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STUDY ON AN ECOLOGICALLY FRIENDLY METHOD TO FIGHT WITH *Pteridium acuilinum* IN MOUNTAIN CONDITIONS

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Abstract

The aim of the experiment is to determine the staged annual mowing of a population of Pteridium acuilinum (harmful species), in a natural grass stand of Chrysopogon gryllus type. The results of the conducted research show a progressive reduction of the harmful species from the first to the last experimental years, ranging from 72.0-78.0 pcs. of plants/m^2 (2014) up to 14.2-15.9 pcs. of plants/m^2 (2019). A positive trend was established regarding the recovery of grass cover and an increase in the number of useful fodder species such as: Festuca arundinaceae Scherb, Agrostis alba L., Dactylis glomerata L., Trifolium hybridum L. and Chrysopogon gryllus L.

Key words*: mechanical control, grass stand, Pteridium acuilinum.*

INTRODUCTION

The problem with the invasive species *Pteridium aquilinum* (L.) Kuhn has been relevant for decades, covering various aspects, such as business, ecological, economic and actually it has transformed into a worldwide problem. Bracken weed infestation leads to a loss of agricultural land and disrupts biodiversity in certain ecosystems. The content of highly toxic substances in *Pteridium aquilinum* has a serious negative impact on the health of farm animals and people, moreover when it is consumed, causes poisoning and carcinomas (Marrero et al., 2001; Vetter, 2009). Bracken disrupts forest ecosystems and limits tree growth (Senyanzobe et al., 2020). *Pteridium aquilinum* extracts and spores can contaminate water sources and are genotoxic (Fernández & Sierra, 2022). The spread of the invasive species in pastures creates conditions for severe degradation, leading to disturbance of biodiversity (Sarateanu et al., 2021), and the application of various agrotechnical measures for weed control, including the use of herbicides or sowing with suitable competitive species, such as *Festuca rubra* and *Vicia cassubica* (Petrov & Marrs, 2000; Stewart et al., 2007; Ghorbani et al., 2006; Milligan et al., 2016; Akpınar et al., 2023). Controlling *Pteridium aquilinum* is very difficult in natural grass areas and requires different approaches. This includes some agrotechnical interventions (ploughing, harrowing, varying frequency of mowing, rolling, controlled burning of the aboveground mass), as the results have been characterized by variable success so far (Stewart et al., 2007; Argenti et al., 2012; Berget et al., 2015, Cervacio et al., 2016). A number of studies indicate that ecological approaches such as grazing control (Alday et al., 2013) and, in particular, staged mowing applied over a long period of time, greatly suppress the development of bracken (Cox et al., 2007). The destruction of the invasive species is very effective when an approach of several mowings per year is applied (Stewart et al., 2008) combined with a long time period of not less than 10 years (Akpınar et al., 2023), as the authors point out that this method is also the most expensive.

The aim of the present study is to destroy an invasive population of bracken that has invaded a completely natural grass area through staged mowing over a 6^{-year} period and to restore the share in the grass cover of beneficial plants from the groups of legumes and grasses.

MATERIALS AND METHODS

For six years (2014-2019), mechanical control was conducted (by mowing - up to two mowings per year, according to the formed regrowth) on an invasive population of bracken, established in a natural meadow (*Chrysopogon gryllus* type at the foot of the Central Balkan Mountain with geographical location: (latitude_N - 42° 51'35.45", longitude_E - 24.41° 36' 34" and 448 m above sea level (Krushaka locality), Bulgaria. The experimental area bordered on the west with a catchment area (The Osam River), and from the east with a coniferous forest massif. The experiment was carried out using the method of long plots (Tsade's method) in four replications, with 200 m^2 experimental plot size. The experimental variants were of the same type (by mowing), as for each individual variant were provided two periods (early and late). The following variants for mechanical control by mowing the harmful grass stand up to twice a year were studied as mowing variants/dates:

1. Mechanical mowing/dates of mowing: 01 June 1st mowing and 20 July - 2nd mowing (variant 1)
2. Mechanical mowing/dates of mowing: 10 June 1st mowing and 28 July - 2nd mowing (variant 2)
3. Mechanical mowing/dates of mowing: 20 June 1st mowing and 10 August - 2nd mowing (variant 3)
4. Mechanical mowing/dates of mowing - 30 June 1st mowing and 25 August - 2nd mowing (variant 4)

The removal of the bracken above-ground biomass was carried out with hand-held professional motorized brush cutters - STIHL FS 261 with a large cutting diameter (520 mm), suitable for use in hard-to-reach areas.

Study indicators

The following indicators were studied:

Phenological observations of the invasive population of bracken.

The density of bracken (number of plants/m^2) - was calculated in each variant (using measuring tapes of 5 pcs.).

Botanical composition of the grass stand (%) - determined by weight, by analyzing grass samples taken immediately before mowing, establishing the percentage share of the invasive species and the main botanical groups (grasses and legumes, and motley grasses). Changes in the botanical composition of the grass stand were studied from the 2nd (2015) to the 5th (2019) experimental years of each first regrowth.

For the second mowing, botanical analysis was not performed because of the lack of new regrowth from the three main biological groups (grasses, legumes and motley grasses).

The statistical processing of the data was done by two-factor analysis of variance, using the software product *Analysis Toolpak for Microsoft Excel* 2010.

RESULTS AND DISCUSSIONS

According to the results of the two-factor analysis of variance, mowing variants significantly (P <0.001) affected the density of the harmful species, as the interaction between mowing variant and year conditions had the strongest impact (42.7%). The force of their combined action is greater than the independent impact of each one of them (Table 1).

If they are ordered by strength of impact, the factor of mowing variants takes the second place with 11.9%, being almost equal in terms of impact to the factor of conditions of the year, which registered 11.0%.

Variant 3 shows the best results, in terms of reduction of the harmful species, after the first mowing on average over a 6-year period, when mowing was conducted on 20 June.

Table 1. Results of two-factor analysis of variance and Strength of impact of factors in (%) after 1st mowing on population density of *Pteridium aquilinum* (L)

Source of Variation	SS	df	MS	F	P-value	F crit	Degree of factorial impact, %
Conditions in the experimental year	4221.4	5.0	844.3	6.1	0.0001	2.3	11.0
Variants/mowings	4584.1	3.0	1528.0	11.1	0.0000	2.7	11.9
Interaction	16418.4	15.0	1094.6	8.0	0.0000	1.8	42.7
Within	13194.8	96.0	137.4				
Total	38418.7	119.0					

In the second mowing of the invasive *Pteridium aquilinum* population, factors differed significantly in their effect on the density of the harmful species.

Here, the factor of conditions of the experimental year has the strongest impact with 83.6% (Table 2).

The factor of mowing variants has a very small impact here with only 4.1%.

The interaction of both factors, such as variants of mowing by conditions of the year (4.6%) is significantly less than the conditions of the experimental year as an independent factor (83.6%).

A proven lower number of bracken plants after the second mowing was reported for 4 and 3 variants, with respective mowing dates of 25 August and 10 August.

Table 2. Results of two-factor analysis of variance and Strength of impact of factors in (%) after 2nd mowing on population density of *Pteridium aquilinum* (L)

Source of Variation	SS	df	MS	F	P-value	F crit	Degree of factorial impact, %
Conditions of the experimental year	48814.2	5.0	9762.8	208.1	0.0000	2.3	83.6
Variants/mowings	2373.5	3.0	791.2	16.9	0.0000	2.7	4.1
Interaction	2685.5	15.0	179.0	3.8	0.0000	1.8	4.6
Within	4504.4	96.0	46.9				
Total	58377.6	119.0					

The analysis of the dynamics in the density of the bracken by years shows a significant tendency to limit the harmful species by mowing. The application of mechanical control in the first year (2014) led to a slight decrease in the bracken density. After the mowing of the harmful mass (first mowing) in June (01 June and 20 June), the population of bracken in the experimental/mowing variants (variants 1 and 3) varied within the limits of 17.1 plants/m^2 up to 17.2 plants/m^2. A significantly higher density per unit area of the invasive bracken population was recorded in the next experimental variants (2nd and 4th), from 71.2 plants/m^2 up to 72.0 plants/m^2 (Figure 1). The second mowing, carried out in stages on the later dates (20 July, 28 July, 10 August, 25 August), had no effect on the density of the invasive bracken population. The values for all experimental variants are within the range of 72.0 plants/m^2 up to 76.0 plants/m^2 (Figure 2), which confirms the resistance of the invasive species due to its reproduction mechanisms (very strong and branched root system and strong spore formation on the aerial part of the plant).

In the second experimental year (2015), a significant share of the noxious plants per unit area were destroyed. The bracken density after the first mowing (on 01 June, 20 June, 30 June), and after the second mowing (on 20 July, 10 Augus, 25 Augus), in variants 1, 3 and 4 (Figure 1), was reduced from 43.2; 44.8 and 39.2 plants/m^2 up to 30.8, 31.2 and 12.8 plants/m^2 (Figure 2). An exception is the first experimental variant (variant 1), where the course of mowing (two mowings carried out on 01 June and 20 July) has a smaller effect on the reduction of harmful plants from 58.3 to 49.8 plants/m^2.

In the third experimental year (2016), both readings (mowings) showed a statistically significant reduction in weed density. This is strongly expressed in the 3rd and 4th variants, as in the specified variants and terms the density of the harmful species was reduced from 23.2 plants/m^2, 24.0 plants/m^2 after the 1st mowing (Figure 1), up to 12.8 and 14.4 plants/m^2 during the second mowing (Figure 2) of the grass stand (variants 3 and 4).

In the 4th experimental year (2017), after the first mowing of the grass stand on 01 June and 10 June in the first two variants (variants 1 and 2), the density of the bracken moved within the limits of 57.6 plants/m^2 at variant 1 to 40.8 plants/m^2.

For variants 3 and 4 mowed on 20 June and 30 June, similar results were reported, as the density of the specified species was within the limits of 40.0 plants/m^2 up to 44.8 plants/m^2. After the second mowing at the later dates for the different variants, the course of reduction is positive and shows significantly fewer harmful plants per unit area.

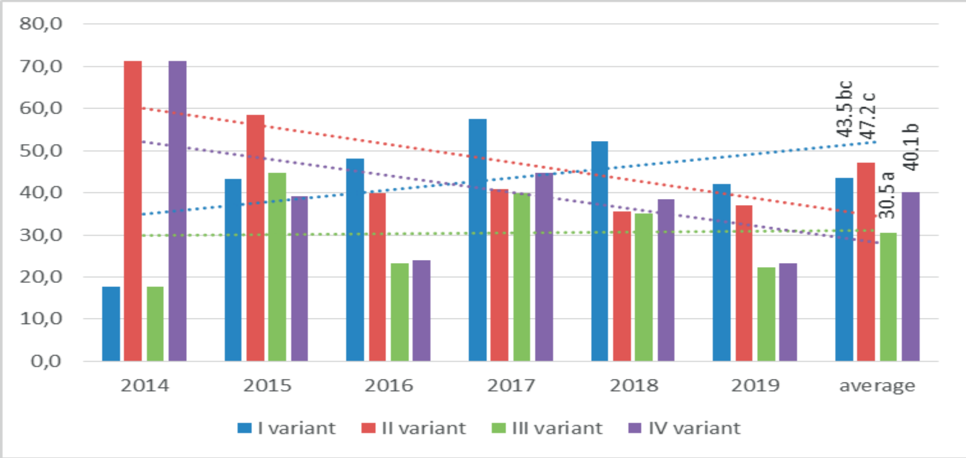

Figure 1. Density of *Pteridium aquilinum* L. (number of plants/m^2) by years and variants (second regrowth)

During the year, both readings (mowing dates) showed a significant reduction in weed density in all experimental options.

In the experimental plots, the destruction of the bracken population by mowing is most visibly expressed in the 3rd variant (mowing dates 20 June and 10 Augus and the 4th variant (mowing dates 30 June and 25 Augus). The course of reduction after the first and second mowing in the indicated variants reduced *Pteridium aquilinum* share in the grass cover (variant 3) from 40.0 to 17.6 plants/m^2, and from 44.8 to 18.4 plants/m^2 (variant 4).

The effect of mowing on the reduction (suppression) of the invasive population of *Pteridium aquilinum* was most significant in the last two experimental years (2018 and 2019).

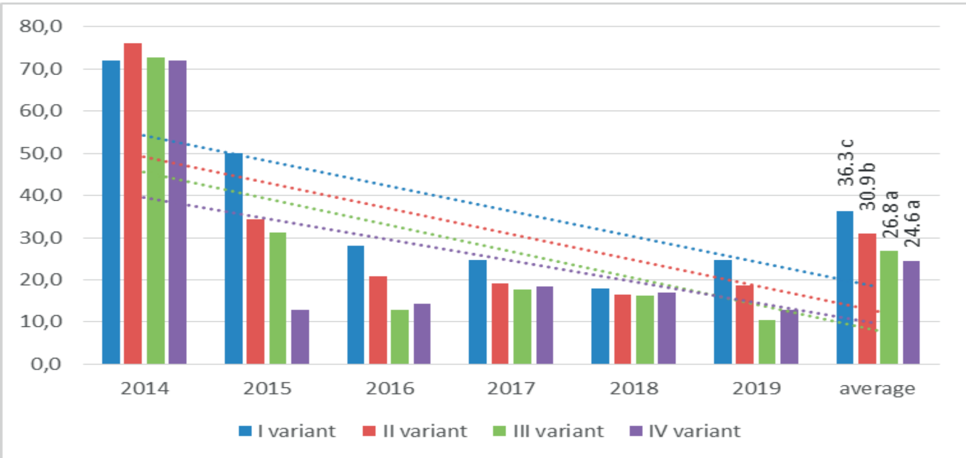

Figure 2. Density of *Pteridium aquilinum* L. (number of plants/m^2) by years and variants (second regrowth)

In the fifth experimental year (2018), after the first mowing of the grass stand (on 01 June and 10 June), in the first two variants, the bracken density moved within the limits of 52.2 plants/m^2 up to 35.6 plants/m^2 (Figure 1). For the 3rd and 4th variants mowed on 20 June and 30 June similar results were reported, as the density of the specified species was weaker and within the limits of 35.2 plants/m^2 up to 38.4 plants/m^2. In the second stage mowing of the grass stand (Figure 2) and the stipulated terms, the reduction of the invasive species was statistically significant, as a significantly lower number of plants per unit area was recorded.

During the year, both readings (mowings) showed a reduction in weed density, most pronounced in variants of the 2nd mowing (on 10 June and 28 Augus), and the 3rd mowing on 20 June –10 Augus. As a result of the applied mowing in the specified variants, the population of bracken was reduced from 35.6 plants/m^2 after the first mowing up to 16.4 plants/m^2 counted after the second mowing (variant 2), and from 35.2 plants/m^2 up to 16.2 number of plants per unit area (variant 3). Under the influence of the planned mowings, the dynamics in the density of *Pteridium aquilinum* established in the 1st and 4th variants marked a decrease, respectively, after the first dates of mowing (01 June and 30 June) from 52.2 plants/m^2 and 38.4 plants/m^2 (Figure 1), up to 18.0 plants/m^2 and 17.0 plants/m^2 established during the second dates (20 July-25 Augus) of mowing (Figure 2).

In the sixth last experimental year (2019), the destruction of harmful plants was most pronounced. After the first mowing periods, the bracken share was reduced from 46.2 plants/m^2 (variant 1) up to 33.5 plants / m^2 (variant 4). Similar values were reported for mowing variants (variants 2 and 3), as the density of harmful plants was even lower and within the limits of 31.4 plants/m^2 up to 31.6 plants/m^2 (Figure 1). The dynamics in the reduction of the population during the second mowing (Figure 2) confirms to an even greater extent the course of reduction in harmful plants, as in the individual variants (variants 1, 2, 3 and 4) and the corresponding planned dates for mowing (20 July, 28 July, 10 Augus, 25 Augus), their density was reduced to: 24.8, 18.6, 10.4, 12.8 plants/m^2. On average for the 6-year study period, in all variants, the most harmful *Pteridium aquilinum* plants were destroyed during the second mowing periods (Figure 2). The reduction in the density of the noxious grass stand (plants/m^2) for the individual mowing variants is in the interval: 36.3 (variant 1), 30.9 (variant 2), 26.8 (variant. 3), 24.6 (variant 4).

The values show that staged mowing has an effect on the destruction of harmful plants, but requires a long period of time to achieve the maximum effect.

Botanical composition of the grass stand after the mechanical control of the bracken

After the conducted phenological observations and botanical analysis, it was established that the partial formation of useful grass vegetation began in the second experimental year (2015).

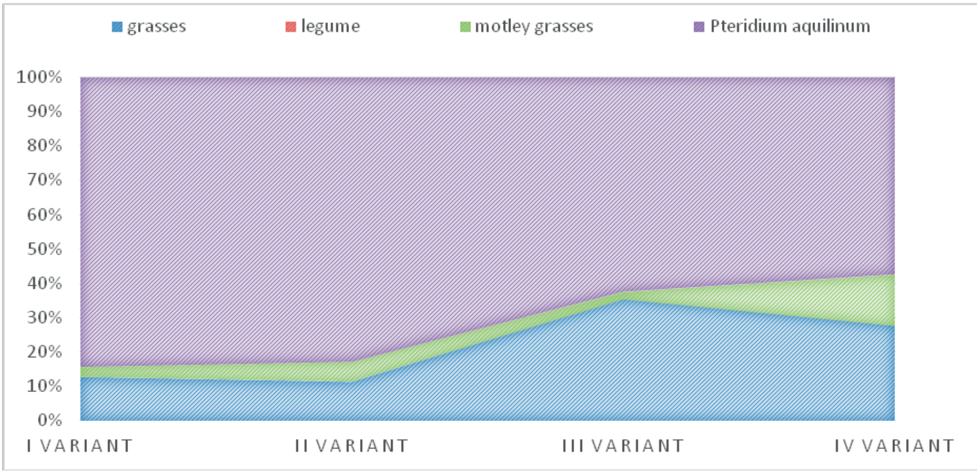

Figure 3. Changes in the botanical composition (%) of *Pteridium aquilinum* (L.) grass stand after the 1st mowing in 2015

In the same year, useful plants were represented only by the group of grasses. They occupied the largest share of 35.4% in the 3rd variant and the smallest in the 2nd variant with 11.3%. After the staged mowing (1st mowing dates) in June, the predominant species in all variants were *Agrostis alba*, *Poa pratensis* and *Dactylis glomerata*. Involvement of species from the group of legumes meadow grasses was not established. The presence of species with low economic value (the group of weeds) also increased, from the 1st to the 4th variants in the interval from 2.8% to 15.0%. The lowest share of *Pteridium aquilinum* was found in the 3rd and 4th experimental variants/mowing, as its aquilinum involvement ranged from 62.5% to 57.4%. In the remaining two variants (variants 1 and 2), *Pteridium aquilinum* dominated with a participation share in the grass cover over 80% (Figure 3).

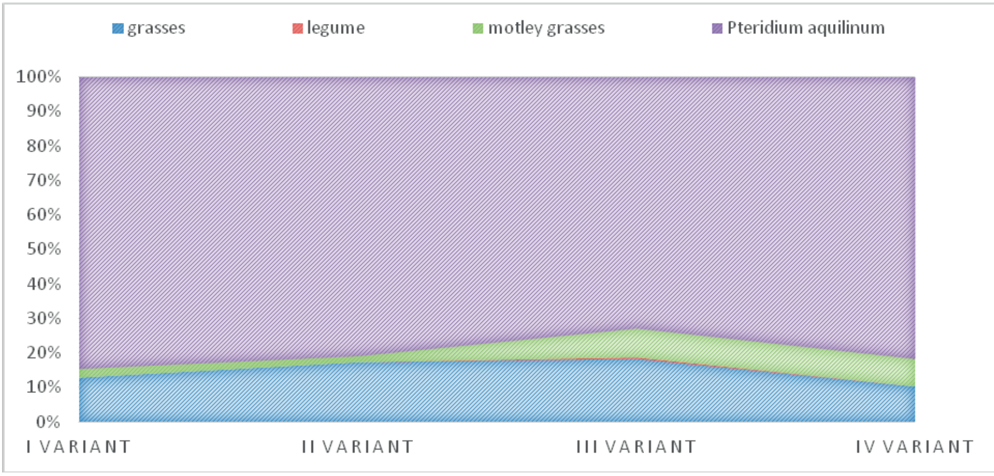

Figure 4. Changes in the botanical composition (%) in grass stand with *Pteridium aquilinum* (L.) after the 1st mowing in 2016

Studying the botanical changes in the experimental year (2016) shows that the recovery of useful plants in the grass stand is less pronounced due to the increased presence of bracken. After mowing the noxious vegetation, grasses dominated as economically important species and plants of low economic value (motley grasses). As a general assessment, the share of beneficial grasses in the grass stand was low. The group of grasses occupied the largest share in the first three variants (variants 1, 2 and 3), the course of increase is in the range of 12.8%, 17.3% and 18.3% (Figure 4). The grass meadow species were observed: *Dactylis glomerata, Agrostis alba, Festuca fallax*.

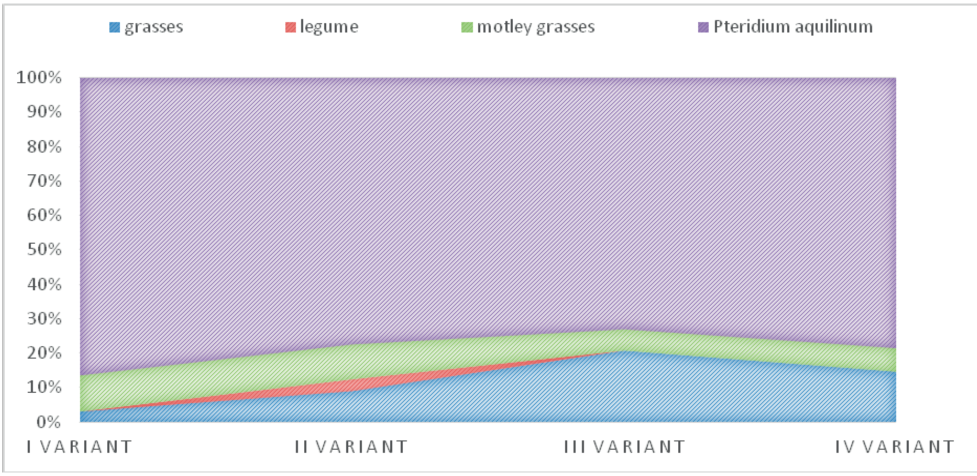

Figure 5. Changes in the botanical composition (%) in a grass stand with *Pteridium aquilinum* (L.) after the 1st mowing in 2017

After the first mowing in June (2017), in the individual variants, the highest share of harmful plants (bracken) was registered in the first mowing variant of 86.3% and lowest in the 3rd variant up to 72.9%.

The partial recovery of useful plants in the same experimental year (2017) was more pronounced despite the dominant position of the invasive species.

In the same year, under the influence of mowing, the grass composition changed followed the trend of the previous years with mainly grasses (Figure 5). The group of grasses has the largest share in the 3rd experimental variant (20.8%) and 4th (14.7%), opposite to the them, the group of legumes registered a significantly lower share ans took 3.4% in the grass stand. In the studied coenosis, *Bothriochloa ischaemum, Agrostis alba* had the greatest presence from the group of grasses.

The staged mowing of the harmful grass stand also stimulated the development of plants from the *Fabaceae family*, but to a much lesser extent, only one representative (*Trifolium hybridum*) was found. The presence of weeds (motley grasses) also increased, as their group occupied a share in the different variants from 6.3% (for variant 3) to 10.5% for the first experimental variant (variant 1).

The relative shares of the three groups (grasses, legumes and motley grasses) in the studied grass stand versus invasive species for the experimental year before the last are shown in Figure 6.

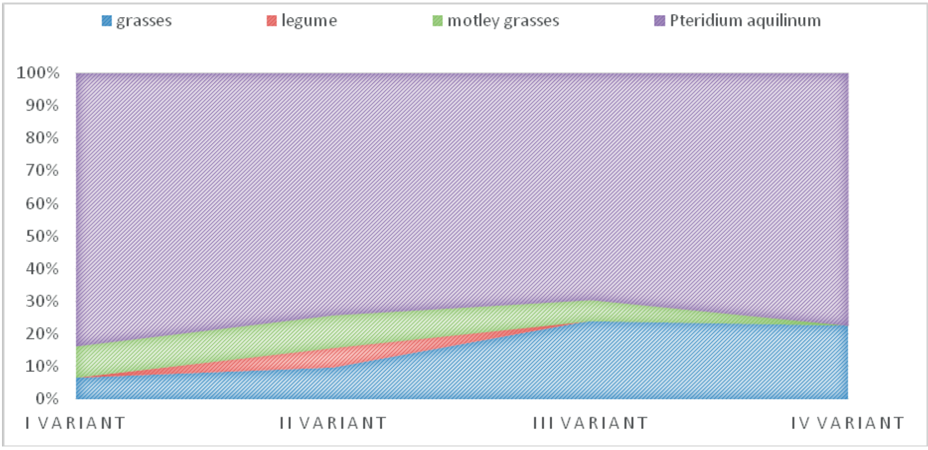

Figure 6. Changes in the botanical composition (%) of the *Pteridium aquilinum* (L.) grass stand after the 1st mowing (2018)

It can be seen that after the first mowing date (30 June 2018 year) the trend from the previous years has continued (Figures 3, 4 and 5) showing a constant high participation of the invasive species. During the year, *Pteridium aquilinum* recorded the largest shares in two of the mowing variants (variants 1 and 4) from 83.7% to 77.2% (Figure 6). There are also changes in the quantitative share of grass groups. The largest share of useful plants continues to be occupied by grasses. Tracking the curve shown shows that their share increased in the interval from the 1st (6.6%), to the 3rd (25.6%), and 4th (22.6%) mowing variants. Under the influence of mowing, the share of useful grass species is stimulated: *Agrostis alba, Festuca arundinaceae, Dactylis glomerata, Triodia decumbens* and *Agrostis capillaris*. Staged mowing of the noxious grass stand increased the share of legumes to 6.0%, as *Trifolium hybridum* and *Trifolium pratense* were found among the representatives of this group. The presence of weeds also increased. They occupied a share in the interval from 7.0% (variant 4) to 10.1% (variant 2).

The changes taking place in the grass cover during the final experimental year (2019) show that after mowing the grass stand, the bracken still retained a higher share compared to the useful vegetation (the grasses of economic importance) - Figure 7.

The largest share of the invasive species (*Pteridium aquilinum*) was in the first two variants from 68.5% to 70.8% and the least in the 3rd variant - up to 57.4%.

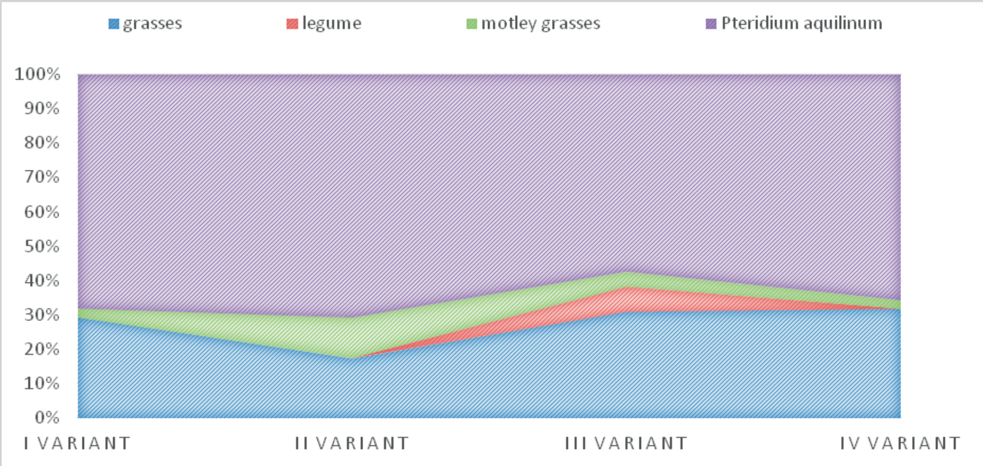

Figure 7. Changes in the botanical composition (%) of the *Pteridium aquilinum* (L.) grass stand after the 1st mowing (2019)

The presence of the useful meadow vegetation is dominated by the group of grasses. It occupied the following shares in the different variants: 29.4%, (variant 1), 17.3% (variant 2), 30.9% (variant 3) and a maximum value of (31.8%) in variant 4.
The tracking of meadow legume crops shows that this group registered the smallest share (7.4%), a trend continuing from previous years. For the conditions of the present experiment, mowing stimulated the emergence mainly of grasses and motley grasses, whereas the group of legumes had the smallest share.
The observed grass (dominant) species during the year were: *Agrostis alba*, *Dactylis glomerata* L. and *Chrysopogon gryllus*. As a result of the mowing, other types of grasses appeared, which had been in a suppressed state, such as *Chrysopogon gryllus* and *Agrostis capillaris*. The group of meadow legume crops had an unsatisfactory share in the grass cover, occupying a share of 7.4%.
Only one representative *Trifolium pratense* was observed in the third experimental variant, as the presence of legumes in the other variants was not established. After surveying the grass stand, the group of grasses from other botanical families (motley grasses) recorded the largest share of 11.9% (variant 2) and the smallest of 2.5% in the fourth experimental variant (variant 4).

CONCLUSIONS

The filed experiment in the conditions of the Central Balkan Mountain in the format of mechanical control shows the positive impact of staged mowing in a natural grass area heavily overgrown with *Pteridium aquilinum*. The mechanical control significantly reduced the population of bracken, as the number of harmful plants progressively decreased during individual years from 72.0-78.0 plants/m^2 (2014) to 14.2-15.9 plants/m^2 (2019), in all experimental variants.
On average for a six-year mowing period (2014-2019), the highest effect of the applied mowings was achieved in var. 3 and 4, as mowings were conducted on 20 June and 10 August; 30 June and 25 August, where the number of harmful plants per unit area was reduced from 72.0-72.8 plants/m^2 up to 26.6-24.6 plants/m^2. Under the influence of mowing, a process of partial restoration of the grass cover and stimulation of the growth and development of the useful grass vegetation was unlocked. It has been established that the course of restoration processes in the grass stand is most pronounced in the group of grasses and motley grasses, and to a much lesser extent in the meadow legume crops. The share of useful forage species such as, *Festuca arundinaceae*, *Agrostis alba*, *Dactylis*

glomerata, Agrostis capillaris, *Trifolium pratense*, *Trifolium hybridum* and *Chrysopogon gryllus* was observed.

To achieve the maximum effect of the applied mechanical control against the harmful grass stand from bracken, it is necessary to extend the time frame from 6 to 10-12 years.

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