- Nitrogen fertilisation in conservation agriculture
- High pressure grazing of cover crops with sheep
- Cover crop sowing density
- Fertilisation with a disc seeder at plant
- With or without – topdressing in a wheat/medic system
- The effect of fertiliser type on canola production
- Soil profile pits with full chemical and biological analysis
- "Intercropping" – examples

13:15 – Lunch

SPONSORS
Winter Grain Trust | Advance Seed

ENQUIRIES – Johann Strauss
E-mail: JohannSt@elsenburg.com

TICKETS – book online
https://www.quicket.co.za/events/65960-blwk-jack-human-bewaringslandbouweek-2019-cawc-jack-human-conservation-agricult/#/

Feature/Turning desert to fertile farmland on the Loess Plateau

WRITTEN BY RICHARD BLAUSTEIN

Soil is not just dirt but a living system with many important functions. Degraded soils impact on food production, erosion, and more, affecting the lives of people around the world. Restoration efforts in China, Zambia and other countries seek to reverse this trend.

Around 3,000 years ago, farmers settled on the fertile Loess Plateau in western China, a region about the size of France. By the 7th century, the rich soils were feeding about one quarter of the Chinese population. But intense pressure on the land eroded the soil. By the 20th century, desertification had condemned the remaining population to poverty. "It was a desperate place," says Juergen Voegele, an agricultural economist and engineer at the World Bank who first visited the region in the mid-1980s. But that would soon change.

Building resilience in healthy and restored soils is essential to help them retain functions in a world of global environmental change

Voegele returned in the 1990s to lead a major 12-year World Bank project to help restore dirt to healthy soils on a vast scale. "This was absolute desert. A few years later the whole thing came back," he says. "We saw birds, butterflies, insects – the whole ecosystem began to recover. Even after hundreds of years of complete devastation, the seeds were still in the ground and things began to happen very quickly. We did not expect that."

By 2009, and the programme's end, approximately 920,000 hectares had been restored of the 65,000,000-hectare region in western China. But elsewhere in China and around the world, soils are still suffering.

In 2015 a landmark report from the United Nations Food and Agriculture Organization (FAO) found that one third of the planet's soils are in bad shape due to erosion, salinisation, chemical pollution, and more.

Since then things have not improved. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), which has released summaries of its soon-to-be-published 2018 comprehensive report, concludes that land degradation affects approximately 3.2 billion people around the world. Unsustainable agriculture expansion, urban expansion, and climate change are among the top causes. According to the IPBES findings, investing in avoiding degradation and restoring degraded land makes financial sense – the short-term gains from activities that lead to degradation are small in comparison to the value of what is lost in the degradation.

The loss of fully functional soils is critical in many ways. Perhaps most obviously soils are useful for growing food, but they also alleviate floods and droughts; support plant, insect, and animal biodiversity; and more. And beyond these basic services, soils will be important for capturing carbon in a fast-changing climate.

At the COP 21 negotiations in 2015 the 4 Per 1000 Initiative was launched. The initiative is a voluntary undertaking, which seeks to spur on actions that target a 0,4% rise of soil carbon content annually and throughout the world. The aim is to sequester carbon to meet the Paris Accord's goal of limiting temperature rise to a 1.5–2.0C rise, in comparison with pre-industrial times.

Many soil scientists are sceptical about sustaining that high increase in soil carbon content, but they agree that soils can retain much more carbon than at present, especially in the developing world. Increasing soil's organic carbon also greatly fosters soil fertility and soil health and would lead to many benefits for farmers throughout the world.

With these local and global considerations, soil experts are making connections between building resilience in healthy soils and agricultural considerations such as soil fertility, while adding new focuses, such as climate change, to their management investigations.

Building resilience in healthy and restored soils is essential to help them retain functions in a world of global environmental change, in which disturbances, such as drought and flooding, are expected. "The fundamental idea of resilience is how the system can respond to a shock," says Johan Six, an agroecologist at the Swiss Federal Institute of Technology (ETH Zurich). "A shock causes a disturbance, but a healthy and resilient soil will be able to recover, rather than deteriorate."

A diversity of fungi, bacteria, and other organisms such as nematodes, mites, termites, and earthworms live in soils and keep the soils healthy. But agricultural practices, changes in land use, climate change, and other soil-degrading processes harm these organisms. Important soil functions disappear with them.

"It is the fauna, the fungi, and microbes that are in the communities of these food webs below ground that make terrestrial ecosystems work," says Diana Wall, a soil ecologist at Colorado State University in Fort Collins, who also chairs the Global Soil Biodiversity Initiative, an international scientific collaboration. "If they were just soil and carbon and no life, we'd be on Mars, where you have soil, but not life in it. It's the life in soil that benefits us."

Biodiverstiy is key for soil health and fertility. A multitude of organisms inhabit the soil, decomposting organic matter and making nutrients available. Illustration: E. Wikander/ Azote

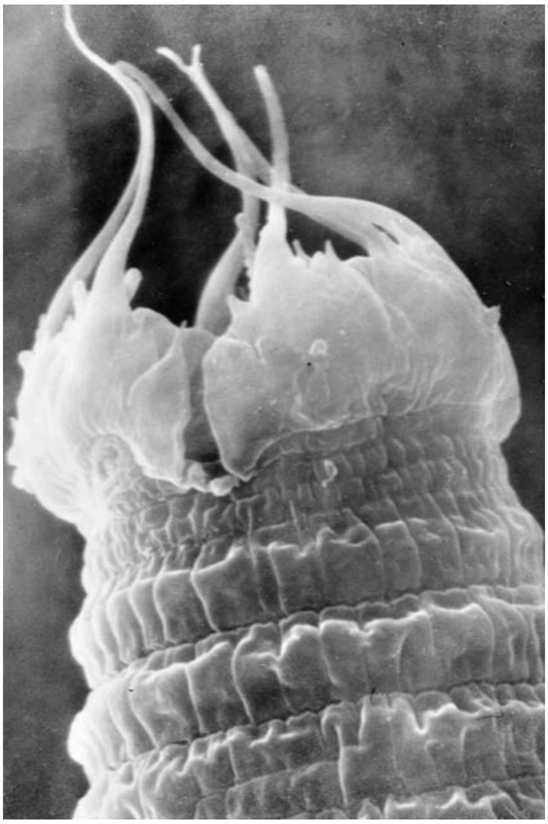
Making soils work again

Richard Bardgett, a soil ecologist at the UK's University of Manchester, has explored soil health and fertility for decades. Soil health, Bardgett says, derives from "a strong interaction between the physical, chemical, and biological components of the soils".

Geology, topography, climate, vegetation, human activity, and time shape these factors and, in turn, determine soil fertility, biodiversity, nutrient recycling, physical structure, carbon retention, and other ecological functions that make for soil health.

Building resilience in healthy soils means managing this complexity: from the chemical make-up of the soil that allows nutrients to circulate, and the presence of microbes and other organisms to break down organic matter, to how often the soil is disturbed by a plough or compressed by heavy machinery. The structure of the soils – which the soil experts sometimes refer to as soils physics – is also important, and centres around large and small clumps of soil that hold together. Six explains that in healthy soils, it is the way the clumps set in place that protects microbial populations and also traps carbon, nitrogen, and other nutrients.

But what most makes soil a living system is biodiversity. Wall notes that "all the different organisms, whether it's different groups of nematodes or the millipedes [and] centipedes, they all have different tasks in soils". She adds that not all species are found everywhere, and particular species serve in particular ecosystems. If they disappear, it is uncertain how their functions will be fulfilled. Wall's recent work on unique nematodes in Antarctic soils that play a key role in carbon cycling underscores the specialisation of soil species in different places.



Soil ecologists are also conducting experiments that explore the key links between biodiversity and resilience. Bardgett and colleagues, for example, have investigated how varied assemblages of species influence soils' potential to cope with disturbance. For example, the researchers inflicted simulated drought impacts on wheat and grasslands in a test area in the United Kingdom. They looked at carbon and nitrogen cycling effects and found that the grasslands' fungal-based soils were better at coping with drought impacts. But once the drought stress ended, the bacteria-based soils with wheat regained their function quicker.

The Loess experience

Soil scientists point to ancient Mesopotamia as a tragic example of soil mismanagement: 5,000 years ago, irrigation with salty water and overworked farm plots devastated food production, eventually leading to population declines in the region.

More recently, the American Dust Bowl of the early 1900s became an iconic example of the devastating effects of mishandling of soils. Yet it led to a successful government response that set down precedents, policies, and science for soils management.

By the 20th century, the Loess Plateau faced similar challenges. The soil of the plateau was sensitive to the changes caused by human activity. In sandy and windblown areas, the soil easily erodes and loses many of its functions if it is deforested. This is precisely what happened in the Loess Plateau, where vegetation cover was reduced over centuries from grazing animals or agriculture, says Voegele.

Fortunately for the people on the Loess Plateau, over millennia enough deep reservoirs of soil remained, even after centuries of erosion, and could serve as a basis for restoration.

Scottnema lindsayae is a nematode species that lives in Antarctica, in the McMurdo Dry Valleys. Scottnema feeds on soil microorganisms such as bacteria, which are the main players of carbon and nutrient cycling. By being their "predator", Scottnema regulates their abundance and biomass turnover, and in doing so it influences the cycling of carbon and nutrients. Researchers have found that this species have a key role in its environment. Relatively to its ecosystem, it has a similar "footprint" on carbon cycling as the entire soil fauna of a temperate forest soil. In other words, if Scottnema disappears from its ecosystem, it would be as if all soil animals, from nematodes to earthworms, disappeared from a normal soil. Photo courtesy of: M. Mundo

A map of China, showing the Loess Plateau in blue hash marks. Illustration: E. Wikander/Azote.

When the programme started in 1994, two urgent challenges for Loess Plateau restoration were overgrazing and property rights for farmers and herders, Voegele says. Although land ownership in China was not possible in the 1990s, China had recently declared the new "household responsibility system", which allowed for decades-long property lease rights. The Chinese World Bank team worked to extend those rights, putting together a handbook and a massive outreach programme that addressed land rights, which, according to Voegele, reached hundreds of thousands of farmers.

Secure land rights gave farmers and herders more incentives to care for the land. "Previously you had a plot for your sheep, but that could be taken away at any moment. So you had no incentive to actively sustainably manage the land," Voegele says. "When you know you have a 20- or 30-year lease, you will plant trees and you will actually manage the land and improve its fertility and its resilience." The land rights extension was critical for the maintenance of the programme's newly constructed, wider land terraces, which help retain water and prevent erosion and which quickly led to higher crop yields.

Ultimately, the World Bank and its partners in China invested US$500 million in the Loess Plateau restoration programme, with US$300 million supplied by the World Bank, Voegele says. The World Bank estimates millions of people's lives were improved.

The efforts also reduced sediment deposits that enter the river and elevate water levels. In that way, soil restoration efforts also decreased the effects of natural flooding events in the Yellow River. However, despite the restoration, managing the sediment presents a challenge, according to Voegele.

Post-restoration, high-yield crops such as wheat and corn are new additions that are also planted in the terraces of the Loess Plateau. Diverse orchards have also been planted that produce fruits, especially apples, and nuts. Notably, the Loess has become a lead exporter in China's large apple industry and is China's largest regional exporter of apple juice.

Though much of the restoration work in the Loess Plateau has been successful, some concerns remain. For example, Kathleen Buckingham of the World Resources Institute has raised the issues that the speed and scale of the project was possible only with low crop diversity and a potential lack of consideration of local knowledge and traditions. Single species agriculture is well known to require intensive chemical input, eroding soil health and fertility.

Further to the west, Bardgett and his colleagues have begun another soils investigation in China's Qinghai-Tibetan Plateau. Supported by the UK's Global Challenge Research Fund and with partners in China at the Northwest Institute of Plateau Biology and the Grassland Research Institute, Bardgett's project examines the effect of land degradation in grassland systems.

The project builds from Bardgett's earlier investigation with diverse plants, where his team documented positive effects on soil health, such as soil stability and carbon retention, from mixed groups of plants' fine roots. This spring, Bardgett will set up different combinations of plants in soils that have different levels of degradation. He says that the investigation will explore plant combinations that can improve soil fertility and examine whether other plant mixtures might

Herders in the Quinghai-Tibetan plateau. Photo courtesy of Richard Bardgett.

Africa: challenges and hopes for soils

Africa's diverse soils are another target for management interventions. Limited organic matter – which is made up of dead plants, animals, and microbes and helps circulate nutrients through soils – and soil erosion are leading causes of poor soils, but the major agent of soil degradation in large regions of the continent, especially for small farm holders, is what the FAO calls nutrient depletion.4

"When you remove a crop – corn or cassava, for example – you remove nutrients from that field, and without inputs like fertiliser, nutrients go down," explains Bernard Vanlauwe, an agroecologist with the International Institute of Tropical Agriculture in Kenya. "It is like removing money from your bank account: the long-term result, you'll be left with zero."

Vanlauwe has worked intensively on what are called "nonresponsive soils," soils that do not gain in fertility by adding nitrogen- and phosphorus-based fertilisers or other "improvements".

He says reversing nonresponsiveness is difficult – it's a particularly resilient state, even if it is not a desirable one for farmers and food production. But where topsoil has not completely eroded, soils can be made healthy and responsive to inputs again. For example, Vanlauwe and Six are working on a multi-stakeholder experiment in Kenya that applies different treatments to soils, using an approach called Integrated Soil Fertility Management (ISFM).

The goal of ISFM is to both maximise crop yield and limit environmental waste, such as fertiliser run-off. The farmer applies organic matter, careful amounts of fertiliser, and other amendments, and selects best plant varieties all tailored for particular local conditions, which could vary within a single plot. So, understanding soil characteristics such as acidity or micronutrient deficiency are key to ISFM.

Six and Vanlauwe and other researchers will run four field trials using ISFM methods looking particularly at the potential for increasing soil carbon and crop yield. They also want to see how this method affects soils in the face of climate change, which potentially will increase the severity of both drought and floods. Varying rainfall is a particular focus of this study.

Sub-Saharan Africa also has many different ecological areas that experience different rates of rainfall and have soils that vary in acidity or salinisation or sodification, where free sodium abounds, often causing soil structure deterioration.

Zambia, for example, has three agroecological zones, distinguished by rainfall and growing season. Soil microbiologist Alice Mweetwa, deputy director for research and graduate studies at the University of Zambia, works with farmers and students across the country to address low soil fertility, low organic matter content, acidic soils that are highly leached of nutrients, and soil crusting, among other challenges.

Herders in the Quinghai-Tibetan plateau. Photo courtesy of Richard Bardgett.

In one three-year project supported by the World Bank, Mweetwa focuses on nitrogen and phosphorus needs in soils growing legumes, which poorer households rely on for protein. In particular, in Zambia's "zone 3", acidic soils and high rainfall combine to leach nutrients, particularly phosphorus, out of the soils. Mweetwa and her team are isolating bacteria that thrive in legume root systems, where they live alongside and work together with a type of fungus that expands plant roots' water and nutrient uptake.

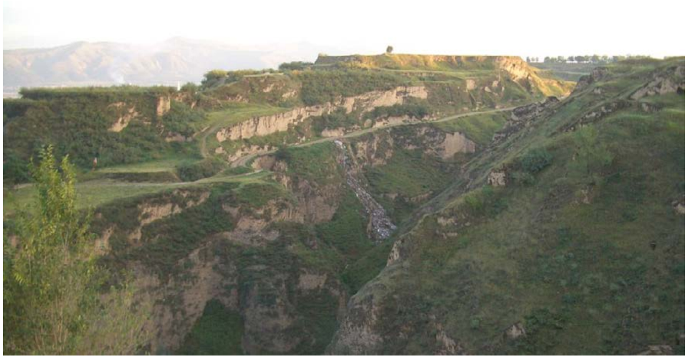
"We have already done the reintroduction to see if what we have isolated can reconnect with the beans, and those results are looking pretty good at the moment," Mweetwa says. An additional benefit is that the fungi, through their root-like filaments, the mycelia, penetrate the earth adding organic matter that stabilises the soils.

One central lesson from her work that Mweetwa stresses is that organic matter, which enhances fertility and soil organisms, is key for resilient healthy soils in sub-Saharan Africa. "If we could 'up' soil organic matter levels using different holistic approaches, that could really help soils," she says. Using cover crops, reducing tillage, and direct application of the fungi that expansively grow mycelia are among the agriculture practices Mweetwa suggests for increasing soil organic matter.

Soils for the future: the soil scientists' lessons

Mweetwa stresses that attention to people and their practices is necessary to enhance resilience in healthy soils. "One of the ways [to improve soils] is to go to a place and see what people are already doing and what system are they familiar with, and then simply enhance that particular system rather than introducing a new thing," she says.

A similar conclusion can be drawn from work in China, says Voegele, who gleaned two general lessons from the Loess Plateau restoration experience: "First of all, never think it is impossible," he says, adding that severely degraded systems could still surprise with natural recovery if managed well. "Number two, don't come in with a solution in the back of your head before you know what's going on in the ground."



The loess plateau north of Linxia city, west of the pagoda of Wanshou Guan. Photo: Wikimedia commons/Vmenkov

Pre-existing underground conditions are important. Cutting-edge technologies such as microfertilisation, in which fertiliser is carefully deposited in small amounts, and precision agriculture, which uses advanced GPS, sensors, and other technologies to carefully calibrate management decisions, might significantly help to correct harmful practices such as over-fertilisation, says Bardgett. But they cannot substitute for the information contained in natural systems.

"One of the key things about resilient [healthy] soil systems in terms of nutrients in natural systems is that there is tight coupling of plant–nutrient demands," Bardgett says. Agriculture disrupts that tight coupling.

Looking at natural systems – with healthy soils where plants and microorganisms live for generations without depleting soil nutrients – provides understanding about how the resources plants need can be provided more sustainably. This could reduce the instances of untimely irrigation or application of fertilisers, where water and nutrients simply run off and do not benefit the plants.

Whether in China, Zambia, or elsewhere, people have begun to value soils more, but attaining good soils management has a way to go. “There is growing awareness of the importance of soils, but fundamentally people don’t walk around recognising it,” Bardgett says. He suggests education and funding is needed to really get “soils at the heart of environmental policy”. And within this policy scope, building resilience in healthy soils will be vitally important in order to safeguard the critical functions that soils provide. When soils aren’t well managed, as in Mesopotamia, the repercussions can be enormous.

“Soils take thousands of years to form, but they can be lost very quickly,” Bardgett warns.

https://rethink.earth/turning-desert-to-fertile-farmland-on-the-loess-plateau/

Healthy Soil & Microbes Make It Rain?

BY AMBER | FEBRUARY 11, 2017

The importance of building healthy soil is greater than organic growing. Even conventional growers are discovering this too. But the idea that organic soil matter will make it rain? Not just the soil, but the microbes it contains, and the ones that live on plants too.

Scientific evidence that this is very possible is building, beginning with a discovery in 1978 that most scientists totally ignored. The entire concept being just too far-fetched to grasp. Things have changed in the past decade or so. And it’s all very interesting.

Fighting a losing battle with wheat disease, plant pathologist Dave Sands from Montana State University wondered if the cause of his dilemma was coming out of the clouds. So he took a Petri dish up there and collected some cloud. Sure enough, the disease that no agricultural product could prevent was riding around in the sky.

Dave’s theory was that pathogenic bacteria was seeding clouds and making it rain on the perfect host to thrive. His contemporaries, however, weren’t copacetic. Everyone knew that dirt particles and soot are what make it rain. Plant harming microbes in the clouds controlling the weather? Total nonsense!

Apparently not, because in the past few years more scientists have found that Sands was on to something 40 years ago. Clouds are literally teeming with hundreds of different kinds microbes! And most of them are very much alive. This is known as “bioprecipitation” – though Wikipedia identifies it as mostly plant pathogens. But the page isn’t current. Not with already dated references retrieved in 2011. A lot can happen in science over 10-15 years.

Only about 40% of the clouds in the sky can make it rain. They have to contain ice – whether precipitation fall is rain, hail, or snow. Some airborne microbes can efficiently catalyze ice formation (a.k.a. biological ice nucleators or IN).

In February 2008, professor of biological sciences Brent Christner from Louisiana State University published the results of a study of bacteria that make it rain in the journal Science. Working with colleagues in Montana and France, the scientists examined precipitation from locations around the world. They found rainmaking bacteria all over the place and established that the most active ice nuclei are biological. They found that unlike dirt and soot particles, the microbes can catalyze freezing at warmer temperatures.

> *"These biological particles could factor heavily into the precipitation cycle, affecting climate, agricultural productivity and even global warming… If present in clouds, biological ice nuclei may affect the processes that trigger precipitation."* — EurekAlert, 28-FEB-2008

The press release goes on to say that this idea of bacteria that make it rain is not so crazy. In fact, snowmaking at ski resorts had already been done using ice-nucleating bacteria for over 60 years at this point.

In January 2009, National Geographic News ran the story, Rainmaking Bacteria Ride Clouds to "Colonize" Earth? Here the evidence that bacteria may be part of a constant feedback between far-flung ecosystems and clouds is reported. A fact that, at the time, Christner told journalist Christine Dell'Amore was "sending ripples through the atmospheric science community." These nucleators were traced from the clouds to the source; the soil and plant ecosystems on the ground.

One such ripple being expressed by Roy Rasmussen, senior scientist at the National Center for Atmospheric Research. He wasn't buying the theory – it wasn't verified, even though snowmaking involved the very same kind of catalyst. But Dave Sands, who had never stopped investigating this feedback loop between the ground and the clouds was beginning to think that drought and microbes are connected. Tired soil that's overgrazed or overworked lacks bacteria, a situation that "could limit clouds' ability to shed rain." It might even be the very choice of species planted. But – proving this required more work.

Just 3 months later in April 2009, Oxford's peer-reviewed journal BioScience published the paper, How Forests Attract Rain: An Examination of a New Hypothesis. Here's another controversial idea – that plant foliage influences the hydrology cycle. The study that supported this theory didn't look at any type of microbe. The focus was how much the removal of even a very localized loss of forest could change the weather of an area as large as a continent.

With that in mind, coupled with Dave Sands' suggestion that even the species planted can affect the population of microbes that make it rain… Yes, foliage could very well have a huge influence on whether a geolocation gets sufficient rainfall, or evolves to having an arid climate. Furthermore, the healthiest soil naturally regenerates its own fertility and microorganism population in perfect balance to sustain the plants rooted in it into perpetuity. It is found in a forest or grassland.

This natural cycle has existed without any assistance from man. It's the very reason that forests and prairies cover land masses. And for that to happen without some form of assistance, the ecosystem would have to have a method of calling for moisture when it's needed.

So, this isn't really so far-fetched at all. Amazing, yes. Crazy, no. Just way more complex than anyone realized – until recently. But back to the discoveries leading up to the current week…

In 2012, Brent Christner had more details on microbes that make it rain to share. Scientific news periodical Microbe published his highly interesting Cloudy with a Chance of Microbes paper in Volume 7, Number 2.

> *"Microbes can be aerosolized from virtually any surface and transported both horizontally and vertically in the atmosphere. They are ubiquitous in the near-surface and free troposphere and are found in clouds at concentrations of about 104 cells m3. There are even reports of viable bacteria and fungi being collected from 10- to 50-km altitudes in the stratosphere and 50 to 100 km above the Earth in the mesosphere. Nevertheless, very little is known about the flux, abundance, and diversity of microorganisms in the Earth-atmosphere system.*
>
> *Remarkably, certain atmospheric conditions may support microbial growth. Rates of heterotrophic production in supercooled cloud droplets suggest that cloud-borne bacterial biomass has the potential to increase by as much as 20% per day. Hence, microbes and their metabolic activities could affect meteorological processes in the atmosphere both by changing cloud chemistry and serving as nuclei for precipitation."*

The biggest issue Rasmussen (National Center for Atmospheric Research) had back in 2009 was whether the concentration of microbial cells was big enough to actually have a significant influence on precipitation. By 2012, Christner and associates from around the world had compiled enough data to provide evidence to override that skepticism.

"Enormous numbers of cells – 10^{24} to 10^{26} – of microorganisms inhabit leaf surfaces globally. About one-third of the ice crystal residues in clouds sampled over Wyoming are biological particles, providing direct evidence for the involvement of bacteria, fungi, and/or plant material in ice-cloud processes…" Additionally, the active ice-nucleators over the Amazon rainforest are different. Biological particles dominate above -25C with mainly secondary organic aerosols from volatiles produced by land plants and animals as cloud condensation nuclei.

So, the purpose of clouds is much more diverse than evaporation and transpiration collection. In fact, the research done up to this point in time shows that the atmosphere is fundamental to microbe dispersal, and the clouds themselves support cell reproduction. In addition to airborne microbes and their metabolic activities affecting the weather.

Naturally, this is just the discovery of a new frontier to study, but it was enough evidence to grab the attention of more scientists. By 2013, atmospheric chemist Kim Prather at the University of California, San Diego was analyzing the chemical composition of IN in the most rain-laden clouds over the Sierra Nevadas, in Wyoming, and on the island of St. Croix in the Carribean. About 40% were biological, often coinciding with dust from as far away as Africa and China, and typically from desert regions.

"In one instance," she tells New Scientist in April 2016, "we were able to see the dust traveling across the Pacific, and anticipate the subsequent snowfall." The journalist, Kate Ravilious, goes on to say that this and earlier research discoveries "amounts to tantalizing evidence that microbes do indeed seed ice in warm clouds… though she has yet caught bacteria in the act."

(Fresh Earth Farms)

Next, Ravilious shares that in 2015, Daniel O'Sullivan at the University of Leeds proved that fungi particles are also up to the task. And soil is a huge reservoir of them. Some microscopic phytoplanktons in the ocean are also ice nucleators. How would they get into the clouds? Easily, after being tossed into the air in the spray from waves.

The researchers weren't implying that microbes control explain Earth's weather, but Christner points out that "microbes don't have to control global precipitation patterns to influence certain regions… I think there are certain conditions and times of year when these things load up the atmosphere and have a significant effect."

So, this is where soil microbes enter into the greater scheme of things. And here's a fascinating theory from this article… Environmental microbiologist Cindy Morris, the colleague of Brent Christner, suspects that the 1930s Dust Bowl drought was brought on by the type of wheat farmers grew. It was highly susceptible to rust. She feels that with so much of it planted in the region, enough bacteria became airborne during plowing to cause "so many ice nuclei that they constipated the clouds."

Two weeks later, New Scientist published another article by Ravilious, Rain spawns more rain when it falls on ploughed land. Now she's concentrating on soil microbes due to a paper published in the journal Nature Geoscience. Scientific research in 2015 found that rainfall stirred up particles in soil. Now Alexander Laskin and colleagues at Pacific Northwest National Laboratory in Washington analyzed what happens when rain falls on turned soil.

The results of this study found that rain flung organic particles in the air via bubbles formed when raindrops hit forming puddles. However, this only takes place in light to moderate rainfall. A heavy rain hits the puddles on the surface so hard that little air bubbles form.

Additionally, scientists in Australia found that rainfall increases the probability of further precipitation in the days that follow the original event. Hence, "rain spawns more rain."

The abstract for this last research article she referenced, published in Atmospheric Chemistry and Physics, notes that the period of recurring precipitation was commonly shorter after 1960. Particularly downwind from coal-fired power plants. An interesting observation, given that soot supposedly induces rain. A distinct line drawn between 1959 and 1960 with more recurring rain before it than after? That's only about a decade after farmers started switching from old practices to synthetic fertilizers. This could point to where it headed into mainstream, because soil microbes don't know what to do with man-made fertilizer.

And here's what started me on the journey we've made to this point on the page. The trip has become longer than I ever anticipated, but I hope you've found it as fascinating as I have…

From Beef Producer just a few weeks ago – *More soil organic matter makes more rain*. Interesting. Big Beef and organic soil building seem an odd pairing. Definitely, a must-check-it-out.

Mr. Newport opens with what a huge reward better soil management offers if up to half of the rainfall in North America comes from evapotranspiration of plants and soil. As some meteorologists say, that is. And since that organic matter increases the amount of moisture a soil can hold, large expanses of healthy soil should make it rain more often.

The inspiration for his article? The recently published conclusions drawn from the first year's satellite data from NASA's Soil Moisture Active Passive (SMAP) project. The analyzation surprised the scientists involved. The data will help them in climate modeling, weather forecasts, and monitoring agriculture.

People involved in the SMAP project refer to the moisture held in the top 2-inches of soil following rainfall as "soil memory." Why not call it moisture retention? Everyone else in the world does. Anyway… they thought that this memory lasted only a few hours. So, finding that one-seventh of that moisture remained 3 days later was unexpected. Especially with the greatest persistence found in the driest regions of the planet.

"I'll remind you this is from depleted soil," Newport says, "which today is the standard the world over. What if we were dealing with healthier soil, with higher organic matter?"

Time for a little math. Start with increasing soil's organic matter by 1% to raise moisture retention per acre by 20,000 gallons. Multiply that by the acreage in his home state, then again by that one-seventh number from the SMAP data. And well, Oklahoma could have an extra 127.8 billion gallons of water for plants to use, air conditioning, and increasing potential rainfall.

Amazing, right? Alan Newport is now totally sold on the idea of building soil for grazing and crops. And he sees that it's not just a benefit for the cattleman or farmer, but for everyone. Because organic matter in the soil can make it rain… more. Higher yields, lower inputs, more profit, and greater drought resilience.

As we all know, if you've got organic matter in soil and refrain from using pesticides, you've got oodles of beneficial microbes. Their job is breaking down soil organic matter into nutrients plants can access. But they can only go about their business when the soil is warm and some moisture is present. But since insecticides and fungicides can eradicate most, even all, of these good microorganisms in the soil. And since the greater share of land on this planet is depleted of organic matter or continuously exposed to pesticides, what they're finding is a mere fraction of what once was, or what is possible.

Wouldn't it be awesome if most conventional farmers in North America got as excited about building soil as Alan Newport? Unfortunately, the more likely scenario is… This knowledge leads to seeding clouds with lab-cultured, even genetically modified microbes. Designer rain. Life could get a lot more costly.

Tomorrow's forecast… Mostly sunny morning hours with increasing clouds throughout the afternoon. There's a 90% chance of Franken showers from 6-8 p.m. Clearing overnight.

More Info & Sources:

EurekAlert (2008)
National Geographic News (2009)
BioScience, Vol. 59, Issue 4 (2009)
Wikipedia
Atmospheric Chemistry and Physics (March 2015)
Cloudy with a Chance of Microbes (Microbe News 2012)
New Scientist (May 2016)
Beef Producer (2017)
MIT News (SMAP Study 2017)

Article from : https://gardenculturemagazine.com/growology/soil-and-organics/healthy-soil-microbes-make-rain/

CLOVER VARIETY WITH UBER NITROGEN FIXATION TURNS SOME HEADS

EWING, Ill. — Legumes have long been known to fix nitrogen. But whether that nitrogen is transferred to the field and made available to future crops is a question that begs an answer. That answer may come soon.

New varieties bred to enhance nitrogen production, and innovative management practices aimed at keeping the plants on the field late into the spring, could reduce the need for other nitrogen sources.

"There are some clovers out there that are probably better for nitrogen fixation than others," said Marc Lamczyk, University of Illinois Extension crop systems educator.

That may be an understatement.

A recent trial at the Ewing Demonstration Center showed that a new variety added 269 pounds of nitrogen per acre over a period of 6½ months. Dixie crimson clover, planted as a control, added only 14 pounds per acre.

Lamczyk and fellow Extension educator Nathan Johanning are studying the benefits of the patented balansa clover variety named FIXatioN, developed by the seed company Grassland Oregon

The numbers achieved at Ewing are eye-popping, but they are not unusual, according to Risa Demasi, co-founder of the seed company, based in Salem, Ore. She points to another trial in Richland, Iowa, in which measured nitrogen was as high as 340 pounds per acre.

"We need to replicate that before we hang our hat on those numbers," she said. "They were pretty wild numbers. The question is when is that nitrogen available for the next crop, and for how long."

The company bred cold tolerance into the Mediterranean-based plant to produce the patented variety.

"Those are really crazy numbers," Demasi said. "… We're not touting those 300-plus numbers. We're trying to be very conservative."

One researcher is developing a nitrogen calculator that may provide some answers. University of Georgia agronomist Julia Gaskin has been working on the system, in which samples are taken of cover crops in the field and nitrogen is measured, along with carbohydrates, cellulose and lignin. The latter three substances tell how quickly the nitrogen may be released.

"We can predict these nitrogen credits or debits, and graph on when that nitrogen will be released," Gaskin said. "The graph is really nice because it can help the farmer say, for instance, that if he takes a nitrogen credit, maybe he should wait until sidedress to apply his fertilizer. It gives them a way to better visualize some of the options in terms of nitrogen management and help them reduce inputs. And there are ancillary environmental benefits."

Gaskin prefers a mixed stand of legumes and grasses, largely because a stand of pure legumes releases most of its nitrogen about the first month after it is killed.

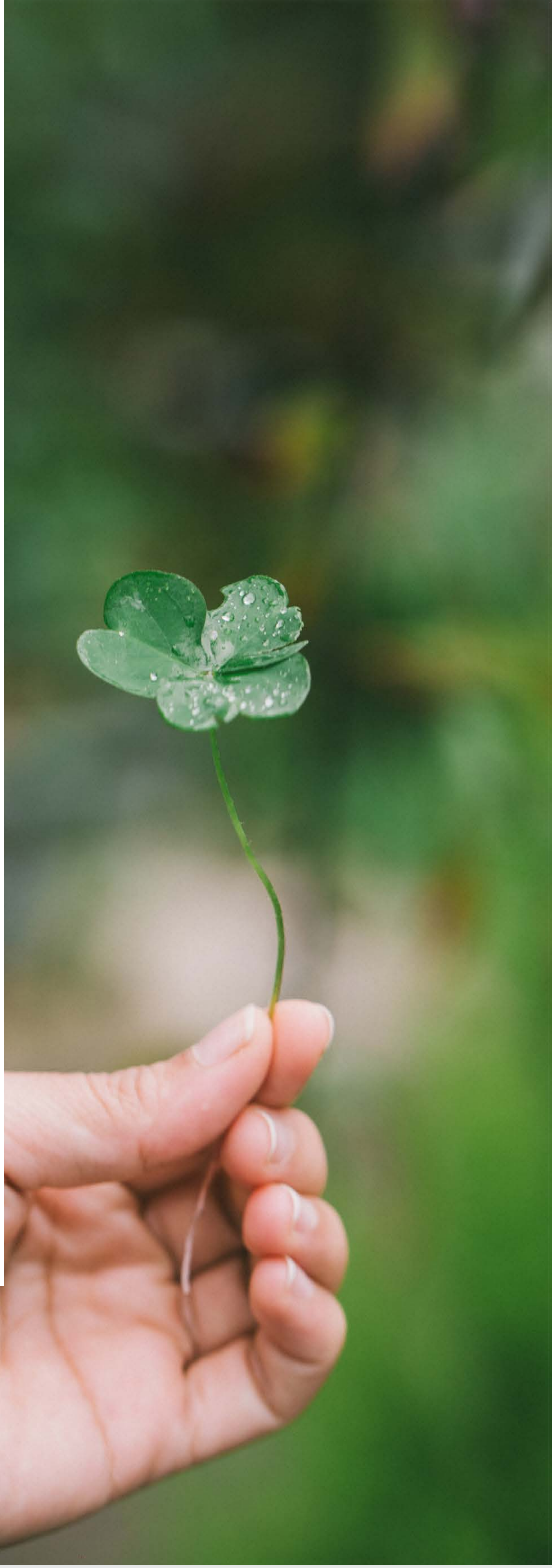
"As a caveat, our conditions are a lot hotter down here," she said. "But we really like grain-legume mixtures. That slows down the nitrogen uptake. A grain is adding more carbon into that system; that slows it down and spreads it out."

Among other things, the researchers at Ewing Field hope to determine the ideal time to plant and terminate FIXatioN.

"The biomass on this balansa was unreal. We had trouble killing it," Lamczyk said. "We maybe should have tried to kill it before we planted. We had trouble with no-till coulters cutting through this stuff. We eventually did get it killed, but it was quite a challenge."

Next year they will consider either killing it earlier or planting the cash crop into it and killing it afterward, when the stems become more brittle.

Article from: https://www.agupdate.com/illinoisfarmertoday/news/crop/clover-variety-with-uber-nitrogen-fixation-turns-some-heads/article_0669c0e4-8223-11e9-bb44-17d4c61de619.html



The Nitrogen Balancing Act: Tracking the Environmental Performance of Food Production

EILEEN L. McLELLAN, KENNETH G. CASSMAN, ALISON J. EAGLE, PETER B. WOODBURY, SHAI SELA, CHRISTINA TONITTO, REBECCA D. MARJERISON, AND HAROLD M. van ES

Farmers, food supply-chain entities, and policymakers need a simple but robust indicator to demonstrate progress toward reducing nitrogen pollution associated with food production. We show that nitrogen balance—the difference between nitrogen inputs and nitrogen outputs in an agricultural production system—is a robust measure of nitrogen losses that is simple to calculate, easily understood, and based on readily available farm data. Nitrogen balance provides farmers with a means of demonstrating to an increasingly concerned public that they are succeeding in reducing nitrogen losses while also improving the overall sustainability of their farming operation. Likewise, supply-chain companies and policymakers can use nitrogen balance to track progress toward sustainability goals. We describe the value of nitrogen balance in translating environmental targets into actionable goals for farmers and illustrate the potential roles of science, policy, and agricultural support networks in helping farmers achieve them.

Keywords: nitrogen balance, nitrogen pollution, supply chain, agricultural production, environmental outcomes

Nitrogen fertilizer poses a huge challenge for modern agriculture (figure 1). Although essential for achieving high crop yields, its abundant use makes fertilizer the dominant contributor to global nitrogen pollution, which poses substantial risks to climate, human health, and ecosystems (Erisman et al. 2013). Nitrogen (N) fertilizer is the dominant source of new anthropogenic N in US landscapes, resulting in estimated ecosystem and health damages of US$157 billion per year (Sobota et al. 2015). At a global scale, anthropogenic contributions to N flows have driven us beyond the "safe operating space" for human development (Steffen et al. 2015). As a result, there is growing interest in N-related indicators that can track progress in reducing N losses to the environment while maintaining or increasing food production (Zhang et al. 2015).

In the United States, small profit margins and increasing public concern about the environmental impacts of food production have driven substantial efficiency improvements in agricultural production (Thomson et al. 2017). Despite these efficiency gains, water quality problems related to N loss from agricultural systems continue and may be worsening. For example, in 2017, the Gulf of Mexico hypoxic zone, which is caused in large part by N losses from crop production upstream, reached the greatest extent ever recorded. This is perhaps not surprising given that, despite significant government payments to upstream farmers, agricultural N loads to the Gulf of Mexico have not declined significantly (Scavia et al. 2017). Consequently, some have concluded that current (voluntary) efforts to improve agricultural sustainability have failed (Ribaudo 2015), and there are increasing calls for regulation. Separately, a growing number of international food retailers and manufacturers have committed to improving the sustainability of their food supply chains. Recognizing that N-fertilizer use dominates the nitrogen footprint of food (Goucher et al. 2017), these industry initiatives seek to improve on-farm environmental performance.

Across multiple scales—farm, watershed, and food supply chain—there is a clear need for environmental performance indicators that are scientifically sound, responsive in the near term to changes in farm management, and credible to broader audiences. Here, we show that the *N-balance indicator* (the difference between N inputs to and N outputs from a field or farm, sometimes referred to as *N surplus*) is a robust gauge of potential N losses from agricultural systems, and we describe how it will allow farmers, food supply-chain companies, and policymakers to track and report progress in reducing the environmental footprint of food. In addition, heeding calls for quantitative targets for the sustainable

BioScience 68: 194–203.
doi:10.1093/biosci/bix164
Advance Access publication 7 February 2018

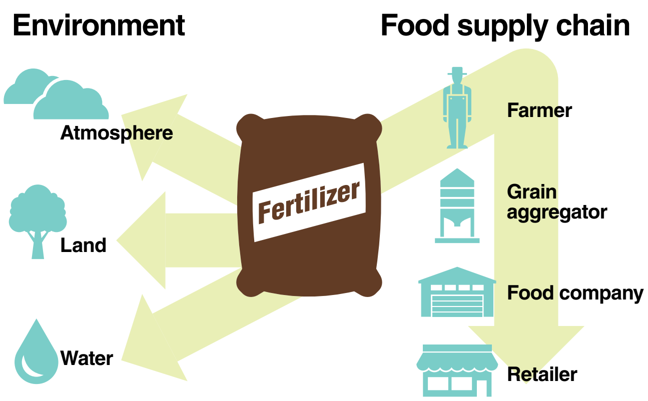


Figure 1. A conceptual diagram illustrating the alternative fates of nitrogen from fertilizer applied to crops. Nitrogen not captured in the food supply chain is likely to be lost to the environment, with impacts on the atmosphere (stratospheric ozone depletion, global warming, and the formation of ground-level ozone, particulate matter, and smog), on land (soil acidification, foliar damage, forest decline, biodiversity loss, and terrestrial eutrophication), and on water (coastal dead zones, freshwater eutrophication, nitrates in drinking water, and biodiversity loss). The most desirable outcome is that as much nitrogen as possible enters the food supply chain and is made available to consumers. The less desirable outcome is that nitrogen is lost to the environment, where it damages human health and ecosystems, and contributes to climate change.

intensification of agriculture (Hunter et al. 2017), we suggest how environmental thresholds can be translated into N-balance targets and propose a framework to help farmers achieve those targets. We focus primarily on N balance in cropping systems, recognizing that farm-scale N balances are already broadly accepted as a sustainability indicator for animal production systems (e.g., de Klein et al. 2017) and that feed (grain) is a major component of the US livestock production footprint.

Current approaches to quantifying environmental progress

Assessing the effectiveness of attempts to reduce N losses from agriculture is challenging for several reasons (Cherry et al. 2008). Most assessments track the adoption of specific practices, such as improved fertilizer management or use of cover crops. Although these practices effectively reduce some types of N losses in research plots under specific agricultural or environmental conditions, performance at this spatial scale does not necessarily translate to the farm or watershed level. This disconnect occurs because larger spatial scales encompass differences in temperature, precipitation, soil texture, soil organic matter, landscape position, and management history, all of which influence soil N pools and N cycling and therefore the impact of a given practice on N losses. Thus, the impact of a specific practice can vary greatly within a watershed, even to the point of having opposite effects on N losses in different places. Furthermore, practices that reduce N losses to the atmosphere may increase N discharges to surface- and groundwater and vice versa (i.e., pollution swapping; Stevens and Quinton 2009). The only practice that will consistently decrease N losses at all locations, by all pathways and for all forms of N, is reduction in N input rates, which risks compromising crop yields.

Given the challenges of a practice-based assessment approach, some have attempted to evaluate environmental progress directly by measuring changes in greenhouse gas emissions or water quality. However, this is difficult and costly because of multiple loss pathways, rapid transformations among different forms of N (e.g., ammonia, NH_3; nitrate, NO_3^-; nitrous oxide, N_2O; and dinitrogen gas, N_2), and high spatial and temporal variability (especially for N_2O emissions). Likewise, inferring progress from water-quality data is complicated by possible impacts of legacy N sources in soil and subsurface water (Van Meter et al. 2016), as well as the potential for climate-change-related impacts—such as increased runoff—to obscure the immediate benefits of practice change (Bosch et al. 2014).

As an alternative to direct measurement, environmental models attempt to determine the fate of agricultural nutrients by using a variety of equations to represent the biophysical system. Models range from relatively simple empirical models based on field measurements to very complex models that attempt to simulate biophysical processes in detail within the soil–crop–air–water system. The comprehensive nature of these process-based models makes them appealing for application to a wide array of crops, geographies, and agricultural management practices. However, they perform poorly when used beyond the applications and conditions for which they are calibrated (Baffaut et al. 2017), and the lack of transparency into model inputs and processes can lead to a credibility challenge for model outputs.

Nitrogen balance as a measure of nitrogen losses to the environment

Although there is value to both modeling and environmental monitoring, we believe a simple field- and farm-level indicator of N loss, responsive to changes in farm management practices, is likely to be both more credible and more useful to an individual farmer. Such an indicator will better help her or him understand the direct impact of farm management changes on environmental outcomes. We propose that *N balance*, which has been widely used in the EU and elsewhere (OECD 2013), is an appropriate indicator for this purpose. Nitrogen balance is defined as the difference between N inputs to, and N removed in products from, an agricultural system. At the spatial scale of a single production field, for example, N balance can be calculated from records of inorganic and organic nutrient applications and crop yield. More sophisticated balances can account for additional N inputs, such as atmospheric deposition and net N inputs from legume fixation, as well

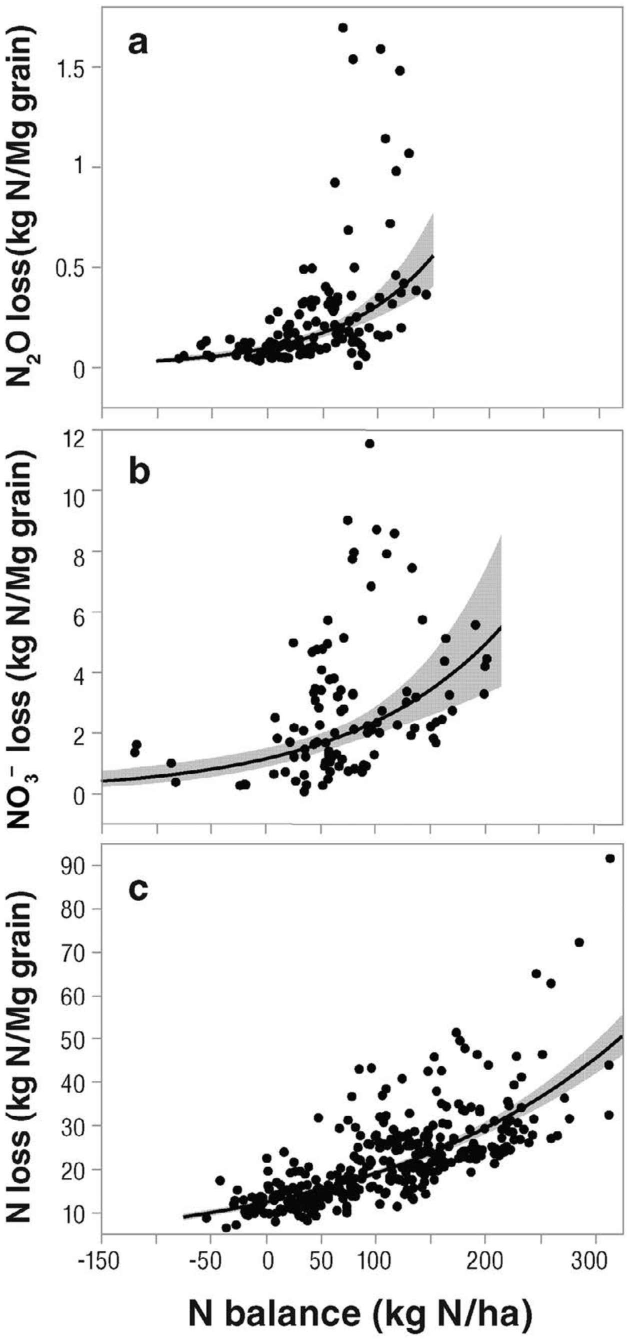


Figure 2. The relationship between nitrogen (N) balance [(N fertilizer)–(N removed in harvested grain)] and (a) yield-scaled N_2O emissions and (b) yield-scaled NO_3^- leaching, derived from published maize cropping system field studies on silt loam and closely related soils in North America. Panel (c) shows the relationship between yield-scaled total N losses and N balance, based on simulations with the Adapt-N model; total losses exceed the sum of N_2O and NO_3^- losses because the total also includes losses in the forms of NO_x, NH_3, and N_2. Note that each panel has a different range of values on the y-axis. Details of the analysis and curve-fitting are provided in the supplemental materials.

as variations in the N content of harvested crop materials and changes in soil organic matter content. At the farm scale, the definition of N balance expands to include inputs and outputs associated with integrated crop–livestock production systems (Soberon et al. 2015). Nitrogen balance can be scaled up to large watersheds (Thorburn and Wilkinson 2013, Cela et al. 2017) and countries (Zhang et al. 2015) and aggregated across industry sectors (Stott and Gourley 2016).

Nitrogen balance for a field, as defined above, is a measure of the extent to which anthropogenic N supply exceeds crop needs. Although modest excess may be required (e.g., to support growth of unharvested plant parts and maintain soil organic matter), a large excess creates a pool of reactive N in soil that is extremely vulnerable to loss and is therefore a potential source of pollution. Assuming steady-state conditions with little or no change in soil organic N stocks, N balance represents a robust estimate of the soil N pool at risk of loss to the environment. To test this hypothesis, we evaluated relationships between N balance and environmental N losses through two complementary approaches, one based on analysis of published field data and the other based on a simulation model (figure 2). We focus primarily on N_2O emissions and NO_3^- leaching, because these have been the subject of supply-chain sustainability initiatives in the United States. To ensure that reductions in N losses are not achieved at the expense of crop yields, we express N loss relationships as yield-scaled N_2O and NO_3^- losses (kilograms N lost per megagram of grain; van Groenigen et al. 2010); the relationship between N balance and area-scaled losses is presented in supplemental figure S2.

The first approach used published field-scale studies of rain-fed maize systems in the north-central United States and southeast Canada from which N balance and yield-adjusted N losses could be calculated, as we detail in the supplemental materials. The resulting empirical relationship between N balance and yield-scaled losses is shown in figure 2a (for N_2O) and 2b (for NO_3^-), together with the 95% confidence interval of the mean response (see the supplemental materials for details). The shape of the best-fit curves in figure 2a and 2b is consistent with biophysical understanding of the fate of N in cropping systems: When N supply exceeds crop uptake requirements, the excess N becomes vulnerable to loss, and N loss rates increase with higher amounts of excess fertilizer. The scatter of individual data points around the best-fit curves reflects variations in weather, soil, and field management that influence N cycling and crop yield in the crop–soil system.

The second approach used a simulation model to estimate the effect of N-fertilizer management practices on N losses at 18 locations in the Corn Belt. We used a research version of Adapt-N, a field-level model that simulates changes in soil N pools, crop N uptake, and losses of N to air and water (Sela et al. 2016; see the supplemental materials for details of model validation). Using this model provides an assessment of the relationship between N balance and environmental

N losses across a wider range of N balance and environmental conditions than can be found in published data from field experiments. In addition, the model simulates all transformation pathways, providing an estimate of total losses to the environment from all forms of N, including gaseous losses (NH_3, N_2, N_2O, and NO_x) and NO_3^- leaching. Inclusion of all major N species, together with the ability to simulate losses over an entire year rather than a growing season, leads to much larger estimates of N loss from model simulations (figure 2c) than from field experiments that only measure one form (figure 2a, 2b). Despite these differences, the results from our model simulations (figure 2c) define a relationship between N balance and yield-scaled total N losses that is both strong and consistent with the analysis of the field-measured N_2O and NO_3^- loss data (figure 2a, 2b).

Together, the analyses of field data and simulation results provide compelling evidence that a robust relationship exists between N balance and environmental N losses. Therefore, N balance is a robust predictor of field-scale N losses when aggregated over multiple sites and years. Relationships of similar form have been noted recently for N_2O and NO_3^- losses separately in North American maize systems, varying slightly depending on soil type, crop rotation, and nutrient management (Zhao et al. 2016, Omonode et al. 2017). Here, the comparable response of both N_2O and NO_3^- to N balance means that management of N balance to mitigate high losses of one form of N is synergistic for the other, thus minimizing the pollution-trade-off risks that exist with some management practices (e.g., drainage water management that reduces NO_3^- losses but could increase N_2O emissions). Relationships similar to those in figure 2 also exist for other crops and regions (e.g., van Groenigen et al. 2010, Cui et al. 2013). Therefore, it is clear that N balance is a robust indicator of potential environmental N losses associated with N inputs applied in crop production.

Entities interested in translating changes in N balance into changes in greenhouse gas emissions and water quality could potentially use empirical relationships such as those shown in figure 2a and 2b. For example, on the basis of figure 2a, a reduction in N balance from 150 kilograms N per ha to 100 kilograms N per ha (at constant yield) would correspond to a decrease in N_2O emissions of 45%. Similar empirical models could be developed for maize grown with manure, for other crops, and for other regions. Likewise, a well-validated empirical model for water quality (similar to figure 2b) could estimate field-scale changes in NO_3^- leaching below the root zone resulting from a specific N balance change. Transport factors such as those included in the SPARROW water quality models (Robertson et al. 2014) could upscale this field-level NO_3^- leaching reduction to NO_3^- load changes in the nearest stream or the outlet of a larger river basin (Woodbury et al. 2017).

Using nitrogen balance to track environmental progress

Given public concern about environmental N losses and the strong relationship between N balance and N losses described above, we anticipate that both individual farmers and the broader agricultural community would be interested in using the N-balance indicator to track N losses from crop production systems as a way of demonstrating a reduced environmental footprint of farming. For example, commodity groups might see value in using aggregated N-balance data to demonstrate industry-wide improvement in mitigating N losses. Supply-chain companies, such as food processors and retailers, might be interested in using N balance to document the impact of their sustainability initiatives. As an example, Unilever has previously reported on total reductions in N pollution along its international supply chain for specialty crops, using aggregated N-balance data obtained from its suppliers under its Sustainable Agriculture Code (Unilever 2010). Likewise, the Stewardship Index for Specialty Crops has adopted a “Nitrogen Use” metric that is related to N balance (SISC 2013) to help track improved N management by its suppliers. Field to Market, a multistakeholder initiative to improve supply-chain sustainability for commodity crops, is in the process of adopting a new metric for cropland N_2O emissions that relies on the relationship between these emissions and N balance. Once adopted, this N-balance-based metric will help track the environmental benefits of various supply-chain sustainability projects.

Policymakers outside the United States have used N balance as an indicator to track progress in reducing the environmental impacts of food production. For example, it has been used across Europe (EEA 2017), where a variety of national policies have been adopted to decrease regional and national N balances. The success of these policies is illustrated by Denmark, which has reduced its country-level N balance by 40% (Dalgaard et al. 2014), with the result that NO_3^- leaching has been reduced by 50% and ammonia emissions have also declined. Other OECD countries also use N balance (OECD 2013) as an indicator of sustainable intensification. In the United States, California (where in some counties over 40% of wells exceed safe drinking-water standards for nitrate) will soon require farmers to track and report nutrient budgets (essentially N balances; Harter 2015).

Setting nitrogen-balance goals: Carrying capacity, thresholds, and safe operating spaces

Hunter and colleagues (2017) noted that the discourse around sustainable intensification has primarily focused on food production goals and that corresponding environmental goals are largely lacking. Nitrogen balance offers an opportunity to set environmental goals that are also connected to farm productivity levels. Zhang and colleagues (2015) translated the “safe” planetary boundary for N (Steffen et al. 2015) into a globally averaged N balance compatible with that boundary of 39–78 kilograms N per ha per year. To mitigate the impacts of N-related air and water pollution at airshed or river-basin scales, however, will require the establishment of safe N boundaries and corresponding N balances at those scales, as well as disaggregation of those N balances across different agricultural systems within those airsheds or watersheds. In Europe, for example, where ammonia-related air pollution is a big concern, regional reductions in N balance have been correlated with reductions in atmospheric N deposition (Dalgaard et al. 2014) but have not yet been related to critical loads for specific ecosystems (e.g., national parks or estuaries). More progress has been made on water quality. For example, in parts of New Zealand, where tourism is threatened by degraded water quality, the N-load carrying capacity of lakes and streams has been quantified and translated into "nitrogen discharge allocations"—based on N balance—at the watershed and farm level (Duhon et al. 2015). In the United States, efforts to restore the Chesapeake Bay have likewise led to identification of ecosystem carrying capacity and the N-load reductions needed to reach it. Cela and colleagues (2017) have described how improvements in N balance on New York State dairies can track progress toward these N-load reduction targets.

The shape of the N-balance to N-loss relationships in figure 2 suggests a possible alternative approach to setting N-balance goals. Figure 2 illustrates dramatically increasing environmental losses above a threshold value of N balance. If further work verifies the N-balance-threshold concept, threshold values of N balance will represent useful targets for environmental performance, and the greatest reductions in N pollution could be achieved by incentivizing producers to reduce their N-balance values to the threshold level. Obviously, different cropping systems, climates, and soils would need appropriately adapted thresholds to account for other major factors governing N losses.

Nitrogen-balance targets must also be supportive of other sustainability goals, especially those related to maintaining soil organic N stocks, a critical factor in long-term soil fertility. Likewise, it will be important to relate N balance to other aspects of farm-level sustainability, such as overall productivity (yield) and profitability. The European Union Nitrogen Expert Panel (EU-NEP), a science advisory group convened by the European fertilizer industry, has introduced the concept of a safe operating space for crop production (EU-NEP 2015; see figure 3). The *safe operating space* is defined by a minimum acceptable level of productivity (to meet food needs), a maximum acceptable level of N balance (to minimize N pollution), and an acceptable range of nitrogen use efficiency (NUE; the ratio of N inputs to outputs). Excessively high NUE risks mining soil organic matter, whereas excessively low NUE wastes fertilizer and other resources.

Modeled after this safe operating space for fertilizer-based European agriculture, similar limits could be defined for other agricultural systems. Such guidelines could also incorporate broader approaches to nutrient management, such as using manure and legumes for N sources, extending crop rotations with winter cover crops, or other options (figure 3). These management practices can promote N retention in long-term soil N pools and enhance internal N cycling, thereby offering significant opportunities to reduce N balances (Gardner and Drinkwater 2009, Zhou et al. 2016). In addition, they recouple carbon and N cycling, mitigating the risk of achieving a small N balance simply by mining soil organic matter. Brentrup and Lammel (2016) showed how coupling extended rotations with improved fertilizer management moved wheat systems into the safe operating space, whereas de Klein and colleagues (2017) attempted to map safe operating spaces for dairy systems. These sustainability targets must be developed for specific agroecological regions and farming systems; one size does not fit all (Gourley et al. 2007, de Klein et al. 2017).

Nitrogen balance: The view from the farm

Our analyses above establish a robust relationship between N balance and N losses. From the perspective of a farmer seeking to reduce N losses, the challenge is identifying what changes can be made to their operation to reduce N balance while maintaining productivity and profitability.

In general, N-balance reductions can be achieved by better matching N inputs and N outputs in time and space while maintaining or increasing yields (Cassman et al. 2002, Snyder et al. 2014). This relationship creates a win–win opportunity for farmers to achieve high productivity levels while reducing environmental impact. For example, Adapt-N simulations (detailed in the supplemental materials) suggest that delaying most fertilizer N application to the maize growing season leads to smaller N balances, with less total N loss, while maintaining crop yields (figure 4). Because delaying fertilizer application usually enables lower N application rates, such improvements in fertilizer management can reduce costs and increase overall profitability (Sela et al. 2016). More broadly, Soberon and colleagues (2015) and Buckley and colleagues (2016) have shown that improved environmental performance (reduced N balance) can go hand in hand with improved production and increased profitability.

For any crop field, the size of the N balance is a function of the local biophysical setting (including factors influencing N losses, such as climate and soil type, that are not controllable by the farmer), the cropping system, and farmer management practices that affect the fate of applied N and determine actual crop yield. This suggests that across a cohort of farms with similar climate, soil type, and cropping system, and with comparable yield levels, N balance is a measure of the effectiveness of farm management practices in tightening the N cycle. As such, comparison of N balance values across cohort farms can be used to identify those farm management practices that best reduce N balance (Dalgaard et al. 2012, Blesh and Drinkwater 2013) and therefore N losses to the environment. Such benchmarking approaches have identified opportunities to improve water and N use efficiency for irrigated maize in Nebraska (Grassini and Cassman 2012) and to improve dairy-farm nutrient management in Australia and New York State (Gourley et al. 2007, Cela et al. 2014).

As an example of how such an approach could help farmers improve N balance, we show data on N balance, fertilizer

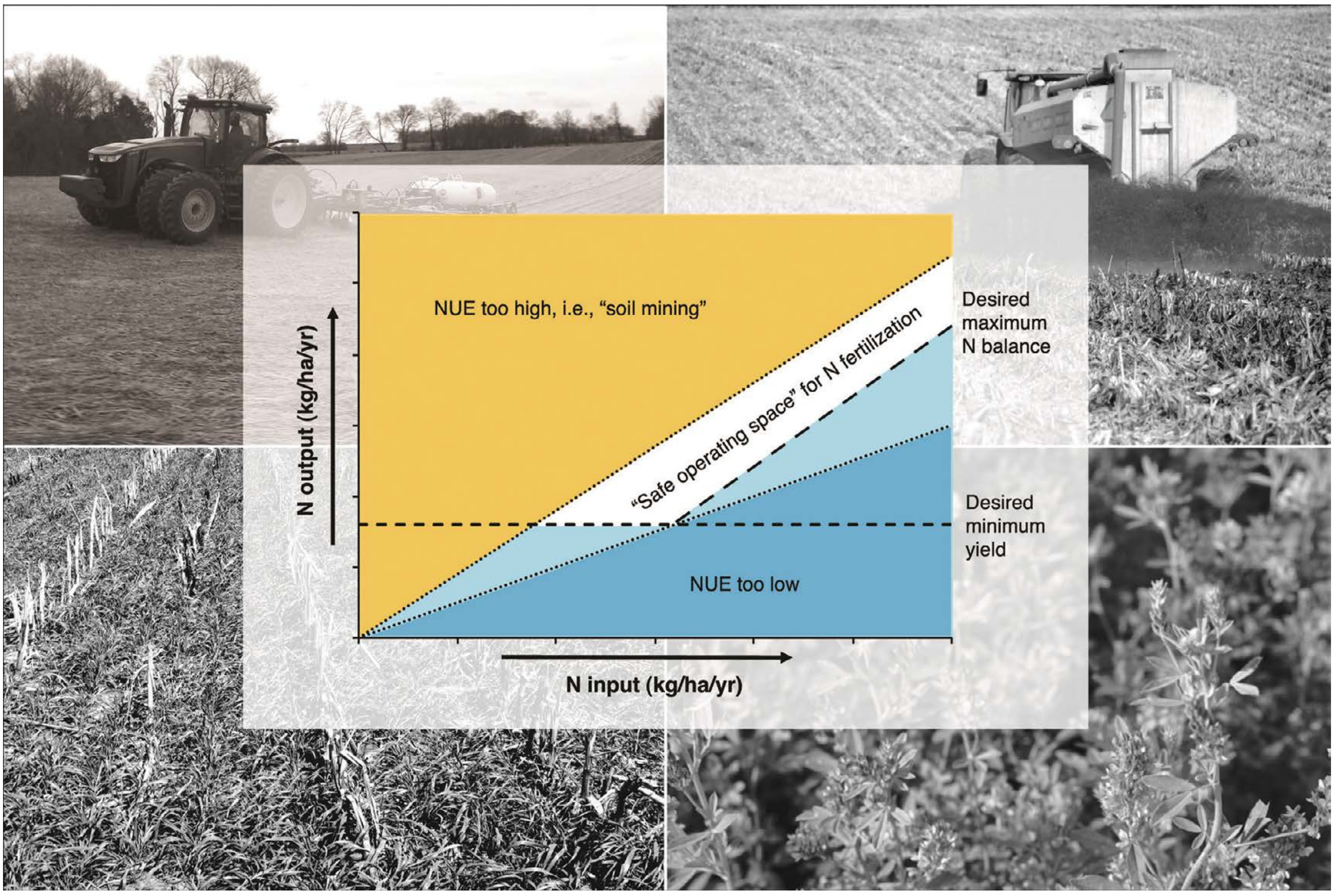


Figure 3. An illustration of the safe operating space concept (inner diagram) in the broad context of nutrient management (outer diagram). The inner diagram (modified from EU-NEP 2015) shows the relationship between total nitrogen (N) input (from fertilizer, manure, and biological N fixation), N outputs (N removed in harvested grain), N use efficiency (NUE), and N balance. A safe operating space requires that NUE is sustained within an accepted range; values that are too low (blue shaded area) are inadequate to meet food production goals and are inefficient for resource use, whereas values that are too high (gold shaded area) risk mining soil organic matter. Likewise, we assume that there is some minimum productivity (yield) goal, shown here by the horizontal dashed line, and some acceptable maximum level of N balance, shown here by the diagonal dashed line. Expert judgment is needed to define appropriate values of N balance, NUE, and yield for a given cropping system and ecoregion. The intersection of these criteria (the white space in the inner diagram) represents the safe operating space for that cropping system and ecoregion. The outer diagram shows the broad suite of approaches to nutrient management (from top left: improved fertilizer management; substitution of manure for synthetic fertilizer; use of legumes as an alternative nitrogen source; use of cover crops to tighten internal nutrient cycling), which can help move a cropping system into the safe operating space.

N rate, and yield for maize production on 66 farms in the Corn Belt (figure 5; details in the supplemental materials). The farms are typical of the region in terms of cropping system (corn–soybean) and the types of crop and soil management practices used. Highlighted in figure 5 is a subset of farms that are in close geographic proximity and share similar soil and climate characteristics, such that variations in N balance most likely reflect different farm management practices. Even within this subset of similar farms, the range in yield and N balance approximates that at the other 49 sites. So for the sake of illustrating the benchmarking process, we assume that N-balance variations among all farms reflect the influence of farm management practices.

Figure 5 shows that for any given fertilizer-N rate or yield, there is a range of N-balance values indicating that farms with a large N balance (in orange) could improve environmental performance by following the practices of small-N-balance farms (in blue). A cooperative data-sharing approach, using anonymized and aggregated N-balance data, could help farmers and their advisors benchmark their N management performance and learn about the best practices of others (Wood et al. 2014). Sewell and colleagues (2017) described the factors that are crucial to the success of such efforts, including the collaborative learning among farmers and advisors that builds the trust essential to data sharing.

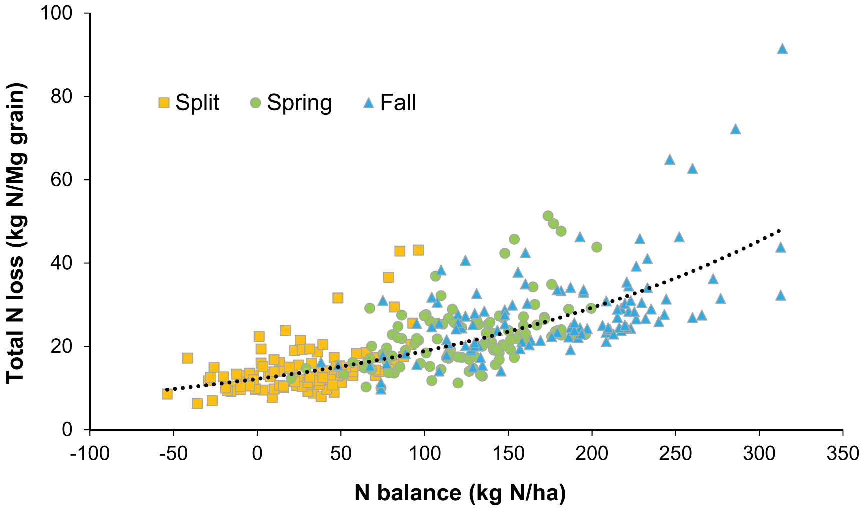


Figure 4. The relationship between nitrogen (N) balance and total yield-scaled total N losses (NH_3, N_2, N_2O, NO_x, and NO_3^-) in Adapt-N simulations of rain-fed maize systems on silt loam soils in the US Corn Belt. Simulations were split into three groups based on the timing of primary N fertilizer application (fall, spring, or split), with side-dress application rates during the growing season adjusted on the basis of Adapt-N predictions of plant N needs.

Polices based on N-balance outcomes could create incentives for farmers to adopt measures that move them toward or into the appropriate safe operating space for their farming system and ecoregion or reward them for meeting other environmental performance targets. Likewise, the shape of the curves in figure 2 suggests that focusing public and private stewardship efforts on regions (or specific farms) with large N balances will increase the efficiency (in terms of pollution reduced per dollar spent) and effectiveness of those efforts. The mapping of N balance at a regional scale can serve to identify "hotspots" of large N balance, which are opportunities for such high-impact focus.

Outcome-oriented policies need not be regulatory to be successful; voluntary efforts to improve N balance offer an opportunity for leadership by the US agricultural community. For inspiration on how to structure such efforts, they might look to New Zealand, which is experimenting with a community-based, collaborative "audited self-management" approach to mitigate N pollution at the watershed scale (Holley 2015). Groups of farmers and other local stakeholders collaboratively manage watershed-level N carrying capacity, determining together how to achieve a specified environmental goal, with auditing by governmental agencies or independent third parties to verify that the goal is met. This approach combines meaningful goal setting and accountability for progress with local self-determination and flexibility in meeting the goal, including the development of highly innovative and verifiable farm-to-farm trading schemes based on N balance. In the United States, Nebraska's Natural Resource Districts already use an audited self-management approach to groundwater allocation (Stephenson 1996), which could be expanded to address broader water-quality goals and replicated elsewhere.

To support such efforts, a cohesive and coordinated research initiative will be needed to refine potential threshold values of N balance, such as those illustrated in figure 2, or other targets for environmental performance. Science must also inform any efforts to identify safe operating spaces for various cropping systems and ecoregions. Science-based recommendations on region- and cropping-system-specific management practices for achieving those targets are also needed. A useful starting point for such efforts is the work of Snyder (2016) in identifying suites of best practices for fertilizer management in specific crops and regions, which could be expanded to consider broader (including landscape-scale) approaches to mitigating nutrient losses such as cover crops, drainage water management, restored or constructed wetlands, or re-integration of livestock into crop production

A nitrogen-balance framework for sustainable intensification

An N-balance approach to agricultural N management can help society meet the twin challenges of increasing food production while reducing N pollution. For such an approach to be successful, policymakers, scientists, private industry, public agency staff, extension agents, crop consultants, and—most importantly—farmers will need to collaborate in developing an implementation framework that both establishes N-balance goals and provides the political, economic, and social support to help farmers achieve those goals.

Historically, policies to manage N-related pollution from agriculture have focused on incentivizing or mandating reduced fertilizer inputs, an approach that is often incompatible with food production goals and that ignores the risks and uncertainties that motivate farmers to apply excess N (van Es et al. 2007). Likewise, promoting particular practices overlooks the highly variable impacts such practices may have on N-loss reductions (including the risk that under some circumstances, a practice may even increase some forms of N loss), as well as potential economic and practical barriers to on-farm implementation. We believe that policies focused on improving N-balance outcomes will be more effective than such approaches. Focusing on outcomes ensures that environmental benefits are achieved while stimulating innovation by individual farmers to develop approaches that work in the context of their farming operation. In addition, because N-balance improvements correspond to improvements in other sustainability indicators that can potentially increase farmer profits, farmers may be motivated to make operational changes that benefit their self-interest.

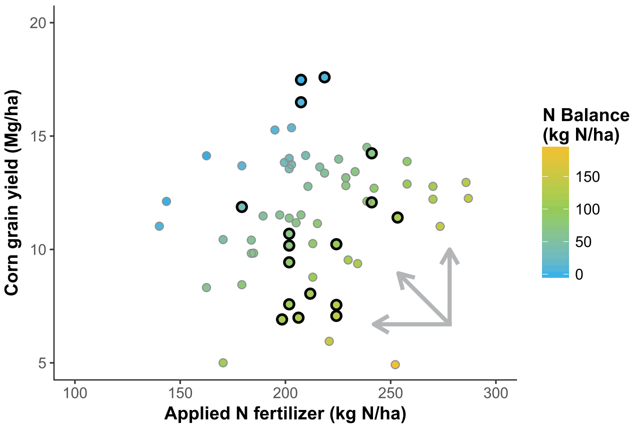


Figure 5. The relationship of nitrogen (N) fertilizer application rate, maize crop yield, and N balance from maize fields on 66 farms in five US midwestern states in 2015. The subset of highlighted farms shown in darker outline is in close geographic proximity, and these farms are assumed to share a similar production environment in terms of soils and climate. The farms are typical of the region in terms of cropping system (corn–soybean) and the types of crop and soil management practices used, although the specific practices differ from farm to farm leading to differences in N balance. Note that at any given fertilizer rate (or yield), there is a range of values of N balance, suggesting that producers could improve both agronomic and environmental outcomes by improving yield (or lowering fertilizer rate), as is shown by the vertical (and horizontal) arrows. More generally, lower-performing producers (those with large N balances) could improve N management and environmental outcomes by adopting some of the practices used by higher-performing producers (with small N balances), as is shown by the diagonal arrow.

systems (Billen et al. 2013, McLellan et al. 2015). Research will also be needed to reduce the uncertainty of N-balance calculations at the field and farm scale by better quantifying N inputs (and losses) from manure and biological N fixation, improving estimates of the N content of harvested crops, and estimating changes in soil organic N stocks.

Private industry investment in innovations and services (e.g., new fertilizer formulations, precision fertilizer application equipment, and sophisticated decision-support tools) can help farmers achieve the needed improvements in N balance. Increased technical assistance will be needed to help farmers incorporate these technologies into their operations. As was noted by Ketterings (2014), outcome-based approaches to farm management are most effective in an adaptive management setting that combines on-farm research, extension, and collaboration with farmers to help them achieve their goals. The US Department of Agriculture's Natural Resources Conservation Service (USDA-NRCS) has introduced a practice standard for nutrient management that incentivizes farmers to use an adaptive management approach. One possible model for doing this effectively is Sweden's "Focus on Nutrients" program (Olofsson 2017), which pairs farmers with advisors who meet regularly to help them calculate, manage, track, and understand their farm nutrient balance and how it relates to farm productivity and profitability. USDA-NRCS staff, extension agents, crop consultants, and others will be crucial in helping farmers achieve their and society's sustainability goals.

Success will depend on the willing engagement of farmers. Although we believe that farmers' innate desire to improve their operations and be good stewards of the land will help motivate improvements in N balance, incentives will be important for recognizing progress and encouraging continuous improvement. Such incentives could be provided through public or private funding and acknowledgment. We believe that the value of such incentives—avoiding the cost of N-pollution damage—will far exceed their cost now and in the future.

Conclusions

Given the legacy effects of N use in crop production on water quality and the intensification of N pollution anticipated to result from future climate change (Suddick et al. 2013), we foresee increasing public demand for evidence that agriculture is reducing N losses. Reconciling further intensification of agricultural production with protection and restoration of the planet is possible with an N-balance framework. Data currently collected by producers on N applications and crop yields, suitably aggregated and anonymized, could be used to begin benchmarking efforts, to develop a baseline of current N-balance status, and to identify regional N-balance hotspots that might receive increased attention and funding from the USDA or other public- or private-sector funders. Proactive development of an N-balance framework—led by farmers and supply-chain entities and in partnership with scientists, private industry, and extension agents—can begin now, drawing on lessons learned elsewhere and laying the groundwork for policy innovations that reward synergistic outcomes of improved food production and environmental performance.

Acknowledgments

We acknowledge funding support from the Walton Family Foundation, the David R. and Patricia D. Atkinson Foundation, and the Atkinson Center for a Sustainable Future, Cornell University. We thank Rodney Venterea of the US Department of Agriculture's Agricultural Research Service for sharing unpublished data on N_2O emissions and N balance and all those whose contributions to Environmental Defense Fund (EDF)–funded workshops on N balance in 2015, 2016, and 2017 helped us to refine the ideas presented here. We appreciate initial analyses by EDF interns Trevor Anderson and Katherine Costas. Comments by Doria Gordon and Josette Lewis of the EDF and by three anonymous reviewers greatly improved the manuscript.

Supplemental material

Supplementary data are available at *BIOSCI* online.

References cited

Baffaut C, et al. 2017. Multisite evaluation of APEX for water quality: I. Best professional judgment parameterization. Journal of Environmental Quality 46: 1323–1331.

Billen G, Garnier J, Lassaletta L. 2013. The nitrogen cascade from agricultural soils to the sea: Modelling nitrogen transfers at regional watershed and global scales. Philosophical Transactions of the Royal Society B 368 (art. 20130123).

Blesh J, Drinkwater LE. 2013. The impact of nitrogen source and crop rotation on nitrogen mass balances in the Mississippi River Basin. Ecological Applications 23: 1017–1035.

Bosch NS, Evans MA, Scavia D, Allan JD. 2014. Interacting effects of climate change and agricultural BMPs on nutrient runoff entering Lake Erie. Journal of Great Lakes Research 40: 581–589.

Brentrup F, Lammel J. 2016. Nitrogen use efficiency, nitrogen balance, and nitrogen productivity—A combined indicator system to evaluate nitrogen use in crop production systems. Paper presented at the 2016 International Nitrogen Initiative Conference: Solutions to Improve Nitrogen Use Efficiency for the World; 4–8 December 2016, Melbourne, Australia.

Buckley C, Wall DP, Moran B, O'Neill S, Murphy PNC. 2016. Farm gate level nitrogen balance and use efficiency changes post implementation of the EU Nitrates Directive. Nutrient Cycling in Agroecosystems 104: 1–13.

Cassman KG, Dobermann A, Walters DT. 2002. Agroecosystems, nitrogen-use efficiency, and nitrogen management. Ambio 31: 132–140.

Cela S, Ketterings QM, Czymmek KJ, Soberon MA, Rasmussen CN. 2014. Characterization of nitrogen, phosphorus, and potassium mass balances of dairy farms in New York State. Journal of Dairy Science 97: 7614–7632.

Cela S, Ketterings QM, Soberon MA, Rasmussen CN, Czymmek KJ. 2017. Upper Susquehanna watershed and New York State improvements in nitrogen and phosphorus mass balances of dairy farms. Journal of Soil and Water Conservation 72: 1–11.

Cherry KA, Shepherd M, Withers PJA, Mooney SJ. 2008. Assessing the effectiveness of actions to mitigate nutrient loss from agriculture: A review of methods. Science of the Total Environment 406: 1–23.

Cui Z, Yue S, Wang G, Zhang F, Chen X. 2013. In-season root-zone N management for mitigating greenhouse gas emission and reactive N losses in intensive wheat production. Environmental Science and Technology 47: 6015–6022.

Dalgaard T, et al. 2012. Farm nitrogen balances in six European landscapes as an indicator for nitrogen losses and basis for improved management. Biogeosciences 9: 5303–5321.

Dalgaard T, et al. 2014. Policies for agricultural nitrogen management: Trends, challenges and prospects for improved efficiency in Denmark. Environmental Research Letters 9 (art. 115002).

De Klein CAM, Monaghan RM, Alfaro M, Gourley CJP, Oenema O, Powell JM. 2017. Nitrogen performance indicators for dairy production systems. Soil Research 55: 479–488.

Duhon M, McDonald H, Kerr S. 2015. Nitrogen Trading in Lake Taupo: An Analysis and Evaluation of an Innovative Water Management Policy. Motu Economic and Public Policy Research. Working Paper 15-07. (3 January 2018; *http://motu-www.motu.org.nz/wpapers/15_07.pdf*)

Erisman JW, Galloway JN, Seitzinger S, Bleeker A, Dise NB, Petrescu AMR, Leach AM, de Vries W. 2013. Consequences of human modification of the global nitrogen cycle. Philosophical Transactions of the Royal Society B 368 (art. 20130116).

[EU-NEP] European Union Nitrogen Expert Panel. 2015. Nitrogen Use Efficiency (NUE): An Indicator for the Utilization of Nitrogen in Agriculture and Food Systems. Wageningen University, Alterra. (3 January 2018; *www.eunep.com/reports*)

[EEA] European Environment Agency. 2017. Environmental Indicator Report 2017—Agricultural Land: Nitrogen Balance. EEA. (3 January 2018; *https://www.eea.europa.eu/airs/2017/natural-capital/agricultural-land-nitrogen-balance*)

Gardner JB, Drinkwater LE. 2009. The fate of nitrogen in grain cropping systems: A meta-analysis of ^{15}N field experiments. Ecological Applications 19: 2167–2184.

Goucher L, Bruce R, Cameron DD, Lenny Koh SC, Horton P. 2017. The environmental impact of fertilizer embodied in a wheat-to-bread supply chain. Nature Plants 3 (art. 17012).

Gourley CJP, Powell JM, Dougherty WJ, Weaver DM. 2007. Nutrient budgeting as an approach to improving nutrient management on Australian dairy farms. Australian Journal of Experimental Agriculture 47: 1064–1074.

Grassini P, Cassman KG. 2012. High-yield maize with large net energy yield and small global warming intensity. Proceedings of the National Academy of Sciences 109: 1074–1079.

Harter T. 2015. California's agricultural regions gear up to actively manage groundwater use and protection. California Agriculture 69: 193–201.

Holley C. 2015. Crafting Collaborative Governance: Water Resources, California's Delta Plan, and Audited Self-Management in New Zealand. Social Science Research Network. Environmental Law Reporter, vol. 45, no. 4. UNSW Law Research Paper no. 2015-15.

Hunter MC, Smith RG, Schipanski ME, Atwood LW, Mortensen DA. 2017. Agriculture in 2050: Recalibrating targets for sustainable intensification. BioScience 67: 386–391.

Ketterings QM. 2014. Extension and knowledge transfer: Adaptive management approaches for timely impact. Journal of Agricultural Science 152: 57–64.

McLellan E, Robertson D, Schilling K, Tomer M, Kostel J, Smith D, King K. 2015. Reducing nitrogen export from the Corn Belt to the Gulf of Mexico: Agricultural strategies for remediating hypoxia. Journal of the American Water Resources Association 51: 263–289.

[OECD] Organisation for Economic Co-operation and Development. 2013. Compendium of Agri-Environmental Indicators. OECD. doi:10.1787/9789264181151-en

Olofsson S. 2017. Focus on Nutrients, a voluntary initiative for environment and economy. Paper presented at the International Interdisciplinary Conference on Land Use and Water Quality Effect of Agriculture on the Environment; 29 May–1 June 2017, The Hague, The Netherlands.

Omonode RA, Halvorson AD, Gagnon B, Vyn TJ. 2017. Achieving lower nitrogen balance and higher nitrogen recovery efficiency reduces nitrous oxide emissions in North America's maize cropping systems. Frontiers in Plant Science 8 (art. 1080). doi:10.3389/fpls.2017.01080

Ribaudo M. 2015. The limits of voluntary conservation programs. Choices 30: 1–5.

Robertson DM, Saad DA, Schwarz GE. 2014. Spatial variability in nutrient transport by HUC8, state, and subbasin based on Mississippi/Atchafalaya River Basin SPARROW models. Journal of the American Water Resources Association 50: 988–1009.

Scavia D, Bertani I, Obenour DR, Turner RE, Forrest DR, Katin A. 2017. Ensemble modeling informs hypoxia management in the northern Gulf of Mexico. Proceedings of the National Academy of Sciences 114: 8823–8828.

Sela S, van Es HM, Moebius-Clune BN, Marjerison R, Melkonian J, Moebius-Clune D, Schindelbeck R, Gomes S. 2016. Adapt-N outperforms grower-selected nitrogen rates in northeast and midwestern United States strip trials. Agronomy Journal 108: 1726–1734.

Sewell AM, Hartnett MK, Gray DI, Blair HT, Kemp PD, Kenyon PR, Morris ST, Wood BA. 2017. Using educational theory and research to refine agricultural extension: Affordances and barriers for farmers' learning and practice change. Journal of Agricultural Education and Extension 23: 313–333.

Snyder CS. 2016. Suites of 4R nitrogen management practices for sustainable crop production and environmental protection. International Plant Nutrition Institute. (3 January 2018; *www.ipni.net/IssueReview*)

Snyder CS, Davidson EA, Smith P, Venterea RT. 2014. Agriculture: Sustainable crop and animal production to help mitigate nitrous oxide emissions. Current Opinion in Environmental Sustainability 9: 46–54.

Soberon MA, Cela S, Ketterings QM, Rasmussen CN, Czymmek KJ. 2015. Changes in nutrient mass balances over time and related drivers for 54 New York State dairy farms. Journal of Dairy Science 98: 5313–5329.

Sobota DJ, Compton JE, McCrackin ML, Singh S. 2015. Cost of reactive nitrogen release from human activities to the environment in the United States. Environmental Research Letters 10 (art. 025006).

Steffen W, et al. 2015. Planetary boundaries: Guiding human development on a changing planet. Science 347 (art. 1259855).

Stephenson K. 1996. Groundwater management in Nebraska: Governing the commons through local resource districts. Natural Resources Journal 36: 761–778.

Stevens CJ, Quinton JN. 2009. Policy implications of pollution swapping. Physics and Chemistry of the Earth, Parts A/B/C 34: 589–594.

[SISC] Stewardship Index for Specialty Crops. 2013. Nitrogen Use, Working Metric Version 1.0. SISC. (3 January 2018; *www.stewardshipindex.org/amass/documents/document/12/SISC_Metric_NitrogenUse_2013-07.pdf*)

Stott KJ, Gourley CJP. 2016. Intensification, nitrogen use and recovery in grazing-based dairy systems. Agricultural Systems 144: 101–112.

Suddick EC, Whitney P, Townsend AR, Davidson EA. 2013. The role of nitrogen in climate change and the impacts of nitrogen–climate interactions in the United States: Foreword to thematic issue. Biogeochemistry 114: 1–10.

Thomson AM, et al. 2017. Science in the supply chain: Collaboration opportunities for advancing sustainable agriculture in the United States. Agricultural and Environmental Letters 2 (art. 170015).

Thorburn PJ, Wilkinson SN. 2013. Conceptual frameworks for estimating the water quality benefits of improved agricultural management practices in large catchments. Agriculture, Ecosystems and Environment 180: 192–209.

Unilever. 2010. Unilever Sustainable Agriculture Code, Version 1. Unilever. (3 January 2018; *www.unilever.com/Images/ul-sac-v1-march-2010-spread_tcm244-464943_en.pdf*)

Van Es HM, Kay BD, Melkonian JJ, Sogbedji JM. 2007. Nitrogen management for maize in humid regions: Case for a dynamic modeling approach. Pages 6–13 in Bruulsema TW, ed. Managing Crop Nitrogen for Weather. International Plant Nutrition Institute.

Van Groenigen JW, Velthof GL, Oenema O, van Groenigen KJ, van Kessel C. 2010. Towards an agronomic assessment of N_2O emissions: A case study for arable crops. European Journal of Soil Science 61: 903–913.

Van Meter KJ, Basu NB, Veenstra JJ, Burras CL. 2016. The nitrogen legacy: Emerging evidence of nitrogen accumulation in anthropogenic landscapes. Environmental Research Letters 11 (art. 035014).

Wood BA, Blair HT, Gray DI, Kemp PD, Kenyon PR, Morris ST, Sewell AM. 2014. Agricultural science in the wild: A social network analysis of farmer knowledge exchange. PLOS ONE 9 (art. e105203).

Woodbury PB, Kemanian AR, Jacobson M, Langholtz M. 2017. Improving water quality in the Chesapeake Bay using payments for ecosystem services for perennial biomass for bioenergy and biofuel production. Biomass and Bioenergy. doi:10.1016/j.biombioe.2017.01.024

Zhang X, Davidson EA, Mauzerall DL, Searchinger TD, Dumas P, Shen Y. 2015. Managing nitrogen for sustainable development. Nature 528: 51–59.

Zhao X, Christianson LE, Harmel D, Pittelkow CM. 2016. Assessment of drainage nitrogen losses on a yield-scaled basis. Field Crops Research 199: 156–166.

Zhou M, Zhu B, Brüggemann N, Dannenmann M, Wang Y, Butterbach-Bahl K. 2016. Sustaining crop productivity while reducing environmental nitrogen losses in subtropical wheat–maize cropping systems: A comprehensive case study of nitrogen cycling and balance. Agriculture, Ecosystems and Environment 231: 1–14.

Eileen L. McLellan and Alison J. Eagle are affiliated with Environmental Defense Fund, in Washington, DC. Kenneth G. Cassman is emeritus with the Department of Agronomy and Horticulture at the University of Nebraska, in Lincoln. Peter B. Woodbury, Shai Sela, and Harold M. van Es are affiliated with the Soil and Crop Sciences Section of the College of Agriculture and Life Sciences at Cornell University, in Ithaca, New York. Christina Tonitto is with the Cornell International Institute for Food, Agriculture, and Development, in Ithaca, New York. Rebecca D. Marjerison is affiliated with the Agronomic Technology Corporation, a Yara International Company.

BLWK Bestuurspan / CAWC Management Team

Lede

Hoppies Uys – hoppies@swdconnect.co.za
Sakkie Rust – sakkie@rautenbachtransport.co.za
MG Lötter – devlei@whalemail.co.za
Hume Schonfeldt – humeschonfeldt@gmail.com
Jakobus Mouton – andre@patat.za.net
Amelia Genis – agenis@landbou.com
Johann Strauss – johannst@elsenburg.com
Pieter Blom (SSK) – pblom@ssk.co.za
Ruan Schutte (GraanSA) - ruan@grainsa.co.za
Pieter Burger (Kaap Agri) – pieter.burger2@kaapagri.co.za
Lombard van Jaarsveld – lombardvj@overbergagri.co.za
Gareth De Bruin (Kaap Agri) - gareth.debruin@kaapagri.co.za
Peter Greeff – peter@orchman.com
Pieter Swanepoel - pieterswanepoel@sun.ac.za

Click on the email address to send a person an email