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Potential of ten alternative grass species under different cutting regimes in Central Europe

Anbauwürdigkeit von zehn alternativen Gräsern bei unterschiedlicher Schnitthäufigkeit in Mitteleuropa

Abstract

Perennial grasslands play an important role as an extensive CO_2 sink. Fodder and biofuels can be produced in an ecologically acceptable manner on such sites. Projected future climate-change scenarios suggest that Central Europe's grasslands will be increasingly affected by drought. In order to determine whether there is potential for some alternative drought-adapted grass species to contribute to herbage production for either forage or biomass, we tested the agronomic performance of ten grass species (*Agropyron elongatum*, *Agropyron intermedium*, *Agropyron desertorum*, *Agropyron trachycaulum*, *Elymus hoffmannii*, *Elymus junceus*, *Bromus inermis*, *Bromus marginatus*, *Festuca arundinacea* and *Panicum virgatum*) in comparison to four reference grasses (*Dactylis glomerata*, *Arrhenatherum elatius*, *Agrostis gigantea* and *Agropyron repens*). Experiments were conducted in small-plot cutting trials at two sites across two growing seasons with either one or multiple cuts per season.

In the one-cut system, *P. virgatum* provided the highest average annual dry matter (DM) yield (14 258 kg ha^{-1}), followed by *A. elongatum* (13 086 kg ha^{-1}). The multi-annual persistence of these two species under the experimental conditions was given only when *P. virgatum* was not harvested before freezing off and *A. elongatum* was harvested only once per year. Moreover, both species are susceptible to lodging. In the multiple-cut system, *F. arundinacea* showed a high yield (12 533 kg DM ha^{-1} average annual yield) and a low presence of associated weeds (only 0.1% surface area). Cultivating this grass species requires considering its only moderate competitiveness during the establishment phase. Based on the rapid establishment of *A. trachycaulum*, this species is expected to be best suited as a cover crop in seed mixtures. The yields of *A. desertorum*, *A. trachycaulum*, *A. repens*, *E. junceus* and *B. marginatus* were below the experimental average (9255 kg DM ha^{-1} at multiple cuttings).

Key words: Grassland, cutting frequency, forage production, biofuel, weeds, wheatgrass, switchgrass, wildrye, tall fescue, redtop, orchardgrass, tall oatgrass

Zusammenfassung

Die Bedeutung von mehrjährigem Grasland als großflächige CO_2-Senke ist hoch. Auf diesen Flächen könnten neben Futtermitteln auch Nachwachsende Rohstoffe ökologisch verträglich produziert werden. Aufgrund des fortschreitenden Klimawandels werden die Grünlandflächen Mitteleuropas künftig häufiger von Trockenheit betroffen sein als bisher.

Um deren Anbaupotenzial unter mitteleuropäischen Bedingungen zu testen, wurden zehn trockentolerante Gräser (*Agropyron elongatum*, *Agropyron intermedium*,

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Agropyron desertorum, *Agropyron trachycaulum*, *Elymus hoffmannii*, *Elymus junceus*, *Bromus inermis*, *Bromus marginatus*, *Festuca arundinacea* und *Panicum virgatum*) angebaut und mit vier standortüblichen, leistungsfähigen Futtergräsern in Vergleich gestellt (*Dactylis glomerata*, *Arrhenatherum elatius*, *Agrostis gigantea* und *Agropyron repens*). Die Parzellenversuche wurden an zwei Standorten über zwei Versuchsjahre bei Ein- und Mehrschnittnutzung durchgeführt.

Bei Einschnittnutzung lieferte *P. virgatum* den höchsten bereinigten Jahresertrag (14 258 kg TM ha^{-1}), gefolgt von *A. elongatum* (13 086 kg TM ha^{-1}). Die mehrjährige Ausdauer dieser zwei Arten war unter den Versuchsbedingungen aber nur gegeben, wenn *P. virgatum* nicht vor dem Abfrosten und *A. elongatum* nur einmal pro Jahr geerntet wurde. Die Lageranfälligkeit der beiden Arten muss beachtet werden. Bei Mehrschnittnutzung konnte *F. arundinacea* sowohl in der Ertragshöhe (12 533 kg TM ha^{-1} korrigierter Jahresertrag) als auch durch das geringe Aufkommen an Begleitflora (0,1% Fläche) überzeugen. Beim Anbau dieser Grasart ist die nur mäßige Konkurrenzkraft während der Etablierungsphase zu berücksichtigen. Aufgrund der raschen Jungendentwicklung von *A. trachycaulum* wird erwartet, dass sich die Art für den Einsatz als Deckfrucht in Saatgutmischungen eignet. *A. desertorum*, *A. trachycaulum*, *A. repens*, *E. junceus* und *B. marginatus* lagen im Ertrag unterhalb des Versuchsdurchschnittes (9254,5 kg DM ha^{-1} bei Zweischnittnutzung).

Stichwörter: Grünland, Schnittfrequenz, Futterproduktion, Nachwachsende Rohstoffe, Unkräuter, Ungräser, Weizengras, Mehrjährige Rutenhirse, Rohrschwingel, Straußgras, Knaulgras, Glatthafer

1 Introduction

Preserving permanent and temporary grasslands is ecologically important. Grasslands are usually superior to crop fields in biodiversity, the capacity to absorb rainfall and water conservation. The conversion of grassland to arable land always leads to carbon losses in the soil (Guo and Gifford, 2002) and often to increased N leaching losses (Kayser et al., 2008).

In the past, the yield performance of Central European grasslands has already been impaired to varying degrees by drought, depending on site and weather conditions. Haas et al. (2008) raise the following points: As climate change progresses, grasslands as permanent crops can be classified as highly vulnerable due to heat waves and subsequent water shortages. In Austria, for example, grasslands in regions with < 600 mm total annual precipitation are particularly threatened; 28% of all current grasslands fall within this risk category. The breeding and targeted use of heat-tolerant crops (species/varieties) with a low water demand – in the sense of a regionally adapted management – has been defined as one option in the framework of the climate change adaptation strategy.

Currently, production is geared towards nutrient-rich forage for high-performance animals and occasionally for recreational animals (Buchgraber and Gindl, 2004). Recently, more importance has been attached to the production of substrates for biogas facilities, combustible materials, raw materials for second-generation liquid biofuels (biomass-to-liquid) or basic ingredients for paper, bioplastics, lightweight concrete, insulating material and as reinforcement in mud bricks (Ashour et al., 2010; Digman et al., 2010; Elbersen et al., 2004; Heaton et al., 2008; Sakulin et al., 2009; Sanderson et al., 2007; Tonn et al., 2011).

Many of the energy plants raised used for these purposes in Europe (such as *Miscanthus* "Giganteus" or short rotation forestry) are traditionally propagated vegetatively. Energy plants that can be propagated by seeds have the following advantages:

- rapid and simple establishment,
- harvest is possible in the seeding year or in the following year, therefore rapid amortization of the establishment costs and
- potential for an inexpensive and rapid return of energy grass (crop) fields into arable land or grassland.

The present study deals with perennial, seed-propagated grass species that have rarely been grown in Central Europe, specifically those that can be expected to exhibit a higher drought tolerance compared with traditional fodder grasses. The focus is on the production of renewable raw materials as well as crude-fiber-rich fodder for extensively farmed animals, combined with a tailored cutting regime (one-cut for material use and combustion, two- or three-cut for biogas or for feeding). This low cutting frequency compared to intensive grassland is designed to reduce harvesting costs and to help reduce substances undesired for certain uses (e.g. nitrogen in combustible materials).

Examining the agronomic traits should help to preselect promising species. The aim is to identify grass species for the Central European region that will provide stable yields, enable various commercial uses, and allow for an ecologically acceptable cultivation.

Data gained from the establishment phase have already been published (Schrabauer et al., 2009; Schrabauer et al., 2010). A follow-up project will evaluate the potential use of the crops (in particular as renewable raw materials and as fodder) and the effects of cultivating the selected grasses on the environment. An evaluation of the actual drought tolerance under artificially induced drought is also envisioned.

2 Material and Methods

2.1 Site description

Field experiments were conducted at two different production sites in Austria: in the Marchfeld and in the alpine foothills. The experimental site in the Marchfeld (Groß Enzersdorf, 48°11'29.9"N 16°33'44.4"E) is characterized by Pannonian climate, that of the alpine foothills (St. Leonhard am Forst, 48°08'50.8"N 15°19'11.0"E) by a Central European transitional climate. The selected sites differ in their long-term mean annual temperature (1.2°C higher in Marchfeld) and in mean total annual precipitation (125 mm higher in the alpine foothills). The long-term annual mean temperature und long-term annual precipitation are 9.9°C and 548 mm in the Marchfeld and 8.7°C and 673 mm in the alpine foothills (Tab. 1). The Marchfeld site is therefore more threatened by drought stress than the alpine foothills. The above-average total annual precipitation (1067 mm) in 2009 at the alpine foothill site needs to be mentioned; in July 2009, torrential rains flooded the experimental plots several times for hours (Fig. 1). The soil type in the experimental plots in the Marchfeld is a "grey" Calcaric Fluvisol (Grauer Auboden), in the alpine foothills a "brown" Calcaric Fluvisol (Brauner Auboden). The topsoil (A-horizon rich in humus) at both sites measures about 25 cm (Tab. 1).

2.2 Experimental design

The test plots were established in a completely randomized design with 3 replicates and were set up identically at both sites. Separate experiments were conducted for the one-cut and multiple-cut systems. The net plot size was 12 m^2 in the Marchfeld and 10 m^2 in the alpine foothills. The space between plots was 1 m, sown with adjacent test grasses.

Ten grass species with potential drought tolerance, along with four reference grass species, were cultivated (Tab. 2). The drought tolerance was determined based on literature references and distribution and cultivation areas. The primary reference source was the Plants Database of the United States Department of Agriculture, Natural Resources Conservation Service (USDA NRCS, 2014).

One of the grasses (*P. virgatum*) has a C_4-metabolism, all the others are C_3 crops. As WOODIS and JACKSON (2008) demonstrated using *Andropogon gerardii* Vitman, C_4 grasses show higher biomass increases than C_3 grasses during summer dry periods in July and August.

Tab. 1. Climate and soil data

	Marchfeld	Alpine foothills
Climate		
Annual mean temperature 1961–2000	9.9 °C	8.7 °C
Annual mean temperature 2009	10.8 °C	9.9 °C
Annual mean temperature 2010	9.5 °C	8.5 °C
Annual precipitation 1961–2000	548 mm	673 mm
Annual precipitation 2009	535 mm	1067 mm
Annual precipitation 2010	717 mm	856 mm
Soil		
Soil type	"grey" Calcaric fluvisol	"brown" Calcaric fluvisol
Water conditions	moderately dry	good
Groundwater level	6 to 7 m	2 to 3 m
pH value (ÖNORM L 1083)	7.5	7.3
Humus content (ÖNORM L 1080)	2.5 %	4.8 %
Clay content (Spindle method)	23 %	14 %

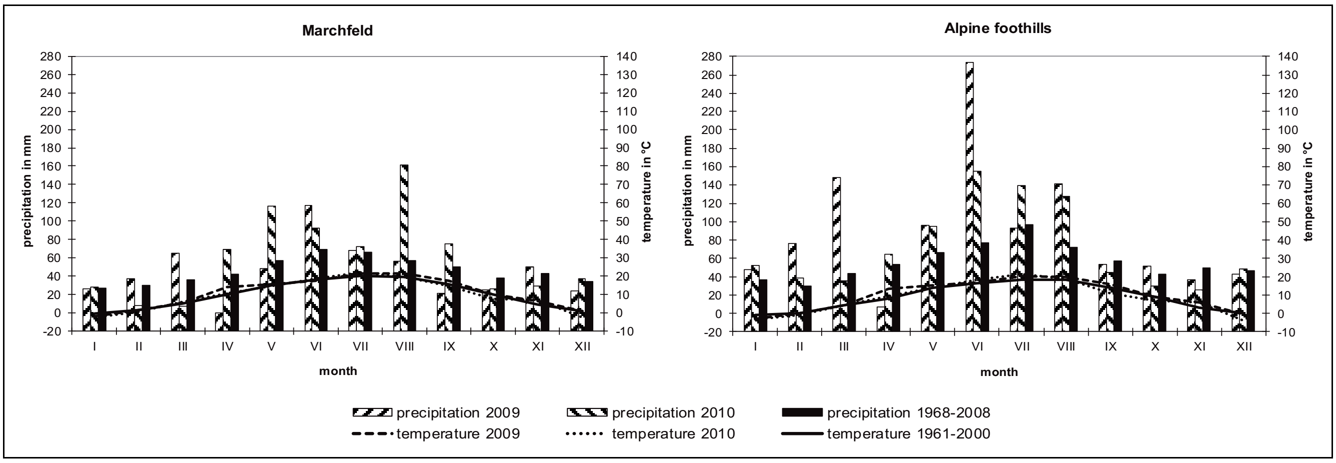

Fig. 1. Precipitation and temperature of experimental sites.

Tab. 2. Scientific and English common name, natural range, variety and cutting system of the tested grass species

Latin name	English name	Natural range[1]	Variety	Cut system in experiment multiple-cut	Cut system in experiment one-cut
Tested grasses					
Agropyron elongatum (Host) P. Beauv.	Tall wheatgrass	Europe, Asia	Szarvasi I	x	x
Agropyron elongatum (Host) P. Beauv.	Tall wheatgrass	Europe, Asia	Anonymous[2]	x	x
Agropyron elongatum (Host) P. Beauv.	Tall wheatgrass	Europe, Asia	Alkar	x	x
Agropyron intermedium (Host) P. Beauv.	Intermediate wheatgrass	Europe	Rush	x	
Agropyron desertorum Schult.	Desert wheatgrass	Europe, Asia	Anonymous[2]	x	x
Agropyron trachycaulum (Link) Malte	Western ryegrass	America, Asia	Revenue	x	
Elymus hoffmannii Jensen & Asay	Green wheatgrass	America	Newhy	x	
Elymus junceus Fisch.	Russian wildrye	Europe, Asia	Anonymous[2]	x	
Bromus inermis Leyss.	Smooth brome	Europe, Asia	Anonymous[2]	x	
Bromus marginatus Steud.	Mountain brome	America	Tacit	x	
Festuca arundinacea Schreb.	Tall fescue	Europe, Africa, Asia	Belfine	x	x
Panicum virgatum L.	Switchgrass	America	Blackwell		x
Reference grasses					
Dactylis glomerata L.	Orchardgrass	Europe, Africa, Asia	Tandem	x	
Arrhenatherum elatius (L.) P. Beauv.	Tall oatgrass	Europe, Africa, Asia	Arone	x	
Agrostis gigantea Roth	Redtop	Europe, Africa, Asia	Kita	x	
Agropyron repens (L.) P. Beauv.	Quackgrass	Europe, Asia	Anonymous[2]	x	

[1] after Hanelt (2001)
[2] Variety name unknown by seed distributor

2.3 Sowing and cultivation in the experiments

Sowing took place in August 2007 and May 2008. The agronomic practice in Central Europe requires rapid establishment. In foreign literature the recommended seed rates, especially for grasses of the genera *Agropyron* and *Elymus*, are designed for longer establishing periods. In the experiment, increased seed rates were used (Tab. 3).

During the establishment phase, clearance-cuts were conducted and weeds removed chemically and manually so that largely uniform and weed-free grass stands were present in autumn 2008. Data gained from the establishment phase have already been published (Schrabauer et al., 2009; Schrabauer et al., 2010).

2.4 Fertilization

During the data collection period 2009 and 2010, each plot was fertilized in April with 200 kg K_2O ha^{-1} a^{-1} (potassium chloride) as well as 60 and 80 kg P_2O_5 ha^{-1} a^{-1} (superphosphate). Additionally, mineral nitrogen fertilizer was applied at a rate of 37.5 kg N ha^{-1} at each cut (calcium ammonium nitrate). Accordingly, the nitrogen amount in the one-cut system was 37.5 kg N ha^{-1} a^{-1}, in the two-cut system 75 kg N ha^{-1} a^{-1} (in 2009), and in the three-cut system 112.5 kg N ha^{-1} a^{-1} (in 2010). The

Tab. 3. Seed rate

	seed rate kg ha^{-1}
Tested grasses	
Agropyron elongatum (Host) P.Beauv.	60
Agropyron intermedium (Host) P.Beauv.	55
Agropyron desertorum Schult.	40
Agropyron trachycaulum (Link) Malte	45
Elymus hoffmannii Jensen & Asay	55
Elymus junceus Fisch.	40
Bromus inermis Leyss.	35
Bromus marginatus Steud.	30
Festuca arundinacea Schreb.	40
Panicum virgatum L.	22.5
Reference grasses	
Dactylis glomerata L.	25
Arrhenatherum elatius (L.) P.Beauv.	40
Agrostis gigantea Roth	20
Agropyron repens (L.) P.Beauv.	100

application took place in April, in the two-cut system additionally after the first cut, and in the three-cut system additionally after harvesting the first and second cut (in both cases within two weeks after harvest).

2.5 Harvest management

One-cut system. The plots of the one-cut system were harvested on 10 September 2009 in the Marchfeld and on 13 September in the alpine foothills. In 2010, harvesting – with the exception of *P. virgatum* – took place on 28 September (Marchfeld) and 4 October (alpine foothills). The biomass of *P. virgatum* was harvested after freezing off on 17 November 2010 (Marchfeld) and 9 February 2011 (alpine foothills).

Multiple-cut system. Here, the plots were mowed twice in 2009 and three times in 2010. In the Marchfeld, the cuts in 2009 were done on 5 June and 10 September, in the alpine foothills on 17 June and 13 September. In 2010, the harvests in the Marchfeld were conducted on 19 May, 28 July and 28 September, in the alpine foothills on 23 May, 26 July and 4 October.

Mowing was done with a mono-axle mower (Marchfeld) and a front mounted drum mower (alpine foothills). The cutting height was 7 cm. For *A. elongatum*, BREDE (2000) recommends a cutting height of at least 15 cm in the multiple-cut system, but this is technically unfeasible using the mowing equipment available to farmers in Central Europe and was therefore not implemented in our experiments. Moreover, such a cutting height would have produced an unsatisfactory result for the tested grasses, which are susceptible to lodging; even at the 7 cm cutting height, subsequent mowing with a scythe was necessary on some occasions.

2.6 Surveys and observations

The assessment methods were oriented by the guidelines of the Austrian variety testing (BFL, 2002) as far as possible. Prior to each harvest the following criteria were assessed once for each plot (measured criteria are the average of at least three measurements per replicate):

- overall projective soil cover in percentage of surface (estimated),
- projective soil cover of individual plant species in percentage of surface (estimated),
- yield share of unplanted species (weeds) in percent (estimated),
- proportion of individual plants with panicles or seed heads. A plant was classified as bearing panicles/seed heads when at least one panicle/seed head was clearly recognizable. Panicles or seed heads that were strongly decomposed (i.e. culms were entirely broken off) were not counted – this is particularly valid for the one-cut system (estimated),
- lodging, a value of 0% = no lodging to 100% = total lodging; 50% corresponds for example to a plant inclination of approximately 45° from the normal orientation or stronger lodging affecting 50% of the plot (estimated),
- disease infestation (infected plant surface in percent, estimated),
- spreading to adjoining plots (mean distance of individual plants outside the plot to the plot edge, measured) and
- long-distance dispersal via seeds of the alien grasses. Visual control surveys were conducted several times per year in a radius of ca. 200 m around the experimental plots.

The harvests were weighed separately for each plot. Based on the dry matter contents determined in the laboratory, the dry matter yields were calculated from the fresh weights in the field. These values were then corrected by reducing the yield shares of unplanted species (weeds). The increase in yield of associated plants and weeds is attributed to a reduced competitiveness of the respective tested grass. This parameter is used to evaluate the persistence of the grasses.

In May 2011, the experimental plots were plowed at the alpine foothill site, planted with corn and treated post-emergence with the herbicides terbuthylazine and s-metolachlor. On 16 September 2011, the soil cover of former experimental grasses under the corn plants was determined (estimated).

2.7 Statistical analysis

The statistical analysis was done using the statistical package SAS 9.1.3. The Levene test was applied to determine variance homogeneity as prerequisite for ANOVA. The SAS procedures GLM and MIXED were used. Fixed factors were species and site, the repeated factor was year. The Student-Newman-Keuls-test and analysis of variance with a Repeated Measurement Analysis were carried out using a significance level of $\alpha = 0.05$. The statistical model considered all interactions with the exception of the threefold interaction. The data on yields and soil coverage are presented as bar diagrams with groupings according to the results of the Student-Newman-Keuls-test. The statistical analysis for yield and projective soil cover data was conducted separately for each experimental year, for each site and for planted/not planted species. Within each statistical analysis, means with the same letter are not significantly different. The corrected annual yield – calculated by adding up the individual cuts – was used for the analysis of the harvest data.

3 Results

3.1 Yield and competitiveness

The corrected annual yield (total yield minus yield of unplanted species) was used to assess the yield potential of the individual grass species. The overall mean value in the multiple-cut system was 9255 kg DM ha^{-1} and in the one-cut system 11 425 kg DM ha^{-1}.

Influence of site on yield. The yields in both cutting systems were higher at the alpine foothill site than in the

Marchfeld (mean value in the multiple-cut system by + 1497 kg DM ha^{-1} and in the one-cut system by + 2997 kg DM ha^{-1}). The influence of site on yield was significant (Tab. 4).

Influence of year on yield. At both sites, the corrected annual yields dropped with the duration of the experiment. From 2009 to 2010, values in the multiple-cut system dropped by −3835 kg DM ha^{-1} in the Marchfeld and by −5283 kg DM ha^{-1} in the alpine foothills (Fig. 2). At the same time, the projective soil cover of weeds in the experimental plots increased from 2 to 13% of surface in the Marchfeld and from 3 to 37% of surface in the alpine foothills (Fig. 4). The average proportion of unplanted weed species in the total yield increased at each cut. Overall, 61 unsown species were counted, of which 34 were forb, 25 grass and 2 clover species. The highest contribution was by orchard grass (Marchfeld) and ryegrass species (alpine foothills).

In the one-cut system, the annual yield without weeds fell from 2009 to 2010 only in the alpine foothills (by −6907 kg DM ha^{-1}, see Fig. 3). In 2010 the projective soil cover of weeds in the one-cut system averaged only 4% of surface and was considerably lower than in the multiple-cut system. The competitiveness and the persistence of the selected grass species were higher in the one-cut system (Fig. 5).

Influence of grass species on yield. In the multiple-cut system, the influence of grass species on yield was significant. In 2009 the highest corrected annual yields in the multiple-cut system – averaged for both sites combined – were recorded for *A. elongatum* “Alkar” (15 616 kg DM ha^{-1}), in 2010 for *F. arundinacea* (11 675 kg DM ha^{-1}). Compared with *A. elongatum* “Alkar”, *A. elongatum* “Szarvasi I” in the multiple-cut system attained −3302 kg DM ha^{-1} (overall mean) less, although the difference was significant only in 2009 in the Marchfeld. The lowest yields were obtained for *E. junceus* (6405 kg DM ha^{-1} in 2009) and *A. trachycaulum* (Link) (3420 kg DM ha^{-1} in 2010, see Fig. 2).

The differences in the competitive ability of the grass species were evaluated based on the presence of the accompanying flora (weeds). The projective soil cover of species that were not planted averaged (overall mean) in the multiple-cut system between 0.1% of surface (*F. arundinacea*) and 26% of surface (*A. trachycaulum*).

At the alpine foothills, only *F. arundinacea* never showed weed growth in the multiple-cut system throughout the experimental period. In contrast, in the Marchfeld, *F. arundinacea*, *D. glomerata*, *B. inermis*, *A. elatius* and *A. gigantea* proved to be strong competitors. The projective soil cover of the accompanying flora in the above species was maximally 3% of surface. In the multiple-cut system, the following species were especially poor competitors: *A. elongatum* (variety “Szarvasi I”), *A. intermedium*, *A. desertorum* and *E. hoffmannii*. In 2010 the projective soil cover of weeds for these grasses at both sites reached at least 20% of surface. *A. trachycaulum* differed conspicuously between the two sites: in the Marchfeld the weed cover peaked at 19% of surface. In the alpine foothills the weed cover peaked at 76% of surface, the highest value in the entire experiment. The differences, however, were not always significant (Fig. 4).

In the one-cut system, *P. virgatum* in Marchfeld showed the highest corrected annual yield in both years (16 197 and 13 324 kg DM ha^{-1} in 2009 and 2010, respectively). In 2010, however, the yield advantages over the other

Tab. 4. F-statistics for the corrected DM yields and percent soil coverage of the selected grasses

Effect	corrected DM yield		Surface projective soil cover by sowed grass species	
	F-statistic	PR > F	F-statistic	PR > F
Multiple-cut system				
Species	27.85	< 0.0001	29.56	< 0.0001
Site	47.97	< 0.0001	50.90	< 0.0001
Year	445.01	< 0.0001	460.61	< 0.0001
Site × species	4.03	< 0.0001	6.33	< 0.0001
Species × year	9.89	< 0.0001	10.91	< 0.0001
Year × site	11.22	0.0010	66.96	< 0.0001
One-cut system				
Species	28.29	< 0.0001	20.84	< 0.0001
Site	32.88	< 0.0001	28.97	< 0.0001
Year	26.13	< 0.0001	7.47	0.0085
Site × species	3.08	0.0164	5.51	0.0004
Species × year	3.70	0.0061	6.13	0.0001
Year × site	65.67	< 0.0001	67.21	< 0.0001

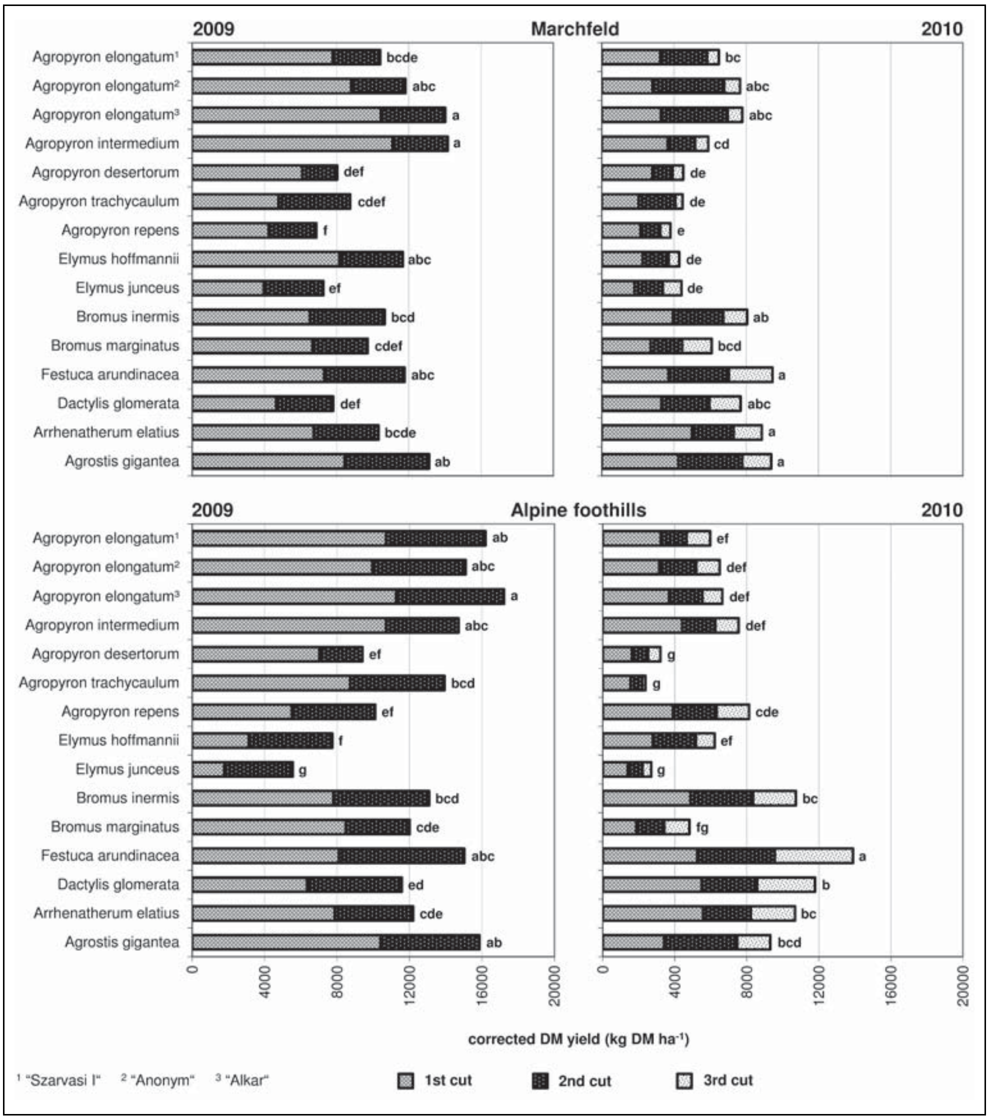

Fig. 2. Corrected annual DM yields in the multiple-cut system in 2009 and 2010 of the Marchfeld and alpine foothill sites.

cultivars of *A. elongatum* as well as over *F. arundinacea* were not statistically significant (Fig. 3). In the alpine foothills, in contrast, *A. elongatum* "Anonym" yielded the highest values in both years (20 197 and 13 052 kg DM ha^{-1} in 2009 and 2010, respectively). The yield difference was not always significant. All three varieties of *A. elongatum* proved to be more competitive in the one-cut versus multiple-cut system. This was reflected in the low proportion of weeds (maximum 365 kg DM ha^{-1} or 3.5% of total yield).

In 2009, *P. virgatum* in the alpine foothills exhibited a high corrected annual yield (19 808 kg DM ha^{-1}). Nonetheless, weeds and other grass species increased again in 2010, reducing the corrected annual yield to 7720 kg DM ha^{-1}. The soil coverage by the associated vegetation here (32% on 23 May 2011) was above the experimental mean of the one-cut system (10%, Fig. 5). The growth rate in spring was slower compared to the other grass species. This advantaged the weed seeds, which therefore had more space to establish. The yield of *P. virgatum* dropped by 61% in the alpine foothills from 2009 to 2010. In the Marchfeld the yield reduction was only 18%.

In the one-cut system, *A. desertorum* reached a maximum projective soil cover of accompanying flora of 24% of surface (alpine foothills, 2010). This also points to below-average competitive ability.

3.2 Invasiveness

The individual experimental grasses spread into adjoining plots within the inter-plot spaces via rhizomes (vegetatively) and via seeds (generatively) increasingly during the experimental period from 2008 to 2010. At the final assessment in autumn 2010, *B. inermis* (48 cm) and *A. repens* (18 cm) exhibited the greatest vegetative spreading (Tab. 5). *B. marginatus* and *A. elatius* showed the strongest generative reproduction, i.e. with an average expansion of 11 cm and 6 cm, respectively, across the plot margins. Both vegetative and generative spreading was recorded in *A. gigantea*. This value increased to 45 cm beyond the plot margins at the end of the experiments. Minimal spreading was recorded for *F. arundinacea* (4 cm), *D. glomerata* (3 cm), *A. desertorum* (3 cm) and *E. hoffmannii* (1 cm). The following species remained inside their plots: *A. elongatum*, *A. intermedium*, *A. trachycaulum*,

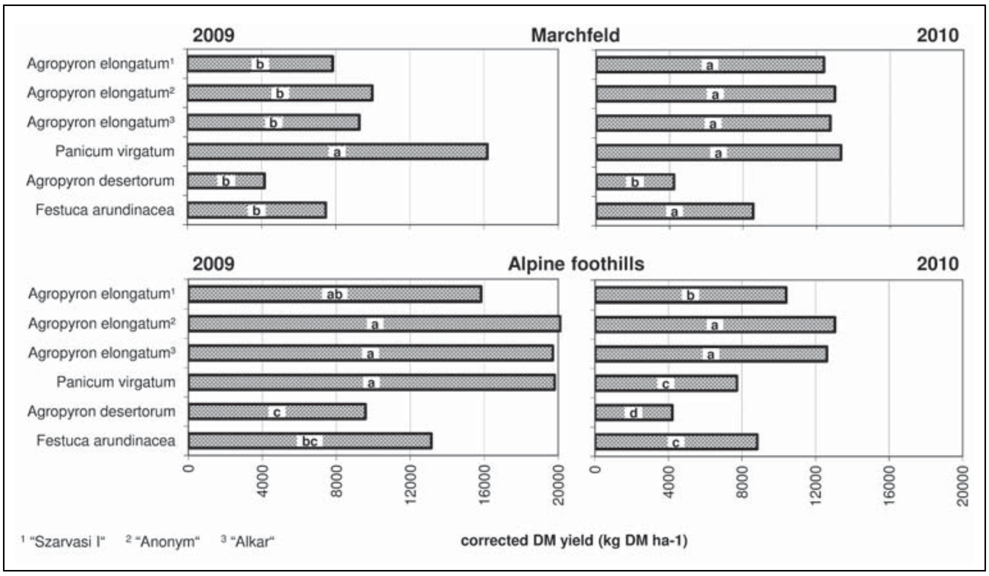

Fig. 3. Corrected annual DM yields in the one-cut system in 2009 and 2010 of the Marchfeld and alpine foothill sites.

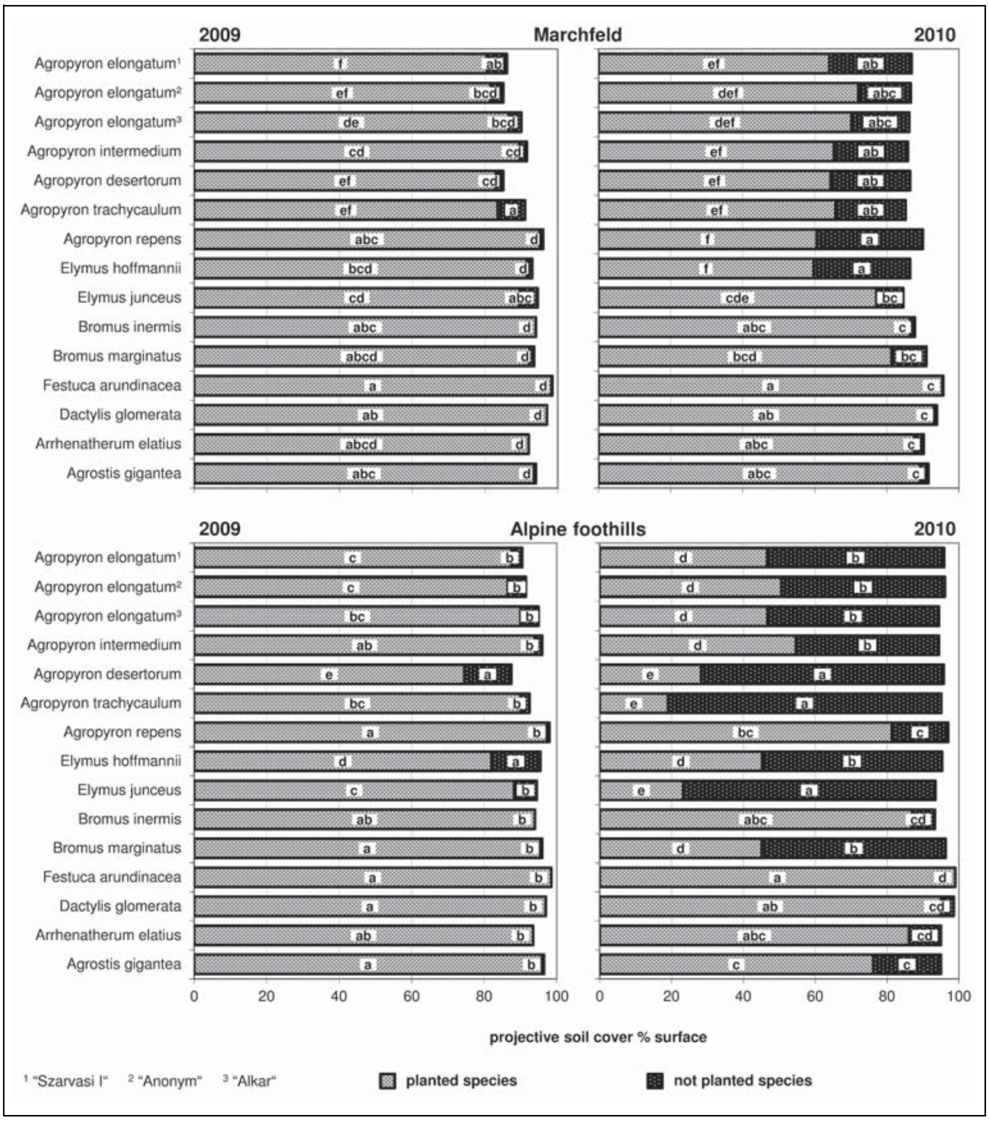

Fig. 4. Projective soil cover of planted species and weeds in the multiple-cut system in 2009 and 2010 of the Marchfeld and alpine foothill sites.

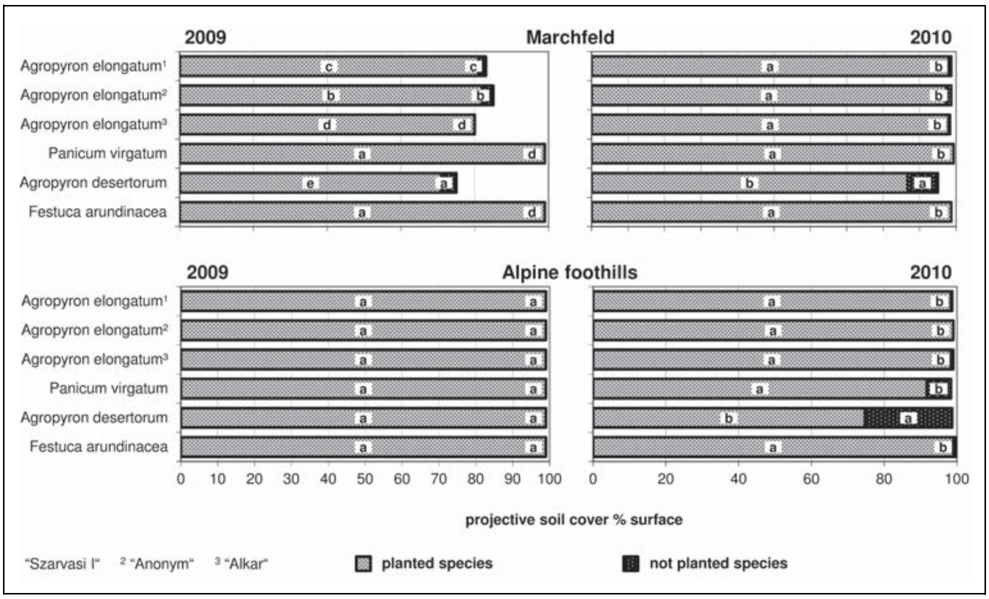

Fig. 5. Projective soil cover of planted species and weeds in the one-cut system in 2009 and 2010 of the Marchfeld and alpine foothill sites.

Tab. 5. Invasiveness and disease infestation of the various grass species, assessed shortly before the cut; median value of Marchfeld and alpine foothill sites combined

	cm spreading to adjoining plots	% infected plant surface last growth	
	autumn 2010	2009	2010
Multiple-cut system			
Agropyron elongatum[1]	0 b	25 cd	11 b
Agropyron elongatum[2]	0 b	15 d	8 b
Agropyron elongatum[3]	0 b	15 d	7 b
Agropyron intermedium	0 b	15 d	13 b
Agropyron desertorum	3 b	38 b	12 b
Agropyron trachycaulum	0 b	50 a	22 a
Agropyron repens	18 b	38 b	28 a
Elymus hoffmannii	1 b	55 a	12 b
Elymus junceus	0 b	25 cd	9 b
Bromus inermis	48 a	15 d	12 b
Bromus marginatus	11 b	33 bc	25 a
Festuca arundinacea	4 b	15 d	5 b
Dactylis glomerata	3 b	35 b	27 a
Arrhenatherum elatius	6 b	37 b	27 a
Agrostis gigantea	45 a	34 b	9 b
One-cut system			
Agropyron elongatum[1]	0 a	68 b	82 a
Agropyron elongatum[2]	0 a	68 b	81 a
Agropyron elongatum[3]	0 a	68 b	78 a
Panicum virgatum	0 a	20 d	30 d
Agropyron desertorum	0 a	78 a	66 b
Festuca arundinacea	0 a	40 c	58 c

Means with the same letter are not significantly different (Student-Newman-Keuls)
[1] "Szarvasi I" [2] "Anonym" [3] "Alkar"

E. junceus and *P. virgatum*. The presented values represent the medians of both experimental sites combined.

The visual control surveys conducted several times per year in a radius of about 200 m around the experimental plots did not reveal any long-distance dispersal via seeds of the alien grasses.

After plowing the experimental plots at the alpine foothill site in May 2011, only *A. repens* and *F. arundinacea* showed regrowth in the subsequent corn crop (soil coverage 40% and 5% of surface; assessment date 16 September 2011).

3.3 Diseases

Disease infestation was similar on both locations. Leaf diseases (*Septoria* spp. and *Puccinia* spp.) were recorded especially at the last growth. An infestation of over 30% of leaf area was recorded in September for *E. hoffmannii*, *A. trachycaulum*, *A. repens*, *B. marginatus*, *A. elatius*, *D. glomerata*, *A. gigantea* and *A. desertorum* (year 2009, median of both experimental sites combined, see Tab. 5). A lower infestation rate (15% and 5% of leaf area in 2009 and 2010, respectively) was recorded for *F. arundinacea*: this species showed one of the lowest infestations of all selected grasses. *F. arundinacea,* however, was the only grass species to become infected by the gray snow mold (*Typhula* spp.) after winter 2009/2010. This was due to this grass's strong growth in late autumn; it developed a high leaf biomass after early harvest in autumn. In 2010 the last cut was conducted 2 to 3 weeks later than in 2009, which effectively prevented a snow mold infestation.

3.4 Panicle and ear emergence/seed heads

At harvesting the first growth, *A. elatius*, *D. glomerata* and *B. marginatus* showed the largest proportion of plants with seed heads (> 50% each; average of both years combined, see Tab. 6). Among the various varieties of *A. elongatum*, "Szarvasi I" was the earliest maturing. In the case of "Szarvasi I", 6% of the plants had already formed seed heads at the first cut in 2010, while "Alkar" and "Anonym" had no ears. *P. virgatum* first formed panicles in July, making it the latest maturing species.

In the subsequent cuts, five grass species (*F. arundinacea*, *D. glomerata*, *A. repens*, *E. junceus* and *E. hoffmannii*) formed neither panicles nor seed heads (≤ 1%).

3.5 Tendency for lodging

When harvesting the first growth (May/June), *A. repens* (in both years) and *A. intermedium*, *B. inermis* and *A. elatius* (in 2009 only) exhibited more than 10% lodging (Tab. 6). This lodging prevented a satisfactory cutting quality, requiring additional mowing with a scythe. In the subsequent cuts, no quality-reducing lodging was recorded (maximum 5%).

Those plots harvested only once per year showed strong lodging. At the September/October assessment period, all grass species showed problems with lodging. At that time, the proportion (median of both years) of lodged plants was 49% in *A. desertorum*, 61% in *F. arundinacea*, 59–64% in *A. elongatum* and 64% in *P. virgatum*. Even at the late date, strong lodging led to a slower drying of the stand and to mowing problems. Significant differences were recorded solely in 2009.

4 Discussion

4.1 Growth and development

The associated flora (weeds) depended on the grass species and in some tested grasses increased with the duration of the experiment. The strong presence of associated flora at the alpine foothills is attributed to the high seed bank in the soil; moreover, the flood event in July 2009 washed in additional seeds.

With the exception of the seeding year, *F. arundinacea* was the strongest competitor of all selected grass species. This is because it showed the fastest regrowth (SCHRABAUER et al., 2010), successfully suppressing emerging weeds. In the seeding year, the poor competitive ability of *F. aruncinacea* can be explained because it is less shade-tolerant than *D. glomerata* (ALLARD et al., 1991; BURNER, 2003) and shows a slower aboveground biomass production during the establishment phase (WILMAN and GAO, 1996).

A. trachycaulum shows a rapid (and competitive) establishment (SCHRABAUER et al., 2009), although the soil coverage rapidly decreases in the years after sowing. Based on this development, the species has potential as a cover crop in seed mixtures and could represent a drought-tolerant alternative to the traditional *Lolium* sp. ryegrasses in Central Europe. Its strong establishment suppresses weeds and non-grass species, and satisfactory yields are achieved from the beginning (SCHRABAUER et al., 2009). At the same time, its minimal regrowth leaves sufficient space for those species with slow seedling establishment. The use of *A. trachycaulum* in seed mixtures may enable replacement by species with slower establishment. JEFFERSON et al. (2007) reported the successful use of *A. trachycaulum* in a seed mixture with *Medicago sativa* L. in Saskatchewan, Canada. In their experiments, the yield of *A. trachycaulum* dropped to an average of 24% in the third year after sowing, accompanied by an increasing yield of *M. sativa*. Additional studies will be required to determine the competitive ability of *A. trachycaulum* when using seed mixtures under Central European conditions.

The insufficient competitive ability of all varieties of *A. elongatum* in the multiple-cut system is attributed to the low cutting height in the experiment (7 cm). BREDE (2000) recommends a cutting height of at least 15 cm. Additional experiments will be required to determine whether the higher cutting can improve the persistence of *A. elongatum* under the given conditions. The present results show that a satisfactory persistence can be achieved by reducing the harvesting intensity to one cut per year.

In *P. virgatum*, strong weed growth occurred despite the one-cut system. This reflects the C_4 metabolism and the early harvest date in 2009. Due to the C_4 metabolism

Tab. 6. Proportion of plants with panicles or seed heads and lodging of the various grass species, assessed shortly before the cut; median values of Marchfeld and alpine foothill sites combined

	% plants with panicles or seed heads				% lodging			
	1st growth		subsequent growth/s		1st growth		subsequent growth/s	
	2009	2010	2009	2010	2009	2010	2009	2010
Multiple-cut system								
Agropyron elongatum[1]	75 c	6 ef	12 cd	22 b	0 d	1 b	0 a	0 c
Agropyron elongatum[2]	26 f	0 f	12 cd	32 a	0 d	0 b	0 a	0 c
Agropyron elongatum[3]	48 d	0 f	12 cd	31 a	0 d	0 b	0 a	0 c
Agropyron intermedium	95 a	0 f	3 e	9 c	15 bc	0 b	0 a	0 c
Agropyron desertorum	73 c	24 d	3 e	0 c	5 cd	0 b	0 a	2 bc
Agropyron trachycaulum	48 d	0 f	95 a	27 ab	0 d	1 b	0 a	0 c
Agropyron repens	15 g	0 f	0 e	0 c	23 b	12 a	0 a	4 a
Elymus hoffmannii	70 c	16 de	0 e	0 c	0 d	1 b	0 a	1 bc
Elymus junceus	12 g	9 ef	0 e	0 c	0 d	0 b	0 a	2 bc
Bromus inermis	50 d	45 c	2 e	2 c	38 a	0 b	0 a	0 c
Bromus marginatus	98 a	21 d	48 b	28 ab	3 d	0 b	0 a	5 a
Festuca arundinacea	40 e	22 d	1 e	0 c	8 cd	1 b	0 a	5 a
Dactylis glomerata	70 c	65 b	0 e	1 c	3 d	0 b	0 a	3 abc
Arrhenatherum elatius	97 a	78 a	13 c	8 c	23 b	3 b	0 a	3 abc
Agrostis gigantea	88 b	0 f	8 d	9 c	0 d	0 b	0 a	0 c
One-cut system								
Agropyron elongatum[1]	88 b	88 a			53 c	64 a		
Agropyron elongatum[2]	93 ab	90 a			54 c	73 a		
Agropyron elongatum[3]	93 ab	88 a			57 c	68 a		
Panicum virgatum	96 a	83 a			85 a	42 a		
Agropyron desertorum	78 c	68 b			58 c	39 a		
Festuca arundinacea	18 d	13 c			70 b	51 a		

Means with the same letter are not significantly different (Student-Newman-Keuls)
[1] "Szarvasi I" [2] "Anonym" [3] "Alkar"

the growth in spring is slower than that of C_3 grasses. This provided the weed seeds, which were more abundant in the alpine foothills than in the Marchfeld, more space to establish. Waller and Schmidt (1983) as well as Sanderson et al. (2004) describe a strategy to combat weeds: glyphosate is applied before the C_4 grasses emerge in order to control weeds with C_3 metabolism, which are already growing at this time. Numerous studies (Casler and Boe, 2003; Mulkey et al., 2006; Adler et al., 2006) have determined that the persistence of *P. virgatum* is reduced when harvesting takes place during the growing season. If the biomass is to be used for combustion (biofuels), the recommendation is to harvest only after a killing frost. This approach enables the plants to shift some soluble carbohydrates into the roots, promoting strong regrowth in next spring.

In the case of fodder production and the production of substrate for biogas facilities (multiple cutting), a late heading of the grasses delays the quality reduction of the biomass (Lange et al., 2003). Both at the first cut as well as at subsequent cuts, *F. arundinacea*, *A. repens*, *E. junceus* and *E. hoffmannii* form only few seed heads and would therefore offer several use options. When producing combustible material or renewable raw material (one-cut system), the seed heads create no problem because the harvest already has a high cellulose content.

4.2 Yield behaviour

Long-term grassland trials in Austria yielded on average between 7340 and 9440 kg DM ha^{-1} a^{-1} (depending on site) in a three-cut system and at a fertilization rate of 30 to 40 kg N ha^{-1} per cut (Trnka et al., 2006). The present results, with an average corrected yield of 9255 kg DM ha^{-1} in the multiple-cut system, also fall within that range. Based on their below-average yield, *A. desertorum*, *A. trachycaulum*, *A. repens*, *E. junceus* and *B. marginatus* are poorly suited for cultivation in Central Europe.

The greater water availability at the alpine foothill site led, as expected, to higher yields than in the Marchfeld site. In the one-cut system, the annual yield without weeds fell from 2009 to 2010 only in the alpine foothills (by 6907 kg DM ha^{-1}). This is attributed to the flood event, which caused temporary lodging in 94% of stands in the experimental plots. This lodging was reflected in the relatively low yield in the following year.

As the experimental period progressed (three years after sowing), *A. elongatum* profited best in the one-cut system. This reflects its slow regrowth after cutting. *F. arundinacea* sprouted rapidly again and was at a clear advantage in the multiple-cut system.

4.3 Invasiveness

Evaluating the invasiveness of alien grasses is particularly important because in extensive cultivation they can potentially migrate into and damage sensitive biotopes (Walter et al., 2005). According to the present results, *B. marginatus* is the most aggressive of the alien grasses; at the final assessment, the species grew 11 cm beyond the plot margins. *A. desertorum* and *E. hoffmannii* expanded considerably less than *B. marginatus*, and all the other alien grass species showed no invasiveness (*A. elongatum*, *A. intermedium*, *A. trachycaulum*, *E. junceus* and *P. virgatum*). Although the alien grasses, with the exception of *B. marginatus*, were not invasive during the study, the short two-year observation period cannot exclude such behaviour under other site conditions and management regimes.

5 Conclusions

5.1 Grasses for multiple-cutting

In temporary grasslands, a high proportion of accompanying flora and weeds should be avoided because it leads to an accumulation of weed seeds in the soil and can impact subsequent crops. This calls for focusing on grasses showing competitive ability both during the establishment phase and throughout the period of use.

The species *F. arundinacea*, *D. glomerata*, *B. inermis* and *A. elatius* are suitable for use in temporary grasslands on arid sites due to the low incidence of weeds. In contrast, *A. gigantea* is unsuitable for this purpose due to its poor competitive ability during establishment.

A. trachycaulum has a special status. Based on its rapid establishment and poor persistence, it can be successfully used as a cover crop in seed mixtures.

In the multiple-cut system, *F. arundincea* provided high yields, formed dense swards and, in the years after sowing, showed the lowest incidence of weeds of all tested grass species. Due to minimal culm formation, this species is particularly suitable for producing substrates for biogas facilities and fodder, but also as a pasture grass. *F. arundinacea* is initially less competitive and less shade-tolerant. The species is therefore not recommended for reseeding. When creating seed mixtures, efforts should be made to avoid the simultaneous use of species that show high competitive ability during their establishment. A timely clearance-cutting is important for the successful establishment of *F. arundinacea*. In areas with climate conditions similar to those at the experimental sites, the final cut of *F. arundinacea* should be conducted in late September at the earliest to prevent snow mold and to optimally utilize the yield potential in autumn.

The often cultivated forage grasses *D. glomerata* and *A. elatius* performed satisfactorily in our experiments. Nonetheless, other grasses were superior with regard to individual features such as growth and development, yield behaviour and invasiveness (Tab. 7).

5.2 Grasses for one-cutting

A. elongatum and *P. virgatum* exhibit a high yield potential; nonetheless, a satisfactory persistence over many years could only be achieved in the one-cut system (and in *P. virgatum* only when harvesting after a killing frost). In the framework of such an extensive use, only coarse, straw-like material could be harvested. Such material is unsuitable as fodder and biogas substrate. In order to achieve a similar persistence in the multiple-cut system as well, increasing the cutting height to at least 15 cm can be considered. But the currently available hay and forage harvesting equipment in Central Europe will make it difficult to achieve this cutting height.

5.3 Grasses less suitable for cultivation in Central Europe

The following species showed little promise with regard to yield or persistence under the experimental conditions: *A. desertorum*, *E. junceus* and *E. hoffmannii*. Based on current knowledge, the agricultural use of these species in Central Europe cannot be recommended.

B. marginatus is an alien grass species and proved to be highly invasive in our experiments. This species is suspected of migrating into valuable ecosystems in large-scale cultivation.

5.4 Summing up

We have identified grasses that, based on detailed experiments at two sites in Austria, have the potential to supplement the plant spectrum currently grown in Central Europe. The selected grass species differ in their growth and development, their yield behaviour and their invasiveness. This calls for different uses and cultivation measures. Different quality criteria are decisive for the various potential uses. These will be examined in a follow-up project.

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Tab. 7. Characteristic features of tested and reference grasses

	rapid establish-ment [1]	high yield	long-term per-sistence	poor inva-siveness	resis-tance of leaf diseases	late heading at first cut	poor heading after first cut	stability against lodging
Tested grasses								
Agropyron elongatum (Host) P.Beauv.	o	+	– (+[2])	+	+	+	–	+ (–[2])
Agropyron intermedium (Host) P.Beauv.	o	+	–	+	+	o	o	o
Agropyron desertorum Schult.	o	–	–	o	o	–	o	o
Agropyron trachycaulum (Link) Malte	+	o	–	+	–	+	–	+
Elymus hoffmannii Jensen & Asay	o	o	–	+	–	o	+	o
Elymus junceus Fisch.	–	–	–	+	+	–	+	+
Bromus inermis Leyss.	o	+	o	–	o	o	+	–
Bromus marginatus Steud.	o	o	–	–	–	–	–	o
Festuca arundinacea Schreb.	o	+	+	o	+ (–[3])	o	+	+ (o[2])
Panicum virgatum L.	o	+	o	+	+	+	–	+ (–[2])
Reference grasses								
Dactylis glomerata L.	o	+	+	+	–	–	+	+
Arrhenatherum elatius (L.) P.Beauv.	o	+	+	o	–	–	–	–
Agrostis gigantea Roth	–	+	o	–	–	o	–	o
Agropyron repens (L.) P.Beauv.	o	–	o	–	–	+	+	–

* + ….. applies – ….. doesn´t apply o ….. on an average
[1] after SCHRABAUER et al. (2009)
[2] at one-cut system
[3] susceptible to gray snow mold (*Typhula* spp.), if the grass coverage is too high during winter

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References

ADLER, P.R., M.A. SANDERSON, A. BOATENG, P.J. WEIMER, H.G. JUNG, 2006: Biomass yield and biofuel quality of switchgrass harvested in fall or spring. Agronomy Journal **98**, 1518-1525.

ALLARD, G., C.J. NELSON, S.G. PALLARDY, 1991: Shade effects on growth of tall fescue: I. Leaf anatomy and dry matter partitioning. Crop Science **31**, 163-167.

ASHOUR, T., H. WIELAND, H. GEORG, F.-J. BOCKISCH, W. WU, 2010: The influence of natural reinforcement fibres on insulation values of earth plaster for straw bale buildings. Materials and Design **31**, 4676-4685.

BFL, 2002: Methoden für Saatgut und Sorten. Richtlinien für die Sortenprüfung. Sorten- und Saatgutblatt. Schriftenreihe 59/ 2002. Bundesamt und Forschungszentrum für Landwirtschaft, Wien.

BREDE, D., 2000: Turfgrass maintenance reduction handbook: sports, lawns, and golf: research-proven strategies for maintaining your lawn, park, sports field, or golf course with less water, fertilizer, mowing, pesticide, and water effort. Chelsea MI, Sleeping Bear Press.

BUCHGRABER, K., G. GINDL, 2004: Zeitgemäße Grünlandbewirtschaftung. 2. Aufl. Graz, Leopold Stocker Verlag.

BURNER D.M., 2003: Influence of alley crop environment on orchardgrass and tall fescue herbage. Agronomy Journal **95**, 1163-1171.

CASLER, M.D., A.R. BOE, 2003: Cultivar × environment interactions in switchgrass. Crop Science **43**, 2226-2233.

DIGMAN, M.F., K.J. SHINNERS, M.D. CASLER, B.S. DIEN, R.D. HATFIELD, H.-J.G. JUNG, R.E. MUCK, P.J. WEIMER, 2010: Optimizing on-farm pretreatment of perennial grasses for fuel ethanol production. Bioresource Technology **101**, 5305-5314.

ELBERSEN, H.W., D.G. CHRISTIAN, N.El BASSAM, G. SAUERBECK, E. ALEXOPOULOU, N. SHARMA, I. PISCIONERI, 2004: A management guide for planting and production of switchgrass as a biomass crop in Europe. 2nd World Conference on Biomass for Energy, Industry and Climate Protection, Rome, Italy, 10–14 May 2004, 140-142.

GUO, L., R. GIFFORD, 2002: Soil carbon stocks and land use change: a meta analysis. Global Change Biol. **8**, 345-360.

HAAS, W., U. WEISZ, M. BALAS, S. MCCALLUM, W. LEXER, K. PAZDERNIK, A. PRUTSCH, K. RADUNSKY, H. FORMAYER, H. KROMP-KOLB, I. SCHWARZL, 2008: Identifikation von Handlungsempfehlungen zur Anpassung an den Klimawandel in Österreich: 1. Phase, 2008. Wien, Lebensministerium.

HANELT, P., 2001: Mansfeld´s Encyclopedia of Agricultural and Horticultural Crops **5**. Berlin, Heidelberg, Springer-Verlag.

HEATON, E.A., F.G. DOHLEMAN, S.P. LONG, 2008: Meeting US biofuel goals with less land: The potential of Miscanthus. Global Change Biology **14**, 2000-2014.

JEFFERSON, P.G., R.P. ZENTNER, F. SELLES, R. LEMKE, 2007: Performance of short-lived perennial grasses grown with and without alfalfa at a semiarid location in southern Saskatchewan. Canadian Journal of Plant Science **87**, 59-65.

KAYSER, M., K. SEIDEL, J. MÜLLER, J. ISSELSTEIN, 2008: The effect of succeeding crop and level of N fertilization on N leaching after break-up of grassland. European Journal of Agronomy **29**, 200-207.

LANGE, G., J. GRÄSSLER, U. VON BORSTEL, 2003: Neue Mischungskonzepte für Grünlandansaaten in Norddeutschland. Mitteilungen der Arbeitsgemeinschaft Grünland und Futterbau **5**, 147-150.

MULKEY, V.R., V.N. OWENS, D.K. LEE, 2006: Management of switchgrass-dominated Conservation Reserve Program lands for biomass production in South Dakota. Crop Science, **46**, 712-720.

SAKULIN, M., K. FRIEDRICH, U. BACHHIESL, R. BRAUNSTEIN, 2009: Policies for reasonable system integration of renewable energy sources in Austria. 2009 International Conference on Clean Electrical Power, 540-544.

SANDERSON, M.A., R.R. SCHNABEL, W. CURRAN, W.L. STOUT, D. GENITO, B.F. TRACY, 2004: Switchgrass and big bluestem yields differ with fire and herbicide management. Agronomy Journal **96**, 1688-1692.

Sanderson, M.A., P.R. Adler, A.A. Boateng, M.D. Casler, G. Sarath, 2007: Switchgrass as a biofuels feedstock in the USA. Canadian Journal of Plant Science **86**, 1315-1325.

Schrabauer, J., J. Humer, P. Liebhard, 2009: Trockentolerante Gräser für eine Futternutzung bzw. energetische Verwertung im semihumiden und semiariden Produktionsgebiet. (Dry spell-tolerant grasses for a fodder use and/or energetic utilization in the semihumid and semi-arid production area.) Arbeitsgemeinschaft für Lebensmittel-, Veterinär- und Agrarwesen (ALVA) Jahrestagung 2009, Salzburg, Österreich, 18.–19. Mai 2009, 77-79.

Schrabauer, J., P. Liebhard, J. Humer, 2010: Rohrschwingel (*Festuca arundinacea*) als Alternative zu praxisüblichen Gräsern für mehrjährige Grünlandbestände zur Futternutzung oder als Biogassubstrat. (Tall fescue (*Festuca arundinacea*) – an alternative forage crop in perennial grassland for a fodder use or fermentation in a biogas plant.) Arbeitsgemeinschaft für Lebensmittel-, Veterinär- und Agrarwesen (ALVA) Jahrestagung 2010, Wels, Österreich, 31 Mai. – 1. Juni 2010, 135-137.

Tonn, B., V. Dengler, U. Thumm, H.-P. Piepho, W. Claupein, 2011: Influence of leaching on the chemical composition of grassland biomass for combustion. Grass and Forage Science **66**, 464-473.

Trnka, M., J. Eitzinger, G. Gruszczynski, K. Buchgraber, R. Resch, A. Schaumberger, 2006: A simple statistical model for predicting herbage production from permanent grassland. Grass and Forage Science **61**, 253-271.

USDA NRCS, 2014: Plants Database. Available from: <http://plants.usda.gov/java/> (13 March 2014).

Waller, S.S., D.K. Schmidt, 1983: Improvement of eastern Nebraska tallgrass range using atrazine or glyphosate. Journal of Range Management **36**, 87-90.

Walter, J., F. Essl, T. Englisch, M. Kiehn, 2005: Neophytes in Austria: Habitat preferences and ecological effects. Neobiota **6**, 13-25.

Wilman D., Y. Gao, 1996: Herbage production and tiller density in five related grasses, their hybrids and mixtures. Journal of Agricultural Science **127**, 57-65.

Woodis J.E., R.D. Jackson, 2008: The effects of clipping height and frequency on net primary production of *Andropogon gerardii* (C_4 grass) and *Bromus inermis* (C_3 grass) in greenhouse experiments. Grass and Forage Science **63**, 458-466.