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Tractor traffic and nitrogen fertilization affect the herbage production of the red clover/grass sward

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Abstract

In recent years, soil compaction caused by agricultural machinery has been recognized as one of the main factors that can lower yields of perennial crops. At the same time changes in grassland fertilization intensity are observed. The objectives of the present study were to evaluate the interaction of different N fertilization rates and the intensity of tractor passes. This study was conducted as a field experiment located on a sandy loam soil classified as *Mollic Fluvisol* in Mydlniki near Krakow, Poland over a four-year period (2009–2012). The field experiment was established with four replications in a split-plot design with fertilization as the main plot and tractor traffic as the subplot. Three levels of N fertilization: untreated (control), 80 and 160 kg ha^{-1} N, and four levels of tractor traffic intensity were applied using the following numbers of tractor passes: no passes (control), two passes, four passes and six passes.

Nitrogen (N) fertilization significantly affected the percentage of only three species – *Trifolium pratense*, *Lolium perenne* and *Festuca pratensis* in the sward. *T. pratense* was negatively affected by with higher N rates but two grasses, *L. perenne* and *F. pratensis*, showed the opposite response. The tractor traffic significantly affected *T. pratense* and *L. perenne* occurrence in the swards. The percentage of *T. pratense* in the sward was reduced by tractor traffic, and this space was occupied by *L. perenne*. Changes in the botanical composition reflected in the herbage production. All investigated grass species increased biomass productivity in direct proportion to N rates. Only *T. pratense* was negatively affected by nitrogen fertilization and since 2011 it started to disappear from the swards treated with higher nitrogen rates. For all investigated components of the mixture no interaction between treatments, tractor traffic and nitrogen fertilization was observed.

Key words: botanical composition, grasses, herbage production, nitrogen fertilization, red clover.

Introduction

Agricultural production systems tend to increase the number of passes and the loads carried on agricultural vehicles, resulting in a potential for increased soil compaction (Newell-Price et al., 2013). According to the European Union Commission, soil compaction is now recognized as one of the main factors that can decrease crop yields and thus is a serious agricultural problem (COM(2006)231 - EUR-Lex - Europa).

Compaction leads to soil structure degradation, which results in worsening physical properties. Increase in bulk density and soil strength, measured as penetration resistance, are associated with the aforementioned changes. The soil compaction leads to reduction in plant yield including decreased production of perennial forage crops (Głąb, 2008). This yield decline is the consequence of both soil compaction and shoot injury caused by wheel traffic. It is a serious problem for perennial crops, where the soil is subjected to compaction without tillage operation. Soil strength is increased year-after-year and all machine traffic during field operation causes direct damage to plants which are reported to be as important in contributing to decreased plant yield as soil compaction. Moreover, perennial forage crop production demands a great intensity of vehicular activity, especially during crop harvesting operations. On the other hand, it has also been reported that yields of perennial plants were not always reduced by compaction and sometimes were larger in compacted soil than in non-compacted soil. These trends could be attributed to better water and nutrient supply and recovery of the soil pore system (Scott et al., 2005).

In recent years, more powerful and heavier tractors and machinery have been used on farms. On the other hand, the extensification in livestock production is promoted by the European Union and this has resulted in the reduction of the stocking rate and fertilizer application (Regulation (EEC) 2078/92). The design and implementation of the resulting national agri-environmental schemes modified to a great extent the direction of grassland system development in the European Union countries. One of the most important changes was in the areas of regulation and incentives to limit grassland fertilizer application in order to reduce nutrient losses and mitigate soil and water pollution. The second direction in grassland system modification was in the area of maintenance of biodiversity and landscape expressed as species richness (Baritaux et al., 2016).

Grasslands are strongly affected by field management. It has frequently been shown that the application of high doses of fertilizers and intensive sward utilization have negative effects on plant species diversity (Tephnadze et al., 2014). Chemical and physical soil characteristics are related not only to natural soil properties but also to fertilization inputs, and influence both species richness and species composition of vascular plants (Marini et al., 2007). Fertilization, especially with nitrogen and phosphorus, can increase dry matter production. However, fertilization may improve not only dry matter productivity, but could also affect botanical composition (Koc, 2013). Large nutrient availability leads to an increase of competitive asymmetry among plant species and to a quick exclusion of short, slowly growing plant species (Gaujour et al., 2012). It has been well established that high-nitrogen fertilizer applications generally decrease species diversity (Klimek et al., 2007). Nitrogen fertilization usually plays a favourable role in the growing conditions of tall grasses like Festuca pratensis, Poa pratensis and Agropyron repens. One of the most important components in the botanical composition of grasslands is legumes. However, the nitrogen fertilization used to increase dry matter yield results in a decrease in legume ratio in the botanical composition (Głąb, Kacorzyk, 2011; Koc, 2013). The question is whether there is an interaction between traffic intensity and level of fertilization in terms of plant growth conditions. However, the interaction between the effect of soil compaction and the effect of fertilization used on grasslands has not been studied thoroughly so far. This investigation is based on the Strategy for Soil Protection (Regulation (EEC) 2078/92) with the aim of filling the gap in knowledge about soil and its environmental and productive functions.

In this study, it was hypothesized that (i) tractor traffic affects biomass production on grasslands and (ii) nitrogen fertilization results in changes in herbage production and botanical composition of swards. The aim of this investigation was to study the interaction of different nitrogen fertilization rates and traffic intensity on grass/red clover mixture with the focus on herbage production and botanical composition of swards.

Material and methods

Site, location, and climate. This study was conducted as a field experiment located in Mydlniki near Krakow, Poland (50°04′ N, 19°51′ E, 211 m a.s.l., slope 2°) over a four-year period (2009–2012). The field experiment was carried out on sandy loam *Mollic Fluvisol* soil (WRB, 2014). Table 1 details some of the soil characteristics.

The climate of the experimental site is temperate-continental. The average annual precipitation reaches 681 mm per year and during the studied period varied from 552 in 2011 to 1010 mm in 2010. The mean daily temperature is 7.4°C and varied from 7.9°C in 2010 to 8.7°C in 2011.

Field trial design and treatments. The soil before compaction was ploughed in the autumn of 2008 and harrowed in March 2009 for seedbed preparation then seeds of red clover/grass mixture were sown. Experimental plots (9 m^2) were established with four replications in a split-plot design with fertilization as the main plot and tractor traffic as the subplot. Each plot was sown with a mixture of 10 kg ha^{-1} of perennial ryegrass (*Lolium perenne* L.) cv. 'Diament', 13 kg ha^{-1} of meadow fescue (*Festuca pratensis* Huds.) cv. 'Skra', 3 kg ha^{-1} of timothy (*Phleum pratense* L.) cv. 'Skala', 2 kg ha^{-1} of Kentucky bluegrass (*Poa pratensis* L.) cv. 'Skiz' and 2 kg ha^{-1} of red clover (*Trifolium pratense* L.) cv. 'Nike'.

Table 1. Basic soil physical and chemical properties of *Mollic Fluvisol* (0–20 cm layer) from the trial location

Parameter	Unit	Value
pH(KCl)		6.5
Organic C	g kg^{-1}	12.5
Total N	g kg^{-1}	1.39
C:N ratio		9.0
P	mg kg^{-1}	107.2
K	mg kg^{-1}	138.0
Mg	mg kg^{-1}	67.9
Solid particle density	Mg m^{-3}	2.65
Sand	g kg^{-1}	560
Silt	g kg^{-1}	270
Clay	g kg^{-1}	170
Texture		sandy loam

The nitrogen fertilizer (ammonium nitrate, 34% N) treatments used were: untreated (control, N0), 80 kg ha^{-1} N (N80) and 160 kg ha^{-1} N (N160). Doses of nitrogen were applied three times a year, in March and after the first and second harvest (in May and July, respectively) in proportions of 50, 25 and 25 %, respectively. Phosphorus and potassium fertilization was always of the value 40 kg ha^{-1} P_2O_5 (triple super phosphate, 46% P_2O_5) and 80 kg K_2O (potassium chloride, 60% K_2O). These doses were applied every year in March and after the second harvest. No organic fertilization was applied on the experimental plots.

Four tractor passes treatments were investigated: no passes (control, P0), two passes (P2), four passes (P4) and six passes (P6). Tractor Ursus C-360 (Ursus Ltd., Poland) of 2056 kg weight was used for traffic simulation. The inflation pressure of the front tires (6.00–16 6PR) of the tractor was 150 kPa and that of rear tires (14.9–28 8PR) 100 kPa. Multiple passes were applied in a wheel-beside-wheel design, after every harvest (three times a year). The traffic intensity was applied at a soil moisture content of approximately 0.30 cm^{-3} cm^{-3} (±0.03 cm^{-3} cm^{-3}). This water content corresponded to the value of the field water capacity.

Measurements. Starting from the following year after sowing, plots were cut at a stubble height of 5 cm three times a year with the first cut being at the moment when approximately 20% of legumes were flowering and the other two cuts done when grasses began to flower. Dry matter (DM) production was determined by cutting each plot using a meadow mower Agria (Agria-Werke GmbH, Germany). Fresh herbage yield was recorded in the field. Herbage samples were taken from each plot and dried for 48 hours at 80°C to calculate the dry matter yield. Botanical composition was based on weight contribution of a particular species in total sample weight. For all kinds of cuts and at all treatments, the central 1 m^2 of the plot was cut with shears to a height of 5 cm. The samples were separated according to their species and dried to a constant weight at 80°C.

Statistical analysis. An analysis of variance for a split-plot design was performed to evaluate the significance of traffic intensity and nitrogen fertilization on the botanical composition and biomass production using the statistical software package *STATISTICA* 10.0 (StatSoft Inc., USA). Means were compared using Tukey's test with a level of significance of $P < 0.05$.

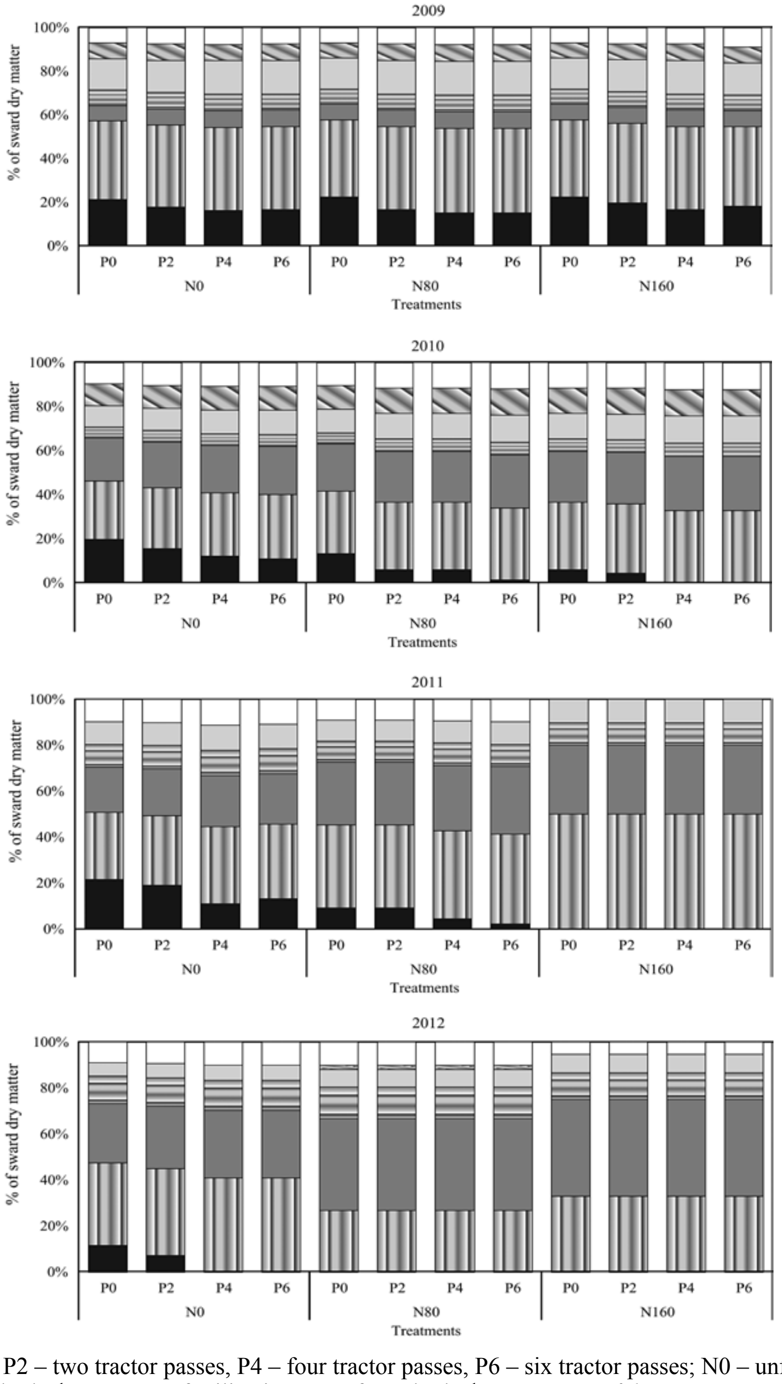
Results

Botanical composition. In the first year of the experiment, before the treatments were applied, the proportion between the species was as follows:

T. pratense 18.2%, *L. perenne* 37.1%, *F. pratensis* 7.4%, *P. pratensis* 7.4%, and *Ph. pratense* 14.8% (Fig.). Other grasses and forbs together accounted for 15.0%. Forbs were mainly represented by *Plantago major*, *Conyza canadensis*, *Capsella bursa-pastoris*, *Taraxacum officinale*, *Chenopodium album* and *Cichorium intybus*. Other grasses like *Poa annua* and *Echinochloa crus-galli* appeared mainly during the period 2009–2010 and subsequently disappeared from the swards.

The botanical composition of swards changed during the four years of the experiment. The participation of two of the tested species, *T. pratense* and *Ph. pratense*, in the sward decreased. In 2012, the percentage of *T. pratense* was only 1.6% and *Ph. pratense* – 7.2%. The contribution of *L. perenne* (35.0% in average) was at the same level during the entire duration of the experiment. Two species, *P. pratensis* and *F. pratensis*, increased their participation up to 36.0% and 12.8%, respectively. According to the analysis of variance both factors, tractor passes and nitrogen fertilization, play a significant role in the botanical composition of swards. Furthermore the interaction between the year and the fertilization was observed.

Nitrogen fertilization significantly affected the percentage of only three species, *T. pratense*, *L. perenne* and *F. pratensis*. *T. pratense* was negatively correlated with higher nitrogen rates and it varied from 13.4% at the N0 treatment to 5.4% at the N160 treatment. Two grasses



P0 – untreated (control), P2 – two tractor passes, P4 – four tractor passes, P6 – six tractor passes; N0 – unfertilized (control), N80 – fertilization rate of 80 kg ha^{-1} N, N160 – fertilization rate of 160 kg ha^{-1} N; TrPr – *Trifolium pratense*, LoPe – *Lolium perenne*, FePr – *Festuca pratensis*, PoPr – *Poa pratensis*, PhPr – *Phleum pratensis*, Gr – other grasses, Fo – forbs

Figure. Effect of tractor traffic and nitrogen fertilization on the botanical composition of swards showed the opposite reaction. *F. pratensis* percentage increased from 19.3% at the N0 treatment to 25.8% at the N160 treatment. For *L. perenne*, the statistically higher percentage was at the N160 treatment (37.9%) when compared with the N0 and N80 treatments. Both species, *Ph. pratense* and *P. pratensis*, were not affected by N fertilization. Two species, *T. pratense* and *L. perenne*, showed significant interaction between fertilization and the year of the experiment. The differences in the reaction of these two species to N fertilization appeared in 2009. The participation of *T. pratense* in the swards increased in the first year of the trial, when higher nitrogen rates were applied, whereas in the following years, the reaction was just the opposite. The percentage of *L. perenne* decreased in 2009 from 37.2% at the N0 to 36.2% at the N160. The following year, this species positively reacted to nitrogen fertilization.

The tractor traffic significantly affected the participation of *T. pratense* and *L. perenne* in the sward biomass. The percentage of *T. pratense* was reduced by wheel traffic, and this space was occupied by *L. perenne.* At the P0 treatment the participation of *T. pratense* was 12.3% and it decreased to 6.5% at the P6 treatment. Other tested grasses were not influenced by tractor traffic.

Dry matter production. The mean annual DM yield of red clover/grass mixture was 10.52 t ha^{-1} DM. The annual biomass production of the tested mixture was affected by the experimental treatments, nitrogen fertilization and soil tractor traffic (Tables 2–6). Fertilization significantly increased plant yields. The lower value for dry matter was obtained at the N0 treatment, 8.38 t ha^{-1} DM in average during the 2009–2012 period. For higher nitrogen rates the yields increased and were 10.20 and 12.28 t ha^{-1} DM for the N80 and N160, respectively. A similar relationship was observed during every year of the trial. Soil compaction caused by tractor wheeling reduced yields from 11.11 t ha^{-1} DM at the P0 to 9.74 t ha^{-1} DM at the P6. This relationship was maintained during the whole experimental period.

The rule that fertilization increased yield of grassland species mixture was not always followed by its individual components. All species were significantly affected by nitrogen fertilization. However, for some species, this effect was different during particular years. Only two species, *T. pratense* and *L. perenne*, were sensitive to tractor wheeling. The highest annual dry matter yield was obtained for *L. perenne* (3.68 t ha^{-1} DM in average). These values for other grasses *F. pratensis*, *Ph. pratense* and *P. pratensis* were 2.48, 1.14 and 0.94 t ha^{-1} DM, respectively. *T. pratense* was characterized by the lowest dry matter production (0.90 t ha^{-1} DM). The variation in herbage production of tested species was observed during the four years of the experiment. Three of them, *T. pratense*, *L. perenne* and *Ph. pratense*, decreased productivity. However, two others increased dry matter yield during this period. Consequently, the total annual yield of the sward was at the same level from 2009 to 2012.

All species were affected by nitrogen fertilization. However, this reaction changed with time. In the first year of the trial, i.e. 2009, *T. pratense* increased the dry matter productivity in direct proportion to nitrogen rates. This relationship was observed for all three cuts. Since 2010, this species started to disappear from swards treated with higher N rates. Starting from 2011, during the time of the first cut, there were not any plants of *T. pratense* at the N160 treatment. Other investigated grass species increased productivity when higher N rates were applied. The two other grass components of the mixture, *L. perenne* and *F. pratensis*, showed interaction with the year. The highest annual herbage productivity of *L. perenne* was recorded at the N160 treatment (6.16tha^{-1} DM) in 2011. This productivity was significantly lower in other years. The annual yields of *F. pratensis* increased specifically during the years of the experiment. However, this effect was found to be higher when treated with higher nitrogen rates.

The most susceptible species to tractor traffic was *T. pratense*. The significant decrease in DM production was noticed during all years and for all cuts. The highest mean annual yield was obtained at the P0 treatment (1.30 t ha^{-1} DM) and the lower mean annual yield at the P6 (0.61 t ha^{-1} DM). Multiple tractor passes slowly eliminated this species and finally it disappeared at the P4 and P6 in 2012. The grasses showed a negative reaction

Table 2. Effect of tractor traffic and nitrogen fertilization on herbage yield (t ha^{-1} DM) of *Trifolium pratense*

Treatments		2009			2010			2011			2012		
		1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut
N0	P0	0.86	0.46	0.45	0.69	0.47	0.46	0.87 a	0.66	0.65 a	0.35 a	0.33 a	0.25 a
	P2	0.76	0.40	0.38	0.56	0.44	0.37	0.71 a	0.60	0.48 a	0.28 a	0.17 b	0.13 b
	P4	0.73	0.37	0.31	0.44	0.38	0.29	0.39 bc	0.36	0.26 bc	0.00 b	0.00 c	0.00 c
	P6	0.71	0.33	0.22	0.35	0.32	0.22	0.49 b	0.39	0.31 b	0.00 b	0.00 c	0.00 c
N80	P0	1.13	0.66	0.74	0.83	0.41	0.39	0.45 b	0.32	0.31 b	0.00 b	0.00 c	0.00 c
	P2	0.91	0.51	0.50	0.34	0.18	0.13	0.43 b	0.33	0.28 b	0.00 b	0.00 c	0.00 c
	P4	0.84	0.44	0.38	0.30	0.18	0.13	0.20 cd	0.15	0.11 cd	0.00 b	0.00 c	0.00 c
	P6	0.78	0.40	0.31	0.08	0.05	0.03	0.08 d	0.07	0.05 d	0.00 b	0.00 c	0.00 c
N160	P0	1.38	0.81	0.93	0.38	0.21	0.16	0.00 d	0.00	0.00 d	0.00 b	0.00 c	0.00 c
	P2	1.14	0.66	0.71	0.31	0.18	0.13	0.00 d	0.00	0.00 d	0.00 b	0.00 c	0.00 c
	P4	0.97	0.50	0.45	0.00	0.00	0.00	0.00 d	0.00	0.00 d	0.00 b	0.00 c	0.00 c
	P6	1.04	0.54	0.50	0.00	0.00	0.00	0.00 d	0.00	0.00 d	0.00 b	0.00 c	0.00 c
Means for fertilization													
	N0	0.76 b	0.39 b	0.34 b	0.51a	0.40 a	0.33 a	0.62 a	0.50 a	0.43 a	0.16 a	0.13 a	0.10 a
	N80	0.92 b	0.50 a	0.48 a	0.39b	0.21 b	0.17 b	0.29 b	0.22 b	0.19 b	0.00 b	0.00 b	0.00 b
	N160	1.13 a	0.63 a	0.64 a	0.17c	0.10 c	0.07 c	0.00 c	0.00 c	0.00 c	0.00 b	0.00 b	0.00 b
Means for tractor passes													
	P0	1.12	0.65	0.70 a	0.63 a	0.37 a	0.34 a	0.44 a	0.32 a	0.32 a	0.12 a	0.11 a	0.08 a
	P2	0.94	0.52	0.53 ab	0.41 b	0.27 b	0.21 b	0.38 a	0.31 a	0.25 a	0.09 a	0.06 b	0.04 b
	P4	0.85	0.44	0.38 b	0.24 c	0.19 c	0.14 c	0.19 b	0.17 b	0.12 b	0.00 b	0.00 b	0.00 c
	P6	0.84	0.42	0.34 b	0.14 c	0.12 c	0.08 c	0.19 b	0.15 b	0.12 b	0.00 b	0.00 b	0.00 c

Notes. N0 – unfertilized (control), N80 – fertilization rate of 80 kg ha^{-1} N, N160 – fertilization rate of 160 kg ha^{-1} N; P0 – untreated (control), P2 – two tractor passes, P4 – four tractor passes, P6 – six tractor passes. For each column, mean values with different superscripts are significantly different ($P < 0.05$), superscripts used only for significant differences according to *ANOVA*, means without superscripts are not significantly different.

Table 3. Effect of tractor traffic and nitrogen fertilization on herbage yield (t ha^{-1} DM) of *Lolium perenne*

Treatments		2009			2010			2011			2012		
		1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut
N0	P0	1.44	0.77	0.74	0.93	0.64	0.62	1.22	0.89	0.88	1.09	1.03	0.77
	P2	1.45	0.76	0.69	1.01	0.78	0.66	1.22	1.01	0.77	1.36	0.93	0.71
	P4	1.54	0.76	0.61	1·08	0.92	0.70	1.16	1.09	0.78	1.33	0.91	0.73
	P6	1.53	0.72	0.48	0.94	0.86	0.59	1.23	0.92	0.75	1.21	0.85	0.71
N80	P0	1.77	1.02	1.10	1.73	0.88	0.83	1.78	1.26	1.22	1.50	0.96	0.79
	P2	1.99	1.10	1.06	1.85	1.00	0.68	1.71	1.33	1.12	1.60	0.94	0.71
	P4	2.02	1.06	0.92	1.61	0.97	0.70	1.68	1.21	1.07	1.46	0.70	0.59
	P6	1.96	1.00	0.76	1.76	0.89	0.59	1.61	1.24	0.96	1.43	0.76	0.58
N160	P0	2.13	1.25	1.42	2.03	1.16	0.89	2.75	1.85	1.70	1.87	1.20	0.90
	P2	2.12	1.19	1.24	2.15	1.22	0.94	2.79	1.91	1.51	1.97	1.04	1.02
	P4	2.21	1.13	0.96	2.07	1.20	0.87	2.86	1.83	1.59	2.02	0.98	0.85
	P6	2.11	1.11	0.99	2.15	1.02	0.73	2.57	1.87	1.38	1.98	0.91	0.72
Means for fertilization													
	N0	1.49 b	0.76 b	0.63 b	0.99 b	0.80 b	0.64 a	1.21 b	0.98 b	0.80 b	1.25 b	0.93	0.73 ab
	N80	1.94 a	1.04 a	0.96 a	1.74 a	0.94 a	0.70 b	1.70 b	1.26 b	1.09 b	1.50 ab	0.84	0.67 b
	N160	2.14 a	1.17 a	1.15 a	2.10 a	1.15 a	0.86 a	2.74 a	1.87 a	1.55 a	1.96 a	1.03	0.87 a
Means for tractor passes													
	P0	1.78	1.01	1.09 a	1.57	0.89	0.78	1.92	1.33	1.27 a	1.49	1.06	0.82
	P2	1.85	1.02	1.00 a	1.67	1.00	0.76	1.91	1.42	1.13 ab	1.65	0.97	0.82
	P4	1.93	0.98	0.83 ab	1.59	1.03	0.76	1.90	1.37	1.15 ab	1.60	0.86	0.72
	P6	1.87	0.94	0.74 b	1.62	0.92	0.64	1.81	1.34	1.03 b	1.54	0.84	0.67

Explanations under Table 2

Table 4. Effect of tractor traffic and nitrogen fertilization on herbage yield (t ha^{-1} DM) of *Festuca pratensis*

Treatments		2009			2010			2011			2012		
		1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut
N0	P0	0.29	0.15	0.15	0.69	0.47	0.46	0.81	0.59	0.59	0.81	0.76	0.56
	P2	0.29	0.15	0.14	0.75	0.58	0.49	0.81	0.67	0.51	0.95	0.66	0.53
	P4	0.31	0.15	0.12	0.80	0.68	0.52	0.78	0.72	0.52	0.97	0.64	0.55
	P6	0.31	0.14	0.10	0.70	0.64	0.44	0.82	0.61	0.50	0.89	0.58	0.52
N80	P0	0.35	0.20	0.22	1.28	0.65	0.61	1.34	0.95	0.92	2.20	1.41	1.13
	P2	0.40	0.22	0.21	1.37	0.74	0.50	1.28	1.00	0.84	2.41	1.39	1.05
	P4	0.40	0.21	0.18	1.20	0.72	0.52	1.26	0.91	0.80	2.14	1.04	0.86
	P6	0.39	0.20	0.15	1.31	0.66	0.44	1.21	0.93	0.72	2.07	1.12	0.86
N160	P0	0.43	0.25	0.28	1.50	0·86	0.66	1.65	1.11	1.02	2.49	1.50	1.11
	P2	0.42	0.24	0.25	1.59	0.91	0.70	1.67	1.15	0.91	2.61	1.30	1.25
	P4	0.44	0.23	0.19	1.53	0.89	0.65	1.72	1.10	0.96	2.53	1.24	1.04
	P6	0.42	0.22	0.20	1.59	0.76	0.54	1.54	1.12	0.83	2.52	1.17	0.87
Means for fertilization													
	N0	0.30 b	0.15 b	0.13 b	0.73 b	0.59 b	0.48 b	0.81 b	0.65 b	0.53 b	0.90 b	0.66 b	0.54 b
	N80	0.39 ab	0.21 a	0.19 ab	1.29 ab	0.69 ab	0.52 ab	1.27 ab	0.94 ab	0.82 a	2.21 a	1.24 a	0.97 a
	N160	0.43 a	0.23 a	0.23 a	1.56 a	0.85 a	0.64 a	1.65 a	1.12 a	0.93 a	2.54 a	1.30 a	1.07 a
Means for tractor passes													
	P0	0.36	0.20	0.22 a	1.16	0.66	0.58	1.27	0.88	0.84 a	1.83	1.22 a	0.93 a
	P2	0.37	0.20	0.20 ab	1.24	0.74	0.56	1.26	0.94	0.75 ab	1.99	1.11 ab	0.94 a
	P4	0.39	0.20	0.17 ab	1.18	0.76	0.56	1.25	0.91	0.76 ab	1.88	0.98 ab	0.82 ab
	P6	0.37	0.19	0.15 b	1.20	0.68	0.47	1.19	0.89	0.68 b	1.83	0.95 b	0.75 b

Explanations under Table 2

Table 5. Effect of tractor traffic and nitrogen fertilization on herbage yield (t ha^{-1} DM) of *Phleum pratense*

Treatments		2009			2010			2011			2012		
		1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut
N0	P0	0.57	0.31	0.30	0.35	0.24	0.23	0.41	0.30	0.29	0.18	0.17	0.14
	P2	0.58	0.30	0.28	0.37	0.29	0.24	0.41	0.34	0.26	0.18	0.16	0.13
	P4	0.62	0.31	0.25	0.40	0.34	0.26	0.39	0.36	0.26	0.19	0.12	0.14
	P6	0.61	0.29	0.19	0.35	0.32	0.22	0.41	0.31	0.25	0.19	0.10	0.12
N80	P0	0.71	0.41	0.44	0.64	0.33	0.31	0.45	0.32	0.31	0.43	0.26	0.20
	P2	0.80	0.44	0.42	0.68	0.37	0.25	0.43	0.33	0.28	0.48	0.25	0.20
	P4	0.81	0.42	0.37	0.60	0.36	0.26	0.42	0.30	0.27	0.40	0.19	0.15
	P6	0.79	0.40	0.30	0.65	0.33	0.22	0.40	0.31	0.24	0.39	0.19	0.16
N160	P0	0.85	0.50	0.57	0.75	0.43	0.33	0.55	0.37	0.34	0.50	0.27	0.20
	P2	0.85	0.48	0.50	0.80	0.45	0.35	0.56	0.38	0.30	0.53	0.24	0.23
	P4	0.88	0.45	0.38	0.77	0.45	0.32	0.57	0.37	0.32	0.46	0.23	0.20
	P6	0.85	0.44	0.40	0.80	0.38	0.27	0.51	0.37	0.28	0.48	0.24	0.16
Means for fertilization													
	N0	0.60 b	0.30 b	0.25 b	0.37 b	0.30 b	0.24 b	0.40 b	0.33	0.27	0.19 b	0.14	0.13
	N80	0.77 ab	0.42 a	0.38 ab	0.64 ab	0.35 ab	0.26 ab	0.42 ab	0.31	0.27	0.43 a	0.22	0.18
	N160	0.86 a	0.47 a	0.46 a	0.78 a	0.43 a	0.32 a	0.55 a	0.37	0.31	0.49 a	0.25	0.20
Means for tractor passes													
	P0	0.71	0.40	0.44 a	0.58	0.33	0.29	0.47	0.33	0.31	0.37	0.23	0.18
	P2	0.74	0.41	0.40 ab	0.62	0.37	0.28	0.46	0.35	0.28	0.40	0.21	0.19
	P4	0.77	0.39	0.33 ab	0.59	0.38	0.28	0.46	0.34	0.28	0.35	0.18	0.16
	P6	0.75	0.38	0.30 b	0.60	0.34	0.24	0.44	0.33	0.26	0.35	0.18	0.15

Explanations under Table 2

Table 6. Effect of tractor traffic and nitrogen fertilization on herbage yield (t ha^{-1} DM) of *Poa pratensis*

Treatments		2009			2010			2011			2012		
		1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut
N0	P0	0.29	0.15	0.15	0.17	0.12	0.12	0.41	0.30	0.29	0.39	0.37	0.27
	P2	0.29	0.15	0.14	0.19	0.15	0.12	0.41	0.34	0.26	0.39	0.31	0.25
	P4	0.31	0.15	0.12	0.20	0.17	0.13	0.39	0.36	0.26	0.45	0.29	0.28
	P6	0.31	0.14	0.10	0.17	0.16	0.11	0.41	0.31	0.25	0.43	0.25	0.25
N80	P0	0.35	0.20	0.22	0.32	0.16	0.15	0.45	0.32	0.31	0.80	0.51	0.45
	P2	0.40	0.22	0.21	0.34	0.18	0.13	0.43	0.33	0.28	0.78	0.49	0.38
	P4	0.40	0.21	0.18	0.30	0.18	0.13	0.42	0.30	0.27	0.79	0.37	0.33
	P6	0.39	0.20	0.15	0.33	0.17	0.11	0.40	0.31	0.24	0.78	0.41	0.31
N160	P0	0.43	0.25	0.28	0.38	0.21	0.16	0.55	0.37	0.34	0.62	0.45	0.35
	P2	0.42	0.24	0.25	0.40	0.23	0.17	0.56	0.38	0.30	0.67	0.39	0.40
	P4	0.44	0.23	0.19	0.38	0.22	0.16	0.57	0.37	0.32	0.76	0.36	0.33
	P6	0.42	0.22	0.20	0.40	0.19	0.14	0.51	0.37	0.28	0.72	0.32	0.28
Means for fertilization													
	N0	0.30 b	0.15 b	0.13 b	0.18 b	0.15 b	0.12	0.40	0.33	0.27	0.42	0.30	0.26
	N80	0.39 ab	0.21 a	0.19 ab	0.32 ab	0.17 ab	0.13	0.42	0.31	0.27	0.79	0.44	0.37
	N160	0.43 a	0.23 a	0.23 a	0.39 a	0.21 a	0.16	0.55	0.37	0.31	0.69	0.38	0.34
Means for tractor passes													
	P0	0.36	0.20	0.22a	0.29	0.17	0.14	0.47	0.33	0.31	0.60	0.44	0.35
	P2	0.37	0.20	0.20ab	0.31	0.19	0.14	0.46	0.35	0.28	0.62	0.40	0.34
	P4	0.39	0.20	0.17ab	0.29	0.19	0.14	0.46	0.34	0.28	0.67	0.34	0.31
	P6	0.37	0.19	0.15b	0.30	0.17	0.12	0.44	0.33	0.26	0.64	0.33	0.28

Explanations under Table 2

to tractor traffic mainly during the third cut. However, this effect on annual production of grass species was not very evident. A significant difference was noticed only for *L. perenne*. For all investigated components of the mixture no interaction between treatments, tractor traffic and N fertilization was observed.

Discussion

It has been widely recognized that nitrogen fertilization increased grassland productivity (Klimek et al., 2007; van Eekeren et al., 2010). All investigated grasses increased their biomass production as a reaction to higher nitrogen fertilization. According to Leps (1999), nitrogen fertilization usually plays an advantageous role in the growing conditions of tall grasses like *F. pratensis*, *P. pratensis* and *Agropyron repens*. Short grasses are usually displaced by tall ones. In this research some small grasses like *Poa annua* disappeared in the third year of the experiment.

One of the most important components in the botanical composition of grasslands is legumes. However, the nitrogen fertilization used to increase dry matter yield usually results in a decrease in legume ratios in the botanical composition (Koc, 2013). In this experiment legumes were represented by *T. pratense*. As expected, this species slowly disappeared when mineral fertilization was applied. In the second year of the experiment *T. pratensis* was absent at the object with N rates of 160 kg ha^{-1}. It persisted at the N0 (nonfertilized) treatment, up to 2012. In the previous author's research (Głąb, Kacorzyk, 2011), the presence of a similar relationship was confirmed for meadows located in mountain regions. Under higher N rates, mineral or organic, the participation of *T. repens* and small grasses decreased.

The results obtained in this field experiment indicated that tractor traffic of red clover/grass meadow significantly affected the botanical composition and herbage production of its components. As more intensive wheeling was applied, a decrease in plant yield was recorded. This relationship has been widely confirmed by other authors (Whalley et al., 2008). It is usually ascribed to unfavourable changes of soil properties. Soil compaction leads to soil structure degradation, which is strongly associated with changes in physical properties of soil like porosity, bulk density, and penetration resistance (Krebstein et al., 2013; Nawaz et al., 2013). The degraded physical environment of the soil due to compaction influences mainly the growth and development of roots. Soil compaction increases mechanical impendence, creates unfavourable growing conditions for roots, and restricts oxygen, water and nutrients supply (Bhandral et al., 2007). Changes in physical properties resulted also in the biological activity of compacted soil. According to Tian et al. (2015), physical properties of soil affected the number and activity of microorganisms and their physiological diversity. Changes in biological activity resulted in processes catalyzed by microorganisms which can modify chemical properties of soil and availability of nutrients (Nosalewicz, Nosalewicz, 2011). It could be expected that reduced root system and the decreased nutrient availability in compacted soils caused lower nutrient uptake by the growing crop and hence decreased shoot growth and crop yield. Kristoffersen and Riley (2005) confirmed this relationship for phosphorus uptake by barley. The results of the current experiment also are based on this theory.

However, the reaction of root systems of perennial forage plans to soil compaction can vary and can be described as positive or negative. It was reported that a common response of the root system to increasing bulk density is to decrease its length and biomass in the upper soil layer (Chen, Weil, 2010). Also, previous researches conducted by the author (Głąb, 2013) confirmed this trend for meadow fescue (*F. pratensis*) and Kentucky bluegrass (*P. pratensis*). Sometimes, the positive correlation between soil density and root characteristics was observed, particularly for perennial crops. In the investigation with tall fescue (*Festuca arundinacea* Schreb.), the soil compaction increased the dry matter, length of roots and their diameter (Głąb, 2007). This effect can be attributed to the activity of dense perennial plant roots and earthworms and is usually responsible for favourable changes in the pore system.

Based on these statements, it can be concluded that the yield depression that is observed here is the result of not only deteriorated soil structure and limited root growth but also is combined with mechanical damage to the above-ground part of plants. This resistance to mechanical stress is usually ascribed to anatomical properties, particularly the area of sclerenchyma cells (Evans et al., 2007).

The results of the current study lay greater emphasis on nitrogen level than intensity of tractor traffic. It can be stated that sometimes it is difficult to compare the proportion between these two factors, fertilization and traffic intensity, in different experiments because they depend on numerous biotic and abiotic parameters. What can influence the final results are soil parameters like water content, initial bulk density, tractor weight and unit pressure, botanical composition of sward, etc. However, the common conclusion from these experiments is that both, N fertilization and traffic intensity significantly affect perennial plant yields. The important question here is whether these factors act in combination with each other or act independent of one another.

Bingham et al. (2010) found no interaction between soil compaction and the N fertilization level in an investigation on young barley plants. It could be stated that these two factors seem to act independently. Bingham et al. (2010) also did not find a significant interaction between compaction and nitrogen supply on root growth and biomass production of barley in the experiment with the deficit nitrogen supply. It could be expected that soil compaction leads to limitation in nitrogen uptake by plants. It is widely recognized that soil compaction caused by tractor wheeling results in deterioration of soil structure and its pore system (Raper, 2005). The consequence is restricted aeration and increased denitrification losses of N-NO_3. Furthermore, it leads to inhibited root growth and decreases mineralization of organic N (Głąb, 2013). All these events presumably result in decreasing fertilizer efficiency and hence biomass production. These relationships should result in significant interaction in plant yields between traffic intensity and the level of N fertilization. However, in this research there was no statistically significant evidence for such interaction.

Conclusions

1. Nitrogen fertilization significantly affected the percentage of only three species, *Trifolium pratense*, *Lolium perenne* and *Festuca pratensis*. Percentage of *T. pratense* decreased with increasing nitrogen rates. The share of *T. pratense* changed from 13.4% in the control (N0) treatment to 5.4% in the treatment with the rate of 160 kg ha^{-1} N. *Phleum pratense* and *Poa pratensis* were not affected by nitrogen fertilization. However, the participation of *T. pratense* in the sward increased when higher nitrogen rates were applied in the first year of the trial, whereas in the following years, the reaction was opposite. The percentage of *L. perenne* decreased in 2009 from 37.2% in the untreated control to 36.2% in the 160 kg ha^{-1} N treatment. In the next year this species positively reacted to nitrogen fertilization.

2. The tractor traffic significantly affected the participation of *T. pratense* and *L. perenne* in the sward biomass. The percentage of *T. pratense* was reduced by wheel traffic, and this space was occupied by *L. perenne*. At the noncompacted treatment, the share of *T. pratense* was 12.3% and decreased to 6.5% when six tractor passes were applied. Other tested grasses were not influenced by the tractor passes applied.

3. The annual biomass production of the tested mixture was affected by both experimental treatments, nitrogen fertilization and traffic intensity. The lower value for dry matter was obtained in the control (N0) treatment without nitrogen fertilization – 8.38 t ha^{-1} DM. The rate of 160 kg ha^{-1} N increased biomass production up to 12.28 t ha^{-1} DM. As more intensive wheeling was applied, a decrease in plant yields was recorded. However, for some species, this effect differed between years.

4. The biomass production of the tested species was affected by nitrogen fertilization. However, this reaction changed with time. The dry matter productivity of *T. pratense* increase in the first year when higher rates of nitrogen were applied. However, in the following years, this species started to disappear due to treatments with higher nitrogen rates.

5. The most susceptible species on soil compaction was *T. pratense*. The grasses showed a negative reaction to tractor traffic mainly during the third cuts. However, this effect on annual production of grass species was not evident.

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Dirvų išvažinėjimas ir tręšimas azotu veikia žolynų produktyvumą

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Santrauka

Pastaraisiais metais žemės ūkio technikos sukeltas dirvožemio suslėgimas yra laikomas vienu veiksnių, mažinančių daugiamečių augalų derlių. Kartu vyksta ir žolynų tręšimo intensyvumo pokyčiai. Šiuo tyrimu siekta įvertinti sąveiką tarp įvairių tręšimo azotu normų ir išvažinėjimo intensyvumo. Lauko bandymas atliktas 2009–2012 m. smėlingo priemolio dirvožemyje (*Mollic Fluvisol*) Mydlniki vietovėje netoli Krokuvos, Lenkijoje. Bandymas atliktas taikant skaidytų laukelių metodą keturiais pakartojimais. Tręštas pagrindinis laukelis, o dirvos išvažinėjimas tirtas daliniame laukelyje. Bandymo metu azotu tręšta trimis lygiais: netręšta (kontrolinis variantas), tręšta 80 bei 160 kg ha^{-1} N, ir tirti keturi išvažinėjimo traktoriumi intensyvumo lygiai: be važiavimų (kontrolinis variantas), du, keturi ir šeši važiavimai.

Tręšimas azotu smarkiai paveikė tik trijų rūšių augalų – *Trifolium pratense*, *Lolium perenne* ir *Festuca pratensis* – procentą žolyne. Didesnės normos azoto turėjo neigiamos įtakos *T. pratense*, o *L. perenne* ir *F. pratensis* – priešingai. Dirvos išvažinėjimas smarkiai paveikė *T. pratense* ir *L. perenne* išplitimą žolyne. Dėl žolyno išvažinėjimo *T. pratense* procentas sumažėjo, o išnykusių augalų vietą užėmė *L. perenne*. Botaninėse sudėties pokyčiai lėmė žolyno produktyvumą. Visų tirtų rūšių augalų biomasės produktyvumas padidėjo proporcingai azoto normoms. Tręšimas azotu neigiamai paveikė tik *T. pratense*, ir nuo 2011 m. jie pradėjo nykti žolynuose, tręštose didesnėmis normomis azoto. Visų tirtų mišinio komponentų nebuvo nustatyta sąveika tarp variantų, dirvų išvažinėjimo ir tręšimo azotu.

Reikšminiai žodžiai: botaninė sudėtis, raudonieji dobilai, tręšimas azotu, žolynai, žolynų produktyvumas.

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