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EFFECTS OF THE MACHINE WHEEL LOAD ON GRASS YIELD

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ABSTRACT Heavy traffic has been shown to have a negative influence on the yield of grass and clover. A full scale grass-clover field trial was established to estimate the effect on clover-grass yields as a function of different wheel loads and tire pressures. The trial comprised 4 different traffic combinations (load and tire pressure) with 35 replicates and 1 traffic free treatment with 245 replicates. The yield in fresh grass was analysed in a linear model that included the effect of traffic intensities, a block effect describing the history of the field, the harvest date, the effect of the location, the effect of mean altitude, the effect of the mean of the EM38-meausremnt and the distance to wood, trees and hedge close to the north, south and east border of the field. No significant interactions were found between time of crop and soil damage and wheel load and tire pressure. However, there was a significant effect of the wheel load in terms of the yield being lower using a wheel load of 4745 kg than for a wheel load of 2865 kg and for all 3 times of load application.

Keywords: Traffic, Tyre inflation pressure, Clover/grass, Yield loss, Auto Steering.

INTRODUCTION Conventional grass-clover crops for silage production is subjected to a high number of passes during the growing season as a result of, for instance, fertilization using slurry tankers (Misselbrook et al., 1996) and multiple passes in material handling operations, such as cutting, racking, collecting, chopping, and transporting. This series of operations typically takes place 3-5 times during a growth season (Misselbrook et al., 1996).In most cases, the traffic is uniformly distributed within the field and the whole filed area is subjected to traffic (Douglas & Crawford, 1991). Traffic has shown to have a significant influence on crop growth through direct damages (Jorajuria et al., 1997; Jorajuria & Draghi, 1997; Chamen et al., 1992) and through modifications of soil physical properties (Hamza & Anderson, 2005; Raper, 2005). For grass and especially clover, the yield is negatively related to traffic (e.g. Frost, 1988a) indicating that the soil compaction may be a significant problem for the forage production. Traffic induced compaction has adverse effects on bulk density of the soil, mechanical impedance, porosity and hydraulic conductivity (Hamza & Anderson, 2005) which may reduce root penetration, water extraction and plant growth (Taylor, 1983).

The increasing weight and sizes of modern machinery makes the risk of soil and crop damages even more eminent and therefore, this study was conducted to supplement existing results from using lighter machinery (Frost, 1988a; Frost, 1988b) to include the ramifications of using heavier machinery and ensuring an updated decision support to farmers.

METHODS

Site and location The field where the studied operations took place was located at the Organic Research Centre Rugballegaard, Denmark ([55.864067° N, 9.800732° E]). The area of the field was approximately 14.5 ha and it was grown with a grass-clover mixture consisting of 32% tetraploid perennial ryegrass, 50% diploid perennial ryegrass, 10% red clover, and 8% white clover. The applied field had earlier been grown as two fields separated by a field path. The area corresponding to the former field path was excluded from the experimental area. Likewise, headland passes of a total width of 18 m peripherals of the field was also excluded from the trial. Electro Magnetic (EM38) measurements were performed to assess the spatial variability of the soil texture in the field (McNeill, 1980). The centre coordinates of each plot were recorded for use in the statistical analysis together with the altitude and the EM38 measurements.

Establishment of the crop The grass-clover crop was established in early April 2007 using Autofarm Autosteer RTK-GPS auto steered tractors (Figure 1). The used equipment was re-built to an extended wheel spacing to eliminate soil compaction during establishment, thereby allowing the plots to be left un-trafficked since august 2006. Furthermore, the plots were turned 35 degrees to minimize the risk of bias errors from old traffic lanes. The establishment procedure consisted of first a harrowing to 10-12 cm depths with a tine harrow, followed by a harrowing to 8-10 cm depths with a wing-tine harrow. Then the crop was seeded with a Nordsten kultiseeder 3030 and rolled with a concrete roller.

Figure 1. The tractor and seed used for establishment of the clover-grass crop in spring 2007. The tractor has been equipped with an RTK-GPS auto steering, making it possible to make a very precise establishment, with no traffic affecting within the plot.

Experimental design Each net plot measured 9 x 1.5 m and the treatments were completely randomized onto the field. The plots were placed in pairs where the distance between the two plot centres was 3 m. The 4 treatments were performed in 2008.

Traffic simulations A Claas Axion tractor equipped with RTK-GPS auto steering and a 15 m^3 Kimadan slurry tanker mounted on two axels were used to perform the simulated traffic treatments in the plots. Figure 2 shows the used machine combination indicating that all 4 axels of the tractor and slurry trailer would traverse each plot affecting the centreline of the plot in the longitudinal direction. The specific load of each wheel for the low load simulation amounted to 2805 kg for the tractor front wheel load, 2865 kg for the tractor rear wheel load, 1775 kg for the trailer front wheel load, and 1760 kg for the trailer rear wheel load. Contrasting to that, the specific load of each wheel for the high load simulation mounted to 2335 kg for the tractor front wheel load, 4745 kg for the tractor rear wheel load, 4435 kg for the trailer front wheel load, and 4435 kg for the trailer rear wheel load.

The tyre specifications were: Tractor front – Michelin 540/65R30 Miltibib; Tractor rear – Michelin 650/65R42 Multibib; Trailer front and rear – Allianca 700/50-30.5 Flotation.

Each traffic was defined as a combination of tyre inflation pressure (100 kPa or 250 kPa) and wheel load (3 Mg or 5 Mg, and a treatment without traffic were carried out (Table 1). At the time of harvesting, the reference treatment (without traffic) was replicated 242 times.

Figure 2. The tractor and slurry trailer used to affect the crop with different traffic intensities.

Yield measurements The harvesting operation was performed using a Haldrup plot harvester modified with aRTK-GPS system used on the tractors. The working width of the harvester was 1.5 m and the plots were harvested at 2 times (May 14th and 15th 2008). The harvest yield was converted from kg plot^{-1} to Mg ha^{-1}, and no adjustment was done for water content.

Statistical analysis The yield in fresh grass (Mg ha^{-1}) was analysed in a model that included effect of treatment, block effect describing the difference between the previous two fields, harvest date, effect of location, effect of altitude, effect of measured EM38, and the distance to forest and hedges close to the north, south and east border of the field. The model may mathematically be written as:

$$Y_i = \mu + \alpha_{t(i)} + \beta_{b(i)} + \gamma_{d(i)} + \delta_1 x_i + \delta_2 x_i^2 + \delta_3 y_i + \delta_4 y_i^2 + \delta_5 x_i y_i + \tau_1 z_i + \tau_2 z_i^2 + \lambda_1 n_i + \lambda_2 s_i + \lambda_3 e + \eta_1 m_i + \eta_2 m_{i\,i}^2 + E_i$$

where

Y_i is the recorded and normalised yield from plot *i*

x_i and y_i ist the center coordinate of plot *i*

z_i is the nean altitute of plot *i*

n_i, s_i and e_i is the logarithm of the distance to wood, trees and hedge in the north, south and east direction

$\mu, \alpha_{t(i)}, \beta_{b(i)},$ and $\gamma_{d(i)}$ is the intercept, the effect of the factors: treatment, block and harvest day

$\delta_1 - \delta_5$ is the linear and quadratic effects of the coordinates and the interaction between the coordinates

τ_1 and τ_2 is the linear and quadratic effect of the mean altitude

λ_1, λ_2 and λ_3 is the linear effect of logaritmic distance to tree in the north, south and east direction

η_1 and η_2 is the linear and quadratic effect of the mean EM38 recordings

E_i is the random effect of plot *i*, which is assumed to be independent and normal distributed with mean zero and constant variance, σ^2.

The variation caused by variation in soil properties was estimated as the joint effect of blocks, coordinates, altitude, distance to trees and EM38 measurements assuming that all plots were traffic free:

$$P_i = \mu + \alpha_1 + \beta_{b(i)} + \delta_1 x_i + \delta_2 x_i^2 + \delta_3 y_i + \delta_4 y_i^2 + \delta_5 x_i y_i + \tau_1 z_i + \tau_2 z_i^2 + \lambda_1 n_i + \lambda_2 s_i + \lambda_3 e_i + \eta_1 m_i + \eta_2 m_i^2$$

In a similar way, the yield caused by the location of each plot was predicted using information about the location of each plot (i.e. by leaving out the two last terms).

All analyses were performed using the mixed procedure of SAS (SAS, 2009) and the parameters were estimated and tested using the method of restricted maximum likelihood (REML).

RESULTS The EM38 measurements varied between 2.6 and 23.0 mS m^{-1} or millisiemens per meter. Both the lowest and highest values were found in the north half of the field.

The first statistical analyses revealed two plots with very deviation results, which where excluded from further analyses.

An attempt was made to improve the model allowing the random effect, E_i to be spatially correlated using different model, but this did not improve the model.

Yield losses The analyses showed significant effect of the treatment and that the yield in the field depended on the location of the plot (*x* and *y* coordinates and altitude) and the distances to trees as well as the treatment history of the two fields (block effect), the EM38 recording and the day of harvest (Table 2).

Table 1 Applied treatment at second harvest, second year

<table>
<tr><th>Treatment</th><th>Treatment explanation</th><th>Wheel load, Mg</th><th>Tyre inflation pressure, kPa</th></tr>
<tr><td>1</td><td>No traffic. Reference</td><td></td><td></td></tr>
<tr><td>11</td><td rowspan="4">Before 1st harvest in 2nd year
Slurry application simulation 2</td><td rowspan="2">5</td><td>100</td></tr>
<tr><td>12</td><td>250</td></tr>
<tr><td>13</td><td rowspan="2">3</td><td>100</td></tr>
<tr><td>14</td><td>250</td></tr>
</table>

Table 2 Analysis of variance table and additional contrasts after the model has been reduced

Effect	Numerator degree of freedom	Denominator degree of freedom	F-value	Pr > F
Block	1	707	16.21	<.0001
X	1	707	6.04	0.014
x^2	1	707	3.39	0.07
Y	1	707	17.72	<.0001
y^2	1	707	64.93	<.0001
EM38	1	707	33.68	<.0001
$EM38^2$	1	707	18.85	<.0001

Altitude	1	707	13.46	0.0003
Altitude^2	1	707	29.57	<.0001
Log distance to forest, North	1	707	35.76	<.0001
Log distance to tree, South	1	707	35.73	<.0001
Log distance to hedge, East	1	707	7.69	0.006
Contrasts				
Wheel load	1	707	9.06	0.003
Tyre inflation pressure	1	707	0.09	0.76
Wheal load×tyre inflation pressure	1	707	1.30	0.26

[a)] Test of net loss of damaging different individual areas in stead of damaging the same area two or four times
[b)] Test for additive effect for repeated treatment of the same area

The adjusted average yields of all treatments are shown in Table 3 – together with an indication of the treatments that are significantly different. The average yield of plots with no subjection to traffic was 23.3 Mg ha^{-1}. None of the treatments involving traffic had an average yield that was significant larger than that. All treatments involving traffic and carried out in the year of harvest or carried out more than once had yields that were significantly lower than the treatment involving no traffic.

Table 3 Effect and standard deviation for each treatment

Treatment no	Time	Wheel Load, kg	Tyre Inflation Pressure, kPa	Estimate, Mg ha^{-1}	Standard error, Mg ha^{-1}	Significant differences[a]
1	-	-	-	23.3	0.19	a b
11	D	4745	100	18.2	0.53	f g
12	D	4745	250	18.7	0.49	e f g
13	D	2865	100	20.0	0.52	d e
14	D	2865	250	19.5	0.52	e f

[a)] Treatments with same letter(s) are not significant different at the 5% level using t-tests

The analysis showed that there were no significant interactions between the factors wheel load and tyre inflation pressure (all P-values larger than 0.2567) – and also there was no significant effect of tyre inflation pressure (P=0.7624). Thus, the effects can be summarised by the main effect of treatment? time and wheel load (Table 2). There was a significant effect of wheel load. At all times, the yield was lower using a wheel load of 5 Mg than for a wheel load of 3 Mg.

The negative effect of compacting the same area by the application of two slurry applications was significant greater than compacting the same area by the application of two harvests (Table 2). Further use of the same track (at two harvesting and two slurry applications) further decreased the yield (Table 2).

The soil texture showed a large variability in the experimental field indirectly indicated by the EM38 or soil conductivity measured within each parcel. The predicted yield for traffic free treatment in all plots varied between 16 and 35 Mg ha^{-1}. A large part of this variation could be identified as being dependent on the location of the plot – coordinates, altitude and distance to trees. Also the EM38 recordings explained a large part of the variation in the data as the contribution for these recordings varied between approximately -2.5 and 2.0 Mg ha^{-1}.

The yield depended significantly on the day of harvest and was estimated to be 1.4 Mg ha^{-1} larger in average (SE=0.32 Mg ha^{-1}) on the second day of harvest than on the first day of harvest.

The inclusion of the covariates reduced the residual standard deviation from 3.8 Mg ha^{-1} to 2.8 Mg ha^{-1} Average standard errors on pair wise treatment comparisons were reduced by approximately 25% by inclusion of the covariates in the analysis.

DISCUSSION Especially grass has a high yield response curve when affected by heavy traffic. Experiments from Northern Ireland, UK, by Frost (1988a) and Frost (1988b) were conducted on fields of ryegrass grown for silage. The traffic treatments in the experiment were a slurry tanker followed by zero, one or three passes of a tractor and silage trailer, and where the axle loads did not exceed 5.3 Mg and tyre inflation pressures of 267 kPa. A split plot design investigated soil loosening 20 days after the first harvest and rolling 6 days later. It showed an average yield from third harvest that were 6% lower for the first pass (3 passes in total) and 23% lower for the third pass (9 passes in total) treatment compared with the zero. Reduction in yield associated with direct physical damage to leaf was evident. The short term adverse effects on grass yield caused by traffic and soil loosening were attributed to higher penetration resistance of the soils, high rates of fertilizer use, resilience of perennial ryegrass and lack of compaction in the soils at the outset.

The compaction and crop damage performed in the experiment had a variable axel load, with the maximum load close to the load used by Frost (1988b), similar is the maximum tyre inflation pressure also close to the maximum pressure used in the experiment, therefore allowing for the comparison with the results from Frost (1988a).

The high load treatment, gave a yield reduction of 21.89% at 100 kPa and 19.74% at 250 kPa compared to the zero traffic treatment. These correspond with the 23 % yield reduction reported by Frost (1988a).

The yield variation in the field was very large. In order to increase the precision of the estimated treatment effect several covariates were included. The adjustment by those covariates introduced some uncertainty and there could be a bias in the adjustment made by those covariates. However, the difference between the treatment estimates before and after adjustment for soil heterogeneity was general small.

CONCLUSION The following conclusions can be drawn from the experiment:

- When comparing the effect from wheel load and tire pressure, high wheel load of 5 Mg always results in a significant higher yield loss compared to low wheel load of 3 Mg. While high tire pressure does not give a significant loss compared to low tire pressure.

- Traffic in early spring, as simulated by slurry distribution, results in yield losses of up to 22 %, with highest losses with the high wheel load. The low wheel load gave a yield loss of up to16 %.

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