Nitrogen – know the system, do the numbers

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Could less intensive cropping programs improve growers' financial and environmental sustainability? Aspects of a CSIRO paper that draws together the multiple scientific and economic strands of decades of nitrogen-related research would seem to suggest the question is at least worth asking.

Aiming to optimise, rather than maximise, yields could open the way to environmental and economic sustainability for growers cropping soils with falling organic matter and nitrogen (N) levels and facing rising fertiliser N costs.

This is one of the messages from a GRDC-funded CSIRO study of nitrogen dynamics and their impact on productivity and profitability.

This comprehensive paper, which draws together the results of decades of Australian N-related research, says soil organic matter content of Australian cropping soils has fallen to 30-80% of comparable soils under native vegetation, with a consequent reduction in soil N reserves. Because N and carbon (C) are bound together in organic matter, lower levels of soil organic matter mean there is less N available to be mineralised into a form available to plants.

The team that undertook the study, prompted by the fact that N levels in Australian soils are declining under modern cereal-oilseed cropping rotations, was headed by CSIRO research scientist Dr Jeff Baldock.

The decline in soil N identified in the paper is an average position, with actual levels determined by factors including environmental conditions, soil characteristics and properties and management practices. This variability means growers need to track the effects of their farming practices on long-term soil productivity and N supply capacity by calculating the impact of their cropping program on soil N reserves each year, the authors say.

N measurement, and management, is complicated by the fact that N is 'tied up' in and released from the soil by the action of soil organisms.

The involvement of microorganisms in this biological process takes on extra importance given the weight placed by the authors on matching N supply to crop demand for the nutrient. Matching the supply of N to crop demand is critical to optimising nutrient use and profitability of grain production, they say, with soil N having a key role in achieving that.

PULSES LIKE THESE LENTILS AND FABA BEANS CAN GENERATE CASH FLOW AND CONTRIBUTE VALUABLE NITROGEN.

Since grain crops access N from the soil and any applied fertiliser N, maximising profits requires knowledge of the amount of N that can be supplied by the soil to ensure that optimum fertiliser application rates can be defined.

Soil-derived N is a limited resource that can make a significant contribution to the amount of N available to a crop, the authors say, and growers need to identify how much available N a soil can provide for a crop prior to and within the growing season to help optimise N fertiliser application rates.

As the capacity of a soil to deliver available N to crops declines, growers become more reliant on fertiliser N, with the potential for lower fertiliser N use efficiency and N loss increasing as fertiliser N rates increase.

Fertiliser N is more likely to be lost through volatilisation, leaching or denitrification than N released from soil reserves and this, combined with the cost of buying and applying fertiliser N, could make growing less, whether by targeting lower yields or changing to less intensive rotations, more profitable and sustainable in the longer term (>10 years) than targeting maximum yields every year.

Targets

Setting and achieving appropriate yield targets is key to profitable grain production, with provision of an appropriate supply of N and other nutrients as they are needed by the crop over the growing season required to optimise profitability, the authors say.

Yield of rain-fed grain crops is usually limited by moisture availability but can also be impacted by lack of N during the growing season, in which case the potential maximum water limited yields will not be achieved. Ironically, having too much N available early in the growing season can result in excessively vigorous vegetative growth that can exhaust soil moisture reserves and lead to crops 'haying-off' due to lack of moisture later in the growing season.

Crop N requirements are estimated using potential grain yield based on water availability (stored soil water at sowing plus growing-season rainfall) plus protein targets. To define an appropriate fertiliser rate that matches N supply with crop demand a grower has to know how much

N will be delivered from the soil. Lower soil N levels mean more fertiliser N will be needed to achieve water-limited yield potential – maximise grain yields, in practical terms – with the required rate of N fertiliser reducing as the N contribution from the soil increases. In simple terms, cereal and oilseed crops are more reliant on fertiliser N in soils with lower N supply capacities.

In many instances the economic optimum – the yield at which profit will be maximised – will be achieved with an N fertiliser rate less than that required to maximise yield, the authors say.

Applying too little fertiliser N will reduce profit due to the opportunity cost associated with forgone grain yield, while the cost of buying and applying excess fertiliser will reduce profit if too much fertiliser is used. The ideal is an application rate between those extremes that will optimise grower profit. This rate will almost always be different from one that will maximise yield.

The biological processes that release soil N from organic matter in the soil are controlled by the same environmental stimuli – temperatures and moisture – that drive plant growth, so N release from the soil during the growing season is generally in sync with a crop's need for the nutrient. This means N from organic matter decomposition is effectively 'metered out' over the growing season, leading to lower accumulations of available N in the soil, which reduces the risk of N loss from the system.

Achieving this synchronisation across a cropping program requires an understanding of crop demand over the growing season and how best to satisfy that demand; with estimation of how much and when N from the soil will be available being the starting point for deciding how much fertiliser N to apply.

Given that buying and applying fertilisers is 20-25% of the variable cost of dryland cereal and oilseed production in Australia – compared to 6-16% for pulses, which obtain a significant part of their N needs through rhizobial fixation of atmospheric N – being able to accurately predict and maintain the provision of N from soil will lead to more profitable grain production.

Failure to understand the amount of N available from the soil at different times throughout the growing season and changes in moisture availability across the season can lead to application of inappropriate rates of fertiliser N, resulting in sub-optimal yields and reduced profitability.

THERE IS NO DOUBT WHEAT CAN BE A PROFITABLE CROP, BUT THE COST OF AND POTENTIAL LOSSES FROM NITROGEN FERTILISER MEAN GROWING LESS BY TARGETING LOWER YIELDS OR WIDENING ROTATIONS COULD BE MORE PROFITABLE AND SUSTAINABLE THAN TARGETING MAXIMUM YIELDS EVERY YEAR.

N cycle

More than 95% of soil N is contained in insoluble organic matter including plant residues and soil microorganisms. However, plants can access N only when it is present in a soluble form: soluble organic nitrogen or ammonium and nitrate forms of inorganic N produced during decomposition and mineralisation processes that are controlled by moisture and soil temperature.

The microbes involved in decomposition of soil organic matter and mineralisation of insoluble organic N into plant-available forms also need N themselves and if the organic matter being broken down does not contain sufficient N to satisfy their requirements they will scavenge available N from the soil, which can lead to it becoming temporarily unavailable to the crop.

Such immobilisation typically occurs when crop residues with high C:N ratios, such as cereal stubbles, decompose in soil with little soil N.

Immobilised N is not lost from the soil system but is 'locked up' in the microbial population and can be mineralised back into a plant-available form later in the season or in following years.

Options

Growers can add N to their soils in one of three forms – as soluble inorganic N in fertilisers such as urea, di-ammonium phosphate (DAP) or mono-ammonium phosphate (MAP), organic N in additives such as manure and compost or biological N from growing grain or pasture legumes that support N-fixing rhizobial bacteria.

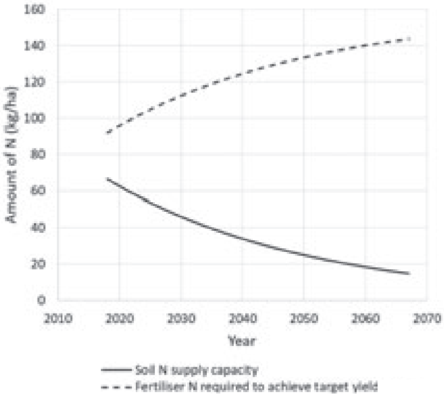
On the other side of the equation, N is removed from paddocks in harvested grain, hay or meat and can be lost through leaching of available N in large rainfall events, volatilisation of ammonia due to high soil pH or poor conditions after surface application of granular urea or denitrification of nitrate in soil that remains wet for prolonged periods.

The potential for N loss increases with the amount of available N in a soil , so matching the supply of available N to crop demand will reduce accumulation of available N and the potential for N loss

Management

Fertiliser N application rates are generally based on results of rate trials that have tended to identify the minimum amount of fertiliser N required to optimise annual profitability. However, soil N data suggest that this approach has resulted in grain growers effectively mining N from the soil.

While this can enhance annual profit,



CHANGE IN SOIL NITROGEN SUPPLY CAPACITY (SOLID LINE) AND FERTILISER NITROGEN REQUIREMENT (DASHED LINE) REQUIRED FOR 3T/HA WHEAT GRAIN YIELD WITH 11% PROTEIN.

decline of soil organic matter reserves and associated N levels diminish the ability of soil to supply the N required to meet crop demand. This increases the difference between the amount of N required by grain crops and the quantity that can be supplied; a gap growers aim to fill with fertiliser N.

A short period of negative N balance is acceptable provided it is followed by a rebuilding phase of regenerative practices such as stubble retention, grain and pasture legume production, green manuring, application of organic amendments and use of appropriate quantities of fertiliser N to enhance crop growth and increase the stock of soil organic N.

If soil N stocks are not replenished the gap between need and supply will increase, leading to an increasing dependence on fertilisers to achieve desired grain yield outcomes, the authors say. And since the efficiency of fertiliser N decreases with increasing rate due to the risk of available fertiliser N being lost through volatilisation, denitrification or leaching; having to increase fertiliser N application rates to compensate for a decreased ability of the soil to supply N is likely to reduce profitability.

In short, assuming other variable costs remain fixed, the economic optimum yield and profitability will decline as the ability of a soil to supply N decreases.

NITROGEN BASICS

Measuring and managing nitrogen (N) availability is challenging because of the strong interactions between the factors influencing the ability of a soil to mineralise organic N and make it available to crops.

However, a GRDC-funded CSIRO study of nitrogen dynamics provides a summary account of some basic facts about N biology that informs decision making about soil N management.

- The production and retention of available N increases, peaks and then declines with increasing soil water content, while mineralisation and the production of available N increase with increasing temperature. This suggests a measure such as 'microbially active degree days' may provide a better indication of environmental impacts on the delivery of available N from soil than some of the other metrics available, according to the authors of the report.
- The content and composition of organic matter as well as soil texture, soil depth and soil biology can all alter the amount of N mineralised, with the characteristics of the organic matter also likely to influence the rate at which soil N is made available to crops.
- Agricultural management practices influence nutrient mineralisation principally through their impact on the quantity, composition and handling of crop and pasture residues. The quantities of residue returned to or onto the soil vary substantially depending on crop species, soil type and environmental conditions, with the species having a strong impact on the composition of the residues.
- Initial nett immobilisation of N is likely where large inputs of cereal residues with low nutrient content are returned to the soil. However this is not permanent, with the immobilised nutrient becoming available later as decomposition resumes. Mineralisation of N is likely to be greater where legume residues are returned but the amount of N returned in grain legume residue declines as the harvest index of the grain legume increases.

Measure

One of the challenges for growers wanting to tackle soil N issues is how to measure what is happening in their soils and their balance sheets, and when to measure soil N levels.

The amount of N mineralisation that occurs between crops has typically been assessed by analysing soil cores prior to sowing, with levels of more than 200kg N/ha having been measured in pre-sowing cores. Summer soil N stocks are generally higher after canola, grain legumes and pastures than after cereals.

For the most useful measure of N availability sampling depth should be the effective rooting depth of the crop to be sown.

Plant and soil test data can be used in a variety of economic measures or indicators, each with its own 'best fit' applications. The researchers suggest growers, or their consultants, use two of these measures – partial nutrient balance (PNB) and nutrient balance intensity (NBI) – at farm or paddock scale to calculate their annual N balances each year.

Each paddock has different annual inputs, extractions and losses of N due to different management practices, soil properties and environmental conditions so it is important for growers to calculate nett N balances to track the impact of management practices on soil N stocks, the authors say.

A negative N balance, indicating the soil N resource is being mined, might indicate that long-term productivity and potential profit is being eroded to maximise short-term returns.

The results of these calculations should be integrated and accumulated year-on-year to account for crop rotations and variations in environmental conditions and yield. This will identify the full effect of applied management practices and trends over time and provide a reference for appropriate action to maintain the resource base and maximise profitable grain yield outcomes into the future.

Robert Norton, Regional Director of the International Plant Nutrition Institute, who used four or five years of data to calculate PNB and NBI across 514 paddocks on 125 farms in south-eastern Australia, found an average nett removal of N across those properties. It is considered likely the actual N losses are greater than Norton's 2016 figures indicate because he did not take account of losses due to leaching, ammonia volatilisation, denitrification or erosion.