An environmental and economic assessment on the impact of possible reductions in the maximum chemical nitrogen allowances for main arable crops.

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Executive Summary

Nitrogen rate recommendations for arable crops are based on an economic optimum (N_{opt}) above which further yield increases do not cover the cost of the additional fertilizer, they are therefore, below the rate to achieve maximum yield. Research also shows that the residual nitrate-N at harvest of a crop remains relatively stable until applications exceed N_{opt}, and then increase steadily as additional fertilizer N is applied. Reducing recommended N rates for arable crops is therefore unlikely to provide any environmental benefit but risks reduced yield and profitability in a farming system with already tight margins.

Arable systems are at risk of N leaching in the autumn and winter due to the mineralization of organic N residues when there is no crop to take up the nitrogen. Establishment and maintenance of over winter green cover is therefore the key action in arable systems to reduce the risk of over winter N leaching. The date of establishment of the green cover is critical to minimizing N loss with earlier established covers maximizing growth and N uptake, and generally is more important than the type of cover or the method of establishment. In addition to the establishment of green cover the level of organic N present in the soil in autumn is important and autumn application of low C:N ratio manures can increase the risk of N loss unless a high N uptake crop such as early sown oilseed rape is established.

Agronomic Impact

Determining Crop Specific Optimum Nitrogen Application Rates

The response of cereal crops to fertiliser N is curvilinear in nature (usually referred to as an N response curve) whereby there is a large response in grain yield to low levels of N input and as N rates increase the marginal increase in grain yield decreases until eventually an additional increment of N gives no increase in yield (Figure 1). At this N rate (N_{max}) the maximum yield is said to have been reached, above this rate yield is likely to decrease particularly if lodging becomes an issue. Fertiliser nitrogen advice for cereals in Ireland is based on maximising the economic return on investment in fertiliser N rather than maximising yield and, given that there is always a cost associated with fertiliser N, the N rate that maximises the economic return, the economic optimum N rate will always be lower than the rate which maximises yield. This is because for N rates at or close to the rate that gives maximum yield the cost of each 1 kg N is greater than the value of the additional grain yield achieved. The economic optimum N rate (N_{opt}) is the N rate where the additional cost of a 1 kg N/ha increment is equal to the value of the additional grain yield achieved with that 1 kg N/ha. Typically between 5 and 10 kg grain will be required to pay for 1 kg N depending on grain and fertiliser prices and the N_{opt} will be located at the point on the curve where 1 kg of N gives an increase in yield equal in value to the cost of that 1 kg N. This point will typically be 20-50 kg N/ha below the rate that would give the maximum yield depending on the shape of the response curve and the relative prices of grain and N.

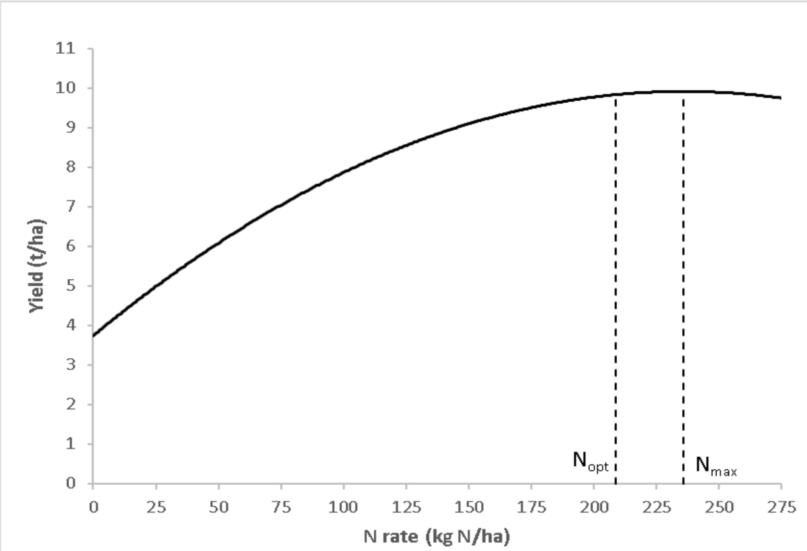


Figure 1. Effect of rate of fertiliser N on grain yield of winter barley. The economic optimum N rate (N_{opt}) and the rate giving maximum yield (N_{max}) are shown.

There is very limited published research in relation to the impact of N fertilizer rate on cereal crops and subsequent water quality, the work of Chaney (1990) which is generally accepted as the best in a north western European context indicates that residual nitrate-N in the soil at harvest changes little for increasing rates of N until N_{opt} is exceeded (Figure 2). There has been no similar work completed in as much detail in Ireland, however, Hooker *et al* (2005) reported a study which compared soil mineral N concentrations under spring barley and winter wheat over 2 years grown with normal and reduced N rates (20% less). The low N fertiliser input treatments in both crops tended to have higher soil water N concentrations than the high input treatments and was significantly higher ($p<0.05$) for winter wheat in the first year.

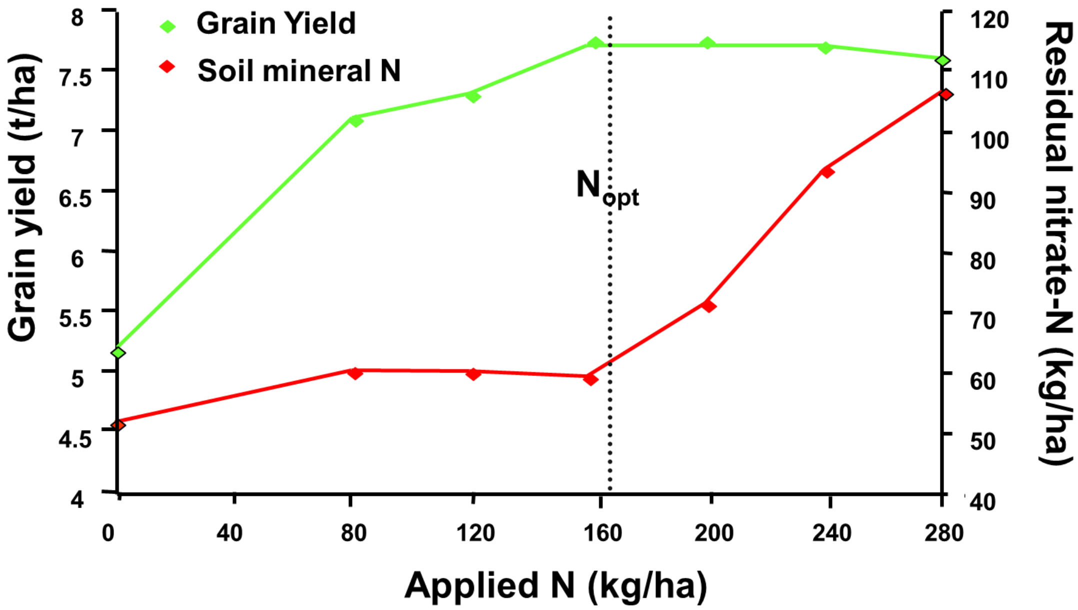


Figure 2. Effect of applied fertiliser N on grain yield and residual nitrate-N in the soil to 90cm depth at harvest of a winter wheat crop (Chaney, 1990).

Fertiliser N rates given in Table 16 of SI 113 of 2022 are for cereal grain yields that are lower than the national average yield as indicated by the CSO and much lower than yields achieved by the best growers in good years e.g. yields of 8.5 t/ha of spring barley and 11 t/ha of winter wheat are common in good years. Being able to achieve such yields with the N rates given in Table 16 of SI 113 of 2022 on a consistent basis with current varieties is unlikely. Therefore the additional N allowance where high yields are being achieved, provided for in the footnotes of Table 16, is critical to maintain productivity of cereal crops in Ireland. As this additional allowance is only applicable where higher yields have been demonstrated by a grower, applications of quantities of N in excess of crop requirements on lower yielding farms is avoided under the regulations. In addition the grain yield potential of crops increases over time as a result of the introduction of new varieties with higher yield potential. This higher yield potential of crops will usually require additional fertiliser N to support the additional yield and the yield-based adjustments allowed under the regulations allow this additional yield potential to be exploited. It should be noted that this relationship between yield and N_{opt} is the reason that the point of infection of the residual nitrate line in Fig. 2 is lower than the current recommendation in Ireland, where wheat yield would be expected to be 2.5 -3.5 t/ha higher than achieved in the 1980's when that research was carried out.

Growers can use the best yield in the previous three years as evidence of higher yield to justify additional N allowance. This restriction does cause an issue for new growers of a crop as they do not have historic yields to demonstrate higher yields and therefore may be restricted from achieving the yield potential of their farm. There is also the potential for three low yielding years to occur in a sequence where growers who have previously demonstrated higher yields have been unable to attain those yields as a result of natural processes. In this situation growers are unable to use the higher rates of N even though they have demonstrated that they can achieve higher yields when seasonal attributes allow. Using sub-optimal N rates can also cause low grain protein which is an issue if growing for a premium market such as malting barley where rejection can occur for low protein.

Economic Impact

Changing from optimum nitrogen rates for tillage crops

The tillage sector operates on tight profit margins. Table 1 presents net margins from the National Farm Survey over the past five years, showing an average net margin of €250/ha for winter wheat and €46/ha for spring barley, respectively. The primary costs associated with cereal production include fertiliser, machinery, and land rental. Fertilisers alone can account for 30–40% of total production costs. Given this significant expense, tillage farmers use fertilisers judiciously, striving to minimise waste at every stage of the process.

Table 1. Net Margins for Winter Wheat and Spring Barley determined by the National Farm Survey

	Net Margin €/ha					
	2019	**2020**	**2021**	**2022**	**2023**	**Average**
Winter Wheat	€82	€82	€442	€891	-€245	€250
Spring Barley	-€163	-€75	€328	€501	-€360	€46
Source: Teagasc National Farm Survey						

Increasing N use above the optimum recommended rates on tillage crops (Wall and Plunkett, 2020) leads to higher costs that are not offset by additional yield. This increased N use will result in no extra margin for the grower and can be further is exacerbated if higher N rates induce lodging and crop losses. Conversely, reducing N use below the optimum recommended rates lowers costs but also reduces yield, leading to lower overall margins.

It is difficult to estimate the average economic impact of reducing N rates from the economic optimum due to variability in the shape of individual N response curves across different sites i.e. crops grown in different soil and weather contexts. Figure 3 shows N response for 3 wheat varieties over 2 years in Oak Park. In the first year (2015) the calculated N_{opt} was above the maximum rate applied in the experiment and estimated as >300 kg N/ha, In the second year (2016) the N_{opt} was estimated as 280 kg N/ha. In both cases the recommended N rate would have been 250 kg N/ha. In 2015 the maximum yield was 12.7 t/ha at 300 kg N/ha, applying the recommended rate reduced the yield to 12.0 t/ha and reducing the recommended N rate by a further 10% to 225 kg N/ha would have reduced yield to 11.5 t/ha. In 2016 the maximum yield of 11.8 t/ha occurred at 300 kg N/ha, the yield at the economic optimum was lower at 11.6 t/ha and the yield at the recommended rate was 11.4 t/ha. Reducing the recommended N rate would have reduced yield further to 11.1 t/ha. The yield loss from a 10% reduction in the recommended N rate therefore varied from 0.5 t/ha in 2015 to 0.3 t/ha in 2016. In situations where there is another factor limiting yield, the yield loss from a 10% reduction in recommended N rate could be minimal.

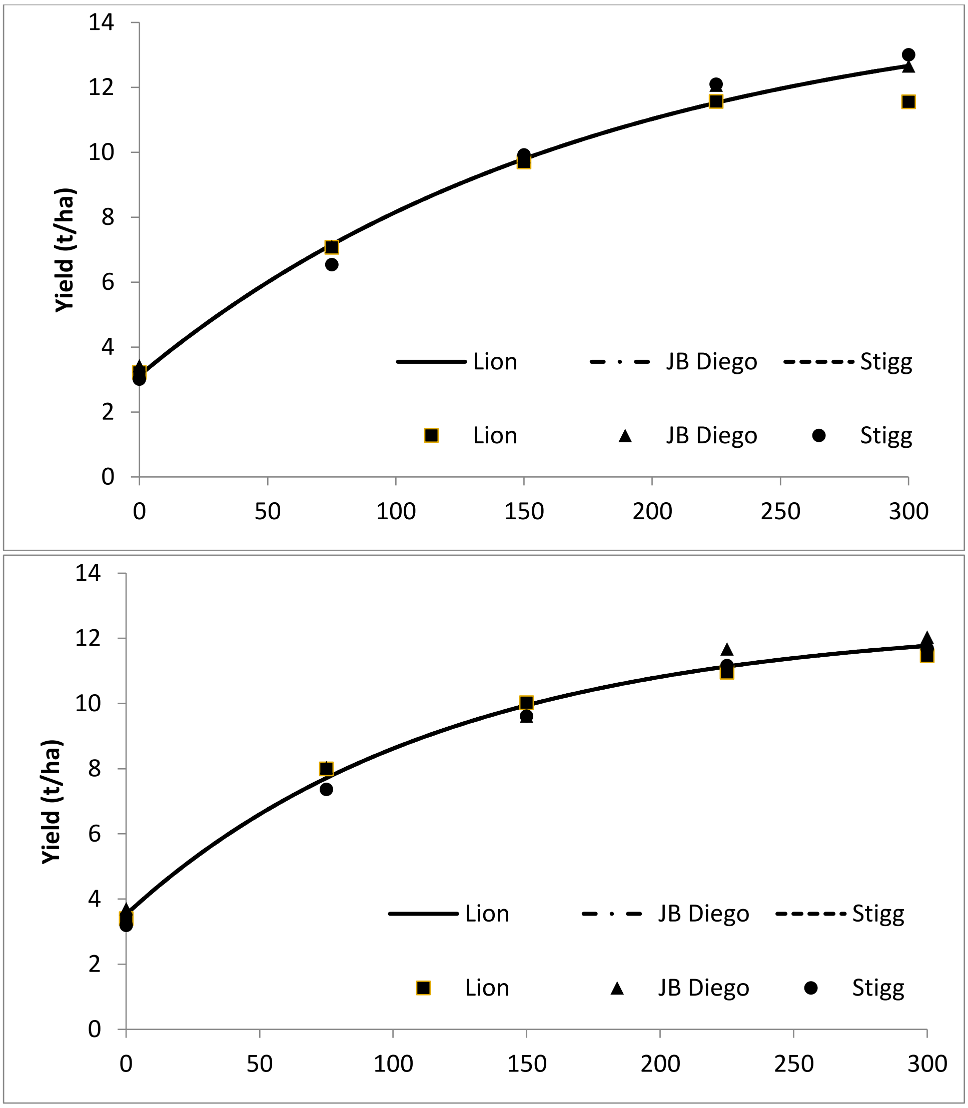


Figure 3. Nitrogen response for 3 wheat varieties in 2015 (top) and 2016 (bottom) as part of the DAFM funded CIVYL project, Oak Park.

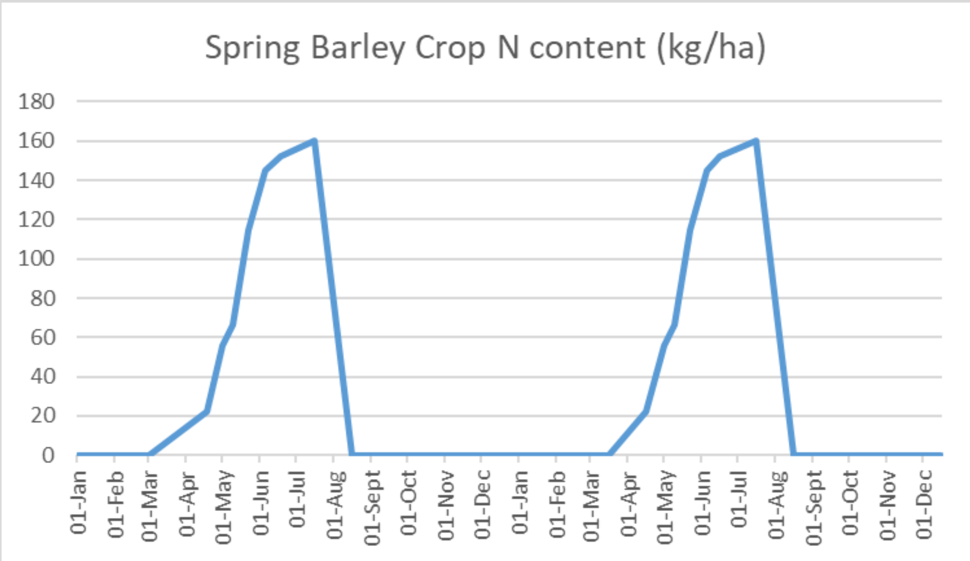
Since recommended N rates are already optimised for both economic and environmental impact, a reduction in applied N will have little impact on the residual nitrate-N at harvest but will increases the risk of significant yield losses, and financial losses for tillage farmers who are already operating on narrow margins.

Mitigating the risk of nutrient loss from tillage soils

Figure 4 shows the temporal profile of N uptake (kg/ha N) for two sequential spring barley crops and two winter wheat crops over an entire 2 year period. For spring cereals, the profile of N assimilation from the soil commences shortly after sowing (late March typically) and ceases once the crop senesces and grain fill has completed (late July typically). Beyond this period there may be a higher risk of N leaching due to mineralisation of crop residues in the absence of a cover crop to take up mineralised N from the soil.

For winter wheat crops the profile of N assimilation commences in the autumn, however, the quantity of N taken up is relatively low until the spring, with on average c. 10 kg/ha N uptake before the end of January. As for spring cereals, N uptake ceases once the crop senesces and grain fill has completed (late July to early August typically). Where no subsequent winter crop is sown there is a higher risk of N leaching in the absence of a cover crop to take up mineralised N.

In contrast to cereal crops, winter oilseed rape (OSR) can take up significant quantities of N in the autumn, particularly if sown before the end of August (Table 2). It should be noted that the data shown in Table 2 is conservative. The OSR crops in these years had not developed very large biomass, with a Green Area Index (GAI) of 1-2 despite the early sowing dates. In the following 2 years the OSR crops were much larger with earlier sowing dates and a GAI of 2-3. This level of GAI equates to an N uptake of 100-150kg/ha N on average. It is worth noting the even the later sown crops still had much greater N uptake than a winter cereal.



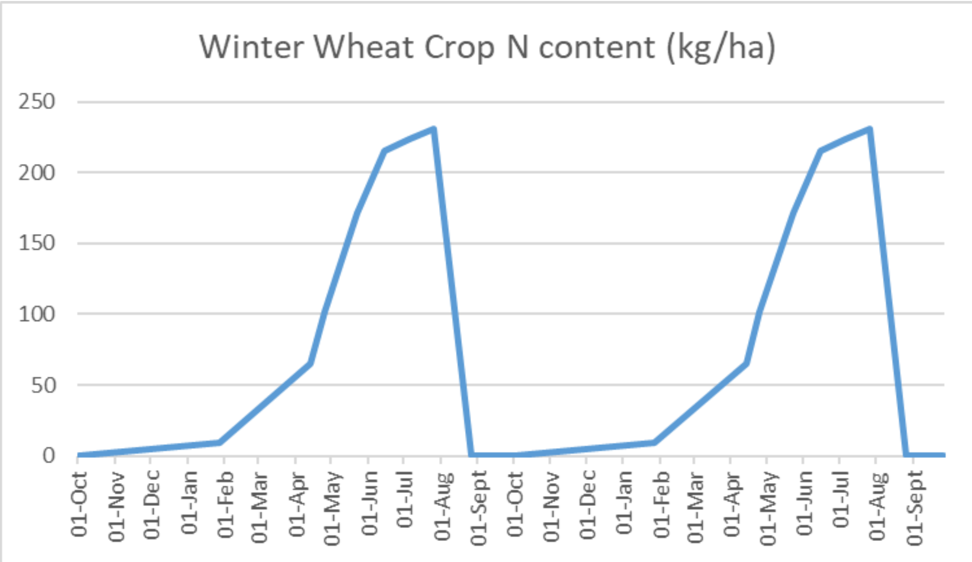


Figure 4. Temporal profile of N uptake (kg/ha N) for two sequential spring barley crops and two winter wheat crops over a 2 year period data from the Spring barley Guide https://www.teagasc.ie/media/website/publications/2015/The-Spring-Barley-Guide.pdf and winter wheat guidehttps://www.teagasc.ie/media/website/publications/2016/winter-wheat-guide.pdf respectively .

Table 2. Over winter nitrogen uptake (kg/ha N) by Oilseed Rape crops between 2018 and 2020 for 3 different sowing dates. For the 3 sowing dates mid-August, end August and mid-September the N uptake was measured in mid- Feb for the first 2 sowings and end Feb for the last.

Year	OSR sowing date		
	Mid - August	**End- August**	**Mid-September**
2018	108	73.5	32.2
2019	55.2	62.6	36.8
2020	54.9	55.0	18.8

Source: Rahimitanha et al. (2022)

Higher nutrient loss risk from tillage soils over the winter period is reflected in the data from the Agricultural Catchment Programme (ACP) shown in figure 5. This data shows that leaching and the delivery of nutrients to water bodies commences in late October to early November as soils become saturated and hydrologic connectivity between the soil and the water body is re-established. Leaching of nutrients ceases in spring as crop N uptake accelerates and soils begin to dry. In a tillage cropping situation the demand for N in the autumn for winter cereals, in most cases, can be supplied from soil reserves and additional applications of N during the late autumn and winter period will potentially increase the risk of nitrate leaching, especially on free draining soils.

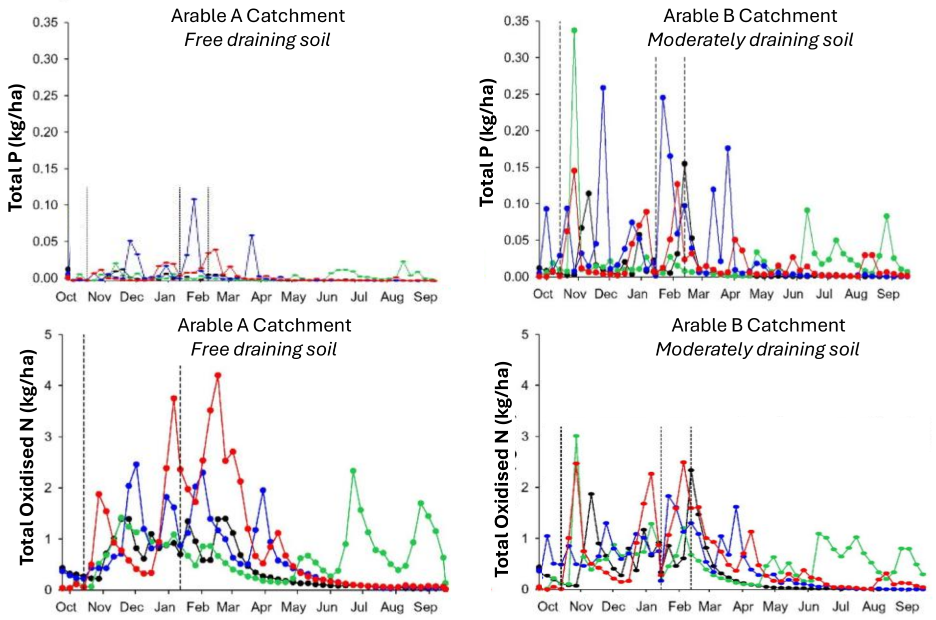


Figure 5. Weekly loads of total phosphorus (P) and total oxidised nitrogen (N) for two headwater catchments with a high proportion of arable land use over four years (October 2010–2014). Black vertical lines represent the regular closed-period beginning and end dates as well as well as the adjacent four weeks prior to the beginning and after the end (Shore et al, 2016).

Reducing nitrate-N losses from tillage systems is most effectively achieved by either reducing the organic N available for mineralisation in the autumn or ensuring the maximum uptake of N in the autumn and holding it in a green crop until such time as soil temperatures have dropped and the risk of remineralisation has dropped (*Thorup-Kristensen et al. 2003*).

Manure use in tillage systems

The application of organic manures to soils with high nutrient P and K demand is good practice and appropriate for the cycling of nutrients, including carbon, in-line with the EU Farm-to-Fork strategy. The application of organic manures to tillage soils further helps to close the nutrient cycling loop and can provide many economic, soil health and environmental benefits. For example, the timely incorporation of organic manure when applied to soils with low P status is an effective nutrient loss mitigation action for both P and ammonia. However, different types of organic manures vary significantly in their nutrient (N, P & K) content and this should be considered when land-spreading in-order to minimises the risk of nutrient losses to water. In particular, the C:N ratio of the manure is critical for determining the risk of N leaching. Manures with a C:N ratio <10:1 would be considered at higher risk of N leaching as the N is in a more labile form of organic matter and can be readily mineralised (Tables 3 and 4).

The potential effects on increasing the N loss risk to water should be considered where autumn applications of manures with high N content and lower C:N ratio are applied to soils (e.g. poultry manure and municipal sewage sludge). Where tillage crops with significant autumn N uptake such as early sown autumn OSR are sown, these present a much lower risk for the application of manures pre-planting. In addition, and in order to avoid transferring the risk of nutrient loss to other enterprises and, or, locations, where these manures are not landspread in autumn consideration should be given to appropriate storage options for these high dry matter manures on farms until spring each year. If these organic manures cannot be stored then applications on less suitable locations (grassland and high P status soils) may result. However, purpose-build storage may not be available on tillage farms at present and field storage including a waterproof cover over the organic manure may be the next best suitable option.

Table 3. Nitrogen availability in manure / compost according to the carbon:nitrogen (C:N) ratio of the manure.

Organic Manure / Material C:N ratio	Nitrogen availability (%)
10.0	>25.0
12.5	17.5
15.0	10.0
17.5	5.5
>20.0	<5.0
Adapted from Table 9A in S.I. 113 (2022)	

Table 4. Carbon:nitrogen (C:N) ratio according of different organic manures and organic materials

Organic Manure/Material	C:N ratio
Straw	80:1
Farmyard manure (FYM)	20:1 light bedding to 40:1 heavy bedding
Cattle Slurry	15:1
Poultry manure	5:1 layers, 10:1 broilers and turkeys
Pig slurry	8:1
Sewage sludge	7-11:1 lime stabilised sludge
Sources: Teagasc (unpublished research data) Peyton et al. (2016) and Ministry of Agriculture, Food and Agribusiness Ontario, (2022)	

Establishment of over winter green cover

Establishment of over winter green cover on tillage soils as soon as possible post-harvest on fields planned for late autumn planted crops and spring crops is key to reducing the risk of nutrient loss during the fallow period. There are differences between cover crop species in terms of N uptake with brassicas generally fast growing and among the most efficient at taking up residual N (*Richards et al, 1996*). The most important factors affecting the N uptake by a green cover are establishment rate and date, whit high plant densities and early establishment resulting in the highest levels of N uptake (*Sheppard et. al. 1993 & Francis, 1995*). Figure 6 shows the effect of sowing date of 2 cover crops, mustard and hairy vetch on biomass accumulation on the 12th December. There was approximately an 80 kg DM/ha reduction in growth for every 1-day delay in planting. this work indicates the early planting of cover crop is critical to produce a large biomass and maximise soil N uptake. However, cover crop establishment on tillage farms often needs to be carried out at one of the busiest times of the year, during harvest, when labour and machinery may be limiting and which can lead to delays in planting and establishment. Investigation of alternative rapid methods of cover crop establishment could aid the broad uptake of over winter green covers.

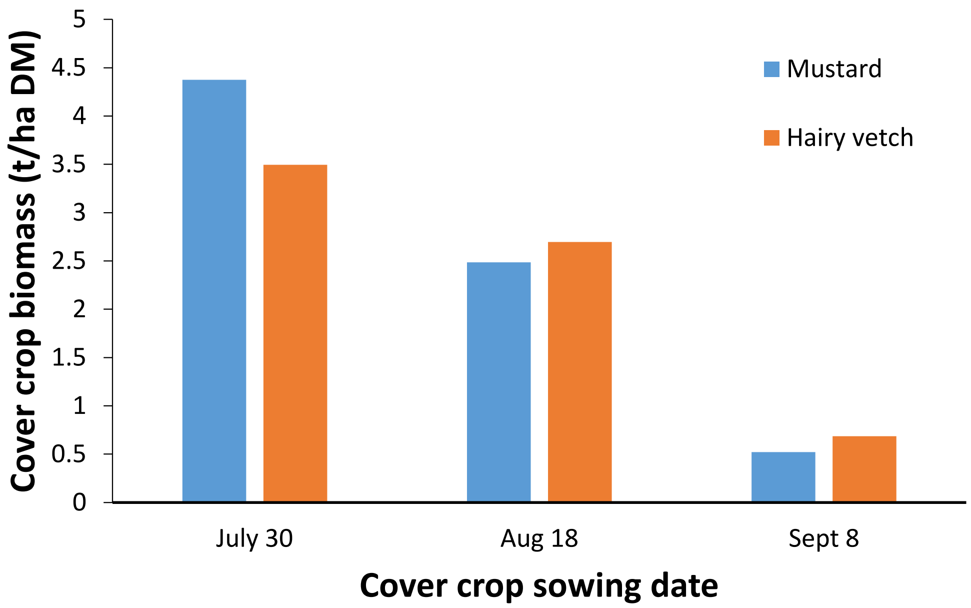


Figure 6. Effect of sowing date on aboveground biomass measured on December 12 of two cover crop types grown on a free draining soil at Oak Park in 2020.

Teagasc research has shown that in circumstances where good natural regeneration has established it can take up relatively high levels of N and reduce soil N concentrations (Premrov et al., 2014). Natural regeneration of green cover can be nearly as effective as a late sown cover crop and consideration should be given to maintaining such green cover *in-situ* beyond the start of September (based on figure 6), rather than attempting to re-establish green cover post shallow cultivation. The existence of good over winter green cover is more important for protecting water quality than the method of establishment of this green cover. It should also be noted that the cost of establishing a sown cover crop is significant in comparison to the narrow margins from spring cereals. Additionally, the use of crop species as cover crops can present agronomic difficulties, for example the use of frequent brassica cover crops will increase the risk of Club root infection which renders the land unsuitable for oilseed rape or field brassica vegetable production for more than 20 years.

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