NITROGEN DYNAMICS IN LEGUME BASED ROTATIONS

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Abstract:

There is increasing interest in legume based cropping systems as an alternative to systems based on nitrogen fertiliser inputs. Systems comprising a grazed, legume based ley followed by a period of arable cropping are common. However, as grass-legume leys provide no economic return from a system without livestock, there is increasing interest in stockless systems which rely on grain legumes and alternative management of forage legumes such as undersowing or companion cropping. Using data from a long-term organic rotation trial in the North-East of Scotland, nitrogen flows in stocked and stockless rotations have been assessed using the NDICEA model. The initial predictions suggest that the stockless and the stocked systems are likely to lead to a reduction in the soil organic matter. The stocked systems have higher estimated leaching and dentrifications losses. However, the assumptions made regarding the amount of green manure that is returned to the system and the nitrogen fixation rates for the legumes are crucial in determining the overall sustainability of the system. In addition, the actual losses from the system will also be affected by the actual weather conditions experienced by each crop.

Introduction:

The inclusion of legumes within crop rotations provides an alternative to nitrogen fertiliser inputs and the high energy costs and greenhouse gas emissions (GHG) associated with their manufacture. In some circumstances, legumes may also contribute to lower nitrogen losses and GHG emissions in the field, although further research is required to quantify the magnitude of these benefits. However, in arable cropping systems that are reliant on legumes for the supply of nitrogen, the management of the soil fertility and the nitrogen supply is vitally important (Stockdale *et al*., 2001). This is because the nitrogen mineralised can exceed the needs of the following crop (e.g. Eriksen *et al*., 1999) or be released out of synchrony with crop demand (Berry *et al*., 2003), which can result in losses to the environment (Ball *et al*., 2007). In North-West Europe crop rotations comprising a grazed legume based ley followed by a period of arable cropping are common. Nevertheless, stockless rotations based on legumes are of increasing interest given the rising price of fertiliser nitrogen. However, as grass-legume leys provide no economic return in a system without livestock, stockless systems will necessarily rely more on grain legumes and alternative management of forage legumes such as undersowing or companion cropping. In this paper we compare nitrogen flows in stocked and stockless organic rotations using the NDICEA (Nitrogen Dynamics in Crop rotations in Ecological Agriculture) model developed for ecological agriculture (van der Burgt *et al.,* 2006).

Keywords:

Legumes, organic, stocked rotation, stockless rotation, N use

Materials and methods:

The data used is from the long-term organic crop rotations trials at SAC at Aberdeen (57° 10.5' N, 2° 15.7' W; 125 m asl) in North-East Scotland. The average rainfall is 820mm and the soil type is a sandy loam of Countesswells association, Dess series (Glentworth and Muir, 1963). This trial originally compared two contrasting stocked ley-arable rotations (Taylor *et al*., 2006). However, in 2007 one of the rotations was converted to a stockless system. The six-course stocked rotation consists of three years of a grass-white clover sward which is followed by spring oats, swedes and spring oats which are undersown with grass-white clover. The manure applications are based on a stocking density of 1.7 livestock units ha^{-1}. The six-course stockless rotation consists of spring beans then spring barley, which are undersown with white clover, followed by spring oats which is undersown with a grass red clover mixture. This green manure (GM) is cut and mulched up to six times during the subsequent season. The GM is followed by either spring wheat, which is undersown with white clover, and then potatoes, or potatoes followed by the undersown spring wheat. There were two replicates of each rotation, and all phases of the rotation occurred in each year. Plots are approximately 30m x 15m in area. Sowing took place using calibrated seed drills / planting equipment at sowing densities and timing typical for each crop in the region.

The nitrogen flows of the two stockless rotations and the stocked rotation have been assessed using NDICEA model version 5.5.1. The model simulates the dynamics of water, nitrogen in the organic matter and inorganic nitrogen, and it has been used extensively in Europe to assess organic fertilization strategies of organic systems (Koopmans and Bokhorst, 2002; van der Burgt, 2004; van der Burgt *et al.*, 2006). The inputs to the model are average weekly temperature, total weekly rainfall and total weekly evapotranspiration, which is calculated according to Makking (1957). Requested crop management data are restricted to planting and harvesting dates, and to the quantities, timings and mineral content of the manure and fertilizer applications. In addition, the yields of the crops are also entered and thus the model is target-orientated. There is no feedback between the resource requirements and the yield. As a consequence of this, the user must ensure there is an adequate nitrogen supply**.** The nitrogen budget has been calculated six times for each rotation, using each phase of the rotation as a starting point. In this scenario, the weather data for 2007 has been used to represent the climate.

Results and discussion:

The stockless rotations have appreciably less nitrogen input than the stocked rotation, Table 1. This was because the model estimated that levels of nitrogen fixation were less for the stockless than stocked systems. In addition, the stocked rotation also had additions of farm yard manure (FYM). However, the nitrogen actually removed by the crop is also slightly higher for the stockless system than the stocked system and therefore the predicted leaching and denitrification losses are also much lower. The model predictions suggest that there will be a decline of nitrogen in the organic matter in the soil over the course of the rotation for the stockless and stocked.

The denitrifcation and leaching losses are lower for the stockless rotations than the stocked rotation, Table 1 and as illustrated for one plot of the stockless rotation in Figures 1 and 2. With the exception of oats following the grass crop for the stocked rotation, the denitrification losses tend to be less than 25 kg N ha^{-1}, Figure 2. The leaching losses tend to be higher across all phases of the stocked rotation. The greatest losses for the stocked are predicted when the ground is bare over the winter period (Figure 1). In contrast, the greatest losses fro the stockless are predicted during the spring wheat crop following the grass-clover crop. This is probably because the spring wheat is not fully utilising the nitrogen released from the mulching of the grass-red clover crop. However, for the oat crop following the grass crop for the stocked rotation, the denitrification and leaching losses may be an overestimate as there is a tendency weed growth, which will utilise some of the nitrogen in the soil, during the period from the oats being harvested and the swedes being planted. In addition, the actual leaching and denitrification losses that occur will be highly dependent on the weather conditions during the growing season and the fallow period.

Table 1. The average annual nitrogen budget for the stocked and stockless rotations

	Stocked	**Stockless**	
		Cereal[1]	**Potatoes**[2]
	Kg N ha^{-1} yr^{-1}	**Kg N ha^{-1} yr^{-1}**	**Kg N ha^{-1} yr^{-1}**
Supply with FYM	39.00	0.00	0.00
Nitrogen fixation	96.83	77.83	80.83
Deposition	12.00	12.00	12.00
Total supply	148.17	89.83	92.83
Removal with produce	65.33	73.00	73.00
Calculated remains	82.83	17.17	20.00
Denitrification	15.83	7.50	7.33
Leaching	89.50	41.67	44.83
Accumulation org. matter	-26.38	-31.45	-31.50

[1] The spring wheat follows the grass – red clover crop; [2] The potatoes follows the grass – red clover crop

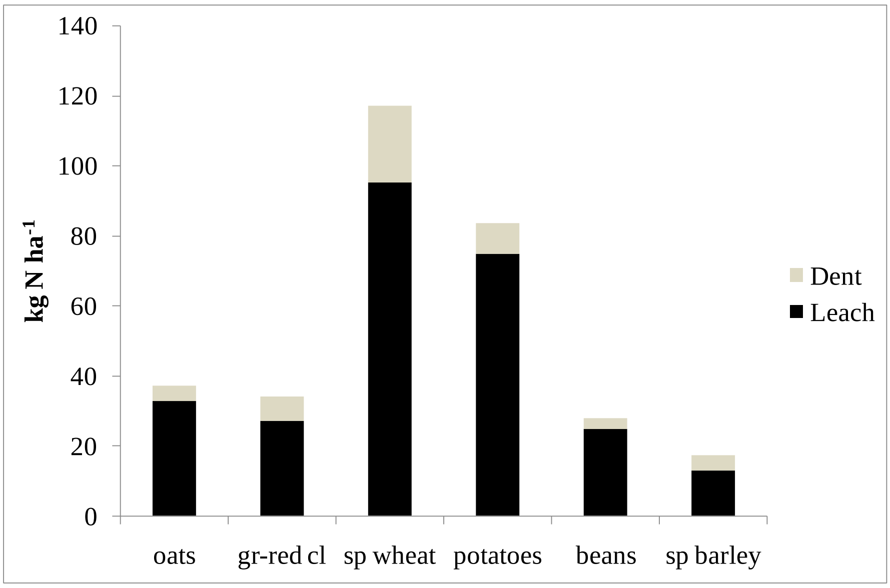

Figure 1. The nitrogen leaching and denitrification losses for each phase of the stockless rotation.

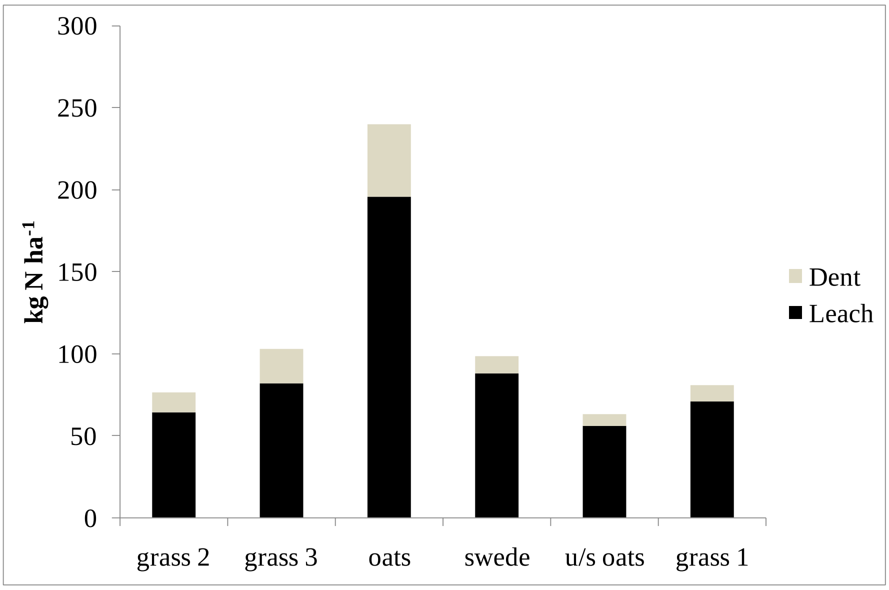

Figure 2. The nitrogen leaching and denitrification losses for each phase of the stockless rotation. (u/s oats = undersown oats)

The model predictions suggest that there is little impact on the sustainability of the rotation as a whole between spring wheat or potatoes following the grass-red clover crop. However, depending on which crop is used as the starting phase of the rotation, there are marginal differences in the differences in the nitrogen fixation, and hence the supply of nitrogen, and the changes in the nitrogen in the organic matter. However, the annual variability in weather conditions will clearly have an impact on the overall sustainability of the stockless rotations as a wet autumn following the potato crop will results in increased leaching compared to planting an undersown spring wheat white clover crop.

However, the results and hence the sustainability of the stockless systems is largely dependent on the assumptions that are made in terms of the amount of and the availability of the nitrogen in the green manure that is added back during the rotation. In addition, the ability of the undersown white clover crops to fix nitrogen throughout the rotation will also impact on the sustainability of the system. With regards to the stocked system, the factors that have the largest impact on the sustainability of the system are the nitrogen fixation, and the actual yield during the periods that the sward is grazed by sheep.

Future work will explore the impact of varying the assumptions in terms of green manure, nitrogen fixation, and the management of the cereal straw. The impact of the variability in climatic conditions on the systems will also be assessed.

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References:

Ball, B.C., Watson, C.A., and Crichton, I., 2007: Nitrous oxide emissions, cereal growth, N recovery and soil nitrogen status after ploughing organically managed grass/clover swards. Soil Use Management 23, 145-155.

Berry, P.M., Stockdale, E.A., Sylvester-Bradley, R., Philipps, L., Smith, K.A., Lord, E.I.,Watson, C.A., Fortune, S., 2003: N, P and K budgets for crop rotations on nine organic farms in the UK. Soil Use Management 19, 112-118.

Eriksen, J, Askegaard, M., Kristensen, K., 1999: Nitrate leaching in an organic / dairy rotation as affected by organic manure type, livestock density and crop. Soil Use and Management 15, 176-182.

Glentworth, R., Muir, J.W., 1963: The soils round Aberdeen, Inverurie and Fraserburgh. HMSO, Edinburgh.

Koopmans, C.J., Bokhorst, J., 2002: Nitrogen mineralization in organic farming systems: attest of the NDICEA model. Agronomie 22, 855-862.

Makking, G.F., 1957: Testing the Penman formula by means of lysimeters. Journal of International Water Engineering 11, 277-288

Stockdale, E.A., Lampkin, N.H., Hovi, M., Keatinge, R., Lennartsoon, E.K.M., MacDonald, D.W., Padel, S., Tattersall, F.H., Wolfe, M.S., Watson, C.A., 2001: Agronomic and environmental implications of organic farming systems. Advances in Agronomy 70, 261-237.

Taylor, B.R., Younie, D, Matheson, S., Coutts, M., Mayer, C., Watson, C.A., Walker, R.L., 2006: Output and sustainability of organic ley/arable crop rotations at two sites in northern Scotland. Journal of Agricultural Science 144, 435-447.

Van der Burgt, G.J.H.M., 2004: Use of the NDICEA model in analyzing nitrogen efficiency. In: Hatch D.J. et al., (eds) Controling nitrogen flows and losses. Proc 12th Nitrogen Workshop. Wageningen Academic Publishers, Wageningen, pp242-243.

Van der Burgt, G.J.H.M., Oomen, G.J.M., Habets, A.S.J., Rossing, W.A.H., 2006: The NDICEA model, a tool to improve nitrogen use efficiency in cropping systems. Nutrient Cycling in Agroecosystems, 74, 275-294.