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Impact of Early Sowing on Winter Wheat Receiving Manure or Mineral Fertilizers

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ABSTRACT

To reduce over-winter nitrate leaching from temperate soil under cereal cropping, nitrate catch crops can be grown between main crops. We hypothesize that earlier sowing can replace catch crops sown before winter wheat (*Triticum aestivum* L.) and improve wheat yields and N uptake.

Early sown (late August) and timely sown (late September) wheat were tested over two cropping seasons (2011-12 and 2013-14) using two contemporary cultivars (Hereford and Mariboss) and increasing rates of N (0 to 300 kg total-N ha$^{-1}$) with animal manure (AM; cattle slurry) or mineral fertilizers (NPK), surface-applied in late March. We measured over-winter N uptake in wheat, harvest yields and N concentrations in grain and straw. Over-winter N uptake was 11 kg ha$^{-1}$ higher for early than for timely sown wheat; at harvest this benefit increased to 19 kg N ha$^{-1}$. Mariboss yielded more straw than Hereford whereas grain yields did not differ. Early sowing increased grain yields by 0.5 and 1.0 Mg ha$^{-1}$ for NPK and AM, respectively, regardless of N rate. Grain and straw N concentrations were higher with NPK than with AM, and NPK showed higher N use efficiency (0.48-0.53) than AM (0.15-0.22). Moving sowing of winter wheat from late September to late August provided higher grain and straw yields; the increased over-winter N uptake suggests that the beneficial effect of earlier sowing may surpass that of a catch crop. Cattle slurry surface applied in late March gave poor N use efficiency and low grain protein content.
Abbreviations: AM, animal manure (cattle slurry); DM, dry matter; NPK, mineral fertilizers; NUE, nitrogen use efficiency; SEM, standard error of the mean

Introduction

Wheat remains a most important cereal crop within the European Union. In 2013 wheat accounted for 62 % of the production of small grain cereals, the largest European producers being France, Germany, and United Kingdom (Eurostat, 2015). In 2015, winter wheat (*Triticum aestivum* L.) occupied 42 % of the area used in Denmark for cereals, corresponding to 23 % of the arable land (Statistikbanken, 2016). On farms specialized in livestock production, autumn sown wheat is a preferred cereal and is often grown with application of animal slurry in the spring. To reduce overwinter leaching losses of nitrogen (N), cereal production in Denmark has become subject to environmental regulations. These involve restrictions on use of N fertilizer (application times and rates), prescribed use efficiencies for N in animal manure (depending on type of manure), and compulsory nitrate catch crops in breaks between main crops (Dalgaard et al., 2014). Up to 14% of the arable land may carry catch crops on farms with intense cereal production. However, national regulations of N use and nitrate catch crops may differ even within regions with comparable climate and production systems (Aronsson et al., 2016).

Fodder radish (*Raphanus sativus* L.) has been introduced as a nitrate catch crop in breaks between cereal crops: seeds can be applied pre-harvest and subsequently the radish grows vigorously and may accomplish a significant reduction in nitrate leaching losses (Hansen et al., 2015; Li et al., 2015). However, when incorporated before planting of winter wheat, much of the N captured by the radish may become re-mineralized, nitrified and leached even at the low soil temperatures prevailing during autumn and winter (Thomsen et al., 2016). Losses of mineralized N
reduce the effect of the catch crop (Thomsen and Hansen, 2014) and call for alternatives. For winter wheat one such alternative could be an earlier sowing date.

Field trials established in southeast England during the 1980’ies showed that compared to winter wheat sown in October, wheat sown in September recovered more soil N, produced greater yields of grain and straw, and developed a greater root system (Barraclough and Leigh, 1984; Widdowson et al., 1987; Milford et al., 1993). In more recent studies on winter wheat grown in southern Sweden (Myrbeck et al., 2012), northwest Germany (Sieling et al., 2005) and eastern Denmark (Rasmussen and Thorup-Kristensen, 2016) grain yields appear to be only marginally improved by early sowing. Even if earlier sowing of winter wheat may reduce nitrate leaching and thereby substitute the effect of a dedicated nitrate catch crop, implementation of early sowing will only become widespread if wheat yields and N use efficiencies are improved.

Previous studies on the effect of early sowing have relied on N added in mineral fertilizers while studies testing the interaction between sowing date, use of animal manure and wheat cultivar could not be traced. Our objective was to examine the effect of sowing date for two contemporary winter wheat cultivars dressed with increasing rates of N in cattle slurry or mineral fertilizers. Over-winter N uptake, harvest yields, and concentrations of N in grain and straw were tested over two cropping seasons in the Askov Long-Term Experiment on Animal Manure and Mineral Fertilizers (Askov-LTE).
MATERIALS AND METHODS

Askov-LTE: Site and Experimental Layout

The Askov-LTE was established in 1894 on the Lermarken site at Askov Experimental Station, Denmark (55°28’N, 09°07’E). Annual precipitation, potential evapotranspiration and temperature are 862 mm, 543 mm and 7.7°C, respectively (1961-1990 averages). The soil is a light sandy loam derived from Weichselian glacial deposits (Nielsen and Møberg, 1984) and classifies as Ultic Hapludalf (Soil Survey Staff, 2014). The topsoil (0-20 cm) has 10% clay (<2 µm), 12% silt (2-20 µm), 43% fine sand (20-200 µm) and 35% coarse sand (200-2000 µm). Soil pH is maintained in the range 5.5-6.5 by addition of magnesium-enriched lime every four years. Sulphur is applied annually at a rate of 12.5 kg ha⁻¹.

The Askov-LTE includes four separate fields (termed B2-, B3-, B4- and B5-field) with a four course rotation of winter wheat (Triticum aestivum L.), silage maize (Zea mays L.), and spring barley (Hordeum vulgare L.) undersown with a grass-clover mixture that is used for cutting in the subsequent production year. The grass-clover crop includes lucerne (Medicago sativa L.), alsike clover (Trifolium hybridum L.), birdsfoot trefoil (Lotus corniculatus L.), perennial ryegrass (Lolium perenne L.), fescue (Festuca pratensis Huds.), and timothy (Phleum pratense L.). The four crops in the rotation are grown in a fixed sequence across the four fields; thus a given field grows only one crop in a given year. Crop protection measures (e.g. pesticides and weed killers) are applied when needed.

The main treatments of the Askov-LTE are unfertilized plots and plots receiving different rates (½, 1, 1½, 2 times the standard rate for a given crop) of nitrogen (total-N), phosphorus (P) and potassium (K) in animal manure (AM) or mineral fertilizer (NPK). One subsidiary treatment (1 PK) takes only P and K in mineral fertilizers. Averaged across the rotation (no additions to the grass-clover crop), 1 AM and 1 NPK corresponds to an annual input of 100 kg
Experiment with Early and Timely Sown Wheat

The present study was embedded in the B2-field (2011-2012) and the B5-field (2013-2014) using the nutrient treatments (Table 1): 1 PK (no N input), ½ NPK, 1 NPK, 1½ NPK, 2 NPK (2 NPK not present in B5-field), ½ AM, 1 AM, 1½ AM, and 2 AM (2 AM not present in B5-field). For winter wheat, nutrient level 1 corresponds to 150 kg total-N, 30 kg P and 120 kg K ha\(^{-1}\). Mineral fertilizers and cattle slurry were surface applied onto the growing crop in late March (Table 2). The grass-clover crop that precedes winter wheat in the rotation was sprayed with glyphosate after the final cut in August and the grass sward ploughed under one week later.

Each plot was then split into four subplots to accommodate two wheat cultivars (Hereford and Mariboss) and two sowing dates. A seedbed was prepared in August in two of the four subplots by harrowing and seeds of Hereford and Mariboss treated with Latitude\(^\text{©}\) (Monsanto, UK) against take-all (Gaemannomyces graminis) were sown in separate subplots (termed early sowing). The remaining two subplots were left undisturbed from ploughing until September. Then seedbeds were prepared as for early sowing and Hereford and Mariboss planted in separate subplots (termed timely sowing). The seeding rate targeted 225 and 350 seeds m\(^{-2}\) for early and timely sown wheat, respectively, and the distance between wheat rows was 12 cm. Table 2 shows the size of the
nutrient treated plots and the subplots subjected to different sowing date and wheat cultivars
together with dates for main field operations. Altogether, we employed 144 subplots in the B2-field
and 92 in the B5-field. Air temperature and monthly precipitation during the two experimental
periods are shown in Fig. 1.

The wheat was harvested at physiological maturity in August using a plot combine
harvester that allowed separate determination of grain and straw yields and left 5 cm of wheat
stubble.

Over-Winter Sampling of Wheat Biomass

To determine wheat N uptake during the autumn and winter periods, aboveground wheat biomass
(divided into green and wilted plant parts) of early and timely sown Hereford was sampled
sequentially at eight dates from late October to mid-March (Fig. 2) in three randomly selected
replicates of 1 NPK and 1½ NPK (only two replicates of 1½ NPK present in B5-field; Table 1).
Each sampling area was defined by a metal frame (610 x 65.4 cm) that was divided into eight
rectangles (50 x 60 cm). Shortly after wheat germination, one frame was placed on the soil surface
just outside the net area of each subplot. The frame covered four wheat rows. At eight dates during
autumn, winter and spring all green plant parts were cut in one randomly selected rectangle of each
frame. At the first sampling all wilted plant parts were removed. At the second sampling wilted
plant parts were removed from the seven rectangles leaving out the one where green plant parts had
been collected at the first sampling. This procedure continued until all eight rectangles had been
sampled. The wilted plant parts from each rectangle were bulked to one composite sample.
Green and wilted plant parts collected over-winter and grain and straw samples obtained at harvest
were dried at 80°C for dry matter (DM) determination and ball-milled subsamples were analysed
for N on a Flash 2000 Organic Elemental Analyzer. Soil contamination of plant samples collected
over-winter was determined as acid-insoluble ash after igniting subsamples at 550°C for 4 h. The
ash was subtracted from the measured biomass yield and the N concentration adjusted accordingly.

**Statistical Analyses and Calculations**

The experimental design in both fields (B2 and B5) was a split-block design with plot (nutrient
source and rate) and sowing date as main factors and wheat cultivar as sub-factor. The statistical
analysis applied the R-Project software package Version 3.1.1 (R Development Core Team, 2014).
All data analyses refer to individual year/field. Linear mixed effect models were used to test the
significance of sowing date (early and timely), nutrient source (AM and NPK), nutrient rate (½, 1,
1½ and 2), wheat cultivar (Hereford and Mariboss), and their interactions on wheat grain and straw
dry matter yields, N concentrations and N uptake using the lmer function of the lme4 package.
Management parameters were fixed effects while field strip (position in the field) and interactions
between field strip and plot, between field strip and sowing date, and between field strip, sowing
date and plot were set as random effects. This allowed us to account for the unbalanced design of
the B2- and B5-fields with different nutrient treatments having different number of replicates. The
significance of management parameters was assessed by ANOVA type III applying the Kenward

For plots dressed with NPK, a quadratic N response model was fitted to the grain yield
data:

\[ Y = aX^2 + bX + c \]
where $Y$ is the yield of field replicates (Mg grain ha$^{-1}$), $X$ is the amount of N applied (kg N ha$^{-1}$), and $a$, $b$ and $c$ are model parameters. Potential grain yield was estimated as the maximum of the function:

$$Y_{\text{max}} = -b/2a$$

For treatments with AM, a linear function was fitted to the wheat yield data as no yield maximum was reached. Nitrogen use efficiency (NUE) was calculated as kg grain N removed per kg total-N applied. For NPK treatments, NUE was calculated as the slope of a linear regression of average grain N yield against rate of N (up to 150 kg N ha$^{-1}$) due to non-linearity at higher N rates. For AM treatments, NUE was based on all N rates.

**RESULTS**

**Over-Winter Nitrogen Uptake**

In 2011-12, the N uptake in early sown Hereford grown in plots receiving 1 and 1½ NPK increased from around 10 kg N ha$^{-1}$ in late October to above 30 kg N ha$^{-1}$ in mid-March (Fig. 2). For timely sown wheat, the N uptake during the same period increased from 4 to 20 kg N ha$^{-1}$. The greater N uptake in early than in timely sown wheat accounted for 11 kg N ha$^{-1}$ at most samplings as an average of plots receiving 1 NPK and 1½ NPK. In 2013-14, over-winter N uptake was generally smaller but at most samplings the difference between early and timely sown wheat were as in 2011-12 (Fig. 2). The proportion of N found in wilted plant parts increased over-winter but differed between the two cropping years. In 2011-12, almost equal amounts of N were present in wilted and green plant parts (Fig. 2). The increased proportion of N in wilted plant parts is ascribed a cold spell in January and February 2012 when air temperature over a short period dropped to -12 °C (Fig. 1). The early sown wheat appeared to be more vulnerable to freezing than timely sown wheat. A
similar temperature drop did not occur in 2013-14 and the ratio between N in wilted and green plant parts was generally smaller and differed less between sowing dates.

Yields of Grain and Straw Dry Matter

The grain yield did not differ between the two cultivars and no interaction was found between sowing time and cultivar (Table 3). The potential grain yields for early sown wheat dressed with NPK and harvested in 2012 and 2014 were 7.7 and 7.6 Mg ha\(^{-1}\), respectively; the corresponding yields for timely sown wheat were 7.3 and 7.2 Mg ha\(^{-1}\). Grain yield responded very differently to N given in AM and in NPK (Fig. 3). While an optimum grain yield was found for NPK, grain yield increased linearly and no optimum was obtained with AM. Early sowing increased yields of grain and straw for AM as well as NPK treated wheat (Table 3; Figs. 3 and 4). The effect of early sowing was more prominent for wheat dressed with AM than for wheat given NPK and significant interactions between date of sowing and nutrient source was found for grain in both years and for straw also in 2014 (Table 3). The time of sowing did not significantly interact with N application rate neither for grain yield nor for straw yield. Interaction between sowing date, N rate and N source was generally absent (Table 3).

In both cropping years, the cultivar Mariboss yielded significantly more straw than Hereford (Fig. 4). For straw yields obtained in 2012, we found an interaction between cultivar and nutrient source (Table 3). Thus, Mariboss responded more to NPK addition than Hereford. The harvest index (grain yield divided by grain + straw yield) calculated across N application rates appeared higher for Hereford (0.55 in 2012 and 0.58 in 2014) than for Mariboss (0.53 in 2012 and 0.55 in 2014) but harvest index was not significantly affected by sowing date or N application rate (data not shown).
Nitrogen Concentrations and Uptake

Concentrations of N in grain and straw responded very differently to increasing rates of NPK and AM (Figs. 5 and 6). Increasing rates of NPK increased N concentrations in grain as well as in straw while N concentrations were little affected by rate of N in AM. Accordingly, the interaction between N source and N rate was highly significant for grain and straw N concentrations in both years (Table 3).

The time of sowing had much less influence on N concentrations in grain and straw than the N source (Fig. 5 and 6). Early sowing generally accomplished a slightly higher N concentration than timely sowing but changes were not significant for grain in 2014 (Table 3). While a significant effect of cultivar on concentrations of N in grain and straw was seen for wheat harvested in 2012, no effect was seen for the 2014 harvest.

Harvested grain removed 52 - 165 and 45 - 146 kg N ha\(^{-1}\) in 2012 and 2014, respectively, while straw removed 12 - 99 kg N ha\(^{-1}\) and 8 - 51 kg N ha\(^{-1}\) (Figs. 7 and 8). For wheat dressed with 75 to 225 kg N ha\(^{-1}\), straw accounted for 16 - 34 % of the total N removed at harvest. The N removal in grain and in straw was generally higher after early than after timely sowing (Table 3). Source and rate of N also had a significant influence on the amount of N removed wheat grain and straw at harvest. More N was harvested with NPK than with AM and the N uptake increased with increasing N rate (Fig. 7 and 8). In general, interaction between time of sowing, N source and N rate was not significant (Table 3) indicating that the different response to N rate for AM and NPK was not affected by sowing time.
DISCUSSION

Potential for Reduced Over-Winter Nitrogen Loss

One aim was to evaluate the potential of early sown wheat in reducing nitrate leaching. This was tested by measuring aboveground N uptake in the Hereford cultivar, grown on plots dressed with NPK close to crop-optimum N rate. Differences in plant N accumulation during the autumn and winter period are considered a valid indicator of changes in nitrate leaching losses (Myrbeck and Stenberg, 2014). In early December, we found that wheat sown in late August contained 18 – 22 kg N ha\(^{-1}\) in green and wilted plant parts; this was 11 kg N ha\(^{-1}\) more than held in wheat sown in late September. The increase in N uptake due to early sowing did not differ between the two NPK treatments reflecting the small differences in soil N (Table 1) and confirming that mineralization of soil N derived from previous applications of N in NPK has little impact on cereal yields and N offtake (Thomsen et al., 2003; Petersen et al., 2010, 2012).

Previous field trials in southern Sweden and eastern Denmark comparing winter wheat sown in late August/early September and late September showed comparable benefits of early sowing (6 to 13 kg N ha\(^{-1}\)) when plants were sampled in October and November (Myrbeck et al., 2012; Rasmussen and Thorup-Kristensen, 2016), and early sown wheat was found to reduce soil mineral N contents by up to 24 kg N ha\(^{-1}\). Studies in southeast England showed that wheat sown in September held more N (20 to 34 kg ha\(^{-1}\)) than wheat sown in October when sampled in early March (Widdowson et al., 1987); this difference was however reduced to 4 -14 kg N ha\(^{-1}\) at crop maturity. A subsequent study on similar sites (Milford et al., 1993) showed differences by early March of 10 – 20 kg N ha\(^{-1}\); this N benefit of early sowing remained until crop harvest. In our study, the N benefit of early sowing was established in the autumn, maintained over-winter and then increased during the subsequent growth period.
It is well documented that N uptake in fodder radish during the period from seeding in July/August until late November may exceed 50 kg N ha\(^{-1}\) (e.g. Li et al., 2015) but when used as nitrate catch crop before wheat sown in late September, N accumulation in radish range from 13 to 24 kg N ha\(^{-1}\) (Thomsen and Hansen, 2014). Thus, the potential benefit of fodder radish in reducing N leaching losses from under subsequent wheat aligns with that obtained by moving the wheat sowing date from late September (normal sowing date in NW Europe) to late August.

Any difference in the accumulation and retention of N in wheat and radish roots is not accounted for here, but the beneficial effect of sowing date may surpass that of fodder radish as the extra N recovered by early sown wheat is removed from the field at harvest. Thus, early sown wheat dressed with 150 kg N ha\(^{-1}\) removed 19 kg N ha\(^{-1}\) more in harvested grain and straw than timely sown wheat. In contrast, N retained from leaching by the radish is returned to the soil where the plant biomass becomes exposed to mineralization. Some of the mineralized N may be captured by the emerging wheat or lost by leaching and denitrification. Thomsen and Hansen (2014) found that the reduction in nitrate leaching obtained by catch crops was halved when catch crops were terminated before sowing of winter wheat instead of left until late autumn or early spring.

**Yield Benefits of Early Sowing**

Previous field studies under NW European conditions and using mineral fertilizers report somewhat diverging results on the effect of sowing date on wheat grain yields. Early studies show yield advantages ranging from -0.1 to +1.2 Mg ha\(^{-1}\) when wheat sowing is moved from late October to late September (Widdowson et al., 1987; Milford et al., 1993). More recent studies report maximum yield gains of 0.2 Mg grain ha\(^{-1}\) (Sieling et al., 2005; Rasmussen and Thorup-Kristensen, 2016). For a number of Swedish sites, grain yield benefits ranged from -0.6 to +0.6 Mg ha\(^{-1}\) when sowing date was moved from mid/late September to late August (Myrbeck et al., 2012).
For wheat dressed with NPK, we found that early sowing increased grain yield by 0.5 Mg ha\(^{-1}\). For AM the increase was 1.0 Mg ha\(^{-1}\) corresponding to the effect of adding 75 kg total-N ha\(^{-1}\) in AM. The benefit of early sowing remained the same regardless of fertilization rate (in 2012 up to 1 NPK). Thus, the foundation for the higher grain yield was established already in the early autumn. The present study cannot single out the mechanisms leading to higher yields but these may include a more extensive root system for early sown wheat (Barraclough and Leigh, 1984; Foulkes et al., 2009; Rasmussen and Thorup-Kristensen, 2016). The establishment of an extensive rooting depth before winter dormancy not only provides greater N uptake in the autumn but may also provide the wheat with a superior starting point when active growth commences in the spring. Differences in root length established early in the growth period have been found to be maintained throughout the growing season and to be positively related to grain yields (Barraclough and Leigh, 1984). An early sowing date may provide a longer vegetative growth phase with a prolonged pre-anthesis period and modifications in wheat N allocation and plant phenology. Thus Ferrise et al. (2010) found that the number of grains per spike was higher for early sown than for late sown durum wheat. We also found that straw yields were higher for early than for timely sown wheat, indicating that early sowing lead to a larger capacity for photosynthesis and storage of photosynthates. However, to provide a mechanistic explanation for the advantages of early sowing, the entire growth cycle from seeding to harvest needs to be examined in greater detail.

Averaged across harvest year, sowing time, source of N and N rate, Mariboss produced 0.5 Mg ha\(^{-1}\) more straw than Hereford. Similarly, Larsen et al. (2012) found straw yields of Mariboss to be higher than those of Hereford. In our study, straw yields were 0.7 Mg ha\(^{-1}\) greater for early than for timely sown wheat (averaged across cultivars, source of N type and N rate). When collected for producing thermal energy or cellulosic ethanol, larger straw yields are beneficial.
Milford et al. (1993) found straw yields to increase by 0.6 Mg ha\(^{-1}\) (range: 0.3 to 0.8 Mg ha\(^{-1}\)) when sowing of wheat was moved from mid-October to mid-September.

### Nitrogen Utilization

In the Askov-LTE, the N application rates are based on total-N. Consequently, wheat grown with AM receives less inorganic N than wheat grown with NPK, and AM plots showed lower yields of both grain and straw than corresponding NPK plots. Any background mineralization of soil organic N derived from previous AM additions appears not to fully compensate for reduced rates of plant available N supplied with AM early in the growing season. The N use efficiency (NUE) for wheat dressed with NPK ranged 0.42 - 0.53; for AM the NUE was 0.15 - 0.22 (Table 4). Thus, the mineral fertilizer equivalent of AM (NUE for AM divided by NUE for NPK) surface applied to wheat in late March averaged 0.37 (range: 0.33 to 0.42). This means that it only takes 37 kg N ha\(^{-1}\) in NPK to replace the effect of 100 kg total-N ha\(^{-1}\) applied with AM and indicates that a substantial part of the ammoniacal N present in AM at the time of application has been lost, most likely by ammonia volatilization (Webb et al., 2013).

The inferior effect of N in surface applied AM implies that even the highest rate of slurry (2 AM = 300 kg total-N ha\(^{-1}\)) only provided a yield corresponding to 111 kg N ha\(^{-1}\) added in NPK. This was reflected in grain and straw N concentrations. Thus, grain N concentration for wheat grown with AM was similar to that obtained for wheat grown on soil receiving only P and K (1 PK plots) and soil receiving 75 kg N ha\(^{-1}\) in NPK. The low N concentration provides poor grain quality in terms of protein (N concentration \times 6.25); for AM grain protein contents ranged from 8 to 9 %. In contrast, concentration of N in grain and straw increased almost linearly with increasing addition of N in NPK. When 150 kg N ha\(^{-1}\) was added in NPK, grain N concentrations averaged 16 mg N g\(^{-1}\) corresponding to a protein content of 10 %; this increased to 13 % when 225 kg N ha\(^{-1}\) was added.
In spring, the additional accumulation of N in early sown wheat averaged 11 kg N ha\(^{-1}\) for Hereford dressed with 1 NPK and 1½ NPK. This difference between early and timely sowing increased during the growing season and ranged at harvest from 14 to 26 kg N ha\(^{-1}\) in grain plus straw, suggesting a superior utilization in early sown winter wheat of fertilizer N added in spring and/or of N mineralized from the soil N pool during the growth period.

In both years, the amount of N removed in harvested grain and straw was significantly higher for early sown than for timely sown wheat. Early sown wheat removed up to 257 kg N ha\(^{-1}\) in 2012 and 196 kg N ha\(^{-1}\) in 2014; the corresponding values for timely sown wheat were 241 and 187 kg N ha\(^{-1}\). The N cycle of agroecosystems is more leaky than that of natural ecosystems (Christensen, 2004) and any cropped soil will be subject over-winter leaching losses of N. Considering the amount of N removed in the present study in harvested grain and straw, the overall N balance of the wheat crop at yield optimum most likely becomes negative suggesting a decrease in the soil organic N pool.

**Practical Implications for Wheat Production**

There are a number of practical implications of early sowing. The seeding rate should be adjusted according to sowing time. A reduced seeding rate at early sowing provides a less dense wheat plant canopy and may reduce early-season attacks by fungi such as mildew and eye spot (Jørgensen et al., 1997). Nevertheless, early sowing may well call for a larger effort in terms of crop protection against weeds, pests and plant diseases. We maximized crop protection by using reduced seeding rate, Latitude treated seeds, relevant wheat cultivars, and by adopting a preventive plant protection scheme.

When wheat is sown in late August, the time window between harvest of the previous crop and sowing of the subsequent wheat crop will be narrow. The practical implication is less time
to prepare for the establishment of an early sown wheat crop which may call for greater capacity in terms of farm machinery and manpower. This practical implication also has to be factored in when evaluating the benefits of early sowing.

CONCLUSIONS

Our study showed distinct yield and N uptake benefits of moving winter wheat sowing from late September to late August. This was true for grain as well as straw yields. The effect of early sowing in reducing N leaching losses may surpass that obtained by establishing a nitrate catch crop before timely sown wheat. However, we also found that surface application of AM in late March provided poor N use efficiency and reduced grain protein compared to that of N applied in NPK.

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Statistikbanken. 2016. Det dyrkede areal efter enhed, område, afgrøde og tid (The cropped area related to area unit, region, crop type and year; in Danish).

http://www.statistikbanken.dk/


**Figure legends**

Fig. 1. Air temperature and monthly precipitation at Askov Experimental Station during the two experimental periods (2011-2012 and 2013-2014).

Fig. 2. Nitrogen in aboveground plant parts of early and timely sown Hereford wheat sampled during late October to mid-March. The wheat was grown in the B2-field (2011-2012) and the B5-field (2013-2014). N in green = N in green plants parts; total-N = N in green and wilted plant parts. Error bars are +/- 1 SEM (Standard Error of the Mean).

Fig. 3. Grain yields of early and timely sown wheat grown in the B2-field (2012 harvest) and the B5-field (2014 harvest) with increasing rates of N in mineral fertilizer (NPK) or animal manure (AM). Values are mean of Hereford and Mariboss cultivars and error bars are +/- 1 SEM.

Fig. 4. Straw yields of early and timely sown Hereford and Mariboss wheat cultivars grown in the B2-field (2012 harvest) and the B5-field (2014 harvest) with increasing rates of N in mineral fertilizers (NPK) or animal manure (AM). Error bars are +/- 1 SEM.

Fig. 5. Concentrations of N in grains from early and timely sown Hereford and Mariboss wheat cultivars grown in the B2-field (2012 harvest) and the B5-field (2014 harvest) with increasing rates of N in mineral fertilizers (NPK) or animal manure (AM). Error bars are +/- 1 SEM.

Fig. 6. Concentrations of N in straw from early and timely sown Hereford and Mariboss wheat cultivars grown in the B2-field (2012 harvest) and the B5-field (2014 harvest) with increasing rates of N in mineral fertilizers (NPK) or animal manure (AM). Error bars are +/- 1 SEM.
Fig. 7. Removal of N in grain from early and timely sown Hereford and Mariboss wheat cultivars grown in the B2-field (2012 harvest) and the B5-field (2014 harvest) with increasing rates of N in mineral fertilizers (NPK) or animal manure (AM). Error bars are +/- 1 SEM.

Fig. 8. Removal of N in straw from early and timely sown Hereford and Mariboss wheat cultivars grown in the B2-field (2012 harvest) and the B5-field (2014 harvest) with increasing rates of N in mineral fertilizers (NPK) or animal manure (AM). Error bars are +/- 1 SEM.