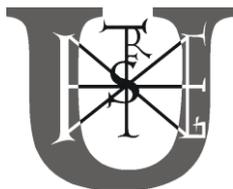


Szent István University



**STUDIES ON THE HUNGARIAN AREA,  
AGROECOLOGICAL IMPACTS AND  
AGROTECHNICAL SUPPRESSION OF OLD WORLD  
BLUESTEM (*BOTHRIOCHLOA ISCHAEMUM* L.)**

**Ph.D. Thesis**

**Szilárd Szentés**

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## INTRODUCTION AND GOALS

Recent studies show that the warming and aridification of climate results in the change of vegetation, helping the worldwide spread and local invasion of C<sub>4</sub> grass species. The prevalent overgrazing of grasslands enhances this process as well. C<sub>4</sub> species utilize water more efficiently, and they also have higher temperature demand than C<sub>3</sub> species. This means a competitive advantage in areas with warm and dry climate especially in periods of limited precipitation. The recent invasion of the native C<sub>4</sub> *Cleistogenes serotina* affecting the arid lowland areas of Hungary is a good example for this trend. Studies revealed that this is caused by the drier climate of the last few decades. In Central Europe and in the Mediterranean Region old world bluestem (*Bothriochloa ischaemum*) could be one of these invasive species beside *Cleistogenes serotina*. The centre of its range of distribution includes the South Siberian steppes, Central Asia and the region of the Aral and the Caspian Sea. It was introduced to the USA in the 1920s for forage production and erosion control purposes. Millions of hectares of grasslands with unfavourable conditions and roadsides have been planted with it (WHITE and DeWALD 1996, HARMONEY et al. 2004). The species have spread from these areas to native plant communities where it became an invasive species. Now the different varieties of old world bluestem are widespread in the USA, and they cause serious nature conservation problems, especially in Texas where the dense monocultures of old world bluestem overwhelm native grass species. Although old world bluestem is known to be a rare species in Central Europe, it can be found everywhere in the different plant communities of Hungary. In Hungary it is a characteristic species of dry rocky grasslands and steppes (*Festuco-Brometea* Br.-Bl. et Tüxen ex Soó 1947). It can be found on warm, dry, sometimes semi-dry, calcareous or slightly acidic, alluvial, rocky, sandy, loam and loess soils being poor in nutrients and humus. Due to disturbance old world bluestem can easily become a dominant species. Its coenological status has not been clearly defined so far as a result of its wide and various range of distribution. In Hungary, old world bluestem dominated stands are classified as subassociations or facies, while in Bulgaria, Croatia, Slovakia etc. they are often considered as associations.

The spread and the growing dominance of old world bluestem negatively influence the physiognomy of grasslands, lead to a diminishing number of species, and thus decrease diversity.

Through its spread old world bluestem can reduce the area of habitats dominated by native plant communities (AFFLERBACH 2013). This reduction may potentially threaten rare species, and can also decrease the number and density of native species (GEORGE et al. 2013).

The invasion of old world bluestem modifies the species composition and ratio of soil microbes, including mycorrhizal species as well (WILSON et al. 2012, ENDRESZ et al. 2013). It also has allelopathic effects making the reintroduction of native species more difficult (GREER et al. 2014).

The overspread of old world bluestem is facilitated by overgrazing as well, since this case the vegetation of grasslands become open, and the microclimate near the soil surface gets even drier. Under these unfavourable abiotic conditions C<sub>4</sub> old world bluestem has competitive advantage over C<sub>3</sub> grass species, for example *Festuca rupicola*, due to its higher level of morphological plasticity and its better water utilization (VIRÁGH et al. 1995, BARTHA 2007a). According to studies on loess

steppes near Albertirsa (BARTHA 2007a), the cover of the dominant *Festuca rupicola* decreased, and the formerly subordinate old world bluestem replaced it as a consequence of overgrazing. After this stress (grazing) ceased the vegetation became close again. As a result, old world bluestem lost its competitive advantage (originating from its C<sub>4</sub> photosynthesis mechanism), and *Festuca rupicola* became dominant again (VIRÁGH 2002).

Most grasslands in Hungary are protected, are situated in Natura 2000 sites, or are part of the National Agri-Environmental Programme. The suppression of species that are harmful from nature conservation and grassland management aspects as well is more difficult in the case of these areas since many agrotechnical measures are limited or prohibited. Consequently, it is of high priority to know the exact range of distribution of this species and the effects of its presence on the species composition and the structure of grasslands. With the help of this knowledge we have to develop effective agrotechnical measures that can help the suppression of old world bluestem.

### **Goals**

1. Defining the exact range of distribution of old world bluestem in Hungary on the basis of former literature and herbarium data.
2. Reviewing the phytosociological role of old world bluestem in Hungarian grasslands with the help of literature data and completing it with new field data.
3. Observing the different states of old world bluestem invasion in native grasslands.
4. Verifying that old world bluestem decreases diversity, and changes the structure of grasslands with coenologic and microcoenologic methods. Observing these changes at different spatial scales and in the different phases of the vegetation period.
5. Defining the list of species that can coexist with old world bluestem at different spatial scales.
6. Studying the impacts of different old world bluestem cover levels on the species composition and spatial heterogeneity of grasslands in the case of different abiotic conditions.
7. Studying the efficiency of different agrotechnical measures in order to suppress old world bluestem and to increase the forage value of invaded grasslands.

## MATERIAL AND METHODS

### Floristic and phytosociological studies

Occurrence data of old world bluestem have been collected from two main sources: from Hungarian journals and other literatures and from the Hungarian phytosociological database (CoenoDat Reference Database). Herbarium data were gathered from the collections of the Botanical Department of the Hungarian Natural History Museum, the Georgikon Faculty of the Pannon University and the Institute of Botany and Ecophysiology of the Szent István University. Occurrence data from herbarium and literature have been illustrated on maps as well. Maps were made with Arcview GIS 3.2 software. Old world bluestem occurrences were marked with numbers on the maps.

For the phytosociological studies 33 sample areas were selected (28 Hungarian, 1 Slovak, 2 Croatian and 2 Serbian areas) on different bedrocks (loess, dolomite and limestone, sand) according to literature and herbarium data and on the basis of our previous field experience. Sample areas include natural grasslands, abandoned pastures and old fields as well. For the coenological analyses 513 pieces of 2×2 m coenologic relevés were made. These were placed in homogenous vegetation patches with different physiognomy and various old world bluestem cover. The cover of each occurring species was given in percentage in the sampling squares.

The naturalness of sample areas has been evaluated according to nature conservation value categories (SIMON 2000). Species were considered to be protected according to the Decree of the Minister of Environment No. 13/2001 (V.9.) (KöM) on the Protected and Strictly Protected Plant and Animal Species, Strictly Protected Caves as well as on the Plant and Animals Species of Community Importance (modified by Decree No. 21/2001 (IX. 28.) (KöM) and decree No. 23/2005 (VIII. 31) (KvVM).

### Microcoenologic analyses

Microcoenology investigates the coexistence of species and the internal diversity of associations. It helps to quantify the changes of associations, the spatial and timely transitions as well as the dynamic and functional aspects of the vegetation (JUHÁSZ-NAGY 1980, VIRÁGH 2007). The impact of old world bluestem invasion on the naturalness of grasslands has been analysed by using small-scale patterns and characteristic functions depicting the spatial distribution of the different species (JUHÁSZ-NAGY és PODANI 1983, VIRÁGH et al. 2006).

One of the study areas is situated in a northwest-southeast valley near Kisfüzes in the Mátra, which is part of the North Hungarian Mountains. The average annual temperature is 9°C, while the average temperature in the vegetation period reaches 16°C. The average annual rainfall is 560 mm, and the average rainfall is 360 mm in the vegetation period. The soil of the sample area is degraded brown forest soil. The other sample area can be found near Fülöpháza in the Duna-Tisza köze region. The average annual temperature is 10.3-10.5°C, while the average temperature in the vegetation period reaches 17.4°C. The average annual rainfall is 530 mm, and the average rainfall is 310 mm in the vegetation period. The main soil type of this area is shifting sand.

In each stand the presence of plant species were recorded along 52.2 m long belt (rectangular 23×3 m) transects of 1044 units of 0.05 m x 0.05 m contiguous microquadrats. All rooting species have been recorded in the different microquadrats, while plants only leaning over them were neglected. The large number and the small size of microquadrats ensure the precise estimation of the frequency and the spatial patterns of species and species combinations (BARTHA et al. 2004). Belt transects can

be better used for the randomization of spatial patterns than linear ones, this way making data analysis easier (BARTHA and KERTÉSZ 1998).

In Kisfüzes 6 rectangular transects had been marked – each having a size of 23×3 m – in the appointed grassland with northwestern exposure during spring 2011. Since the four endpoints of the transects were permanently marked analyses could be carried out precisely every time. Three of the transects were dominated by old world bluestem, while this critical species was very rare (<10% frequency) in the three remaining ones. Two surveys were made, the first was on 12-13th May 2011, while the second was made on 12-13th September 2011. A similar intensively grazed sheep pasture with eroded soil and similar exposure has been selected as reference natural grassland from Belsőbáránd.

In Fülöpháza the reference transect with rare occurrence of old world bluestem was designated on 28th May 2012 in an open perennial calcareous sand grassland originating from a reference natural grassland (*Festucetum vaginatae* Rapaics ex Soó 1929 em. Borhidi 1996). Three pieces of 20-40 year old old fields dominated by old world bluestem were marked as sample areas on 3-4th July 2012 as well. One transect was placed in an open stand with small old world bluestem ramets, another one was designated in a more closed stand with bigger ramets and more litter, while the third transect was made in a closed stand consisting of a dense cover of big old world bluestem ramets. A fourth sample transect (NT) has been also marked nearby in a younger (10-15 years old) old field with sandy soil rich in humus. The vegetation of this grassland is less characteristic, and includes huge ramets of old world bluestem often reaching the diameter of more than 0.5 m).

Three similar (20-30 years old) reference old field transects containing no old world bluestem and having a similar landscape history were used during the analyses as well..

We used the information theory models developed by JUHÁSZ-NAGY (1993) and JUHÁSZ-NAGY and PODANI (1983) to study the accurate fine-scale inner structure of stands and to detect degradation caused by disturbances. This method is suitable for the long-term monitoring of stands as well (BARTHA et al. 2006).

Within-stand coexistence relationships can be measured with different information theory methods. The counting of **species compositions** is one of these measures, since some species do not associate with and avoid each other in spite the fact that they are present in the same stand at the same time. Recently, BARTHA et al. (2011) suggested that beta diversity can be measured by the estimated maximal number of species combinations.

The diversity of species compositions (i.e. **florula diversity**) is a very sensitive indicator of plant community changes. In the case of disturbances the value of the function depicting florula diversity will be reduced, and its maximum will be shifted towards larger plot sizes.

Associatum can be considered as the measure of total spatial dependence among species combinations. It refers to the inner spatial orderliness and heterogeneity of stands. Associatum was estimated at increasing plot sizes.

The spatial coexistence of different species was measured with ISC analysis. Interspecific association was estimated in a space series analysis using 2x2 contingency tables, according to the methods of JUHÁSZ-NAGY and PODANI (1983). In the case of positive association some species were found together more often than expected, while in the case of negative association the opposite was experienced. The significance of associations was detected by Monte-Carlo randomization tests. 999 „random shifts” of the individual patterns of variables were made to test that patterns are spatially independent. We used “random shifts” as a neutral model to avoid false consequences

caused by the aggregated patterns of clonal grasses or by the large size of individual ramets (BARTHA et al 1998, BARTHA and KERTÉSZ 1998, ROXBURGH and CHESSON 1998).

### **Studies on the suppression of old world bluestem**

The experiment was set up on a 20 ha part of a 150 sheep pasture managed by rotational grazing. The study area can be found on a south-south western steep slope 246-247 m above the sea level. This is a secondary grassland, formed on a 40 years old vineyard fallow. Because of the exposure and the sloping of the area the microclimate is dry and warm. In addition, erosion is also strong hindering natural succession processes. Bushes and young trees were cleared off the area by a forestry shredder in 2000. The grassland has been grazed since 2001. Every October the area is also shredded. Neither overseeding nor chemical treatments have been carried out on the grassland since the abandonment of the vineyard.

The phytosociological classification of its vegetation is fairly difficult. The dominant species are *Bromus inermis* and *Poa angustifolia*. Further common species include *Achillea nobilis*, *Plantago lanceolata*, *Verbascum phoeniceum* and old world bluestem. The average total cover of the grassland ranges between 40-70% depending on the phenological state and the actual yearly weather. In addition, the total cover of perennial grass species is very low as well. As a result, there are open patches in the area, and the effects of erosion can be observed as well. Old world bluestem forms close patches, furthermore – contrary to the opinion of ILLYÉS et al. (2007b) – it has dense stands on extremely steep slopes (>70% sloping) as well. In such vegetation patches the cover of other plant species is very small.

The biomass production and the forage value of the plots were defined according to the method of BALÁZS (1960).

In the experiment aiming at to study the suppression of old world bluestem and the changes of forage value 30 pieces of 5×4 m plots were set up in randomized block design in autumn 2009. There were 9 managed plots and one reference area analysed in three repeats. The used management methods were the following: mowing, manuring, mowing and manuring and overseeding with *Lolium perenne*, *Poa angustifolia*, *Festuca rubra*, *Festuca arundinacea*, *Bromus inermis* and *Dactylis glomerata*.

The average height of the different species has been recorded during phytosociological data collection in order to more accurately estimate the aboveground green biomass of the plots (BALÁZS 1960).

For analysing the forage value of the different plots 1 m<sup>2</sup> of the vegetation was cut leaving a 3 cm high stubble on 8th July 2011. 1000 g samples were taken from the cut biomass to define the following parameters: original dry matter content (MSZ ISO 6496:1993), crude protein content (6830-4:1981), crude fat content (MSZ 6830-6:1984), crude fibre content (MSZ EN ISO 6865:2001), crude ash content (MSZ ISO 5984), NDF, ADF and ADL content (Van SOEST 1963).

## RESULTS

### Floristic and phytosociological results

The dissertation contains a table of 531 literature data, 148 herbarium data and 38 occurrence data from the CoenoDat Reference Database of old world bluestem.

Only three mesoregions (from 33) lack occurrence data about this species in Hungary. Most occurrence data (70) come from the Dunazug-hegyvidék. This result can be partly explained by the high number of botanical surveys of this mesoregion. Also many occurrence data could be found in following mesoregions: Duna-Tisza közti síkvidék (47), Bakony-vidék (46) and Cserhát-vidék (44). As a conclusion we can say that there are two main types of occurrence data: hills and medium mountains where the dry and warmer southern slopes provide optimal microenvironment for old world bluestem and those areas of the Great Plain which have a drier climate, and where grazing is a common practice in the whole area.

Based on the literature data of old world bluestem conclusions can be drawn about its ecological requirements and phytosociological status. The species has a high abiotic stress tolerance since in the literature it was registered in 52 different Hungarian coenotaxa, even in plant associations such as *Succiso-Molinietum hungaricae* or extremely dry open perennial calcicolous sandy grasslands. The phytosociological status of old world bluestem varies in these associations according to abiotic conditions and dominance rank of species.

### Microcoenologic results

In the old world bluestem dominated transects of Kisfüzes and Fülöpháza the **average number of species** reached only half of the values registered in the microquadrats of the reference old fields. The number of quadrats with significant species abundance was the lowest in the case of old fields dominated by old world bluestem, while most of these quadrats could be found on the reference old fields. Values measured in the case of natural grasslands ranged somewhere between the above mentioned categories in both sample areas. The number of empty quadrats was the lowest in the reference old fields, while most of them could be found on old world bluestem dominated areas. The omnipresence of litter was generally witnessed in transects rich in old world bluestem. In the old world bluestem dominated stand of Kisfüzes we registered lower species numbers during frequency analyses within the vegetation period. The number of quadrats exclusively containing old world bluestem significantly increased. This can be traced back to the fact that old world bluestem invigorates by autumn, its competitive advantage increases, and it accumulates a huge amount of litter as well. As a result, microhabitats become even poorer in species. While the species of the autumn period – replacing springtime species, and growing strong by autumn – can be found on the reference areas, they are missing from the stands dominated by old world bluestem.

Significant spatial association has been found between the presence of old world bluestem and microhabitats lacking subordinate species in the case of sand and loess based habitats. This positive association could be witnessed in each transect dominated by old world bluestem. In the reference transects of Kisfüzes positive spatial association could be also registered in autumn, that is the negative impact of old world bluestem was already visible at the initial phase of its invasion when its frequency was still low (reaching only 2-9%).

According to the **interspecific association (ISC)** analyses, spatial association was relatively stronger on sandy sample areas. In the case of old world bluestem infested old fields significant relations were twice as frequent on loess based habitats, and three times rarer on sandy areas compared to the reference plots. As for negative associations, the ratio of old world bluestem was found to be 33.3% in sandy areas both in the case of natural grasslands and old world bluestem dominated old fields. In the old world bluestem dominated microhabitats the majority of species have been overwhelmed. No significant association could be registered among the other codominant grass species and subordinate species, consequently these grass species do not hinder the introduction and the survival of these latter ones.

In general, it can be stated that deep rooting and high growing species, those having stolons and large species growing a rosette are less susceptible to the impacts of old world bluestem. Negative correlation could be detected only in the close proximity of the stems. Smaller species and those having a late development pattern are usually badly affected by the proximity old world bluestem.

In the old world bluestem dominated transects the **number of species exceeding the frequency level of 5%** reaches only about half of those registered in the reference areas. This is true for both sample areas. This confirms the fact that – similarly to the other aggressive grass species (HÁZI et al. 2011) – old world bluestem virtually overwhelms every species, even those fairly common ones (GABBARD and FOWLER 2007, SCHMIDT et al. 2008).

During our research beta-diversity has been measured by the witnessed **number of species combinations** (BARTHA et al. 2011). The experienced numbers of species combinations confirmed the diversity decreasing impact of old world bluestem on both sample areas. Old world bluestem dominated stands reached only  $\frac{1}{3}$  of the reference values in Fülöpháza and only  $\frac{1}{10}$  of them in the case of Kisfüzes. By autumn, species combinations have been decreased in Kisfüzes due to the smaller number of species which was the result of the increasing dominance of old world bluestem. Consequently, the internal structure of the stands has been significantly degraded. The standard deviation values of species combinations were found to be high among the different transects in both sample areas, which is an indicator of degradation.

Also there is a significant difference among the maximal values of **florula diversity** recorded in the reference and the old world bluestem dominated transects. Compared to the reference old field transects, its value has been decreased by 50% in Fülöpháza, and by 90% in Kisfüzes due to the invasion of old world bluestem. Values measured in the case of the investigated natural grasslands range somewhere in the middle both regarding the number of species combinations and florula diversity. This is because in the middle phase of old field succession diversity is usually higher than at the end of the process since this time the introduced weeds and the native species of the natural grassland are still mixed (BARTHA 2007b).

The functions of sampling scale showed that during spring analyses reference transects reached maximal florula diversity values at the quadrat size of 0.2 m, while those infested with old world bluestem reached their peak values at 0.3 m quadrat sizes in Kisfüzes. Presumably, it can be explained by the growing stems of old world bluestem and the increasing amount of litter accumulated by the plant, which significantly affect spatial patterns as shown by other studies before (CLELAND et al. 2007, SUZUKI and KUDO 1997).

The placement of transects in the coenostate-space showed in both sample areas that competition and disturbance significantly influenced spatial patterns on the reference old fields. In the old world bluestem dominated stands competitive exclusion – that is the impact of the plant – was the major force affecting spatial patterns in each case.

The above mentioned results verify that most investigations taking only alpha-diversity into consideration, and using 2×2 m big or larger sampling units (van der MAAREL 2005) significantly underestimate changes in the structure of grasslands caused by the spread of old world bluestem.

With the help of microcoenology the **phases of old world bluestem introduction** into grasslands can be well characterized. At the beginning of the introduction process (phase "A") old world bluestem stems are still small, and they mostly grow vertically. Consequently, although old world bluestem is already present in some neighbouring microquadrats, it does not reduce the number of species there. Only a small amount of litter can be witnessed in the quadrats, and it covers the surface of the soil in a thin layer. In the case of continuously and optimally grazed sheep pastures the process usually stops in this stage. Small old world bluestem stem fit into the spatial pattern of the grassland, and they fill the empty surfaces. As long as the pasture is grazed by an optimal number of animals and is continuously managed an old world bluestem invasion is unlikely to happen. However, if grazing ceases it is very likely that the next stage of old world bluestem invasion is to come. In phase "B" the structure of the plant association can be characterized with "large patches", where only a few microquadrats have still higher species numbers. New slant stems emerge from the rhizomes growing upwards. As a result, the diameter of the stems start to increase (20-30 cm), and larger old world bluestem patches can be found in the stand as well. The litter cover of old world bluestem becomes thicker in patches, but there are still some open surfaces on the ground where annual and pioneer species can temporarily survive. In the next stage (phase "C") large old world bluestem stems reaching even the diameter of 50-80 cm become dominant, especially in the case of old fields. Old world bluestem can form such huge ramets due to the lack of competition. Depending on the velocity of the process first these ramets are neutral from the point of the whole plant association, but later they overwhelm the other species if they exceed a certain closing threshold (phase "D"). In this phase even the least intensive grazing practices facilitate the growing of the plant since grazing animals start with the other more valuable and more delicious species, and either do not eat old world bluestem at all, or graze only a small part of the plant. As a result, these other species will be "overgrazed", they get weaker, and finally they disappear. By the end of this phase old world bluestem becomes absolutely dominant, and mostly propagates by vegetative ways. Many new slant stems emerge from the rhizomes growing upwards. At the end of the introduction process (phase "D") the frequency of old world bluestem and its litter rapidly increases, and their cover becomes homogenous. As this phase further develops old stems fall into pieces, and the formerly separated stems merge into one another. In these cases only a few other species are able to grow through the thick litter layer in some of the quadrats. This state can be stabilized for a long period, even for decades. Due to the thick litter layer and the allelopathic compounds produced by old world bluestem the introduction of other species is greatly hindered.

### **Results of the research aiming at the suppression of old world bluestem**

**Mowing activities** carried out at the end of July and in October had a negative impact on species composition since they further dried the microclimate of the grassland

during the long drought period. **Manuring** (by using a dose of 20 t/ha) had the best effect on common grass species. In the first year the cover of *B. inermis* and *P. angustifolia* significantly increased, while old world bluestem cover remained below 5% during the whole period. The post-impacts of manuring could be witnessed in the second year as well. The cover of grass species was the most even here within the investigated period. Besides, other dicotyledonous species emerged in a huge number by summer, which could become the basis of good quality forage in the summer drought period or in case grass species grow old. The combination of **mowing and manuring** had the same effect on *B. inermis* and *P. angustifolia*, but the cover of old world bluestem increased, and exceeded 20% by autumn in the first year. This ratio was slightly mitigated by the drought of the third year. This could be explained by the fact that due to the mowing activities in July there were no competitors on the area in the most optimal period (between the end of July and September), and the plant could invigorate fast. Overseeding with *Lolium perenne* seemed to be successful in the first two years, but it totally disappeared from the grassland by the third year. As a result of *Poa angustifolia* overseeding the cover of this species was twice as big as the reference value even at the end of the third year. In the case of this treatment old world bluestem covered only 3-4% of the area during the whole research. As a result of overseeding the cover of *Festuca rubra* did not fall below 20% until July 2011, but due to the drought hitting the end of the year it significantly weakened, and totally disappeared by summer 2012. The cover ratio of the two most common grass species did not change significantly. From the different overseeding treatments the use of *Dactylis glomerata* led to the highest green mass yields. The cover of this species continuously increased during the first year, and reached its peak value (70%) in the second one. The cover of *P. angustifolia* and *B. inermis* decreased in these plots. The cover of old world bluestem remained almost the same although the cover of grass species reached the highest levels on these plots. The cover of the other species of the grassland suffered the greatest decrease in these plots. Overseeding with *Bromus inermis* rapidly increased the cover of the species, although the cover values of the third year were virtually equal to the reference values. This can be traced back to the drought which killed the newly sown plants. In these plots both the cover of *P. angustifolia* and old world bluestem increased. The cover of other species was significant as well. Beside *Dactylis glomerata* only *Festuca arundinacea* survived all the three years from those species originally missing from the grassland, but its cover fell back to 4.3% by July 2012 as a result of the long drought. As opposed to the two most common grass species the cover of old world bluestem did not seem to be reduced by the end of 2012. The cover of the three species reached its peak value in 2011 in the **reference** plots. Old world bluestem reached its peak cover value in autumn, while the other two species did so in May. A significant fluctuation – which was often experienced in the other areas – could be also witnessed among grass species on the reference plot.

### **Yield**

From the point of yield plots being mowed and manured reached the highest values (16 t/ha green mass) on the average of the three years. Beside them manured plots and those overseeded with *Dactylis glomerata* exceeded the level of 13 tons of green mass per hectare per year. The lowest yield levels (7.5 t/ha/year) were registered on mowed plots. Reference plots ranked 6<sup>th</sup> in the order of yield. From overseeded plots the average yield of areas overseeded with *Lolium perenne* proved to be the lowest. The yields of *Bromus inermis* and *Festuca arundinacea* – both known to be drought tolerant – turned to be lower than expected.

### ***Chemical composition analyses***

The average **dry matter content** of the samples originating from the variously treated plots ranged between 920.77 g/kg forage (*Lolium perenne*) and 926.23 g/kg forage (*Dactylis glomerata*). The significant differences of chemical composition between the two species have been already published by VAN NIEKERK et al. (2006). The highest **crude protein content** was registered on plots overseeded with *Lolium perenne*, while the lowest values were measured on plots overseeded with *Dactylis glomerata*. The impact of manuring fell beyond our expectations. Presumably, it can be explained by the fact that the quantity and quality of second growth have been significantly decreased by drought, consequently no major differences could evolve. In the case of **crude fibre content** the reference plot had far the highest value, while the lowest results were registered on the mowed plots. 2:1 crude fibre:crude protein content – which is optimal from forage production purposes (NAGY and VINCZEFFY 1993,) – has been best approached by *Lolium perenne* and *Poa angustifolia*, while the worst ratio of the above mentioned compositions was measured in the case of *Dactylis glomerata*.

### **New scientific results**

1. The exact Hungarian range of distribution of old world bluestem has been defined based on 531 literature, 148 herbarium and 38 CoenoDat Reference Database mentioning. At the moment, from the 33 Hungarian mesoregions only three (Upper Tisza region, Marcal basin and North Hungarian basins) lack location data about this species.
2. Based on the analysis of the latest Hungarian literature old world bluestem has been found in 52 Hungarian plant coenotaxa from dry semi-desert sandy grasslands and loess walls to wet marshy habitats.
3. With the help of microcoenologic methods I defined the four stages of old world bluestem introduction to middle aged old fields and degraded grasslands.
4. The used microcoenologic methods could be perfectly used for the spatial and timely monitoring of the diversity reducing impact of old world bluestem appearing at different spatial scales in loess and sand based old fields. I described the degree of the diversity reducing impact of the species within the vegetation period. The species reaches the maximal value of its diversity reducing impact in autumn.
5. I found the group of species which include those taxa that can coexist with old world bluestem at different spatial scales on different types of habitats. I could also identify those species suppressed by old world bluestem.
6. Based on the macro and microcoenologic analyses I found that apart from the extremely dense old world bluestem stands there is no direct connection between the actual cover of old world bluestem and the diversity of the vegetation. It is explained by the fact that the same level of old world bluestem cover can be developed in many different ways and at various speeds. In addition, the same old world bluestem coverage can be developed with very different development forms and litter cover.
7. According to my analyses, it can be stated that old world bluestem is more likely to invade ruderal and middle aged old fields and open surfaces where

internal self-regulating mechanisms are not developed enough, but an appropriate amount of nutrients and water is available. By becoming invasive it significantly slows and hinders the regeneration of grasslands.

8. Based on my research aiming at the suppression of old world bluestem I found that in extreme dry and steep habitats it cannot be suppressed by manuring applying a dose of 20 t/ha, by early summer mowing and autumn shredding activities or by overseeding with grass species that are available in commerce. The highest yields were measured in the case of manured and mowed plots. Since total cover and the number of species have been slightly increased as a result of manuring this treatment can be best advised on similar grasslands from the tested treatment methods.

### **Novel scientific results**

1. Old world bluestem has a negative effect on the number of grassland species and the composition and the naturalness of the vegetation already at the beginning of its invasion.
2. According to my analyses, it can be stated that old world bluestem is more likely to become invasive on ruderal and middle aged old fields and open surfaces where internal self-regulating mechanisms are not developed enough. In such areas this species significantly slows and hinders the regeneration of grasslands.

## CONCLUSIONS AND RECOMMENDATIONS

The collected occurrence data of literature and herbarium origin verify the nationwide spread of old world bluestem. Only three mesoregions lack occurrence data about this species in Hungary. It can find favourable conditions in many habitats from dry grasslands to open dry forests associations, including disturbed stands, secondary associations and old fields as well. Most occurrence data come from hills and medium mountains where the dry and warmer southern slopes provide optimal microenvironment for the propagation of the species. Also many occurrence data could be found in those mesoregions of the Great Plain which have a drier climate, and where grazing is a common practice in the whole area, or it has been the means of land management before. Since the size of degraded and abandoned areas is expected to increase also in the near future, it is very likely that old world bluestem will further expand its range of distribution in Hungary.

Based on the literature data of old world bluestem conclusions can be drawn about its ecological requirements. The species has a high abiotic stress tolerance since it was registered even in plant associations such as *Succiso-Molinietum hungaricae*, which can be found on soils of extreme water balance. In such stands old world bluestem may appear in those years when the vegetation period is extremely dry. The species was also witnessed in extremely dry, open perennial calcicolous sandy grasslands and open dolomite rock grasslands as well as in their "analogous" pairs developed on acidic bedrocks (e.g. the calcifugous sandy grassland of the Nyírség or the open Carpathian silicate rock grassland). Its extreme xerotolerance is confirmed by the fact that this species can be also found on loess walls, furthermore it was registered in shrub forests and robinia forests containing *Anthriscus cerefolium* as well. Its salt tolerance can be well described by the fact that it also occurs in habitats such as *Artemisio santonici-Festucetum pseudovinae*. Besides, old world bluestem was also witnessed in pioneer weed associations (e.g. associations dominated by *Vulpia myuros*).

The competitive advantage of the species – which originates from its C<sub>4</sub> type photosynthesis mechanism and its morphological plasticity – can be useful for the plant especially in degraded habitats and places where abiotic stress factors are present, which could be experienced in the majority of the investigated stands.

The **invasion** of the species can be traced back to the extreme environmental conditions caused by the **steepness of the slopes**. Since old world bluestem can also tolerate extremely dry microclimate it is expected that its cover will increase in similar habitats in the near future, especially due to anthropogenic disturbances and in years hit by heavy drought.

The species can be frequently observed in areas which used to be managed by **burning** in the former years. Open surfaces developed this way provide a great opportunity to the introduction of pioneer and invasive species similarly to younger old fields.

Old world bluestem can become invasive especially in old fields and cleared grasslands where other competitive stand forming grass species are present only at a lower level. **Overgrazing and then the cessation of grazing** also help the spread of the plant. In the case of overgrazing newly formed open surfaces provide the basis for the introduction of old world bluestem. During the overgrazing of grasslands the treading of animals enhances erosion, which leads to drier microhabitats lacking nutrients in the case of steeper slopes. This is also favourable for the spread of grass species using C<sub>4</sub>

photosynthesis. The nutrient lacking environment and low total cover values – where the cover of well competing species is especially low – greatly facilitate the spread of old world bluestem.

The introduction of the species is also helped by the removal of **sods, former mining activities** or the **clearing of shrubs**. If the species is already present in an area, it can also become invasive after shredding or mowing activities performed in an inappropriate time. Presumably, the species behaves as an internal invader during the **drying out of former wet habitats** and in the case of some **cleared xero- and xeromesophyll grasslands** as well. It is expected that old world bluestem dominated grasslands will be stabilized at those places where **mowing or shredding activities** only aim at stopping the introduction of shrubs.

The **development forms** of old world bluestem can be well used as indicators since they show the degree of its dominance and the role of the species in the plant association. If it is **introduced** to a stable grassland **slowly under optimal grazing conditions**, it will be controlled by the other species of the plant association. As a result, it will not cause significant reduction in the number of species, diversity loss or great changes in the internal structure of the grassland, and its invasion will be very unlikely to happen. Old world bluestem forms small and medium sized tussocks. It can propagate vegetatively and generatively as well, but only to a limited level. **Under extremely stressful conditions** it forms a short grassland, develops only shallow roots, grows its stems close to one another, and propagates mostly vegetatively. As a result of treading it does not develop large tussocks, and does not overwhelm the other species. In **tall and close grasslands** stems are situated further from one another, they become larger, internodes get longer, and most of them blossom, that is the plant tries to overgrow the grassland, and to reach possible open surfaces located in the vicinity. In **ruderal and middle aged old fields** and open surfaces where internal self-regulating mechanisms are not developed enough the species can become invasive this way significantly slowing the regeneration of grasslands. In this case it can propagate generatively and vegetatively as well, it develops deep roots, grows many stems, forms huge tussocks, and produces a large number of offsprings (BARTHA 2007a).

Old world bluestem often produces a significant amount of litter which stays around the plant for a long time this way negatively affecting diversity (DEÁK et al. 2011).

Due to its overwhelming impact the spread of old world bluestem also brings **land management related issues** into the limelight. Controlling this species is very difficult and expensive in many cases (MITTELHAUSER et al. 2011; RUFFNER and BARNES 2012), although from vegetation dynamics aspects waiting for the end of natural regeneration processes without any intervention can be also an option. This latter process may take even decades.

**Grazing** could be another means of management, but due to the bad forage value of the plant it can become a real solution only in the case of actually and optimally grazed sheep pastures by preserving phase "A". It is also important to prevent the development of new large open surfaces during treading and grazing, and animals shall not be allowed to selectively graze according to their taste. This way old world bluestem cannot make use of its competitive advantage due to the 2-3 cm height of the grassland. According to the relating literature data (GILLEN and BERG 2001) and our experience, grazing with beef cattle is the best way of utilization.

Based on international literature data **controlled burning** can be a relatively cheap solution requiring minimal labour for getting rid of the accumulated litter (RYSER et al

1995). In the prairie of Texas (RUCKMAN et al. 2012, ANDRUK 2014) and West Australia (GOSPER et al. 2011) the spread of old world bluestem could be stopped by high intensity burning.

In the North American prairies late **mowing** with hay removal is a common management practice. This solution is favourable for the survival and the spread of species using C<sub>3</sub> photosynthesis (CHU et al. 2006), furthermore it also enhances the introduction of new species (BONANOMI et al. 2006). On the other hand, mowing proved to be insufficient for stopping the spread of old world bluestem in our research areas, therefore according to our analyses mowing alone is not advised be used for the control of this species. According to our research results, **overseeding** alone did not suppress old world bluestem either, especially under extremely dry conditions where the competitive power of the other common grass species was reduced. From the overseeded plots the highest yield level was registered in the case of *Dactylis glomerata* reaching 13 t/ha green mass per year. But this high yield – exceeding the other measured values only by 1-2 tons per hectare – was associated with the lowest crude protein level, and a significant reduction was also observed in the number of species in these plots. **Nutrient supply** also did not suppress old world bluestem, but the highest yields – 16 tons of green mass per hectare – could be measured in the case of manured and mowed plots. Since total cover and the number of species have been slightly increased as a result of manuring this treatment can be best advised on similar grasslands from the tested treatment methods.

According to the present knowledge, old world bluestem is very difficult to permanently suppress, therefore further research is necessary to define which methods could be best used for this purpose. The restoration of habitats which is the following step is also an extremely difficult task due to the allelopathic compounds produced by the species (GREER et al. 2014), which are unfavourable for the majority of grassland species. Consequently, further analyses are necessary to exactly define the impact of these allelopathic compounds on other plants. Of course, the ideal solution is the prevention of the spread of old world bluestem through optimal grassland management by using appropriate methods. A recent research carried out in Inner Mongolia found that the spread of grass species using C<sub>4</sub> metabolism is affected by the temperature of the vegetation period, while the impact of grazing was not significant (AUERSWALD et al. 2012). As a result, the role of old world bluestem may significantly change in the Hungarian plant associations due to the warming climate if climate change disturbs the balance of C<sub>3</sub> and C<sub>4</sub> species. Consequently, investigating the behaviour of invasive species and those causing inner invasion still remains an important issue in the ecology of associations (FOLLAK 2011, ŠLIC et al. 2012).

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## PUBLICATIONS RELATED TO THE TOPIC OF THE STUDY

### **Proofread foreign language articles published in journals with impact factor:**

1. Fraser L. H., Pither J., Jentsch A., Sternberg M., Zobel M., Askarizadeh D., Bartha S., Beierkuhnlein C., Bennett J. A., Bittel A., Boldgiv B., Boldrini I. I., Bork E., Brown L., Cabido M., Cahill J., Carlyle C. N., Campetella G., Chelli S., Cohen O., Csergo A. M., Diaz S., Enrico L., Ensing D., Fidelis A., Fridley J. D., Foster B., Garris H., Goheen J. G., Henry H. A. L., Hohn M., Jouri M. H., Klironomos J., Koorem K., Lawrence-Lodge R., Long R., Manning P., Mitchell R., Moora M., Müller S. C., Nabinger C., Naseri K., Overbeck G. E., Palmer T. M., Parsons S., Pesek M., Pillar V. D., Pringle M.R., Roccaforte K., Schmidt A., Shang Z., Stahlmann R., Stotz G. C., Sugiyama S., Szentes Sz., Thompson D., Tungalag R., Undrakhbold S., van Rooyen M., Wellstein C., Wilson J. B., Zupo T. (2015): Worldwide evidence of a unimodal relationship between productivity and plant species richness. *Science* 349 (6245): 302-305. IF: 31,477
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### **Proofread foreign language articles published in journals without impact factor:**

1. Bartha S., Zimmermann Z., Horváth A., Szentes Sz., Sutyinszki Zs., Szabó G., Házi J., Komoly C., Penksza K. (2011): High resolution vegetation assessment with beta-diversity — a moving window approach. *Agricultural Informatics*. 2(1): 1-9.

### **Proofread Hungarian articles published in journals without impact factor:**

1. Szentes Sz., Sutyinszki Zs., Szabó G., Zimmermann Z., Járdi I., Házi J., Bartha S., Penksza K. (2012): A fenyérfű (*Bothriochloa ischaemum* (L.) Keng 1936) gyep-fajösszetételére gyakorolt hatásainak vizsgálata mikrocönológiai módszerekkel. *Animal welfare, etológia és tartástechnológia* 8(1): 88-102.
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