Building crop rotation sequences to cut down your carbon footprint

By Lisa Matthews, Department of Agronomy, Stellenbosch University

Deciding what to include in a crop rotation sequence is an important decision that impacts management, pests and diseases, the infrastructure or machinery that will be needed and, as we found, it also impacts greenhouse gas (GHG) emissions. We saw that replacing synthetic nitrogen (N) with nitrogen-fixing legumes and using diverse rotation systems integrated with cover crops or livestock effectively cut down on emissions.

Agriculture is unique as an industry because it involves one part human action and two parts nature. A producer selects the seed, oversees the planting, fertilises or sprays, but after that, it is up to natural processes for produce to grow. It is common knowledge how much production is impacted by the environment. Moderate temperatures and the right amount and distribution of rain throughout the season are needed. What is not well known is how much agriculture impacts the environment. Farming uses the most land globally and is responsible for approximately a quarter of human caused GHG emissions.

Crop-rotation systems

Different dryland crop rotations in the Swartland in the Western Cape were studied. The trial, situated on Langgewens Research Farm, is a conservation agriculture trial where different rotation combinations of cereals, canola, lupins, and sheep have been followed for over 20 years. To determine the carbon footprint, an inventory of all the emissions was collected.

The annual changes in soil organic carbon and biomass production and yield were also observed. Some GHG emissions were measured directly from the soil. The closed chamber method was used whereby a section of soil is enclosed, and air samples are taken over time to detect flows of nitrous oxide and methane (two potent GHGs). The rest of the emissions were modelled through activity data and emission factors.

Three four-year rotation sequences were investigated. The first crop rotation system was three years of wheat, followed by one year of canola. This system produces cash crops every year and relies fully on fertiliser for nitrogen demands. The next system was a sequence of wheat, canola, wheat and cover crops. Here one year of producing cash crops is traded for a very diverse mixture of forage cereals, legumes, and Brassicas that fix nitrogen (replacing 15kg of nitrogen the following year) and boost the soil.

The third system was integrated with livestock. Every second year a medic pasture is established and grazed by Dohne sheep, a wool and meat breed. The sequence is wheat, medic pasture with sheep, canola, medic pasture with sheep. In this system, the medic pasture fixes most of the nitrogen required by the cash crops, lowering the application of fertiliser to 26kg N for wheat and 48kg N for canola. This is a significant reduction from the nitrogen used in the cash crop-only system of 87kg N for wheat and 80kg N for canola.

There is a connection between N fertiliser and GHG emissions. It takes a lot of energy to manufacture nitrogen fertiliser, and by the time it has made its way onto the farm every kilogram of N could represent anything between 3 to 10kg of CO_2 that was released during its production and distribution. This is an example of an indirect or embedded emission, where GHGs are released during the manufacturing of an input or material. Other than its embedded emissions, once N is applied, it contributes further because some of it forms nitrous oxide. Nitrous oxide is a GHG along with carbon dioxide, methane, and fluorinated gases.

Nitrous oxide emissions

Agriculture is responsible for approximately 80% of human-caused nitrous oxide emissions. Although it is released in small amounts, it is a potent GHG as 1kg of nitrous oxide causes as much warming as 273kg of carbon dioxide. Any additions of N to the soil, regardless of whether it is in the form of fertiliser, nitrogen fixed by legumes, compost or animal manure, could potentially increase nitrous oxide emissions.

Estimating exactly how much nitrous oxide is released is difficult. This gas is formed in the soil by microbes and is strongly influenced by changes in temperature, and N and water available. There is a lot of variability in how it forms so weekly to biweekly samples were taken to best capture what was occurring. Throughout the year emissions remained very low, and then following an unusual summer rainfall, a burst of nitrous oxide was released. What is even more interesting is that this burst only occurred in the systems that had livestock or legumes.

In systems reliant on fertiliser, following application, the plant quickly uses it up, and by the end of the season very little remains. In systems that rely on organic forms of N, these forms must first be mineralised before the plant can take it up. It essentially acts as a long-term storage of N that drips nutrients to the plant over the season. However, after the plant is harvested, the sudden availability of moisture releases a bit of N into the soil leading to the nitrous oxide burst.

Although releases of nitrous oxide contribute negatively to the carbon footprint, it points out an important difference in how rotations can affect the quality of the crop. There was a steadier supply of N throughout the season – especially towards the spring when the wheat was in its nutrient-hungry grain-filling stage in systems that had organic sources of N such as legumes or animal manure.

Differences in quality

Between 2000 and 2020, the average protein content of wheat remained at around 13% in the wheat-pasture-canola-pasture rotation. In the rotation that had one year of cover crops in between wheat and canola phases, wheat protein content dropped roughly 1% to just under 12% in 2020.

Finally in the wheat-wheat-wheat-canola system, despite having the highest usage of N fertiliser, the wheat protein content dropped by almost 2% from 12,5 to 10,5%. Another way to look at it was that over 90% of the wheat harvested from the two rotations that had legumes incorporated were bread grade, while only 75% of the wheat from the wheat and canola-only rotation made bread grade.

Having higher-quality wheat is a definite economic benefit; in addition, the yields were also higher. In the wheat-wheat-wheat-canola rotation, the average yields for 2021 were 3,2t/ha for wheat and 1,3t/ha for canola. In the wheat-canola-wheat-cover crops rotation, the yields were 4,6t/ha for wheat and 2,2t/ha for canola. Finally, the yields for the wheat-pasture-canola-pasture rotation were 5,4t/ha for wheat and 2,9t/ha for canola. These yield benefits are so significant that in the end sacrificing one year of harvesting crops for a cover crop phase is worth it.

Other sources of emissions that differed between rotations were fuel and agrochemicals. Due to some phases not requiring a tractor to spray or apply fertiliser frequently, fuel usage was essentially diluted over the four years. For this reason, less fuel was consumed in the crop-livestock rotation system, and the most fuel in the cash crop-only system.

Looking at soil carbon levels, no difference was found between rotation systems; however, all systems increased over 20 years from 0,9 to 1% to 1,4%. This positive increase is attributed to conservation agricultural practices of no tillage, crop rotation, and permanent soil cover.

So, putting it all together: Compared to the rotation system of wheat-wheat-wheat-canola, rotation wheat-canola-wheat-cover crops had 35% less GHG emissions per product output and 15% less emissions per hectare, and rotation wheat-pasture-canola-pasture had 11% less GHG emissions per product output and 7% less emissions per hectare. If the medic pastures were grown as fodder production phases and the emissions from the livestock not included, this rotation would have had 55% less GHG emissions per product output, and 35% less emissions per hectare.

Cutting emissions

Emissions were cut by replacing fertiliser with legumes that fix N, either through the medic pastures or cover crops. Yields were increased by improving the soil. N fertiliser alone was responsible for almost 70% of the GHG emissions in the wheat-wheat-wheat-canola system. In the crop-livestock system, emissions from livestock (enteric fermentation and excreta) were the main source of emissions.

Other inputs that caused smaller amounts of emissions were fuel, seed and agrochemicals such as herbicides and fungicides. Soil carbon sequestration was an additional climate mitigation benefit in all systems. Diversifying the rotation by incorporating livestock and legumes into rotations decreased the global warming potential of wheat and canola production.

The main benefit of the sheep was to ensure the medic pasture phases were profitable. It is also important to remember that livestock cause emissions too, so stocking at too high rates or causing overgrazing would probably increase GHG emissions instead.

The different phases of a rotation system should not be managed individually. Each year impacts the next. Different rotation phases can be used to support your system and build it up over time. Yield is not the only thing being produced; N, manure, soil carbon, and ecosystem services which can act as home-grown inputs are also produced. Long-term yield differences are sometimes difficult to see but over time they can make a huge difference to productivity, profitability, and sustainability.

To summarise the findings:

- Reducing emissions can go hand-in-hand with reducing costs.
- Why buy N when you can fix it yourself? Reuse resources across the farm as much as possible.
- The benefits of well-designed crop rotation and taking care of your systems take time to realise, but it is worth it in the end.

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For more information regarding the study, email pieterswanepoel@sun.ac.za.