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HOW DOES THE ALFALFA SEEDING RATE INFLUENCE THE STAND DENSITY AND PRODUCTIVITY?

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ABSTRACT
Optimizing the seeding rate could lead to a good stand establishment and cost-effective alfalfa production. To achieve high forage yields, alfalfa producers commonly use seeding rates above 20 kg/ha. Unfortunately, a scientific contribution to analyzing some agro-technical measures, including the appropriate seeding rate of alfalfa in temperate conditions in the Republic of North Macedonia, has been missing in the last decades. Given the dramatic ongoing climate changes, there was an urge to assess the productivity responses of several alfalfa cultivars to different seeding rates. In order to examine the effect of two seeding rates (8 and 16 kg/ha) on the stand density and dry matter yield of four alfalfa cultivars, from which one domestic (Debarska) and three imported (Banat VS, NS Jelena, Nijagara), a field experiment was conducted over three successive years (2023-2025). The treatments were distributed according to a randomized complete block design with three repetitions. Even though the higher seeding rate of 16 kg/ha resulted in significantly higher average number of plants (134) and stems (367) per m^2 in comparison with the lower seeding rate of 8 kg/ha, it obtained a lower average dry matter yield (20.9 t/ha) due to intraspecific competition of plants which cause plant mortality and productivity decrease. Among the examined cultivars, the highest productivity was recorded with NS Jelena (22.5 t/ha), confirming its genetic potential for intensive cultivation and high drought tolerance.

Keywords: alfalfa cultivars, dry matter yield, plant and stem density, seeding rate.

INTRODUCTION

The seeding rate is a fundamental agrotechnical measure that ensures good stand establishment and stable yields. Depending on environmental conditions, the applied stand establishment methods, and the chosen cultivar, the alfalfa seeding rate ranges from 4 to 40 kg/ha (Lloveras et al., 2008; Hakl et al., 2021). In North Macedonia, alfalfa is the most prevalent forage legume, cultivated on 17.7 hectares in 2024 (State Statistical Office of the Republic of North Macedonia, 2025). To achieve high forage yields, farmers apply high seeding rates exceeding 20 kg/ha, resulting in less cost-effective production. Unfortunately, there is a weak collaboration between farmers and scientific researchers, and an optimal seeding rate should be determined based on the actual impacts of global climate change. Understanding the relationships among seeding rate, stand density, and forage yield in more productive years would help determine the optimal seeding rate for alfalfa cultivation.

Numerous studies have documented the effect of different seeding rates on the plant density at the beginning of stand establishment and during the following vegetation years, as well as the impact of the seeding rates on alfalfa forage yield (Min et al., 2000; Hall et al., 2004; Glaspie et al., 2011; Berti et al., 2014; Rojas-García et al., 2017; Berti & Samarappuli, 2018; Kim et al., 2021).

Plant density is a very important factor for alfalfa productivity (stable yield) and longevity throughout its entire use period (Hall et al., 2004; Stanisavljevic et al., 2008). Plant density is the product of the distance between and within seeding rows and the amount of seed used per unit area, and it directly impacts yield. Determining the optimal density is a complex task, because alfalfa is a perennial crop (4 - 5 years life span, even more in ideal cultivating conditions), whose productivity decreases over time (Beković, 2005; Stanisavljević, 2006). Plant density is a significant factor influencing yield (Volenec et al., 1987; Lamb et al., 2003), forage quality (Min et al., 2000; Hakl et al., 2010), and alfalfa longevity (Min et al., 2000; Stanisavljević et al., 2012).

The number of plants per m^2 throughout the vegetation period highly depends on the seeding rate. Plant mortality in the year of stand establishment is usually higher at higher seeding rates than at lower seeding rates. Higher rates increase plant density but also intensify intra-specific competition, resulting in a higher percentage of plant mortality (Hall et al., 2004, 2010). In research conducted in Missouri and Pennsylvania (USA), Hall et al. (2004) found that, in the year of stand establishment, the highest seeding rate (20.2 kg/ha) resulted in 8 times as many dead plants as the lowest seeding rate (6.7 kg/ha). Six months after stand establishment, a decrease in density was observed at seeding rates above 17 kg/ha. According to Volenec et al. (1987), with an increase in stand density up to 172 plants per m^2, the yield per unit area increases, but the mass of individual plants decreases. On the other hand, an increased percentage of stand thinning is observed at higher seeding rates only in less favorable soil conditions during the year of establishment. Soils with superior conditions supported better plant emergence and long-term maintenance of high plant density (Hakl et al., 2021).

In the years following the stand's establishment, it continues to thin due to winterkill, pest invasion, and intraspecific competition (Tesar & Marble, 1988). In each subsequent year, plant density decreased at all tested seeding rates compared to the previous year (Hall et al., 2012). Studying the stand density of several alfalfa cultivars, Georgieva and Nikolova (2012) report an average of 1,313 plants per m^2 in the first productive year. The decrease in density over the following three years was disproportionate, with the greatest thinning occurring in the second productive year, when the number of plants per unit area decreased by 58.3%.

Several scientific studies have documented the correlation between the stand density, yield, and plant longevity (Min et al., 2000; Stanisavljević et al., 2012; Burnett et al., 2020). According to Berti & Samarappuli (2018), to obtain an optimal forage yield without irrigation, a minimum of 73 plants per m^2 is required in the year of stand establishment. They recorded a maximum total yield in the seedling, first-, second-, and third-productive years, with 73, 52, 37, and 36 plants per m^2, and 575, 495, 435, and 427 stems per m^2, respectively. Brummer et al. (2002) stated that an alfalfa seeding rate of 15-18 kg/ha is commonly recommended, usually resulting in 800 plants per m^2. At the end of the seedling year, the stand density decreases to 200-400 plants per m^2.

The objective of this study was to assess if a higher seeding rate (16 kg/ha) results in a higher plant and stem density as well as a higher alfalfa average forage yield.

MATERIALS AND METHODS

The study was conducted over three growing seasons (2023-2025) in the Skopje region, North Macedonia. The region has a continental sub-Mediterranean climate, with very hot and dry summers and moderately cold winters. During the experimental period, the lowest annual precipitation (394 mm) was recorded in 2024, which is even drier than the long-term average (502 mm). In each year of the study, the average monthly temperatures during the vegetation period were within the optimum frame for plant growth and development, ranging from 11.3 °C to 26.9 °C. The soil of the experimental area was alluvial, with a pH of 7.7, 2.47% organic matter, 9.2% $CaCO_3$, 247 mg/kg phosphorus, and 226 mg/kg potassium at a soil depth of 30 cm.

The treatments were arranged according to a split-plot design in a randomized complete block design (RCBD) with three replications. The dimensions of the basic plot were 1 m x 3 m, and the distance between the plots was 50 cm. The treatments included: a) four alfalfa cultivars (from which Debarska is a national cultivar and Banat VS, NS Jelena, and Nijagara are imported cultivars originating from the Republic of Serbia) and b) two seeding rates (8 and 16 kg/ha). Sowing was completed manually in April 2023. Standard cultivation practices were carried out before the trial was established. During the growing seasons, weeds were manually removed.

Harvesting was performed manually at an approximate stem height of 5 cm. According to Kalu & Fick (1981), the plants were mowed at the early flowering stage (10% of the plants had flowers). After each cut, a 300 g sample was taken from each plot, dried at room temperature to constant weight, and the percentage of dry matter (DM%) was determined. DM% was used to calculate the dry matter yield (DMY). In each productive year (2023, 2024, and 2025), five cuttings were performed. The count of plants per m^2 was determined on an identical marked area of m^2 in each plot, at the beginning and at the end of each vegetation period. The number of stems per m^2 was counted immediately after each cutting, using a square meter quadrate.

The collected data were analyzed using a linear mixed-effects model and a generalized linear mixed model in RStudio software (version 4.3.3) (R Core Team, 2024). Treatment mean value differences were compared using a Tukey test at a significance level of P=0.05.

RESULTS AND DISCUSSION

Dry matter yield (DMY)

The average dry matter yield in each productive year was highest in the first cut and lowest in the last cut, except in the first productive year (2023), in which the highest hay yield was achieved in the second cut. Comparing the two seeding rates in each productive year, almost equal hay yield was recorded in all cuts without any significant statistical differences (Figure 1). Alfalfa DMY during the 1st, 2nd, 3rd, 4th, and 5th cut represented 26.4%, 28.2%, 21.1%, 16.1% and 8.2% of the average DMY for the entire studied period (2023-2025). In contrast to our findings, Sun et al. (2011) obtained a different fluctuation of DMY per cut in their six-year experiment. The largest share of the total average yield is from the first cut (37%), and productivity decreases in subsequent cuts. Specifically, it represents 26%, 22%, and 15% in the 2nd, 3rd, and 4th cut, respectively. In the same line are the results of Djaman et al. (2020), who examined the productivity of several alfalfa cultivars with different dormancy ratings and revealed a trend of decreasing yield from the 1st to the 4th cut, whose share in the total average yield was 33%, 29%, 22% and 16%. Many other researchers also emphasize the dominance of the 1st cut, which represents 30-50% of the total yield (Hoy et al., 2002; Zhang et al., 2014; Li & Su, 2017; Jin et al., 2021; Wang et al., 2021).

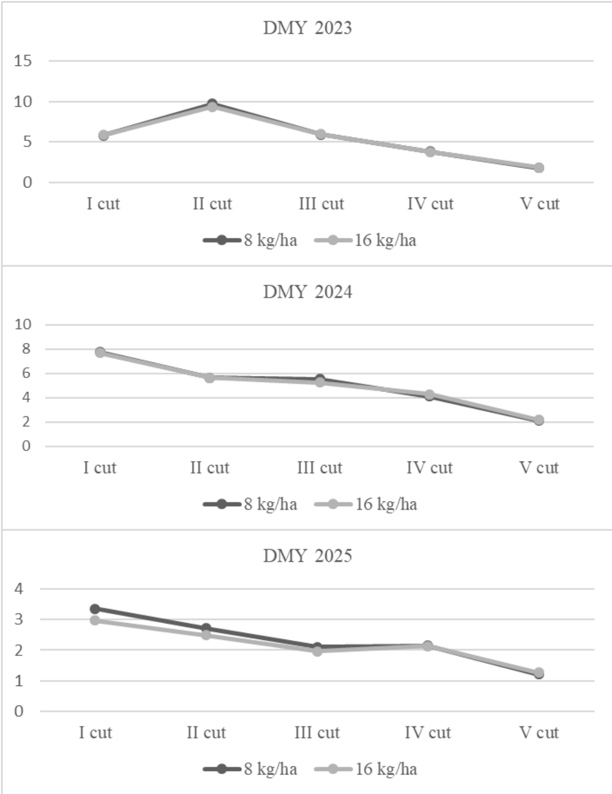

Figure 1. Average DMY (t/ha) per cut under different seeding rates during 2023, 2024, and 2025

According to the cited references, the decline in alfalfa productivity over one growing season is supported by scientific evidence. The decline in productivity can result from physiological, agrotechnical, and environmental factors. Multiple harvesting in a single vegetation causes cumulative stress on plants and decreases carbohydrate reserves in the root system, which are essential for regeneration after each cut. At the same time, climatic conditions become less favorable throughout the vegetation period. Shorter day lengths shorten the photoperiod, and high summer or early-autumn air temperatures can reduce or inhibit photosynthesis, resulting in reduced biomass accumulation. Among other things, towards the end of the growing season, plants allocate more energy to renewing their root systems to overwinter successfully than to producing above-ground biomass. All of these phenomena contribute to a downward trend in productivity within a growing season.

Among the examined cultivars, NS Jelena achieved the highest yield, 22.5 t/ha, with a significant difference compared to all cultivars (Figure 2). In a study in the Republic of Serbia, where different cutting schedules were tested, the highest average DMY (14.6 t/ha) was achieved by cultivar Nijagara, which is also tested in this research (Katanski, 2017). The obtained results are in accordance with the findings of Milic et al. (2014, 2019), who, among several cultivars, recommend NS Jelena, whose genetic potential would be maximally exploited in an intensive cutting system (4-5 cuts per vegetation season). These findings explain the highest productivity of NS Jelena, which had the best response across all three consecutive years of this research, during which five cuts were carried out.

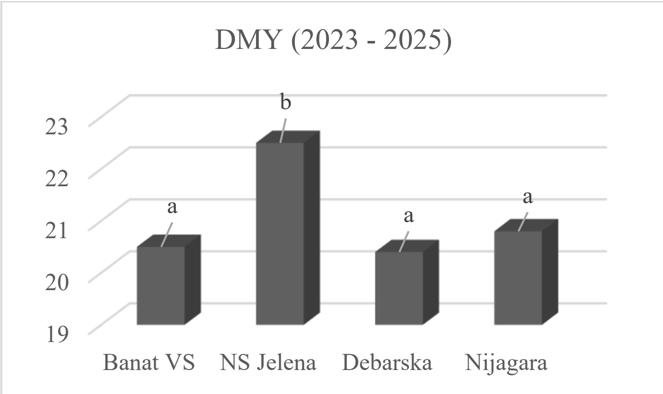

Figure 2. Average DMY (t/ha) for the studied period (2023-2025) represented by cultivars

[a] Lowercase letters indicate statistically significant differences between cultivars

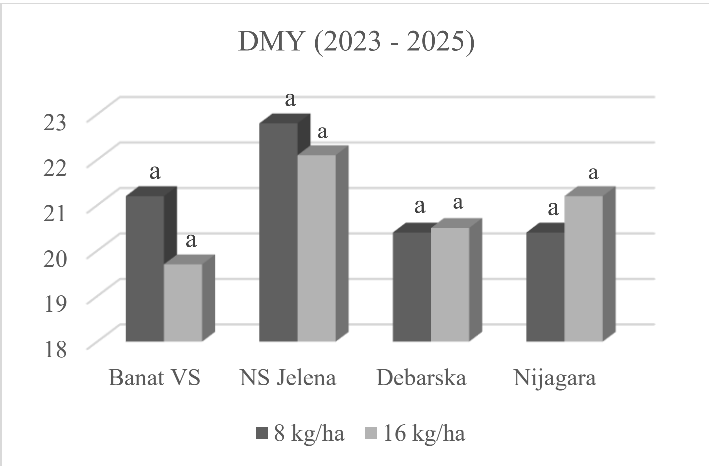

Figure 3. Average DMY (t/ha) for the studied period (2023-2025) under different seeding rates

[a] Lowercase letters indicate statistically significant differences within the cultivar

Assessing the influence of seeding rate on DMY, no significant differences in yield were observed across the tested cultivars (Figure 3). Thus, the results of this experiment indicate that the cultivars' productivity does not depend on seeding rate but instead on their dormancy rating. Significant differences in hay yield obtained, depending on cultivar choice, have also been reported by Pembleton et al. (2010) and Avci et al. (2018). Sarraj (1987), in a study conducted nearly 40 years ago, concluded that differences in productivity among five alfalfa cultivars are due to the different dormancy groups to which they belong. Several authors have investigated the productivity of alfalfa cultivars with varying dormancy rates (Brummer et al., 2002; Wang et al., 2009; Rimi et al., 2010; Xu et al., 2012; Djaman et al., 2021; Donmez & Hatipoglu, 2023). Alfalfa fall dormancy (FD) is a characteristic that is defined as the response of plants to a shortened photoperiod (day length) and reduced air temperatures, with the onset of autumn (Teuber et al., 1998; Castonguay et al., 2006).

The choice of an appropriate cultivar, i.e., knowledge of its dormancy rate, is of exceptional importance because it determines the production method (cutting schedule), resistance to low and high temperatures, and persistence. NS Jelena has an FD rating of 6

(Rhouma et al., 2017) and is suitable for intensive cultivation (multiple cuts per season), as evidenced by its higher productivity compared to the other tested cultivars. Since it is derived from crossing Greek and Serbian alfalfa populations, it is suitable for cultivation in temperate climates across Europe, including North Macedonia. Thanks to its high tolerance to drought, it could respond positively to dramatic climate change and to more arid conditions during the vegetation season.

Number of plants and stems per m^2

Plant density is one of the yield components, which, in addition to quantifying biomass production, also has an impact on the quality of the forage and the longevity of the stand (Min et al., 2000; Brummer et al., 2002; Lamb et al., 2003; Hakl et al., 2010). The two examined traits (number of plants and number of stems per m^2), which are closely related to stand density, showed statistically significant differences among seeding rate treatments (Table 1).

Seeding rate is a crucial factor that influences stand formation, regulates plant density, and, in turn, indirectly affects production (Hakl et al., 2021). Kim et al. (2021), the highest tested seeding rate of 40 kg/ha, proportionally associate with the highest number of plants per m^2, and in a similar direction are the published results of Stout (1998), who claims that the stand density increased significantly when the seeding rate increased from 5.6 to 16.2 kg/ha, but with its further increase the number of plants equalized. This research shows an increase in the number of plants and stems per m^2 as the seeding rate increases from 8 to 16 kg/ha, but this tendency may not continue linearly with further increases in the seeding rate. Sowing alfalfa at higher rates than 17 kg/ha initially results in a higher stand density, but in the long term, the stand thinning occurs as a result of increased intraspecific competition, which causes a higher percentage of plant mortality when higher seeding rates are applied (Dhont et al., 2004; Lloveras et al., 2008; Abdel-Rahman & Abu Suwar, 2012).

Table 1. Average number of plants per m^2, stems per m^2, and DMY (t/ha) under different seeding rates for the studied period (2023 – 2025)

Seeding rate (kg/ha)	**Number of plants (m^2)**	**Number of stems (m^2)**	**DMY (t/ha)**
8	106 **a**	308 **a**	21.2 **a**
16	134 **b**	367 **b**	20.9 **a**

[a] Lowercase letters indicate statistically significant differences in each column

Apart from the traits describing plant density, the seeding rates examined in this study did not lead to statistically significant differences in the achieved hay yields (Table 1). Thus, when sowing at 8 kg/ha, a slightly higher DMY (21.2 t/ha) was recorded compared to the rate of 16 kg/ha, from which an average of 20.9 t/ha DMY was produced. Our results align with those of Wang et al. (2017), Lu et al. (2019), and Xu et al. (2021), indicating that the seeding rate has no significant effect on average yield over two or more years. In the same direction are the results of Sarraj (1987), who, comparing several seeding rates (12, 16, and 20 kg/ha), obtained similar yields of fresh and dry matter, indicating that the use of high seeding rates is not justified if good agricultural practices are applied prior to and during the stand establishment. Years later, Berti et al. (2014) came to the same conclusion, stating that the increase in seeding rate to achieve a satisfactory and stable yield should be offset by the labor invested and by timely, complete seedbed preparation.

CONCLUSION

The results of this research on the impact of seeding rate on alfalfa yield and stand density are scientifically supported and of practical importance to alfalfa producers. Even though a higher seeding rate (16 kg/ha) has implications for stand density and resulted with significantly higher number of stems (367) and plants (134) per m^2 than the lower seeding rate of 8 kg/ha (308 stems and 106 plants per m^2), significant difference in obtained DMY was not recorded (20.9 t/ha vs 21.2 t/ha). These findings can be explained by the increased competition between plants that occurs in stands with higher density, particularly when using high seeding rates, which ultimately results in high plant mortality, i.e., natural thinning of the crop. The average DMY per cut during each productive year (2023, 2024, and 2025) has also not shown any significant differences between assessed seeding rates. Comparing the tested cultivars in terms of productivity, NS Jelena was advantageous for intensive cultivation and tolerance to variable and low precipitation during the harvest season.

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