NUTRIENT BALANCE IN REGIONAL FARMING SYSTEMS AND SOIL NUTRIENT STATUS

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Abstract

This paper reports major findings from a National Land and Water Resources Audit investigation, which was strongly supported by the Australian fertilizer industry and State and Commonwealth Government agencies. It provides *regional assessments* of farm gate nutrient balance (employing a simple budget model) for the six major plant nutrients (N, P, K, S, Ca and Mg) at Statistical Local Area (SLA) scale over 5 years. The model used did not assess impacts of nutrient recycling, nor nutrient losses by fixation, leaching, erosion or by gaseous processes. Broad assessments of soil fertility status in Australia's agricultural zone were also provided, together with four industry case studies on nutrient management.

Spatial and temporal trends are reported as a series of published maps and interpolated surfaces. Both positive and negative signals on nutrient management were discerned. These are discussed in relation to future directions for nutrient management in Australia. The more detailed industry case studies gave valuable insights into regional nutrient management issues and offered scope for improving nutrient use efficiency.

Introduction

Fertilizers and legumes have had a profound impact on the development of Australian agriculture, transforming and sustaining the productive capacity of our naturally infertile agricultural soils.

After an initial build-up phase (where the nutrients most limiting yield potential were progressively corrected), the requirement for continued soil fertility maintenance exists. In the maintenance phase, annual nutrient inputs are adjusted to meet nutrients lost through soil processes (such as leaching or immobilisation) and from nutrients exported through the farm gate in harvested products. The introduction of commercial soil testing during the 1970's enabled nutrient management decisions to move from broad district guidelines towards site-specific management.

Auditing nutrient balance in regional farming systems and assessing the current nutrient status of agricultural soils can be justified on both productivity and environmental grounds.

Through a partnership between the Audit, the Australian fertilizer industry, State and Commonwealth agencies, regional assessments of farm gate nutrient balance and contemporary soil fertility status were made and associated. These assessments provide new insights into how nutrients are being managed within Australia's agricultural zone and also indicated where improvements might be made in the future.

Key Findings

Trends in Soil testing

The use of soil testing by farmers increased markedly during the 1990's, and especially in eastern Australia. Soil testing in WA remained high and steady during the same period. This is a most positive signal, indicating that farmers are using modern tools as aids for making better nutrient management decisions.

Trends in Fertilizer Use

Consumption of N, P and K fertilizers in Australia have increased in recent years, with the growth in N use accelerating 2.5 fold during the 1990's. For the first time, consumption of N fertilizers now greatly exceeds P consumption. The reasons for this upsurge in N use, particularly in the cropping regions, is most likely associated with a range of factors, including:

- deterioration in the legume content of pastures in some areas,
- a growing awareness and promotion that rates of organic N mineralisation in agricultural soils were not meeting N demands of intensively cropped rotations or zero-tilled soils,
- increased plantings of N-fertilized canola crops,
- adoption of shorter-stemmed, higher yielding cereal varieties, less prone to lodging and "haying off",
- introduction of high analysis ammonium phosphate fertilizers from the 1970's and 1980's to cropping regions of southern Australia (replacing traditional superphosphate application) and increased use of urea in cropping regions, and
- declining protein levels in wheat (identified and widely promoted in 1989), and the introduction of premium prices for higher protein grades of wheat.

Legume N Fixation - a major contributor to N supply

Despite the upsurge in N fertilizer use, most southern Australian farming systems still relied substantially on legume N fixation to replenish soil N reserves after cropping cycles and to provide quality livestock feed. On land where legumes were grown, the average accretion of N through atmospheric fixation was estimated to vary from <5 to >300 kg N/ha/year, with areas >100kg N/ha being common. In some regions, especially in southern Australia, N fixation contributed over 60 per cent of the total N input to farming land.

In tropical and sub tropical regions, N accretion from legume fixation was mainly through grain legume crops and was correspondingly lower.

These N-enriched soil organic reserves need to be progressively decomposed by soil biota to release N for subsequent plant growth. However, in the more reliable and productive cropping regions, N demand may exceed N supply where land is intensively cropped, and greater reliance on N fertilizer results.

Factors affecting Fertilizer Decisions

During the course of this assessment, it was confirmed that land use and climate have a major impact on fertilizer use decisions in the agricultural regions of Australia. This confirms a widely held, but possibly intuitive view.

Firstly, trends in the levels of fertilizer nutrients used were consistently lower in more arid, low yielding environments of the cropping zone than in more reliable, higher yielding regions. Thus, in lower rainfall regions, conservative investments decisions on fertilizer use are made by farmers to match lower anticipated returns per hectare.

Secondly, adverse seasonal conditions experienced in the drought year, 1994, markedly depressed fertilizer use generally during this year *and* the next year. This was especially noticeable across the dryland cropping regions of Australia. In irrigated areas, less impact was evident.

Thirdly, sugar cane and horticultural production systems used substantially higher levels of fertilizer nutrients (kg nutrient/ha) than dryland crop and pasture systems. The use of fertilizers on pastures was now generally low in many cropping areas.

Soil Quality Assessments

Soil Acidity

An estimated 85 per cent of agricultural land in Australia has soil pH values within the range optimal for plant growth. However, soil acidity looms as a significant regional issue in all States: an estimated 13.6 million hectares of agricultural land were strongly acidic, having soil pH_{Ca} values below 4.8. These areas now require remedial treatment.

Soil organic matter (SOC)

SOC contributes critically to the chemical, physical and biological status of soil health, including the retention and cycling of soil nutrients. The organic carbon reserves in soils (which reflect soil organic matter content) were primarily determined by regional climatic conditions: as rainfall decreases and/or temperature increases, soil organic matter levels decrease. Nationally, 25% of the land assessed had organic carbon values less than 1% and 25% had values exceeding 2%.

Land management practices can modify soil reserves of organic matter: the reserves were lower in cropping zones (greater soil disturbance) than under permanent pastures and higher in irrigated soils. Very low levels exist in the drier Mallee soils of southern Australia, where conservation farming practices should continue to be promoted.

Assessments for Nutrient Exports

The quantity of nutrient exported annually in agricultural products varies with the nutrient, production levels per hectare and with nutrient concentrations in the product harvested. In general, the quantity of each nutrient exported annually from each SLA (kg/ha) was: N >>K > P and Ca > S > Mg. Some broad generalisations on the levels of nutrient exported include:

Lower nutrient exports occurred in the more arid cropping regions in most states; northern slopes of the Great Dividing Range (GDR) of Victoria; coastal and Tableland regions of NSW; the Central Highlands/Southern Midlands of Tasmania; and western parts of the Burdekin basin.

Highest nutrient exports occurred usually from dryland regions of higher productivity and from irrigated areas

Assessments of Nitrogen Balance

Fertilizer N was mainly used on crops, sugar cane and horticulture. Negligible N was applied to dryland pastures, but it was used on irrigated pastures. In the cropping zone, use of N appears to have increased, both in scale and level of application, but its use depends on seasonal rainfall conditions which encourage farmers to apply N to optimise yields and attain desired protein grades in wheat.

N balances mainly varied from neutral through to being moderately positive for both grazing and cropping systems of land use. Negative balances existed in Queensland, the Wimmera, Mallee and north west regions of Victoria (where low levels of N fertilizer were used) and the north west Slopes and Plains (NSW) and parts of SA. These regions often had low or moderate soil organic matter status. Positive balances existed in regions where dairying and horticulture are major forms of land use.

Phosphorus Status and Balance

Soil P status

Following a long history of P fertilizer applications, the P status of most of Australia's agricultural soils has been raised. Nevertheless, an estimated 1.4 million hectares of agricultural land still had very low surface soil P levels (<10mg/kg Colwell soil P). These areas tended to be mainly in the drier regions in each State, where lower input farming is practised, and were especially evident in SA.

An estimated 24.6 million hectares, located in all States, and comprising 28% of the land assessed, had soils of marginal P status (10 to 20mg/kg Colwell P). High values (>80mg/kg) existed on 3.2

million hectares, and these were mainly concentrated in Queensland, NSW and Victoria. These levels were often associated with intensive, irrigated agriculture, especially dairying and horticulture.

P Balance Estimates

In cropping regions, P applications appear now directed to the cropping phases of rotations, with many pastures relying on residual soil P reserves. Indeed, P fertilizer use on dryland pastures is now low (< 5kg P/ha), but was higher on irrigated pastures. In cropping regions with more reliable rainfall, higher P application levels were used compared with the more arid cropping regions.

Over large areas of the agricultural zone, P balance was estimated to be either neutral or slightly positive. Moderate to highly positive P balances existed in regions of Victoria and Tasmania, where dairying and horticulture are the main forms of land use. These regions also had mainly moderate to high soil P status.

Negative P balances existed in major regions of Queensland, the Wimmera and northern slopes of the GDR of Victoria and the Riverina and northern Slopes of NSW. In most of these regions, soil P status was assessed as marginal.

Potassium Status and Balance

Soil K Status

Most agricultural soils had adequate to high natural reserves of potassium (K), with inland soils tending to be higher than coastal soils. Soils potentially deficient in K (< 80 mg K/kg) existed mainly on sandier soils in all States (0.9 million hectares) and a further 7.7 million hectares were assessed as having marginal K status (80 to 120 mg K/kg).

K Balance Estimates

K fertilizer consumption has continued to increase from a low base, but its use is mainly confined to areas where dairying, horticulture and sugar cane are the major forms of land use.

Negligible K fertilizer is applied to dryland crops, except in WA where recent research identified K deficiency as a major limitation to crop and pasture yield and grain quality. In these regions of WA, K balance changed from being negative to neutral or slightly positive as farmers began to apply K fertilizers.

In Queensland and WA, K fertilizer use appeared to be applied to soils of low K status, but in south eastern Australia was used to maintain the moderate K status of soils.

In regions where no K was applied, K balances varied from being moderately to highly negative, but in most of these regions adequate K reserves existed in surface soils.

Neutral K balances were confined to coastal regions of NSW, the Burdekin basin and more arid cropping regions of NSW and southern Queensland.

Sulfur Status and Balance

Soil S Status

Areas of potentially low S soils may occur in SA and NSW, but in these areas substantial S reserves may also exist in the subsoil following past applications of S in superphosphates or gypsum. A surface soil S value of < 5 mg S/kg may be indicative of S deficiency. In regions where fertilizers of low S content have replaced the traditional applications of superphosphate (which contains 10% S) the residual value of soil S should be further examined. Large areas of agricultural land had extractable soil S values between 5 and 10 mg S/kg. More than 50 percent of the area assessed had values > 10mg S/kg.

S Balance Estimate

The balances for S produced for 1995/96 varied from being neutral to highly positive, except for significant areas in Queensland where negative balances existed. These balances probably relate to the use of superphosphates and gypsum in many regions of Australia and to low usage in some Queensland regions. Regions with neutral S balance sometimes occurred on soils of low or marginal S status. Highly positive balances were usually recorded in dairy and horticultural regions, which also had reasonably high soil S status.

Soil Ca Status and Balance

Soil Ca status (eastern Australia)

Agricultural surface soils in eastern Australia appear well endowed with Ca reserves, although some potentially low values existed along coastal regions of Queensland. The current reserves of Ca (and Mg) in agricultural soils of WA are unknown and needs to be assessed.

Ca Balance Estimates

In 1995/96, Ca balances varied from neutral through to highly positive across southern Australia, which again can be linked to the regular use of superphosphate and soil conditioners. Negative Ca balances existed in significant parts of south eastern and central Queensland, but in these regions the Ca status of surface soils is high.

Soil Mg Status and Balance

Soil Mg Status

Surface soils in eastern Australia's agricultural regions appear well endowed with Mg reserves, although levels were lower than those determined for Ca. Some potentially low values may exist along coastal regions of Queensland. The current reserves of Mg in agricultural soils of WA need to be evaluated.

Mg Balance Estimates

Mg fertilizer use was mainly confined to horticultural enterprises and some dairy areas. Negligible or very low use occurred elsewhere.

Mg Balances were mainly either negative or neutral. Negative balances were especially noticeable in Queensland, the Riverina and south west Slopes of NSW and parts of SA. These areas are highly productive regions, where negligible Mg fertilizer was applied, but adequate reserves of Mg exist in surface soils. Again, positive balances existed in dairy and horticultural regions of Victoria, Tasmania and NSW.

Industry Case Studies on Partial Nutrient Balance

A detailed study of N and P fluxes in a plant and ratoon banana crops grown in northern Queensland under irrigation showed a positive N balance (*with substantial gaseous and leaching losses of applied N*) and a positive P balance in the plant crop and a small negative P balance in the subsequent ratoon crop. New industry guidelines for managing N and P inputs are now being promoted actively within the industry.

Markedly negative partial balances for N, K and Mg were determined for two cropping rotations commonly used in the inland Burnett region of Queensland. Ca balances were positive. The depletion of K and Mg was exacerbated by the removal of peanut stubble as hay and by increased frequency of growing high yielding grain legume crops. Soil testing was recommended for improving fertilizer decisions in this region.

In a single year assessment of nutrient balance in the southern NSW rice growing region, industry data were used to show negative N, P and K balances occurred, but S, Ca and Mg balances were positive. For N, P and K the balances became substantially more negative where rice stubbles were burnt, which remains standard industry practice.

Using published data and industry statistics for the Gippsland dairy region of Victoria, partial nutrient balances for N, P and K were estimated to be positive for a "typical" dairy farm. This study confirmed the findings presented for this region of Victoria. It also demonstrated that appreciable quantities of these nutrients are fed as supplementary feeds and are voided as excreta in laneways and dairy sheds.

Directions for Balanced Nutrient Management in Agriculture

Over much of the Australian agricultural zone, nutrient management has moved beyond the soil fertility "build up" phase into the nutrient "maintenance" phase. Regular applications of superphosphate in the past, especially in southern Australia, have improved the P, S (and Ca) status of agricultural lands from their naturally infertile state. Nevertheless, attention now needs to focus on those regions where low or marginal soil nutrient status (eg. soil P and K) and highly negative balances were broadly identified.

N fertilizer applications to crops are now increasing (still augmented by large contributions from legume N fixation). Continuation of recent trends in N fertilizer use must be balanced against increased risks of soil acidification and the potential loss of soil cations leached with nitrate. Soil acidification remains a serious threat in some regions of all states and is part of achieving balanced plant nutrition.

Estimated farm gate nutrient balance for N, P, S, and Ca were predominately neutral or moderately positive. These findings are positive ones, but take no account of off-site losses of nutrients (which could turn positive balances into negative balances). Indeed, the four industry /regional case studies indicated that improvements in nutrient use efficiency are still required in two key areas:

- Quantification of losses of specific nutrients by soil processes (e.g. Case studies 1, 2, 4 and 5); variable and often high removal of nutrients in harvested crops and stubbles (Case studies I, 2, 3 and 4); and the development of farming practices that optimise nutrient use efficiency (Case study 1). The key issue here is to identify the regions and industries most at risk to nutrient loss and to devise practical measures to minimise future risks.
- The need for defensible decision support systems on nutrient management remains a priority, in order that optimal fertilizer use is achieved on farms. These should include estimates of nutrient loss, either by soil fixation, leaching or by overland flow in intensive farming systems (Moody *et al* 1996;Nash and Murdock 1997; Anderson *et al* 1998; Fleming and Cox 1998; Ridley *et al* 2001). There is a definite need to identify areas at risk to off-farm leakage of nutrients.

In Queensland and other regions such as the Wimmera and Riverina, negative nutrient balances need further regional analysis and interpretation. This type of balance, if estimated consistently, infers that soil nutrient reserves are being depleted by current practices. In the longer term, such balances may not be sustainable even though in the short term the soils may have adequate or high nutrient reserves.

Temporal trends in K balances recorded in WA, demonstrated benefits which accrue from detailed regional research and subsequent extension to farmers: again another positive outcome from the past decade. This type of research and the approaches of the detailed case study should be encouraged in the future.

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