Photosynthesis Characteristics of ×*Festulolium* and *Lolium*×*Boucheanum* Sward
Fotosintētiskās darbības rādītāji ×*Festulolium* un *Lolium*×*boucheanum* zelmenī

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Abstract. The productivity of grasslands and pastures mostly depends on cultivated grass varieties. Festulolium (×*Festulolium* Asch.&Graebn.) is among the most persistent and productive grasses used in many European countries, especially in adverse environments. The aim of the present research was to study photosynthesis activity and crop yield of local and foreign varieties of festulolium and hybrid ryegrass *(Lolium×boucheanum* Kunth.) under agro-ecological conditions of Latvia. The most significant indices of photosynthetic activity – leaf area index (LAI) and net photosynthesis productivity (NPP) – during growth period till first cut were investigated. Field trials were established on sod-gleyic soil *(Luvic Epigleyic Phaeozem (Calcaric)* – WRB 2006), fine sandy loam; fertilizers – 120 kg ha^{-1} of N, 78 kg ha^{-1} of P_2O_5, and 90 kg ha^{-1} of K_2O. The average NPP for festulolium, hybrid ryegrass and perennial ryegrass varieties varied from 5.63 to 8.29 g m^{-2} day^{-1}. No positive correlation between NPP and dry matter (DM) yield was established. The average LAI was within the range of 1.94–2.91, and a relationship between LAI and DM was found.
Key words: ×*Festulolium*, *Lolium×boucheanum*, productivity, photosynthesis.

Introduction

Under climatic conditions of Latvia, forage grasses are the main fodder source in cattle breeding. Efficient farming requires better use of grass.

Greater sward productivity may be obtained through use of hybrid combinations of contrasting grass species. Festulolium hybrids are among the most persistent and productive grasses of the grasses used in many European countries, especially in adverse environments (Nesheim, Bronstad, 2000; Kohoutek, Odstrcilova et al., 2004).

In all grasses the basis of growth is photosynthesis. However, the accumulation of dry matter is not the result of a single process, but represents the net balance between a number of processes. Leaf development and age, as well as leaf photosynthetic capacity influence the grass yield (Kolomeychenko, 2005). In optimal photosynthetic and moisture conditions perennial grasses can achieve good growth and photosynthetic productivity. The optimal fertilization level can help improve the photosynthesis (Bumane, Adamovich, 2006).

Leaf surface area and net photosynthesis productivity are the most significant indices of photosynthesis (Adamovich, 2002). Leaf surface area is usually expressed as leaf area index (LAI) which represents leaf area per unit ground surface area and shows how many times leaf surface is grater than soil area occupied by plants (Robson, Parsons, Williams, 1989). Net photosynthesis productivity (NPP) characterizes the increase in plant dry matter (DM) production per leaf area unit of time, expressed in g m^{-2} day^{-1} (Ничипорович, Строгонова и др., 1961).

Several enviromental and physiological factors determine the rate of photosynthesis: light intensity, temperature, mineral content, and water. Grass photosynthesis is affected also by sward management (Robson, Parsons, Williams, 1989). In the grass crops the leaves are not only the photosynthesis organ, but the harvestable fraction as well. Increase in leaf area results in greater light interception and canopy photosynthesis. Higher photosynthesis productivity leads to an even grater rate of leaf area expansion and biomass production (Parsons, Penning, 1988). The increase in leaf area significantly reduces interception of light by plants, thus having a negative effect on the NPP and sward productivity (Adamovich, 2002). Development of leaves in shade may lead to a decrease of about 30% in leaf photosynthesis in vegetative grass canopy (Nosberger, Staszewski, 2002). Frequent defoliation repeatedly interrupts leaf area growing before canopy is reaching the maximum yield. The following more lenient defoliation extends each regrowth period so that the crop may be close to maximum yield before it is harvested. However, under intermittent defoliation there is increasing rate of tissue death (Robson et al., 1989).

Photosynthesis productivity for perennial ryegrass, Italian ryegrass, tall fescue and intergeneric hybrids is highest during the recovery period for the first cut, and is lower during the periods following the second and third cut. The difference in photosynthesis productivity rates between the first and second cut is highly significant. A close relationship between photosynthesis productivity value and DM production has been found. In some researches DM production of various grasses has declined between the first and third cut corresponding to the changes in photosynthesis productivity over the growing period (Gaborcik, Ilavska et al., 2006).

The aim of the present research was to study the most important indices of photosynthesis (leaf area index and net photosynthesis productivity) and crop yield of festulolium (*×Festulolium* Asch.&Graebn.) and hybrid ryegrass *(Lolium×boucheanum* Kunth.) foreign varieties under agro-ecological conditions of Latvia.

Materials and Methods

Field trials were conducted at LLU Research and study farm "Vecauce", Latvia. Soil: sod-gleyic *(Luvic Epigleyic Phaeozem (Calcaric)* – WRB 2006), fine sandy loam, medium cultivated, medium drained, pH KCl – 7.1, P_2O_5 – 579 mg kg^{-1}, K_2O – 238 mg kg^{-1}, organic matter content – 31 g kg^{-1} of soil. Swards were composed of: perennial ryegrass 'Spidola' (control); festulolium – 'Perun' *(L. multiflorum×F. pratensis),* 'Punia' *(L. multiflorum×F. pratensis),* 'Saikava' *(L. perenne×F. pratensis)*, 'Lofa' *(L. multiflorum×F. arundinacea)*, and 'Hykor' *(L. multiflorum×F. arundinacea)*; hybrid ryegrass – 'Tapirus' *(L. multiflorum×L. perenne)*. The total seeding rate was 1000 germinating seeds per m^{-2}. The plots were fertilized as follows: N – 108 kg ha^{-1}, P_2O_5 – 78 kg ha^{-1}, K_2O – 90 kg ha^{-1} (in the sowing year); N – 120 kg ha^{-1}, P_2O_5 – 78 kg ha^{-1}, K_2O – 90 kg ha^{-1} in the year of sward use. Dynamics of plant leaf area index and net photosynthesis productivity, expressed in g m^{-2} day^{-1}, were determined for first cut.

Sampling of each variety plants was carried out in 2 replications at 7–10–day intervals after spring regrowth till first cut. The sampling plot, in the area of 0.05 m^2, was cut by hand using sickle. The cut biomass was used to determine the LAI employing the disc method. The fully developed grass leaves were removed and weighed, and then 100 discs with a diameter of 3 mm were cut and weighed. A sample leaf area was calculated and expressed in square meters per 1 m^2 of sown area considering the leaf disc mass and the area. Net photosynthesis productivity was determined following the method described by Kidd, West and Briggs (Ничипорович, Строгонова et al., 1961). Dry weight and leaf area were determined at the beginning and end of each week. NPP was calculated as weekly increase in dry weight divided by the average leaf area of sample and then expressed for one day period (Ничипорович, Строгонова et al., 1961). Data were statistically analyzed employing analysis of variance, and correlation and regression analyses.

Meteorological conditions were different in wintering and vegetation periods. The main indices – average daily temperature and precipitation – for spring growing season till first cut are shown in Table 1.

In the year 2003, the cold winter with black frost and dry spring, hot July and first part of August followed by mild temperatures and rainfalls in the second part of August. Whereas in 2004, winter was mild, spring – dry and cool, but summer – rich in

Table 1

The air temperature and precipitation during the vegetation period compared with meteorological norm, 2003–2006

Month	Average daily air temperature, °C					Precipitation, mm				
	2003	2004	2005	2006	Norm	2003	2004	2005	2006	Norm
April	4.2	6.9	6.0	5.8	4.8	29	3	17	20	42
May	12.3	10.2	11.2	11.6	11.1	16	43	43	28	40
June	14.3	13.3	14.3	16.2	15.1	49	118	49	24	51

Table 2

The net photosynthesis productivity, g m^{-2} day^{-1}, and leaf area index on average for 2003–2006

Parameters	Varieties						
	Spidola	Lofa	Saikava	Hykor	Perun	Tapirus	Punia
Net photosynthesis productivity	5.63	7.48	8.29	6.99	7.30	7.94	7.85
$S_{\bar{x}}$	0.88	0.53	0.79	0.31	0.23	0.17	0.45
Leaf area index	2.01	2.28	1.94	2.91	2.53	1.98	2.66
$S_{\bar{x}}$	0.35	0.38	0.38	0.37	0.45	0.25	0.37
$LSD_{0.05}$ for NPP=3.02, for LAI=0.63							

precipitation and cool. Early snow cover without frost contributed to snow mildew formation in the winter of 2004/2005. The year 2005 was characterized by a late and cool spring and hot and dry July. In 2006, cold and long winter with sufficient snow cover was followed by an extremely hot and dry summer.

Results and Discussion

In the Latvian climatic conditions, most of the dry matter yields are produced by the first cut grass. According to our results, NPP and LAI for festulolium, hybrid ryegrass and perennial ryegrass individual grass species were different during regrowth period till the first cut.

On the average between four years of trial, the highest NPP was observed for festulolium cv. 'Saikava' – 8.29 g m^{-2} day^{-1} (Table 2). Perennial ryegrass demonstrated not only the lowest average value of NPP but also the lowest DM yield. Though there were differences between NPP values of the investigated varieties, they were not statistically significant (p>0.05). In the four years of trials, festulolium cv. 'Hykor' and 'Punia' gave the highest average values of LAI – 2.91 and 2.66 respectively. Differences between LAI values of investigated varieties were statistically significant (p<0.05).

Weather conditions affect leaf development and photosynthetic capacity. The dry and warm weather in May 2003 led to faster reaching of the maximum LAI and its reduction afterwards. The leaf photosynthesis was influenced by current meteorological conditions and by the leaf age. Greater leaf area did not provide increase in plant DM production per leaf area in the year 2003, and correlation between LAI and DM production was not significant (p>0.05).

In the year 2003, the highest net photosynthesis productivity was shown by festulolium cv. 'Hykor' – 6.68 g m^{-2} day^{-1}. NPP of perennial ryegrass cv. 'Spidola' was 3.37 g m^{-2} day^{-1}, and all festulolium and hybrid ryegrass cultivars exceeded it. In the year 2003, the average NPP of festulolium cultivars was by 74% higher compared to perennial ryegrass, and no close relationship between NPP and DM yield production was established (p>0.05).

In the year 2004, formation of leaf area was slow due to late and cool spring. Determination of festulolium and hybrid ryegrass leaf area dynamics showed that development of the maximum LAI was achieved before ear emergence stage. There was an upward trend of plant leaf area expansion over spring growing season till reaching maximum LAI. With the ageing of leaves, their photosynthetic capacity declines. A downward trend of NPP over spring growing season till first cut was observed. NPP was the highest during the first ten days of spring regrowth, but lower at ear emergence stage (Fig. 1).

In the year 2004, the highest net photosynthesis productivity was exhibited by festulolium cv. 'Saikava' – 8.97 g m^{-2} day^{-1}. This year for festulolium and hybrid ryegrass swards a significant (p<0.05) negative correlation was observed between the DM yield formation during spring growing season till first cut and the NPP (Fig. 2). It was determined that LAI and DM production had close relationship which was expressed by an equation of linear regression (p<0.01) (Fig. 3). In 2004, the maximum LAI was achieved by festulolium cv. 'Perun' – 3.6.

Generally, in spring 2005, the weather conditions as well as net photosynthesis productivity and leaf area dynamics were similar to those in the year 2004. The maximum LAI was achieved before ear emergence stage. An upward trend of plant leaf area expansion over spring growing season till reaching maximum LAI and a downward trend of NPP over spring growing season till first cut were observed. NPP was the highest at the beginning of spring regrowth, but the lowest at ear emergence stage (Fig. 4).

In the year 2005, hybrid ryegrass cv. 'Tapirus' had the highest net photosynthesis productivity – 9.23 g m^{-2} day^{-1}. NPP of perennial ryegrass cv. 'Spidola' was 5.53 g m^{-2} day^{-1}, and all festulolium and hybrid ryegrass cultivars exceeded it. The average net photosynthesis productivity of festulolium cultivars was by 45% higher than that of perennial ryegrass. There was a significant ($p < 0.05$) negative correlation between the DM yieldformation during spring growing season till first cut and the net photosynthesis productivity for festulolium and hybrid ryegrass swards (Fig. 5). It was

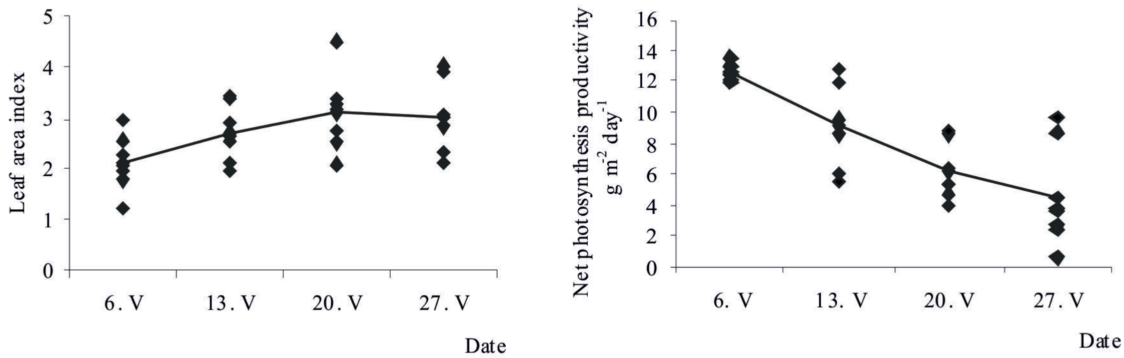

Fig. 1. Indices of photosynthesis for festulolium and hybrid ryegrass swards, 2004.

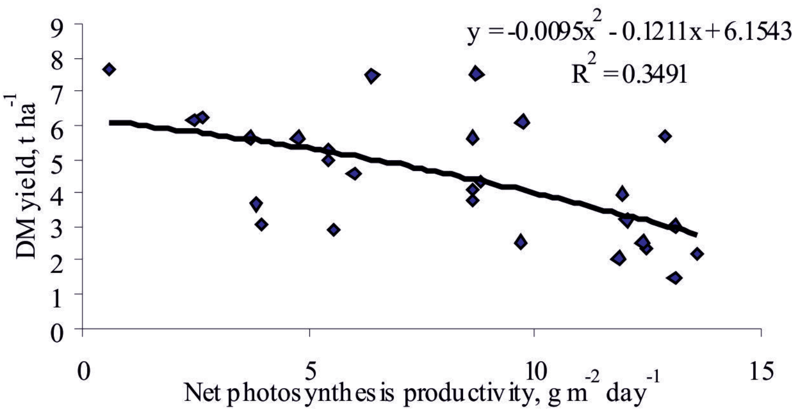

Fig. 2. The relationship between net photosynthesis productivity and plant dry matter yield in 2004, p<0.05.

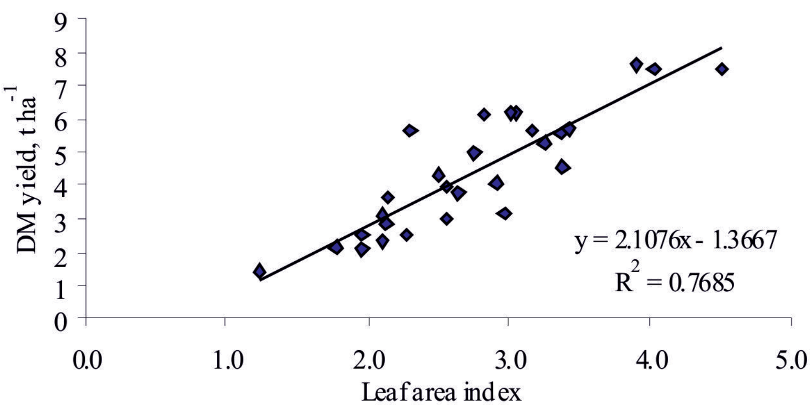

Fig. 3. The relationship between leaf area index and plant dry matter yield in 2004, p<0.01.

also determined that LAI and DM production had a close relationship which was expressed by an equation of linear regression (*p*<0.01) (Fig. 6). The maximum LAI (3.5) was achieved by festulolium cv. 'Hykor'.

In the year 2006, the dry and hot weather at the beginning of summer led to small average leaf area formation for all investigated varieties, and plant leaf area expansion over spring growing season till reaching maximum LAI was slow (Fig. 7). That year all varieties had the lowest LAI values compared to other trial years.

The rate of photosynthesis which a leaf exhibits in high light intensities declines faster with age. Smaller

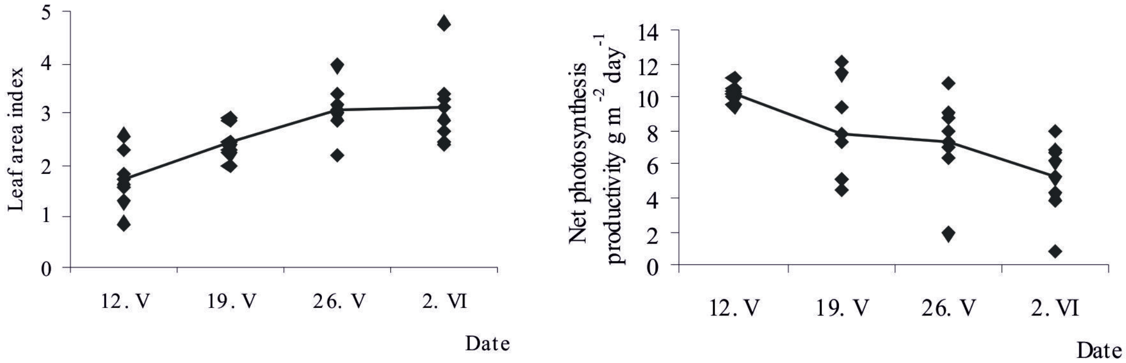

Fig. 4. Indices of photosynthesis for festulolium and hybrid ryegrass swards in 2005.

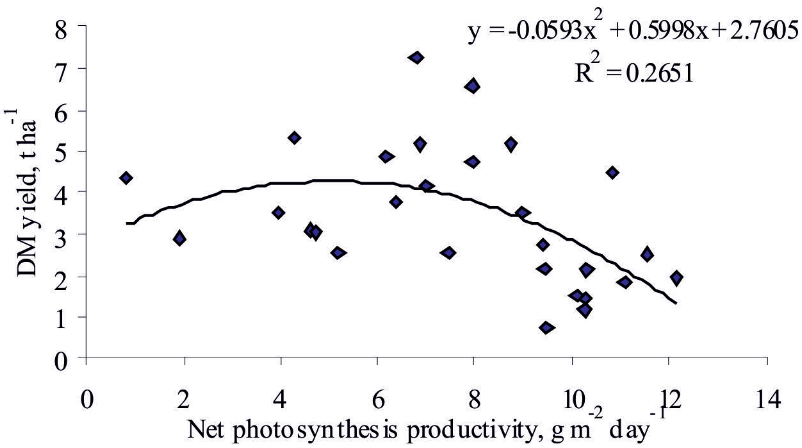

Fig. 5. The relationship between net photosynthesis productivity and plant dry matter yield in 2005, $p<0.05$.

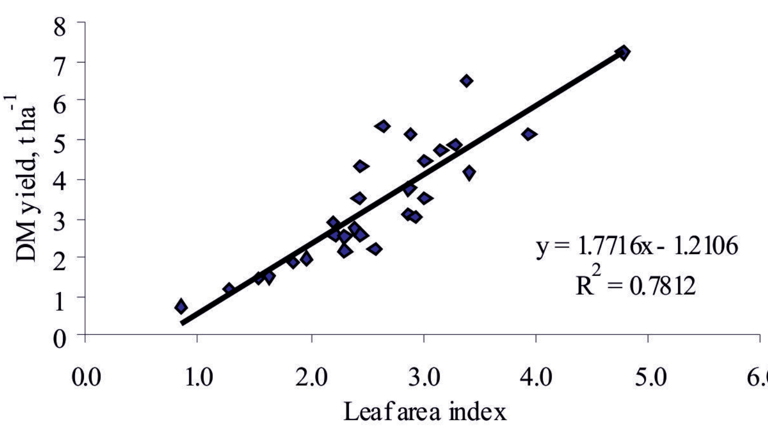

Fig. 6. The relationship between leaf area index and plant dry matter yield in 2005, $p<0.01$.

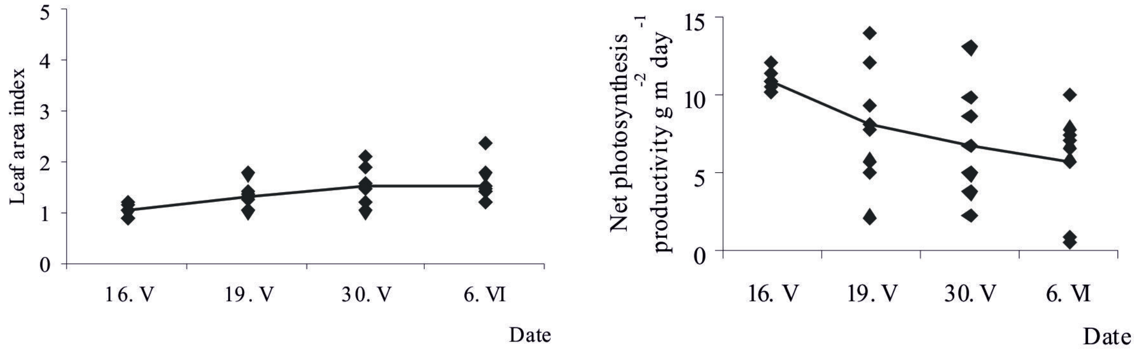

Fig. 7. Indices of photosynthesis for festulolium and hybrid ryegrass swards in 2006.

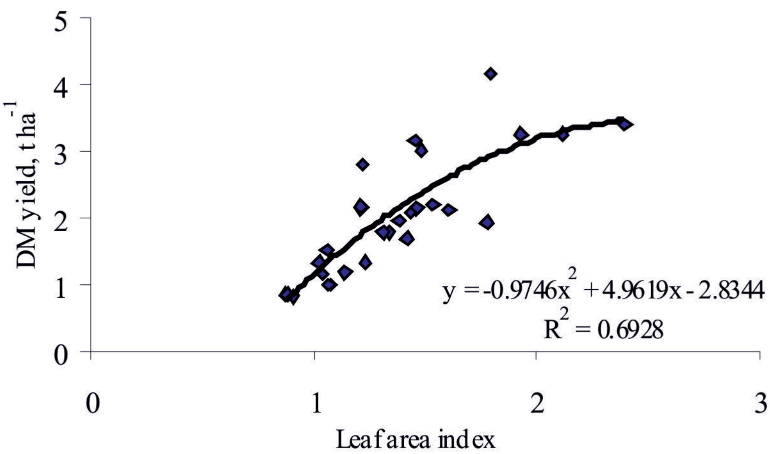

Fig. 8. Dependence between leaf area index and plant dry matter yield in 2006, $p<0.01$.

increase in leaf area and better light saturation in sward did not lead to higher photosynthetic capacity. In the year 2006, the highest NPP was demonstrated by hybrid ryegrass cv. 'Tapirus' and festulolium cv. 'Punia' – 9.27 and 9.11 g m^{-2} day^{-1} respectively. NPP of perennial ryegrass cv. 'Spidola' was 5.98 g m^{-2} day^{-1}, and all festulolium and hybrid ryegrass cultivars exceeded it. The average net photosynthesis productivity of festulolium cultivars was by 36% higher compared to perennial ryegrass. Correlation between net photosynthesis productivity and dry matter yield production was not significant ($p>0.05$). There was a significant correlation between leaf area index and dry matter production ($p<0.01$) (Fig. 8). That year, maximum value of LAI, i.e., 1.8, was achieved by festulolium cv. 'Hykor'.

Our results confirmed the data of other researchers (Parsons, Penning, 1988; Robson, Parsons, Williams, 1989; Nosberger, Staszewski, 2002) regarding changes in grass canopy photosynthesis during sward growth and at different leaf ages. The amount of leaves in a sward is a very important parameter as leaves intercept solar energy and provide photosynthesis. LAI values are influenced by the age of a sward (Būmane, 2009). Our trial also confirmed that increase in DM yield of grasses is closely associated with leaf area increase. Initially, increase in leaf area led to a grater biomass production, and a significant correlation between leaf area index and dry matter production was established in the years 2004, 2005, and 2006. It is found in the literature that there is a significant positive correlation between LAI and DM for tall fescue cultivars and their intergenetic hybrids (Gaborcik, Ilavska et al., 2006).

Leaves in herbage plants are not only the main organ which takes part in photosynthesis, but also a part of the harvested yield. The great influence of sward management regime on LAI and DM yield should also be noted. For the frequently defoliated swards of perennial ryegrass maximum weight of herbage harvested has been obtained between LAI 2 and 3. It has been determined that the relationship between net canopy photosynthesis and LAI for frequently defoliated swards is linear (King, Grant et al., 1984). At a three-time cutting regime, LAI values from 2.3 to 5.8 have been observed for festulolium 'Perun' (Gaborcik, Zametakova, Rataj, 2004). Following lenient defoliation average growth rate is lower overall, compared to frequently defoliated swards, and growth rate may actually decline during regrowth (Parsons, Johnson, Harvey, 1988). Defoliation intensity affect on the growth and production of tall fescue DM has been reported (Adamczewski, Donaghy, 2005). Other researcher has reported that large leaf area during particular years has resulted in a negative effect on the DM production (Adamovich, 2002). Three cuts during the vegetation season correspond to the lenient defoliation regime. Our research results did not show significant correlation between LAI and DM production in the year 2003 when leaves aged faster due to the dry and warm weather and the loss of green matter in leaf turnover was higher.

Leaf area expansion leads not only to higher dry matter production but also to greater shadow in swards. A significant negative correlation has been established between LAI and NPP for perennial ryegrass sward (Būmane, 2009). Within a vegetative sward the increase in leaf area results in the decrease of photosynthetic capacities because of mutual shading of leaves (Woledge, 1972; Рунце, 1986). This is the reason why data regarding correlation between net photosynthesis productivity and dry matter yield production are different. Some data indicate a significant positive correlation (Gaborcik, Ilavska et al., 2006), but some do not confirm a close relationship between NPP and DM production (Daepp, Suter et al., 2000; Adamovich, 2002).

Increase in dry matter yield for grasses is closely associated with leaf area increase, which was also proved by the results of our trials. The increase in leaf area resulted in the decrease of NPP indices because of mutual shading of leaves. Relationships between NPP and DM yields were characterised by weak negative linear correlation in all trial years; however, these relationships were significant at 95% probability level only in the years 2004 and 2005.

Our results showed that harvesting grasses at the beginning of ear emergence stage extends the regrowth period. On the one hand, it leads to increase in biomass production close to maximum, but, on the other hand, it decreases the photosynthesis productivity. It is necessary to achieve the best balance between photosynthesis and plant tissue production, and the amount of leaf removed by grazing or cutting (Hodgson, 1985). In Latvia, the highest NPP values (10.2–12.7 g m^{-2} day^{-1}) have been achieved in 24–32 days after the beginning of spring regrowth, which was influenced by meteorological conditions in the particular regrowth period.

Conclusion

1. Increase in grass dry matter yield was closely related to leaf area increase. A significant (p<0.01) positive correlation was established between the dry matter yield and leaf area index during regrowth period in spring till the first cut.
2. The influence of leaf area on net photosynthesis productivity was different in different periods of regrowth. Net photosynthesis productivity of festulolium and hybrid ryegrass swards decreased during the regrowth period in spring till the first cut.
3. The highest NPP (10.2–12.7 g m^{-2} day^{-1}) for festulolium, hybrid ryegrass and perennial ryegrass varieties was achieved 24–32 days after renewal of vegetation, which was greatly influenced by the weather conditions during leaf formation.
4. Relationships between net photosynthesis productivity and dry matter yields in all trial years were characterised by a weak negative linear correlation; however, they were significant only in two trial years.

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Anotācija

Auzeņairenes *(×Festulolium* Asch.&Graebn.) ir perspektīvs kultūraugs Ziemeļeiropā, kur klimatiskie apstākļi nav pietiekami labvēlīgi aireņu audzēšanai. Pētījumi veikti, lai noteiktu ārzemju un vietējās izcelsmes auzeņaireņu un hibrīdo aireņu *(Lolium×boucheanum* Kunth.) šķirņu produktivitāti. Līdz pirmajam pļāvumam noteikti fotosintētisko darbību raksturojošie parametri – fotosintēzes tīrā produktivitāte (FTP) un lapu virsmas laukuma indekss (LLI) –, kā arī to ietekme uz sausnas ražu. Veģetācijas perioda sākumā notiek strauja augu audu veidošanās, kas savukārt nodrošina fotosintezējošās virsmas palielināšanos un rezultātā arī kopējo sausnas ražas palielinājumu. To apstiprina arī mūsu pētījumu rezultāti. Trijos izmēģinājuma gados auzeņairenes, hibrīdās airenes un ganību airenes šķirnēm tika konstatēta būtiska pozitīva sakarība starp LLI un sausnas ražas veidošanos veģetācijas periodā līdz vārpošanas fāzei. Palielinoties lapu virsmas laukumam, savstarpējā noēnojuma dēļ FTP rādītāji samazinājās. Tādēļ dati par sausnas ražas palielinājumu atkarībā no FTP ir atšķirīgi. Ir pētījumi, kuros konstatēta būtiska pozitīva korelācija starp FTP un sausnas ražu (Gaborcik, Ilavska et al., 2006), un ir arī pētījumi, kuros būtiskas likumsakarības nav novērotas (Daepp, Suter et al., 2000;

Adamovich, 2002). Mūsu pētījumu rezultāti daļēji saskan ar iepriekš literatūrā publicēto: sakarību starp FTP un sausnas ražu visos izmēģinājuma gados raksturoja vāja negatīva lineāra korelācija, tomēr šīs sakarības bija būtiskas 95% ticamības līmenī tikai 2004. un 2005. gadā. Pētījuma rezultāti liecina, ka auzeņaireņu un hibrīdo aireņu pļauja vārpošanas sākuma stadijā, no vienas puses, nodrošina lielāku biomasas ieguvi, bet, no otras puses, samazina FTP rādītājus. Augstākā FTP tika sasniegta 24–32 dienas pēc veģetācijas atjaunošanās, un šos rādītājus lielā mērā ietekmēja meteoroloģiskie apstākļi lapu veidošanās laikā.