Some Agronomic, Economic and Environmental Considerations associated with the Nitrate Directive and the Tillage Sector

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Summary

The requirement to establish a green cover within six weeks of ploughing/cultivating land destined for spring crops, where the ploughing/cultivation takes place before January 15th, is causing difficulties for Irish cereal growers. The main concerns, about the effective ban on ploughing before January 15th, include yield reduction and extra costs caused by difficulty in achieving good seedbeds. There are also concerns about pest and disease carryover, machine capacity and malting barley quality. These potential implications were considered in this review.

The extent of the impact of ploughing restrictions will vary from season to season depending primarily on weather conditions. Crop yield reductions due to poor seedbed quality, moisture loss during cultivation and/or delayed sowing will occur. A 6.5% yield drop is estimated. Seedbed preparation is also likely to require more energy input during cultivation, to compensate for the absence of natural weathering, adding to machinery costs. An average cost increase of €18.50/ha is estimated. The shorter ploughing work window also demands increased ploughing capacity, adding a further estimated €19/ha to machinery costs. This analysis indicates that the current ploughing date restrictions increases costs and impacts significantly on the competitive position of Irish spring cereal production relative to the UK where no ploughing restrictions are imposed. This amounts to an estimated increase in cash costs of 9%. This loss of competitiveness could have serious implications for the industry. The impact of a change of plough date, from January 15th to a period in late November / early December, on nitrogen leaching risk, was considered. Loss of nutrients is part of a normal ecosystem cycle and is a complex process which can be influenced by agronomic practice. It is concluded that the majority of the mitigating effect of a green cover on nitrate leaching will have taken place by December. Growth and consequently nitrogen removal from the soil in December and January is low to negligible due to low temperatures. This indicates that maintenance of the green cover in December and January is unlikely to give additional substantial reductions in nitrate leaching. Furthermore low soil temperatures during December and January will lead to relatively low rates of mineralisation of nitrogen both from the native soil organic N or from incorporated green material. This would indicate that it is likely that any increases in the risk of leaching would not be substantial, should revised dates in the late November / early December period be agreed.

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Introduction

The requirement to establish a green cover within six weeks of ploughing/cultivating land destined for spring crops where the ploughing/cultivation takes place before January 15th is causing difficulties for growers. In effect this prevents ploughing until after January 15th. Concerns include increased difficulty in achieving good seedbeds, critical to the success of spring barley in particular. This is especially the case on heavier textured soils. There are also concerns regarding pest and disease carryover; negative effects on malting barley quality; increased ploughing capacity requirement; and increased power requirements to obtain a suitable seedbed. Ultimately these effects impact on costs and competitiveness.

This paper considers this topic under two main headings:

- Agronomic and Environmental considerations
- Impact on costs and competitiveness

The scenario of changing the allowed date of green cover removal (i.e. plough date) from January 15th to an earlier date is considered.

Agronomic and Environmental Considerations

Loss of nutrients in soils is inevitable and part of a normal ecosystem cycle. Farming practice can of course influence these processes. In developing an appropriate action programme, due regard must be given to the impact of such processes on environmental, agronomic and cost factors. In the following sections the effect of the current (January 15th) and modified (late November – early December) plough restriction dates are considered.

Agronomic Impact

Yield effect

Restricting ploughing to after mid-January is likely to lead to a general trend for later drilling, and poorer quality seedbeds resulting in poorer crop establishment, particularly on heavier textured soils. This is due to the absence of or a shortened period of weathering on the soil leading to poorer quality seedbeds. The impact of late ploughing on yield will depend on soil type, extent of cultivation and weather conditions. While extra cultivation can partly compensate for the lack of beneficial weathering on ploughed soil, the action of the extra cultivation can cause excessive moisture loss and poor subsequent germination and early crop growth, particularly in dry spring conditions. While it is difficult to be definitive about yield effects, yield reductions in spring crops of up to 0.5 to 0.625 t/ha for March ploughing compared to December ploughing were suggested in the 1980s in Ireland (ACOT leaflet). More recent European research would suggest yield loss of 0.42 t/ha for spring ploughing with spring barley in Norway (Njos and Borreson, 1991) and from zero to 33% reduction with spring ploughing across a range of spring crops in Sweden (Stenberg *et al*., 1999).

Irish research on seedbed conditions showed that where spring barley was established in good seedbeds a yield increase of 3% to 10% was recorded compared to crops established in poor soil conditions at the same time (cultivation/sowing was carried out some days earlier in wetter soil conditions) (Conry 1999). While this is not completely analogous to conditions created by ploughing time differences, it does show the effect of poor crop establishment, as caused by soil conditions, on crop yield.

Recent (unpublished) work in the UK shows the importance of grain number per unit area in determining the yield potential of spring barley (Figure 1). Grain number is determined in the early stages of the crops lifecycle prior to ear emergence, being a combination of plant number per unit area, shoot number per plant and grain number per ear. The work showed that there was a strong relationship between light interception by healthy green tissue pre-anthesis, and grain number per unit area (Figure 2). Given that the findings of the work were the same in the west of England and in the north east of Scotland it is likely that the same relationships will exist in the Irish climate. Clearly therefore any restriction which limits the growers' ability to establish a complete spring barley crop cover as early as possible will restrict yield potential and competitiveness.

Figure 1: The relationship between grain number per unit area and yield: Rosemaund (Rm) UK and Aberdeen (Ab), Scotland.

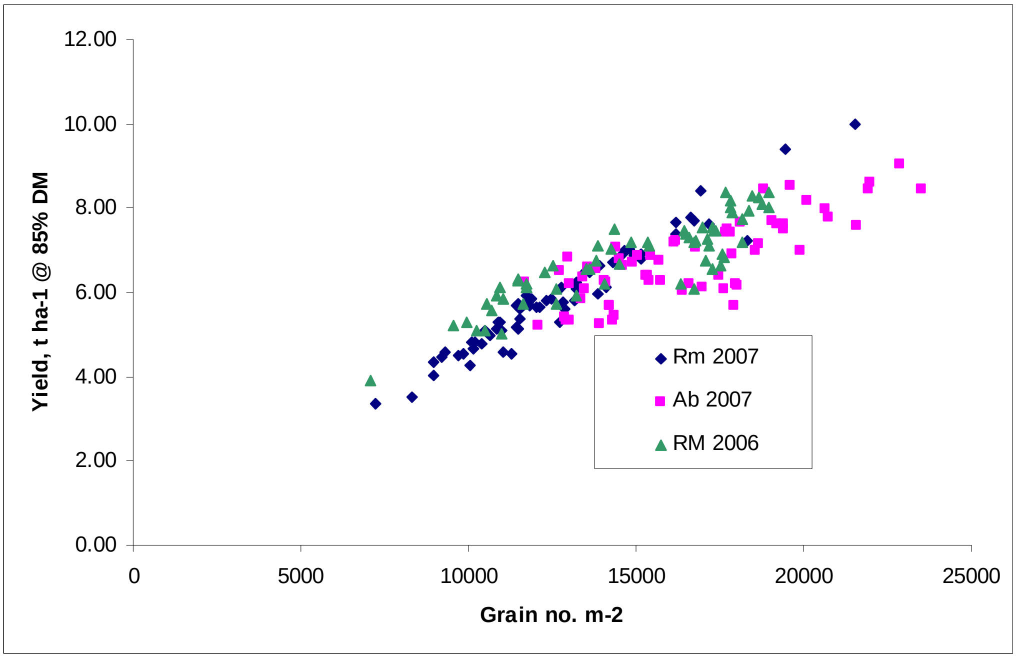
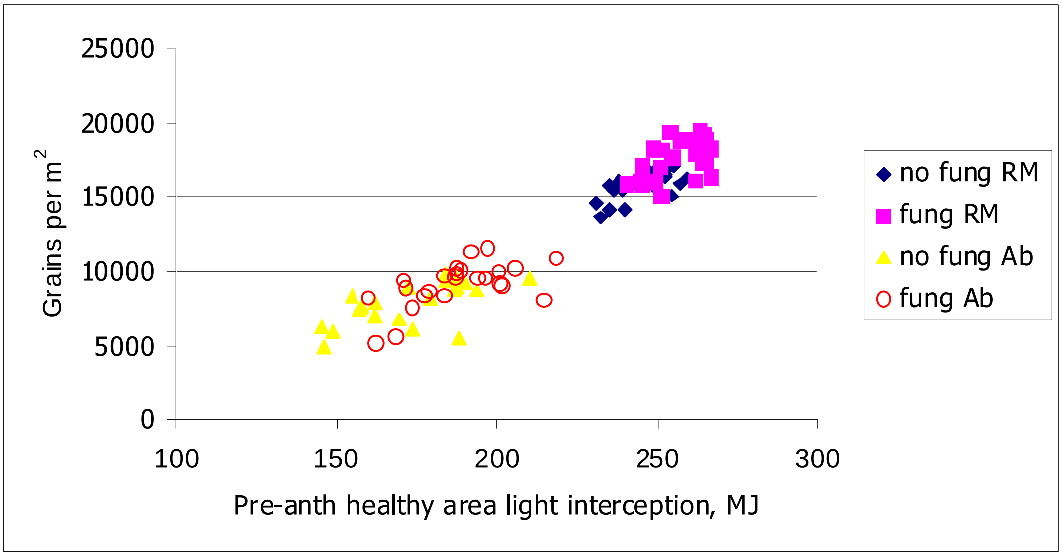


Figure 2: The relationship between light interception by healthy green canopy and grain number per unit area at Rosemaund (RM) UK and Aberdeen (Ab), Scotland (2006).



Quality Impact – malting barley

Where ploughing is delayed due to the nitrate regulations the late incorporation of biomass and its consequent late breakdown could result in increased nitrogen release late in the season. This may lead to increased grain nitrogen which negatively affects malting barley quality. Malting barley is up to four times as profitable as feed barley and is currently being compromised by late ploughing which could result in serious problems for growers and the industry.

Pest and Disease Effects

It is well accepted that the presence of vegetation, particularly volunteer cereals and grasses, can act as a green bridge for pests, particularly aphids which act as vectors for BYDV, and diseases such as net blotch and rhynchosporium. Traditionally advice has been to eliminate this green bridge as early as possible to reduce the risk of carryover of pests and diseases. Restrictions on the removal of the green cover before January 15th can lead to substantially shortened periods between overwinter vegetation destruction and sow of the subsequent crop, particularly where poor weather occurs after January 15th.

Vegetables and potatoes

Vegetable and potato growers are also seriously compromised by the ploughing and green cover rules. Early potato and early vegetable crops are normally planted in early to mid February. Thus it is obvious from the details given on weathering of soil for spring barley that growers of early vegetable and potatoes will also be seriously compromised by these rules.

Environmental impact

The risk of nitrate leaching, associated with a change in plough date to a late November / early December date, could be affected by one or both of two mechanisms.

1. Removal of vegetative cover at an earlier date may reduce the amount of nitrogen accumulated by the vegetative cover, thereby reducing its effect on nitrate leaching. (There would be six weeks less of potential N accumulation by the vegetative cover).
2. Ploughing at an earlier date may lead to an increased amount of nitrogen mineralised over the fallow period. (There may be increased mineralisation due to soil disturbance).

The majority of the mineral N likely to be captured by a cover crop is already taken up by early December. In order to minimise nutrient loss to the aquatic environment it seems therefore that the optimal approach would be early establishment of green cover to capture soil mineral nitrogen, which is ploughed into the soil in early in December to leave a rough soil surface which is resistant to surface erosion and loss of soil particles and P to surface waters (Silgram 2005).

Effect of earlier destruction of the vegetative cover on N leaching

Most nitrates will be lost during the early part of the drainage season. The start of the drainage season can occur at any time under Irish conditions but will usually occur between September and November, depending on rainfall patterns. The presence of actively growing vegetation has been shown to be an effective method of reducing leaching where good growth is achieved before drainage starts (Davies *et al.*, 1996; Lord *et al.,* 1999). Therefore growth and associated N accumulation by a vegetative cover in September and October will account for a large proportion of the overall effect of a vegetative cover in reducing nitrate leaching. Work at Oak Park has indicated that in a high leaching risk site the effects of a green cover will generally have reached their maximum by early December (Hooker *et al.*, 2008; Premrov *et al.*, 2008) figure 3. At this stage the majority of the nitrate in the soil will either have been accumulated by the green cover or already leached below the root zone of the green cover. In any case the growth and consequently, the N accumulation by an overwinter vegetative cover below 6 ^{o}C is usually limited and therefore relatively little extra N uptake by green cover will occur after November as temperatures will generally be less than 6 ^{o}C in December and January.

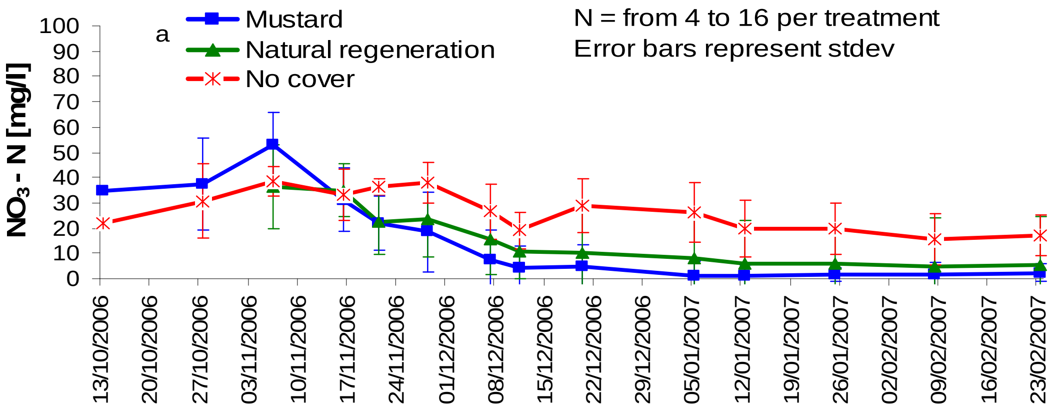


Figure 3: Mean Soil solution NO_3-N concentrations from no cover, mustard and natural regeneration over-winter cover treatments at Oak Park in for drainage season 2006/07. (Premrov *et al.*, 2008)

Delayed incorporation of green cover can have negative implications for nitrate leaching. Incorporating green cover too close to drilling of the spring crop can result in N accumulated by the green cover not being released in time for uptake by the spring crop. This situation can occur under the current regulations where ploughing is delayed by adverse weather conditions in January and February. Where the nitrogen is released after the requirement of the spring crop has been satisfied, the released nitrogen will remain in the soil after the crop has been harvested and will be susceptible to leaching over the following winter period. Under UK conditions Davies *et al.*, (1996) found no evidence of recovery of N from a cover crop ploughed in February/March by a subsequent spring crop and indicated that there could potentially be carryover of N from one green cover to the next i.e. N released from the green cover becoming available after the requirement period of the spring crop will be present to be taken up by the next green cover. Experiments at Oak Park have generally found negligible N benefits to a spring barley crop from a range of cover crops when incorporated in March just before spring barley drilling. This would suggest that where cover crops are incorporated too late in the spring, the nitrogen contained in their tissues may be released too late for uptake by the spring sown crop and therefore be susceptible to leaching during the following winter drainage period. Earlier incorporation, which would be facilitated by earlier ploughing, may lead to better recovery of N released from the green cover by the succeeding spring crop.

Effect of ploughing on mineralisation

Many studies have indicated that soil cultivation can stimulate mineralisation of nitrogen in the soil. However nitrogen mineralisation in the soil is temperature dependent. Vale *et al.,* (2007) and Vale (2006) reported that N mineralisation in arable soils was relatively low at soil temperatures below 10 ^{o}C (see Figure 4 below). They also reported that for temperatures less than 25 ^{o} C the mineralisation rate was tripled for each 10 ^{o}C increase in soil temperature. Conversely if the soil temperature is reduced by 10 ^{o}C the rate of mineralisation would be reduced to one third of its starting value. Earlier Irish research also supports this effect (Herlihy, 1979).

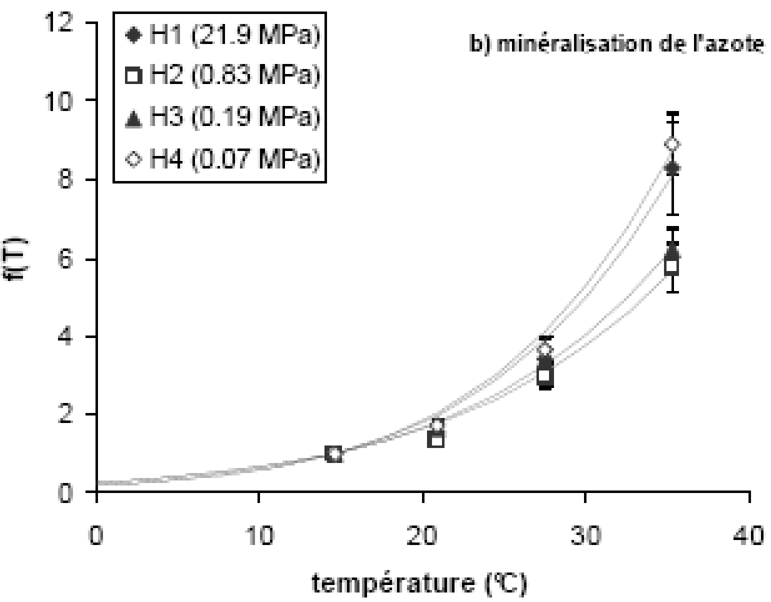


Figure 4: Effect of temperature on rate of mineralisation of nitrogen in soil at 4 levels of soil water tension (H1-H4). *Source (Vale 2006)*

By December soil temperatures in Ireland have generally declined to relatively low levels (~5 ^{o}C) in most cases (Table 1) indicating that the rate of soil N mineralisation would be low. Differences between mean soil temperature in December and January are generally relatively small (0.8-1^{o}C). This suggests that ploughing in December rather than January is unlikely to lead to substantially increased nitrogen mineralisation.

Table 1. Mean soil temperatures at 10 cm depth for meteorological stations located in arable crop producing areas of Ireland.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cork airport	4.9	4.8	6.3	8.6	11.8	15.0	16.8	16.0	13.8	10.8	7.4	5.9
Kilkenny	4.0	4.3	6.1	9.2	12.9	16.6	18.2	17.0	14.1	10.5	6.5	4.8
Casement	4.2	4.0	5.6	8.3	11.9	15.5	17.1	16.1	13.3	10.1	6.3	4.9
Mullingar	3.6	3.9	5.7	8.5	12.0	15.4	16.9	16.0	13.5	10.1	6.1	4.5
Rosslare	5.2	5.4	6.9	9.7	13.3	16.6	18.3	17.4	14.8	11.5	7.9	6.2
Birr	4.1	4.4	6.3	9.3	12.9	16.4	17.8	16.8	14.0	10.6	6.5	5.0
Dublin airport	4.1	4.4	6.2	9.2	12.9	16.4	18.0	16.9	14.1	10.7	6.7	5.0

Source: www.met.ie

Studies from abroad have compared the effect of different times of cultivation on N mineralisation. Stenberg *et al.,* (1999) reported significantly lower N leaching following November ploughing compared to September ploughing in Sweden. This suggests that the release of N was much lower after the November ploughing date when soil temperatures were lower than for the September sowing date. Mitchel *et al.,* (2000), working in the UK, reported that N mineralised from residues incorporated in November was less than half that compared to either September or October incorporation dates. There was little difference in mineralisation between November incorporation and January incorporation.

With regard to a source of readily mineralisable nitrogen many Irish tillage soils have been in arable production for a long number of years and have reduced organic matter content. There is likely to be low levels of mineralisable nitrogen available in these soils. Work in Northern Ireland indicated that N mineralisation in an arable rotation over the winter period was low (Watson *et al.,* 2007)

Impact on Greenhouse Gases

Yield reduction caused by enforced late ploughing can result in a greater output of greenhouse gas per tonne of production (Berry *et al.*, 2008). The negative impact of reduced yield on the GHG costs of production are even greater if the impact of reduced productivity on indirect land use change is taken into account e.g. Kindred *et al.,* (2008).

The situation in Northern Ireland and the United Kingdom

Spring barley is the most significant crop on an area basis in Ireland and therefore it is imperative that Irish growers are not put at a competitive disadvantage compared to growers in other European countries when producing this crop. A comparison of the Irish Action Programme with those of Northern Ireland and England reveals substantial differences in relation to requirements governing the management of land destined for spring crops over the preceding winter period (Anon 2006, Anon 2008a).

In Ireland, as already indicated, it is a requirement to maintain a green cover on arable land destined for a spring sown crop over the preceding winter and this green cover may not be removed by ploughing or use of a non-selective herbicide before January 15th. Such a measure has not been included as a mandatory requirement in either England or Northern Ireland. Indeed in both areas ploughing/cultivation of land between harvest of a crop and sowing of a spring crop is put forward as one of a number of management options for fallow land over the winter period. (Anon 2006)

Development of Action Plan in England

In England during the consultative phase before the current Action Programme was finalised a requirement for a cover crop '*where ground would otherwise be left bare overwinter, except in the case of crops harvested after 1 September (e.g. sugar beet)'* was included in the consultation document released prior to final drafting of the Action Programme (Anon 2007). However following a large number of comments, the majority of which were not supportive, this requirement was not included in the final Action Programme with the following reasoning used; '*We recognise there are a range of practical difficulties associated with establishing and maintaining cover crops, and indications are that many farmers would most likely switch to winter sown crops rather than comply with the cover crops rule. This would undermine the effectiveness of the measure at reducing nitrate losses…*' Anon 2008.

Comments made by UK stakeholders included

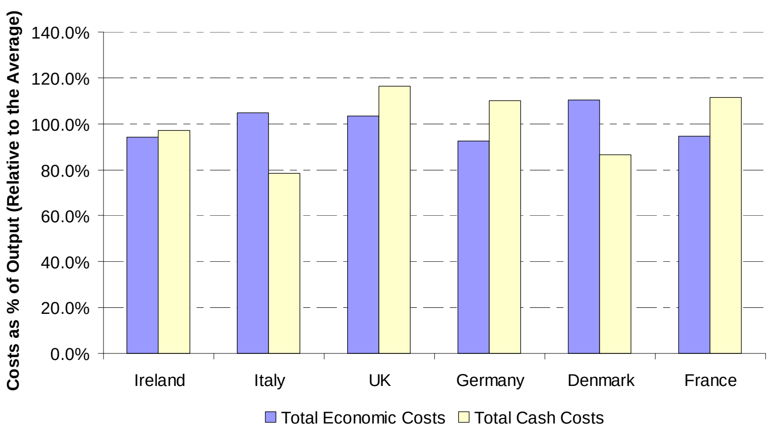
- Prevention of weathering of ploughed land over the winter months which is vital to the successful establishment of many spring crops on heavy / medium soils.
- Creation of difficulties with the control of weeds, pests and diseases.
- Generation of additional costs to be borne by the farmer (e.g. seed, fuel, time, chemical use, reduced yield of the following crop).
- Increase in the carbon footprint of agricultural production.
- Potential loss of biodiversity / wildlife due to the removal of over-winter stubbles which are an important habitat for seed-eating birds.
- Encouragement of a general move to winter cereal growing, with production of sugar beet, peas and other spring crops ceasing in some areas.

Impact of current restrictions on costs and competitiveness

Baseline Competitive Position

The competitive position of Irish cereal production relative to our main competitors within the EU has been provided by Carroll *et al.*, (2008) using data from the Farm Accountancy Data Network (FADN) from the European Commission. The approach adopted in Carroll *et al.,* (2008) was similar to that used by Thorne (2005) but the most recent work used the latest available data from FADN. Further information on the definition of terms and methodology used can be obtained in Thorne (2005), and a summary is provided in Appendix I.

Figure 5: Cash and Economic Costs of EU Cereal Production (2004/2005)



Source: Carroll et al., (2008)

Figure 5 shows that Irish cereal producers maintained a competitive advantage relative to the average of all EU countries in the analysis, when cash costs and economic costs were considered, for the period 2004/05. This outcome is similar to that observed for the period 1996 to 2003. For example, Irish cereal producers had the third lowest cash cost: total output ratio compared to the other countries examined for 2004/05, at 3 per cent lower than the average of all countries. Even when total economic costs were measured Irish cereal producers maintained a competitive advantage compared to the average of all countries. Cash costs are considered an indicator of competitive position in the short term, whereas economic costs are considered an indicator of competitive position in the medium to long term, given that an imputed charge for owned resources is included in the latter figure.

Assumptions Regarding Potential Impact of Ploughing Restrictions on competitiveness

For the purpose of estimating the impact of ploughing restrictions on the competitiveness of cereal production in Ireland it was necessary to assume that the competitive position of spring sown crops does not differ from the competitive position of the average cereal enterprise in Ireland. This assumption was necessary given that the level of detail necessary to conduct a crop specific competitiveness analyses is not available from FADN. In addition, given that the main source of imports of cereals into Ireland is from the UK, the estimated impact of ploughing restrictions on the competitiveness of Irish cereal production is examined relative to the UK where no ploughing restrictions are in place. In terms of the potential impact on competitiveness due to delayed sowing of spring cereal crops it was necessary to make certain assumptions regarding (i) the potential loss of work days and the impact on costs; (ii) the potential increase in secondary cultivation machinery costs; and (iii) the potential impact on yield. These assumptions follow.

Loss of work days and impact on costs

If ploughing dates are restricted, the available work days for the operation are reduced. It can be assumed that without restriction, ploughing would be carried out from at least December 1st through possibly to the beginning of March. While we do not have accurate Irish data at this point on workdays, we can use other data sources to make a reasonable assessment. Using data from the East of Scotland (Eradat Oskoui 1986), between 1st December and 15th January on heavier soils there are approximately 20 workdays when ploughing would be possible from a soil moisture perspective. From 15th January to 1st March approximately 18 days are available indicating a doubling of ploughing capacity is needed to plough within the current rules. These are based on a 75% probability of this number of days being available i.e. 18 out of 24 years. Wetter conditions would prevail in the other 25%. While the tillage areas of Ireland would have higher rainfall than the East of Scotland and consequently less working days for a given soil type, this data suggests that the available work days are halved with consequent effects on machine capacity requirement and costs.

The effect of plough work day restrictions – An example of potential costs

The impact of work day availability on costs depends on: the machinery system already on the farm; the size of farm and to a lesser extent other factors such as field size; alternative use for tractors etc. A cost analysis using the **Oak Park machinery cost programme** was carried out assuming a grower unit with 200ha for spring cropping. The original situation assumed a single four-furrow mounted plough was used to plough all the land requiring about 32 ploughing days which would require most of the available plough period before restrictions applied (i.e. 1^{st} December through to March). Assuming the current ploughing ban is in place, the most realistic and cost effective option to increase capacity assuming labour availability would be to purchase a second plough of similar capacity and to upgrade a second tractor on the farm to operate this plough. This would allow the ploughing to be achieved in 16 plough days (note in East of Scotland data above only 18 days were available). Even allowing for the reduced individual plough costs (less repairs, longer replacement cycle and reduced depreciation per plough), the net effect on this example is to increase overall farm machinery costs by €19/ha, most of this additional cost is due to the increased tractor size requirement.

If labour was not available to operate the second plough, the option of a larger single plough (6 to 8 furrow), and a proportional increase in tractor size, would further increase costs because of the poor utilisation of a very high-powered tractor in the non-ploughing period.

While the actual costs incurred will vary depending on individual situations, the example quoted here would not be unusual. For the purpose of estimating the impact on competitiveness the estimated cost of €19/ha was assumed.

Increase in secondary cultivation (seedbed preparation) machinery costs

The effect of weathering (frost and rain) on over-wintered ploughed land reduces the energy required for subsequent cultivation. The difference in time between early and late ploughing, soil type and weather conditions will determine the extent of this difference. In general, increased energy demand will increase total machinery costs (fuel, labour, depreciation, repairs etc) in proportion, as work-rate will be lower.

As an example, the work-rate of a cultivation/sowing unit could be reduced from 0 to 40% depending on conditions, with a consequent increase in machinery costs of from zero to €37/ha respectively (based on €56/ha cultivation cost from the Oak Park machinery costing programme). For the purpose of estimating the impact on competitiveness the average of the estimated costs from the Oak Park machinery costing programme was calculated to be €18.50 per hectare i.e. that on average late ploughing increased subsequent cultivation costs by €18.50/ha.

Impact on Spring Barley yield

For the purpose of estimating the impact of the current ploughing restrictions on yield and competitiveness, the effect of seedbed quality on yield (see earlier section on 'yield effect') is used. The average of the 3 to 10% yield increase based on Irish data from Conry (1999) was assumed. Based on the input data from FADN used to compute the competitiveness indicators this yield disadvantage for spring ploughing relative to winter ploughing is equivalent to a 6.5% yield reduction.

Impact of Increase in Costs and Reduction in Yield on the Competitiveness of Irish Cereal Production

Based on the cost and yield assumptions outlined above the impact of ploughing restrictions on the competitiveness of spring sown cereal crops in Ireland relative to the UK is estimated in Figure 6 below.

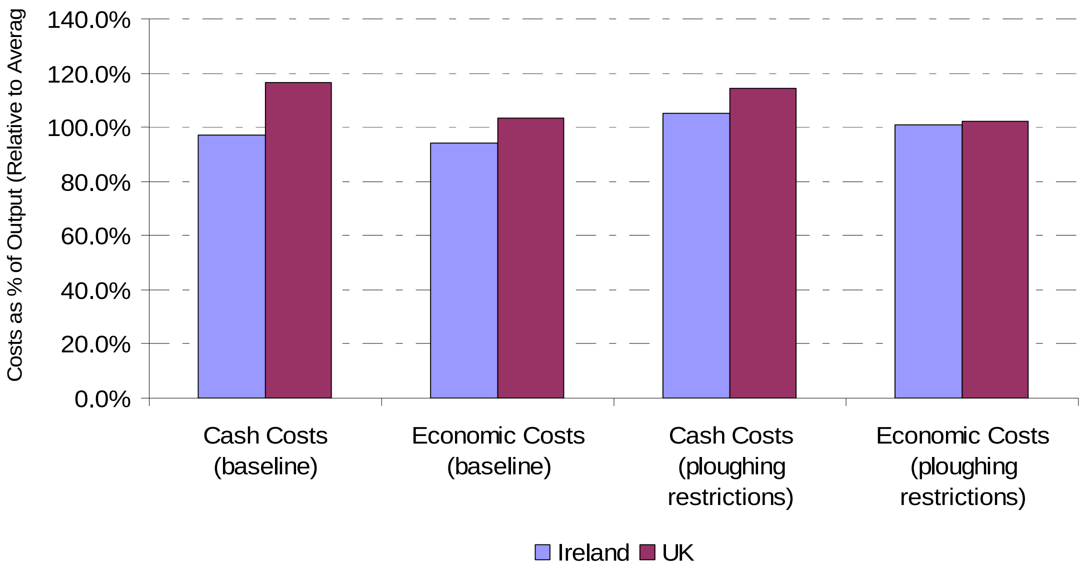


Figure 6: Actual and Estimated Cash and Economic Costs of Cereal Production in Ireland and the UK

Figure 6 shows the negative impact of ploughing restrictions on the competitiveness of spring sown cereal crops in Ireland relative to the UK, where no ploughing restrictions are imposed. On a cash cost basis, costs as a percentage of output (relative to the average of EU countries examined) are estimated to increase by 9 per cent in Ireland relative to the UK. While this estimate of cash costs still leaves cash costs as a per cent of market based output in Ireland lower than the UK position, the margin between the two countries is reduced significantly. In the baseline position when no ploughing restrictions are imposed the margin between cash costs in Ireland and the UK is 19%, where as in the scenario where ploughing restrictions are imposed the margin between costs in the two countries is reduced to 10%.

Conclusions

In the current climate of increasing costs, volatile market prices, and volatile Sterling/Euro exchange rates, the competitive position of Irish cereal crop production is of paramount importance. This must be considered when restrictions on agronomic practice are being considered. The findings from this review indicate that:

- The current imposition of a winter ploughing restriction in Ireland impacts significantly on the competitive position of Irish spring cereal producers relative to the UK where no ploughing restrictions are imposed.

- Restricting ploughing to after mid-January can lead to later drilling, and poorer quality seedbeds resulting in poorer crop establishment and consequent yield reductions

- Competitiveness is also affected by increased machinery costs due to the need for extra ploughing capacity and more intensive secondary cultivation

- Where yields decline, a pro-rata increase in GHG emissions per tonne of production is likely, impacting negatively on the environment.

- Based on a review of the international literature and work carried out at Teagasc Oak Park, it is our view that any increases in the risk of leaching resulting from changing the date from January 15th to an earlier date (late November / early December) is unlikely to be substantial. This conclusion is based on two key points;

    - Most of the effect of a green cover on N leaching will have occurred before December

    - Soil temperatures in December and January will be low resulting in low to negligible nitrogen mineralisation rates as a result of green cover destruction and/or ploughing.

Appendix I

Measuring Competitiveness

Data

The Farm Accountancy Data Network (FADN) was the primary source of data used in this analysis. The aim of the network is to gather accountancy data from farms for the determination of incomes and business analysis of agricultural holdings. The concept of the FADN was launched in 1965, when Council Regulation 79/65 established the legal basis for the organisation of the network.

The network consists of an annual survey carried out by the Member States of the European Union. Derived from national surveys, the FADN is the only source of micro-economic data that is harmonised, i.e. the bookkeeping principles are the same in all the countries. The information collected, for each sample farm; for each member country is transmitted by Liaison Agencies (FADN, 2003) Teagasc is the liaison agency for Ireland

FADN data itemises cost on a whole farm basis only, and some method of allocating these costs to the specific enterprises analysed in this research had to be attempted. For the majority of cost items, whole farm costs were allocated to the specific enterprise activity according to the share of specific enterprise output in total farm output. A number of exceptions to this general rule were adopted for individual cost items at the enterprise level.

Measurement

Total costs as a percentage of the total value of output was used for comparing the competitiveness of cereal production in the selected member states. Measuring costs of production, in terms of output is consistent with traditional production theory, which aims to minimise costs or maximise net revenue per unit output.

Competitiveness in the market place for commodities, such as cereals, is largely determined by costs of production (Boyle, 2002). However, this is not entirely the case as quality differences and transport costs to the point of purchase are also important. Therefore, it was considered important to examine the competitiveness of cereal production in terms of total costs of production as a percentage of the value of output.

Costs were defined in the following way:

(i) **Total cash costs**, which include all specific costs, directly incurred in the production of a given commodity, for example fertiliser, feedstuffs, seeds etc. plus external costs such as wages, rent and interest paid, plus depreciation charges.

(ii) **Total economic costs**, which includes all of the cash costs identified above, except interest charges, plus imputed resource costs for family labour, equity capital and owned land.

The calculation of total economic costs for the competing countries was one of the most problematic exercises in this analysis. If long-term competitiveness is to be examined the assumptions regarding the measurement of opportunity costs for family labour, owned land and other non-land capital must be as realistic as possible. The valuation methods adopted for the research in this study are outlined below:

- Family labour was assigned an opportunity cost equal to the cost of hired. The hired labour charge was determined from the FADN data.
- Owned land was assigned an opportunity cost equal to the cost of rented land, which was also determined from the FADN data. This approach follows the methodology adopted by Boyle *et al.,* (1992), Boyle (2002), and Fingleton (1995).
- Non-land assets also proved to be a problematic resource for valuation purposes.

Boyle *et al.,* (1992) and Boyle (2002) recommended using a (i) real interest rate which takes into account taxes, subsidies and inflation adjustments and (ii) a depreciation rate. However, Fingleton (1995) recommended using a long-term interest rate, rather than a real inertest (derived from the FADN data) as proposed by Boyle, derived by subtracting the price deflator for private consumption from the nominal long-term interest rates for each country for each relevant year. Both of these approaches were considered but were not adopted for the research. Application of a derived real interest rate substantially increased the spread of rates charged on non-land assets between the countries examined. In addition the application of a long-term interest rate was not considered appropriate given the record of real interest rates over the time period for Ireland. Due to high inflation in Ireland in this time period, the computed long-term interest rate was negative in some time periods. For this study a nominal interest rate was applied for each of the countries for each relevant year. This approach was considered to provide more realistic opportunity costs for the purpose of valuing non-land assets in this analysis, than the two methods identified above.

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