Nitrogen fertiliser use efficiency in ryegrass (*Lolium perenne* L.) seed crops

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Increasing rates of nitrogen (N) fertiliser are being used by ryegrass seed growers even though the debate over optimum N fertiliser application rates and timings continues. Over or under estimations of fertiliser N requirements potentially decrease economic returns for the grower and/or increase health and environmental concerns for the wider community. Sustainable N fertiliser application is achieved when productivity, security, protection, economic viability and acceptance objectives are all achieved and these are largely determined by N fertiliser use efficiency. This research project was established to examine the sustainability of N fertiliser use when applied at several rates during autumn, winter and/or spring. The use of monolith lysimeters and 15N-labelled fertiliser allowed fertiliser N to be traced within the air, crop, soil and leachates.

Twenty four monolith lysimeters (500 mm diameter, 700 mm long) of a deep-profiled Templeton silt loam on a sandy loam (Udic Ustochrept, USDA), were extracted from a 7 year old pasture in March 1996 and 1997 on Lincoln University farm land, Canterbury, New Zealand. The pasture was sprayed with glyphosate at recommended rates, and remaining pasture was cut to soil surface and removed. Lysimeters were hand cultivated and the equivalent of 150 kg/ha of superphosphate fertiliser was applied to match normal farmer practices. The lysimeters were sown with perennial ryegrass (*Lolium perenne* L.) cv. Grasslands Nui in three rows, 150 mm apart, on the 26 April 1996 and 28 April 1997 at a rate equivalent to 10 kg seed/ha in accordance with general practice for a grass seed crop. Fungicide was applied prophylactically to control fungal diseases; weeds were controlled by hand. Application timings of granular urea N were: (1) 4 weeks after sowing when soil temperature at 9 am at 100 mm depth was above 8°C (autumn), (2) when soil temperature at 9 am at 100 mm depth rose above 4.5°C (winter), and (3) when soil temperature at 9 am at 100 mm depth rose to approximately 8°C (spring). Application rates in 1996 were 0 (control), 150, 200 or 250 kg N/ha. These were increased in 1997 (0, 200, 250, 300 or 350 kg N/ha). Soil moisture status was monitored using permanent tensiometers and irrigation was applied to maintain soil moisture between 70 and 90% of field capacity. Seed harvest (December, 1996 and 1997) was followed by destructive sampling of the soil (January, 1997 and 1998) and the subsequent tracing of 15N fertiliser. The effects of thousand seed weight (TSW) and N concentration on the vigour of the seed harvested from the lysimeters during the 1996 and 1997 seasons was measured by seedling emergence from soil at autumn (10°C) and winter (5°C) temperatures, seedling weight, accelerated ageing at different temperatures (40-43°C) and bulk electroconductivity.

On average, volatilisation and denitrification losses from winter applied N fertiliser (9%) were considerably lower than that from N fertiliser applied during autumn (15%) or spring (19%) because of conditions which encouraged denitrification during autumn and volatilisation during spring. The results of this research indicated that, under field conditions, urea N application rate largely determines volatilisation losses, but that volatilisation losses may be significantly ($P<0.05$) reduced by smaller more frequent applications, as a critical threshold pH was not reached. Seasonal and yearly changes in soil conditions largely determined denitrification losses of applied fertiliser N.

15N-labelled urea applied during winter and spring was not found in leachates during 1996 or 1997. The addition of autumn N fertiliser did not significantly increase nitrate leaching as 15N-labelled urea losses were small (3.9 and 4.3 kg N/ha) during 1996 and 1997. Soil derived N contributed 78 and 88% (1996 and 1997, respectively) of the nitrate leached beneath autumn

fertilised lysimeters, but more soil derived N was leached below autumn fertilised lysimeters (26 and 30% more in 1996 and 1997, respectively) as compared with unfertilised lysimeters. During late winter in 1996 and 1997, leachate nitrate concentrations from autumn fertilised and unfertilised lysimeters exceeded World Health Organisation (WHO) limits for drinking water. The application of autumn applied N fertiliser contributed both directly (15N) and indirectly (increased soil derived N mineralisation) to leaching losses which has importance in the overall environmental impact of a ryegrass seed production system.

Seed yield (308.5 g/m^2 in 1996 and 451.4 g/m^2 in 1997) and seed quality (thousand seed weight, seed N content, germination, seedling weight) were maximised when N fertiliser use efficiency (apparent N recovery (ANR), yield efficiency) was maximised by applying fertiliser in autumn (50 kg N/ha), winter (50 or 100 kg N/ha) and spring (150 kg N/ha). Further increases in spring N fertiliser stimulated vegetative growth, but not seed yield. Results suggest that the combined effect of the N fertiliser timings and zero water stress increased seed yields by decreasing seed abortion (floret site utilisation in unfertilised plots was 25%, floret site utilisation in N fertilised plots was 37%).

Recovery of winter (40%) and spring (43%) applied 15N-labelled fertiliser in the crop at seed harvest was much higher than autumn (18%) applied 15N-labelled fertiliser in 1996 and 1997. Recovery in the roots and soil of 15N-labelled fertiliser applied in winter (52%) and autumn (59%) was higher than N fertiliser applied in spring (37%).

Risk : benefit analysis indicated that autumn N fertiliser, and application rates in spring above 150 kg N/ha, were associated with a high risk of loss and small benefits in seed and herbage N recovery. Winter N fertiliser, and spring applications up to 150 kg N/ha, had substantial benefits with much lower risk.

Gross margin analysis indicated that ryegrass seed production was unsustainable without N fertiliser application as income from seed yields and hay did not cover costs. Increases in gross margins were largely dependent on N fertiliser application rate ($r^2 = 0.92$) and the effect of N fertiliser on seed yields ($r^2 = 0.99$), as seed is the major form of income in herbage seed production.

Ryegrass seed lots differed significantly ($P<0.05$) in emergence at autumn (10°C) and winter (5°C) temperatures; these vigour differences were significantly ($r^2 > 0.90$) related to laboratory techniques such as accelerated ageing and seedling dry weight. Seed lot electroconductivity was less sensitive and reflected only large vigour differences between harvest years. Seed lot N concentration, thousand seed weight and age had significant ($P<0.001$) effects on seed vigour while N concentration had more influence on seed vigour than thousand seed weight.

Smaller lysimeters (180 mm diameter, 300 mm long) were extracted from the large lysimeters during destructive sampling in 1997. This was done to monitor the fate of residual 15N and the effect of previous N fertiliser application on subsequent leaching losses and pasture production during a nine month period after seed harvest. Residual fertiliser (16 to 55 kg N/ha) leaching losses (<0.5 kg N/ha) and pasture uptake (0.6 to 4 kg N/ha) were largely restricted by the immobilisation of 15N into soil organic pools and by the expanding root mass. Root mass, soil mineral N and soil microbial biomass N were significantly ($P<0.05$) greater in fertilised treatments than unfertilised treatments at pasture harvest; clay fixed N, anaerobically mineralisable N and total N were not affected. In the short term, N mineralisation rates were increased by previous fertiliser application but there is little evidence of a longer term effect on N mineralisation rates.

Applications of N fertiliser in autumn, combined with winter and spring, maximised productivity, N recovery (ANR), N and water yield efficiency, and economic returns. However, autumn N fertiliser was associated with low crop recovery (15N) and high N losses (both leaching and gaseous losses which are associated with adverse environmental impacts); winter and spring N applications provide less risk to the environment with greater benefit in yield.

Additional key words: *nitrogen use efficiency (NUE), sustainability, ^{15}N-labelled fertiliser (15N), seed yields, nitrogen losses, fertiliser fate, seed vigour, residual fertiliser.*