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Promilleafgiftsfonden for landbrug

Nitrogen utilisation efficiency varies between different soil types

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Background

Danish recommended rates of nitrogen (N) application to cereals are based on the economic optimum, i.e. the fertiliser N application rate where the economic value of the marginal yield just covers the cost of the last applied kg of N. These recommended N rates are surprisingly similar across soil types, despite yields being significantly higher on the loamier soils compared to sandy soils. For instance, the Danish recommended N application rate for winter wheat is 179 kg N ha^{-1} on coarse sand and 212 kg N ha^{-1} on sandy clay loam, but the expected yield on coarse sand is only 54 hkg ha^{-1} compared to 86 hkg ha^{-1} on sandy clay loam. The same pattern holds true for spring barley, winter barley and winter rye. This suggests that the nitrogen use efficiency (NUE) that can be obtained in practical agriculture differs between soil types. This brief report addresses this question, based on an analysis of a larger set of N response field trial data from Denmark.

Dataset

The analysis was performed on two datasets, one containing 626 spring barley trials and one containing 1049 winter wheat trials. Both datasets contain field trial data on the yield response to increasing nitrogen application. Application rates in winter wheat trials span from 0 to 300 kg N ha^{-1}, typically in increments of 50 kg N ha^{-1}, albeit before 2015 most trials had a maximum application rate of 250 kg N ha^{-1}. In spring barley trials application rates span from 0 to 200 kg N ha^{-1}, typically in increments of 40 kg N ha^{-1}.

The winter wheat dataset consists of 1049 individual trials carried out from 1987 to 2018. The spring barley dataset consists of 626 individual trials carried out from 1987 to 2018. The experiments were all carried out as part of the Danish National Field Trial System, which conducts farmer-field trials in commercial farms from all over Denmark. Therefore the different trials differ in cropping and fertilizations history, and consequently in the amount of nitrogen supplied from the soil organic nitrogen pool during the growing season. In order to minimize the effect of previous history the analysis was carried out on a subset of data which fulfilled the criteria listed below:

- Nitrogen yield in harvested grain = had to be measured (typically using NIR-analysis)
- Previous crop = Wheat, barley, rye or triticale
- Economically optimal nitrogen application rate >50 kg N ha^{-1}
- Soil mineral nitrogen content in spring < 50 kg N ha^{-1}
- Soil type had been determined by measurement (0-25 cm depth)
- Number of trials carried out on same soil type >10

Excluding the data that did not fulfil the selection criteria left 351 winter wheat trials and 155 spring barley trials. The total number of observations of harvested nitrogen in grain in the two datasets were 1987 observations of winter wheat and 874 observations of spring barley. The distribution of trials on different soil types is shown in table 1. Soil types are based on top soil (0-25 cm) texture and corresponds to the classification of soil types used in the Danish regulatory system.

Table 1. Total number of field trials at each soil type

	Coarse sand	Fine sand	Sandy loam	Sandy clay loam	Clay	Organic	Total
Winter wheat	28	63	148	112	0	0	351
Spring barley	50	45	38	22	0	0	155

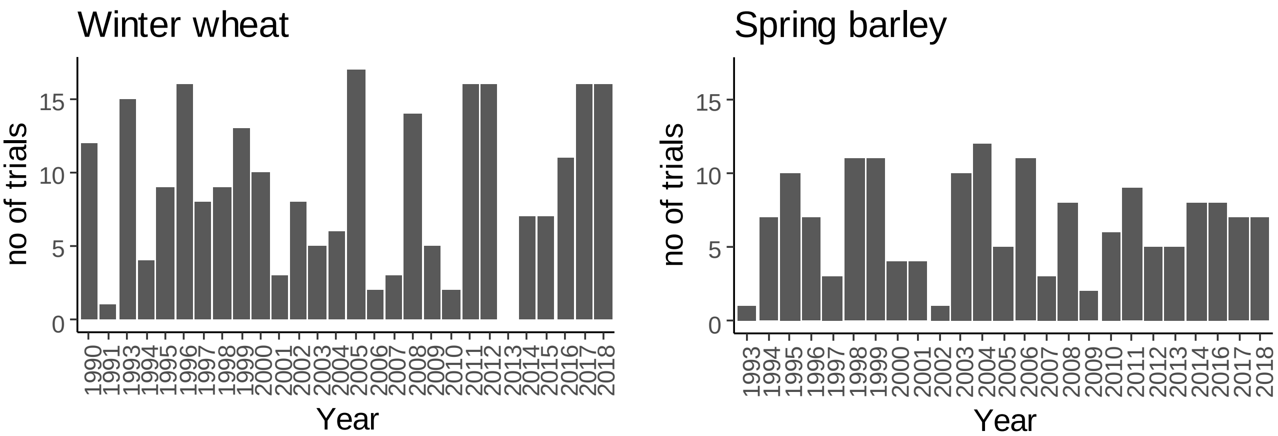


Figure 1. Number of trials in winter wheat and spring barley for each year. Note that the first winter wheat trials included in the analysis were carried out in 1990, while for spring barley no trials before 1993 fulfilled the selection criteria.

The number of trials in each year is shown in Figure 1. Although the number of trails vary between years, there is no systematic change in the number of included trials over the study period.

Application of manure in previous years can increase soil fertility through mineralization of organic nitrogen from the added manure. This effect can last for several years following manure application. The mineralization potential of the soil in each trial was estimated from manure application in previous years. Briefly, the nitrogen mineralization in the harvest year was calculated as a percentage of the sum of the amount of total N applied in manure for each of the 5 years prior to the harvest year. The percentage of total N mineralized in each year after application is shown in Table 2. Information about manure application in previous years was collected for each trial site from farmers nutrient management plans or in a few cases from interview data.

Table 2. Proportion of total manure N applied mineralized in each year after application

	Pig slurry % of TN mineralized	Cattle slurry % of TN mineralized
1st year	4	6
2nd year	2	3
3rd year	2	2
4th year	1	2
5th year	1	2
Total	**10**	**15**

The calculated manure N mineralization effect for the four different soil types in the dataset is shown in Figure 2. The calculated mineralization, and thus the nitrogen supply for the crop, was slightly higher on sandy soils than on loamy soils. This is likely due to the fact, that the Danish livestock production is concentrated in the areas of Denmark with more sandy soils. However, the average difference between soil types was not more than 3-5 kg N ha^{-1}. The differences in soil nitrogen mineralization from differences in manure application in these subsets of data are thus negligible and will not be considered in the subsequent calculation of NUE in this report.

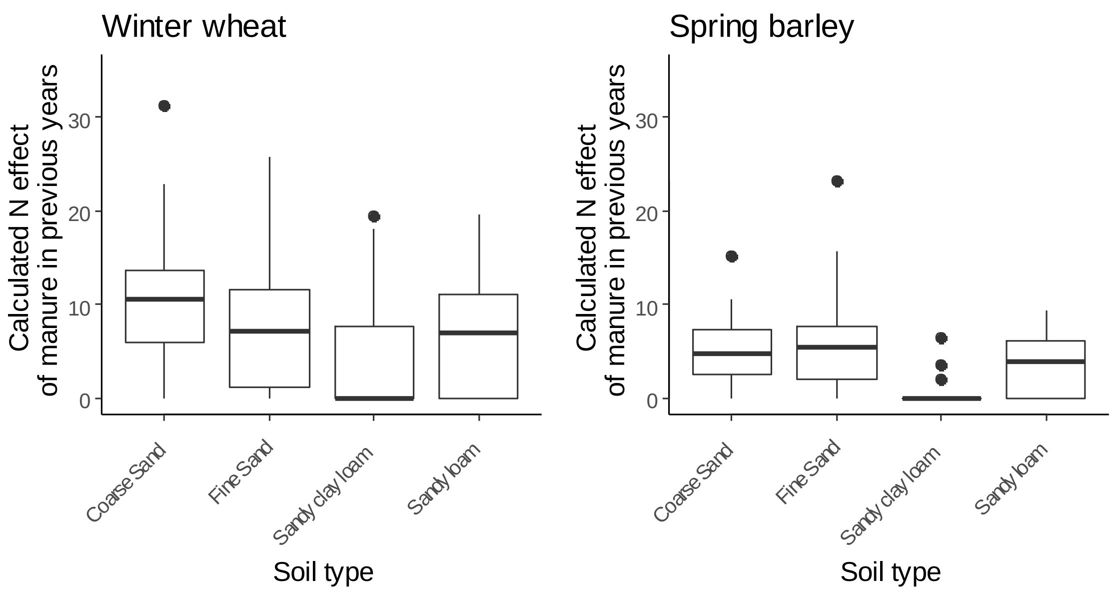
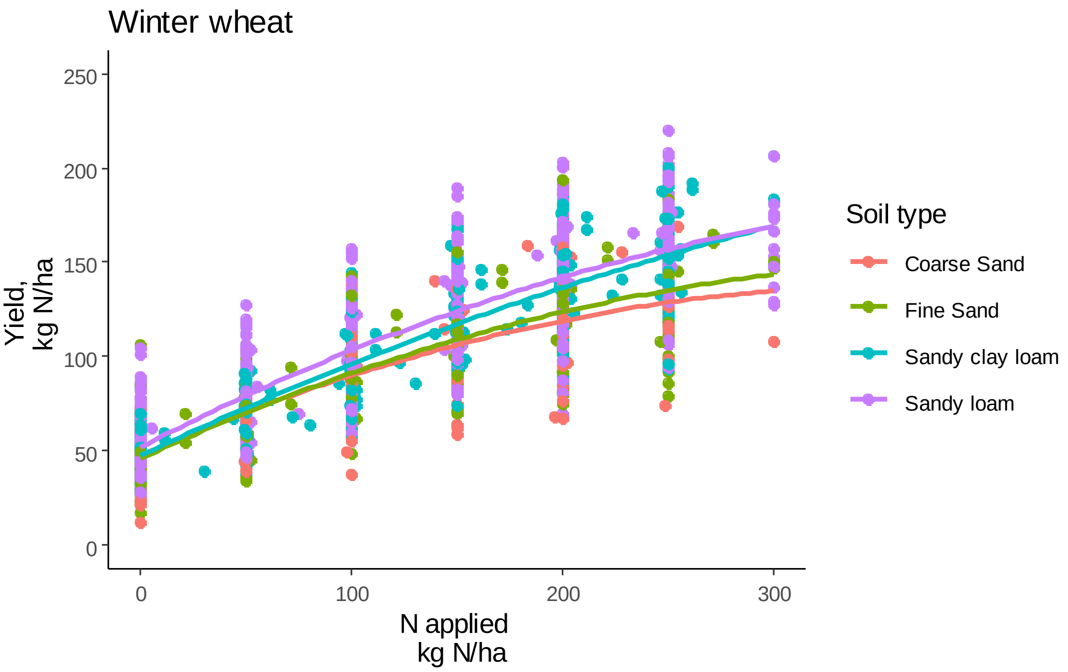


Figure 2. Box plots of calculated nitrogen mineralization from manure application in five years prior to the harvest year.

Yield response

Nitrogen uptake in the grain continued to respond all the way up to an N application rate of 300 kg N ha^{-1} in winter wheat and 200 kg N ha^{-1} in spring barley (Figure 3). For winter wheat, nitrogen yields were similar at all soil types at low nitrogen application rates, but at an N application rate of above 100 kg N ha^{-1}, nitrogen yields were slightly higher for loamier soils. For spring barley, nitrogen yields were higher at the loamy soils at all application rates.

It should be noted that yield in the analysed field trials are typically 10-15% higher than the yields obtained in commercial agriculture. No correction have been applied to normalise the yields to national average yields.



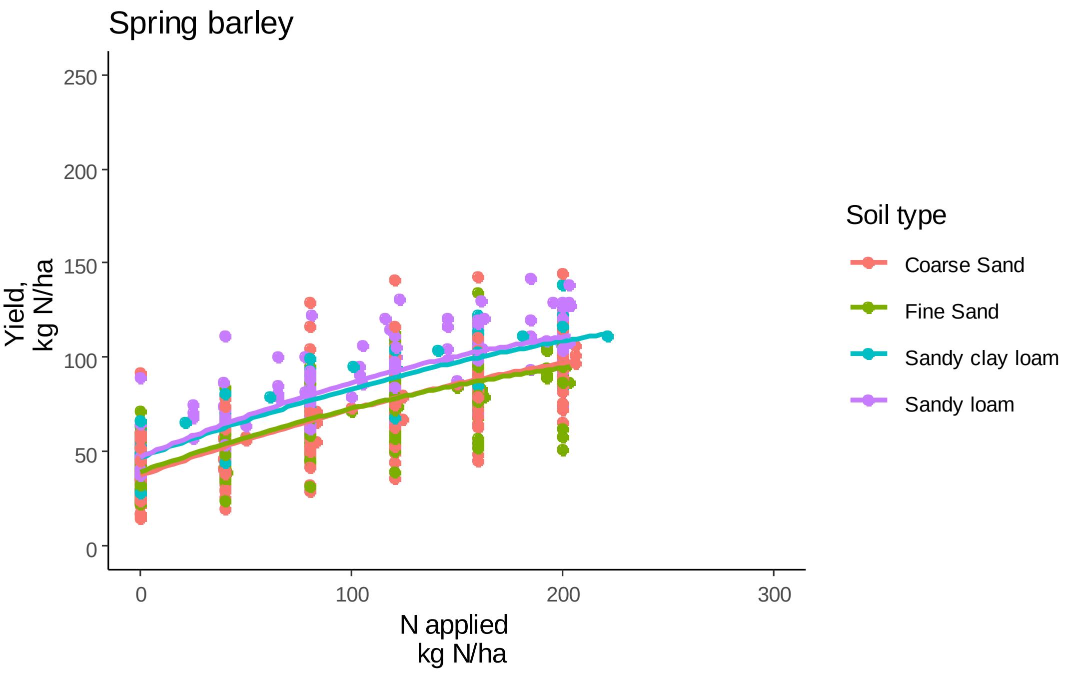


Figure 3. Nitrogen yield in harvested grain in field trials in winter wheat and spring barley as a function of nitrogen application rate.

Nitrogen use efficiency

Nitrogen use efficiency **(**NUE) was calculated according to the EUNUP guidelines (EU Nitrogen Expert Panel, 2016). Briefly, NUE was defined as:

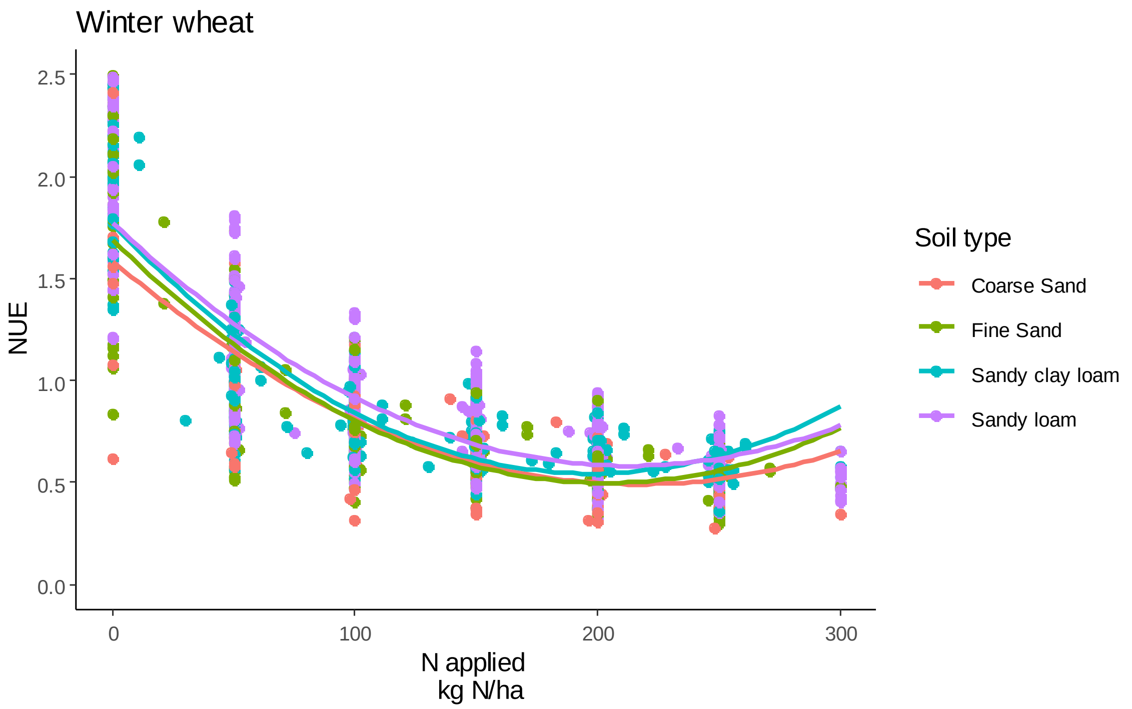
NUE = N-harvest / N-input

N-harvest was defined as the harvested N in grain. Essentially this corresponds to assuming that all straw is incorporated back into the soil after harvest. Regardless of the actual use of straw, for the purpose of comparing NUE between soil types, the same use of straw should be assumed in all trials. Since straw N yield was not measured, assuming that straw is removed is the most accurate way of comparing NUE in these trials.

N-input was calculated as mineral fertiliser N applied + atmospheric N deposition + N in seed

Relative national average atmospheric nitrogen deposition from 1990 – 2017 was obtained from Ellerman et al. (2019) These were recalculated to absolute values using the 2017 annual nitrogen deposition of 56.000 tons year^{-1} for the total Danish land area estimated by Ellerman et al. (2019). National average area specific nitrogen deposition has decreased from 21 kg N ha^{-1} y^{-1} in 1990 to 13 kg N ha^{-1} y^{-1} in 2017. No data is available for 2018, however, for this analysis, it is assumed that the nitrogen deposition for 2018 is equal to 2017. Nitrogen deposition from 2015 to 2017 have been in the range of 13 – 14 kg N ha^{-1} y^{-1}.

Nitrogen from seed grain was assumed to be 2.3 kg N ha^{-1} y^{-1} for both spring barley and winter wheat. This corresponds to seeding rates of approximately 160 kg ha^{-1}. Seeding rates are not recorded in the datasets.



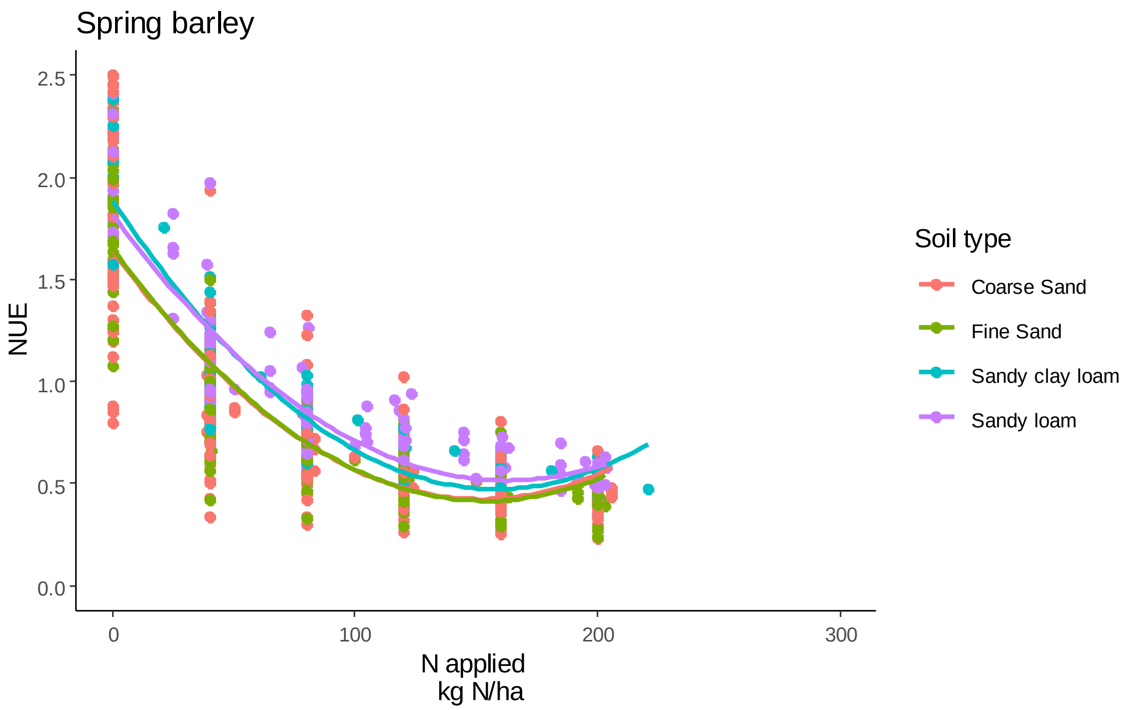


Figure 4. NUE in field trials with winter wheat and spring barley at different N application rates. Note that all NUE at the application rate 0 N is not shown since some are above 2.5.

NUE is slightly higher on loamier soils than at the sandy soils at all application rates for both winter wheat and spring barley (Figure 4). It was tested whether this difference was significant at relevant nitrogen application rates, i.e. 190-210 kg N ha^{-1} for winter wheat, and 140-160 kg N ha^{-1} for spring barley. This was done by a linear model which tested whether NUE differed between soil types, and which included a random effect of trial year on the intercept, in order to take account of differences in growing conditions between trial years. For both winter wheat and spring barley there was a significant effect of soil type on NUE ($p<0.001$). Pairwise comparisons showed that coarse and fine sand was significantly different from sandy loam and sandy clay loam, while the sandy and loamy soils had similar NUE (Table 3 and Figure 5). NUE was approximately 0.1 to 0.07 lower on sandy soil compared to the loamy soils for winter wheat and spring barley, respectively.

Tabel 3. NUE on different soil types at 190-210 kg N ha^{-1} for winter wheat and 140-160 kg N ha^{-1} for spring barley as estimated marginal means. Similar letters denote that soil types are not significantly different. Pairwise comparison performed with Tukey's adjustment for multiple comparisons

	Winter wheat	Spring barley
Coarse sand	0.55 a	0.49 a
Fine sand	0.58 a	0.50 a
Sandy loam	0.66 b	0.58 b
Sandy clay loam	0.65 b	0.57 b

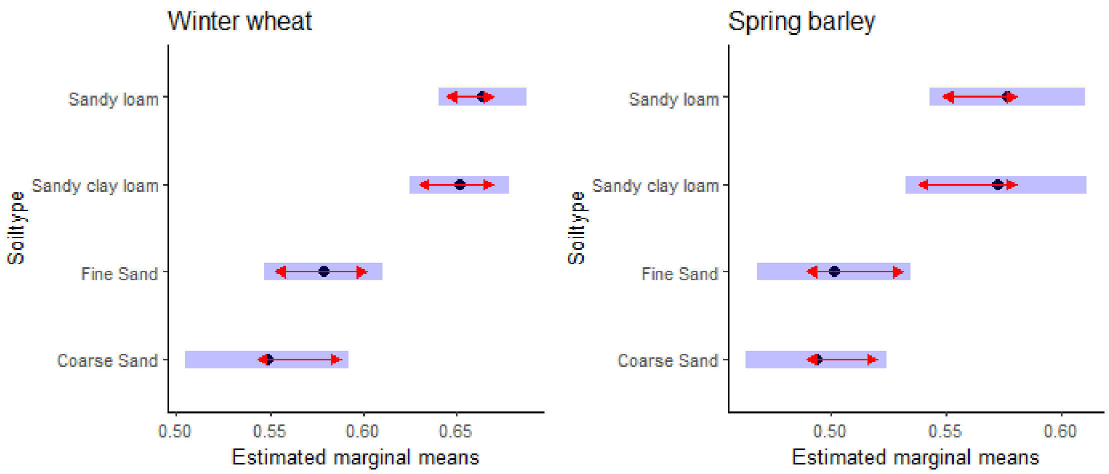


Figure 5. NUE on different soil types at 190-210 kg N ha^{-1} for winter wheat and 140-160 kg N ha^{-1} for spring barley as estimated marginal means. The blue area denotes confidence intervals for estimated marginal means. Non overlapping red arrows denote that there is a significant difference between the NUE at the contrasting soil types.

In Danish farmers nutrient management plans the recommended N application rate is adjusted for previous cropping, effect of manure in previous years and leaching in the previous year (higher or lower than in a normal year). This 'adjusted recommended N rate' is what the farmer is recommended to use in the field and is obligated to use in his nutrient management plan. The NUE at this application rate is thus the relevant NUE in practical agriculture. Therefore, it was tested if NUE was different between soil types at the adjusted recommended rate. Results are shown in Table 4 and Figure 6. It is evident, that the difference in NUE between soil types is less clear when NUE at the adjusted recommended rate is considered, however, it is evident that the NUE is approximately 0.07 to 0.1 lower on coarse sand compared to the loamy soils. NUE at the adjusted recommended rate on fine sand is less different from the loamy soils than when fixed application rates are considered. There may be two reason for this pattern. Firstly, the average adjusted recommended application rate is slightly lower at fine sand than at coarse sand, leading to NUE being calculated at a slightly lower nitrogen application rate (Figure 7). Secondly, the trials in this analysis are only characterised by topsoil texture, and the underlying soils of the fine sand sites can be either sandy or loamier. The yield at fine sand sites with underlying loamy soils can be equivalent to the yield on loamy soils. These two factors will both increase NUE and explain why NUE at fine sand is higher at practical N application rates.

Tabel 4. Groupings from pairwise comparisons of NUE at the adjusted recommended rate on different soil types. Similar letters denote that soil types are not significantly different. Pairwise comparison performed with Tukey's adjustment for multiple comparisons (350x250)

	Winter wheat	Spring barley[1]
Coarse sand	0.52 a	0.49 a
Fine sand	0.59 ab	0.56 b
Sandy loam	0.63 b	0.62 b
Sandy clay loam	0.59 ab	0.58 b

[1]Model residuals for both fixed and random factor does not fulfil the assumption of normality

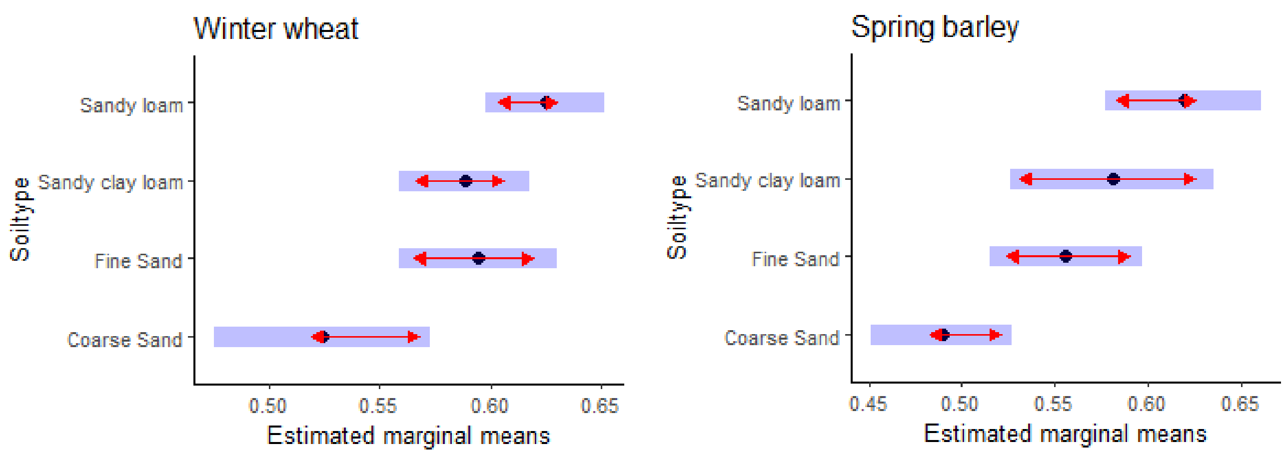


Figure 6. NUE on different soil types at 190-210 kg N ha^{-1} for winter wheat and 140-160 kg N ha^{-1} for spring barley as estimated marginal means. The blue area denotes confidence intervals for estimated marginal means. Non overlapping red arrows denote that there is a significant difference between the NUE at the contrasting soil types. Note that the model for spring barley does not fulfil the assumption of normally distributed residuals.

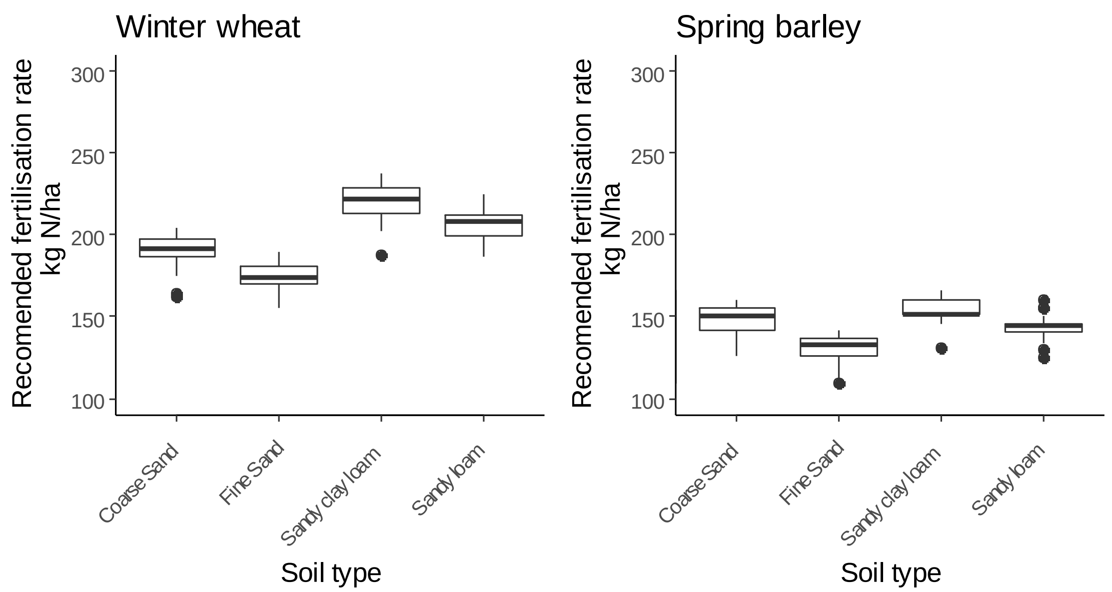


Figure 7. Box plot of adjusted recommended application rates in the field trials.

Conclusions

This analysis of Danish national farmer-field trials with winter wheat and spring barley demonstrates that NUE was approximately 0.05 to 0.1 lower on sandy soils compared to sandy loam or sandy clay loams.

However, when proper nitrogen management is performed by adjusting the recommended N rate based on previous cropping and fertilization history, the main difference is between coarse sand and other soil types.

References

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