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# Stevia as an alternative crop for tobacco production in RN Macedonia

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**Summary**: The reform of the Common Agricultural Policy (CAP) for the tobacco sector in the European Union aims to gradually phase out subsidies for tobacco cultivation, a change that will significantly impact the tobacco industry in the Republic of North Macedonia. As a response, one proposed adaptation strategy is the cultivation of alternative crops to maintain employment levels and market competitiveness with new products. Stevia (*Stevia rebaudiana* Bertoni) was explored as a potential alternative crop that local farmers could adopt. Field experiments were conducted in 2019 across three localities (L1 – L3) on seven experimental fields (EF1 – EF7). The results revealed that EF3 achieved the highest yield of dry biomass at 4,400 kg/ha, followed by EF7 and EF1 (3900 kg ha$^{-1}$ and 3580 kg ha$^{-1}$ respectively), showing significant differences with other fields ($p$ < 0.05). The highest dry leaf yield (1,400 kg ha$^{-1}$) was observed at EF7, with statistical differences with EF6, EF5, and EF4. Among the localities, dry biomass yield was significantly higher at L3 (3,250 kg ha$^{-1}$) and L1 (3,115 kg ha$^{-1}$), compared with L2 (2,450 kg ha$^{-1}$). Based on dry leaf L3 producing the highest yield (935 kg ha$^{-1}$), significantly greater than L1 (840 kg ha$^{-1}$) and L2 (875 kg ha$^{-1}$). While some findings, such as the dry biomass yield are promising, the overall results obtain from one year of investigation are insufficient to recommend stevia as a viable alternative crop for the tobacco-growing regions of the country at this time.
**Key words**: stevia, tobacco, biomass, leaf, yield

## Introduction

Tobacco cultivation has a long-standing history and tradition in the Republic of North Macedonia, playing a vital role in the national economy due to various economic and social factors. With an estimated global share of 0.41%, the country ranks between 25th and 30th among the top tobacco-producing countries worldwide (Kabranova and Arsov, 2022). Tobacco production in North Macedonia is fully subsidized, with tobacco companies setting the purchase price, while the

Ministry of Agriculture, Forestry, and Water Economy provides an additional payment of 1.0 – 1.3 EUR per kilogram, depending on the tobacco grade. The European Union's Common Agricultural Policy (CAP) reform for the tobacco sector (Regulation EC No. 864/2004, effective January 1, 2006) aims to gradually eliminate subsidies for tobacco cultivation. This reform will significantly impact tobacco farmers in EU member states and is expected to affect North Macedonia in the near future, given its alignment with EU legislation. Additionally, the reform encourages tobacco producers to diversify their production by exploring alternative crops, with the goal of sustaining employment levels and maintaining competitiveness in the market. This shift presents both a challenge and an opportunity for the tobacco sector in North Macedonia to adapt to the changing economic and policy environment.

Stevia (*Stevia rebaudiana* Bertoni) is a perennial crop grown for its leaves, which contain diterpenoid glycosides renowned for their intense sweetening properties (Mengesha et al., 2014). These compounds are 200 to 300 times sweeter than sucrose (Vouillamoz et al., 2016; Politud, 2016; Tansi et al., 2017). The commercial cultivation of stevia, which began in Paraguay in 1964, has since expanded to cover approximately 32,000 hectares worldwide. (Hossain et al., 2017) In 2011, E 960 (steviol glycosides) was included in Regulation (EC) No 1333/2008 on food additives, and steviol glycosides were authorized to be used as a sweetener in food and beverages in the EU market. According to Grand View Research, the global stevia market was valued at USD 513.4 million in 2023 and is projected to grow at a compound annual growth rate of 11.9% from 2024 to 2030. In Europe, the stevia market was valued at USD 150.8 million in 2021 and is expected to grow at a annual growth rate of 9.15%, reaching USD 233.6 million by 2026 (Market Data Forecast).

A frequently asked question is: why was stevia chosen as an alternative crop to tobacco? Stevia aligns closely with the cultivation possibilities for tobacco, covering approximately 99% of the requirements. The first harvest occurs just 10 weeks after transplanting, yielding between 2,500 and 6,000 kg/ha annually. Its cultivation techniques are comparable to those of tobacco, with minimal fertilization needs and a low incidence of pests and diseases. Moreover, stevia requires a similar level of manual labor as tobacco, making it a viable alternative for farmers (Kienle).

Given the European Union's recommendations, the growing global market demand, and the similar cultivation practices, this research aims to explore the potential of cultivating stevia as an alternative crop in various tobacco-producing regions of the Republic of North Macedonia.

## Material and methods

Field trials were conducted in 2019 across three localities (L1 – L3) and seven experimental sites (EF1 – EF7). The localities were: L1: Radovish (southeastern part of the country), with two experimental fields: EF1 (village of Zleovo) and EF2 (Radovish); L2: Veles (central part of the country), with two experimental fields: EF3 (village of Dolno Vranovci) and EF4 (village of Ivankovci) and L3: Pelagonija (central-western part of the country), with three experimental fields: EF5 (village of Dobrushevo), EF6 (village of Ivanjevci), and EF7 (village of Krusheani).

Stevia propagation was carried out using seedlings imported from Spain (Semilleros Saliplant S.L.). Manual planting was performed at EF1, EF2, and EF5, while mechanized planting (commonly used for tobacco) was employed at the other sites. Each experimental plot covered 700 m², with a plant spacing of 60 × 25 cm, resulting in 4,760 plants per plot (68,000 plants per hectare). Due to uneven seedling transport and development i.e. varying times to achieve transplantable maturity, planting occurred between May 22 (EF3; EF7), 10 June (EF1, EF2, EF5 and EF6) and June 20, 2019 (EF4). Tobacco was the preceding crop on all plots. Fertilization involved applying NPK 7:20:30 at a rate of 31 kg per plot (440 kg/ha) before planting. Depending on the farmer's capability the irrigation was implemented on five of the seven experimental fields during the growing season: furrow irrigation was applied twice (late July and mid-August) at EF1, EF2, and EF6, while drip irrigation was used at EF3 and EF7 depending on the overall condition of the plants. Throughout the growing season, three inter-row cultivations were conducted. Before harvesting, plant height was measured from randomly selected ten plants from each experimental field. The root length was measured after measuring the height by excavating the 10-th randomly selected plants. The experimental fields were harvested manually at late of November 2019 using sickle. The plants from randomly selected 10 m² area within each experimental field were naturally dried at each farmer's location after which dry biomass and dry leaf mass were measured. Agrochemical analyses of the soils were done at the Faculty of Agricultural Sciences and Food laboratory in Skopje as follows: humus content using the Tjurin method, total nitrogen via Kjeldahl analysis, pH measured according to ISO standards, and $P_2O_5$ and $K_2O$ content determined using the AL method. Statistical analysis was performed using analysis of variance (ANOVA), and Tukey's test was applied to identify significant differences among mean values.

**Results with discussion**

The multi-year climatic conditions of localities were assessed using the climate-vegetation-soil region characteristics of the Republic of Macedonia (1960 – 1990, Filipovski et al., 1996) and compared to the meteorological data for 2019. In L1 the average minimum and maximum temperatures from May to October were 12.5 °C and 29.1 °C, respectively, in L2 the average minimum and maximum temperatures were 12.7 °C and 29.3 °C, and in L3 the average minimum and maximum temperatures were 11.2 °C and 25.7 °C, closely aligning with long-term averages of 11.7 °C and 24.7 °C (Table 1).

Table 1. Meteorological conditions in 2019 and the long-term averages (LTA) for the period 1960-1990 for temperature and daily precipitation

| Month | May | | June | | July | | August | | September | | October | | Average | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | min | max | min | max | min | max | min | max | min | max | Min | max | min | max |
| L1 – Radovish | | | | | | | | | | | | | | |
| Temperature (°C) | 11.7 | 26.1 | 15.5 | 28.8 | 15.4 | 31.8 | 16.4 | 34.6 | 12.0 | 28.5 | 8.1 | 25.1 | 12.5 | 29.1 |
| LTA (°C) | 10.1 | 22.7 | 13.3 | 27.0 | 15.4 | 29.9 | 15.1 | 29.7 | 11.9 | 25.6 | 7.3 | 19.0 | 12.3 | 25.8 |
| Precipitation (mm) | 4.0 | | 6.0 | | 9.0 | | 4.0 | | 7.0 | | 6.0 | | 5.0 | |
| LTA (mm) | 9.3 | | 6.7 | | 5.5 | | 4.0 | | 4.8 | | 6.7 | | 5.3 | |
| L2 – Veles | | | | | | | | | | | | | | |
| Temperature (°C) | 11.2 | 25.6 | 15.5 | 30.5 | 15.8 | 31.8 | 16.3 | 34.7 | 12.1 | 28.4 | 8.0 | 25.0 | 12.4 | 29.3 |
| LTA (°C) | 10.2 | 24.4 | 14.5 | 28.6 | 16.0 | 31.4 | 15.6 | 31.3 | 11.8 | 27.2 | 7.6 | 20.3 | 12.7 | 27.3 |
| Precipitation (mm) | 5.0 | | 11.0 | | 9.0 | | 4.0 | | 8.0 | | 5.0 | | 6.0 | |
| LTA (mm) | 9.1 | | 7.0 | | 5.1 | | 4.0 | | 4.8 | | 6.1 | | 5.1 | |
| L3 – Pelagonija | | | | | | | | | | | | | | |
| Temperature (°C) | 10.0 | 21.7 | 13.3 | 26.4 | 13.4 | 28.4 | 14.2 | 30.9 | 11.3 | 25.2 | 8.2 | 21.5 | 11.2 | 25.7 |
| LTA (°C) | 9.2 | 21.5 | 18.1 | 26.2 | 13.9 | 28.5 | 13.8 | 28.7 | 10.6 | 24.3 | 6.3 | 18.0 | 11.7 | 24.7 |
| Precipitation (mm) | 2.0 | | 4.0 | | 10.0 | | 1.0 | | 8.0 | | 5.0 | | 7.0 | |
| LTA (mm) | 12.2 | | 8.9 | | 6.6 | | 5.0 | | 6.9 | | 9.5 | | 7.1 | |

The temperatures recorded in all three localities are within the acceptable range for stevia growth. Ceunen and Geuns, (2013) concluded that temperature and light intensity are important factors for stevia growth. For instance, shading of the plants is known to decrease dry leaf biomass significantly. Midmore and Rank (2002) has been investigated the effect of temperature on S.

rebaudiana growth in various locations. A day/night temperature of 25/20 $^0$C appeared to be optimal for plant growth and steviol glycoside production. Yadav et al. (2011) emphasized that stevia requires a warm climate with minimal temperature fluctuations below its critical thresholds for consistent production. Research conducted in Egypt revealed that climatic conditions, such as temperature, and length and intensity of photoperiod, greatly affect stevia production and quality, as evident from the remarkable increase in yield during the summer compared with winter (Allam et al. 2001 in: Yadav et al., 2011).

Based on agrochemical data, the soils were characterized by low levels of organic matter (humus) and total nitrogen but had a good supply of potassium. Phosphorus content varied, being low in three fields (EF4, EF5, and EF7) while adequately supplied in the other four fields. Soil pH varied across the sites, ranging from strongly acidic (EF5 and EF6) to acidic (EF4 and EF7) and neutral (EF1, EF2, and EF3) (Table 2). Stevia prefers an acidic to neutral soils with a pH range of 6 – 7 (Shafiq u Rahman et al., 2019). According to Zeng et al. (2013), stevia can tolerate slightly wider pH ranges under managed conditions, with pH 5.5 – 8.0 supporting acceptable growth. However, soils with pH below 5.5 have been associated with stunted growth and reduced leaf biomass in stevia (Zaman et al., 2015). Therefore, with the exception of EF5 and EF6, the soil pH in the other experimental fields generally met the crop's requirements (Table 2). The results of biometric measurements and the achieved yields are presented in Table 3.

Table 2. The values of the agrochemical analyses of the soil

| EF | Parameters | | | | |
|---|---|---|---|---|---|
| | Humus (%) | Total N (%) | pH (in $H_2O$) (%) | $P_2O_5$ mg/100 g soil | $K_2O$ mg/100 g soil |
| EF1 | 2.10 | 0.118 | 6.9 | 18.43 | 15.26 |
| EF2 | 2.10 | 0.118 | 7.1 | 17.64 | 16.74 |
| EF3 | 3.11 | 0.126 | 7.2 | 38.43 | 16.94 |
| EF4 | 1.32 | 0.64 | 6.0 | 1.96 | 36.10 |
| EF5 | 1.25 | 0.083 | 5.3 | 1.18 | 25.63 |
| EF6 | 1.85 | 0.111 | 5.2 | 5.88 | 25.03 |
| EF7 | 1.96 | 0.109 | 6.2 | 31.10 | 30.10 |

Table 3. Results of biometric measurements and yields by experimental field

| Experimental field | EF1 | EF2 | EF3 | EF4 | EF5 | EF6 | EF7 |
|---|---|---|---|---|---|---|---|
| Irrigation | + | + | + | - | - | + | + |
| Root length (cm) | 14.8$^{ab}$ | 13.6$^{b}$ | 12.4$^{b}$ | 10.2$^{c}$ | 12.0$^{b}$ | 12.4$^{b}$ | 16.3$^{a}$ |
| Plant height (cm) | 61.4$^{b}$ | 55.1$^{b}$ | 69.0$^{b}$ | 49.4$^{b}$ | 63.2$^{b}$ | 66.2$^{b}$ | 100.6$^{a}$ |
| Dry biomass yield (kg ha$^{-1}$) | 3.580$^{ab}$ | 2.650$^{b}$ | 4.400$^{a}$ | 2.100$^{bc}$ | 1.570$^{c}$ | 1.890$^{c}$ | 3.900$^{ab}$ |
| Dry leaves yield (kg ha$^{-1}$) | 750$^{ab}$ | 930$^{ab}$ | 1.240$^{ab}$ | 630$^{c}$ | 530$^{c}$ | 640$^{bc}$ | 1.400$^{a}$ |

EF – Experimental Field; + irrigated, - not irrigated. Means followed by the same letter within a row are not significantly different according to Tukey's HSD test at $p<0.05$.

The longest root length, 16.3 cm, was observed at EF7, showing statistically significant differences compared to the other experimental fields (Table 3). Zeng et al. (2013) reported that stevia root length varies significantly depending on soil texture and irrigation practices. In sandy loam soils with drip irrigation, root lengths ranged from 14 to 18 cm, whereas clayey soils under furrow irrigation resulted in shorter roots (9 to 12 cm). These findings align with our data, suggesting that irrigation methods played a critical role in influencing root development. Khan et al. (2012) emphasized that planting time significantly impacts root length, with early spring planting resulting in longer roots (15 to 18 cm) compared to late summer planting (8 to 12 cm). In our investigation, the shorter root length observed at EF4 (10.2 cm) may be attributed to delayed planting or suboptimal environmental conditions. Furthermore, Shock (1982) found that water stress could reduce root length to as low as 9 to 11 cm, depending on its severity. This observation corresponds with EF4 shorter roots, potentially indicating insufficient irrigation or inadequate water management practices.

As a perennial crop, stevia typically reaches a height of 50 –70 cm under plantation conditions (Hossain et al., 2017). In our investigations, the tallest plants were observed at EF7 - 100.6 cm, where the soil type was mollic vertic gleysol and drip irrigation was employed showing statistically significant differences at the 0.05% level compared to the other experimental fields, where plant heights ranged from 49.4 cm (EF4) to 69.0 cm (EF3) (Table 3). Similarly, Zaman et al. (2015) reported that the tallest stevia plants (91.3 cm) were grown on non-calcareous soils, emphasizing the role of soil characteristics in plant height. Plant spacing, set at 60 × 25 cm in our research, also influences plant height. Tansi et al. (2017) found that the tallest plants (61.2 cm) were achieved with a spacing of 60 × 30 cm, compared to 40 × 60 cm and 60 × 60 cm, where plant heights were 55.7 cm and 50.8 cm, respectively. This highlights the importance of optimizing plant density to maximize growth. The time of planting is another critical agronomic factor affecting stevia growth. In Mediterranean climates, the optimal planting period is from March to May, adjusted to the specific climatic conditions of the locality (Angelini et al., 2018). In our experiments, planting dates were delayed. However, at EF7, where planting occurred earliest (May 22, 2019), combined with the use of drip irrigation, the tallest plants were produced. In contrast, other EF's, where planting was conducted on June 10 and June 20, exhibited shorter plants, likely due to suboptimal planting times and potentially reduced vegetative growth duration. Optimal planting times have been corroborated in other studies. Khan et al. (2012) demonstrated that in the agro-environmental conditions of Bangladesh, the tallest stevia plants were obtained when planting occurred between March 15 and April 15. Early planting allows plants to fully exploit favorable environmental conditions, resulting in enhanced vegetative growth. This aligns with our findings at EF7, where earlier planting led to superior plant height compared to later planting dates.

The highest dry biomass yield (4,400 kg ha$^{-1}$) was recorded at EF3, with statistically significant differences compared to EF2, EF4, EF5, and EF6, followed by EF7 and EF1 (3900 kg ha$^{-1}$ and 3580 kg ha$^{-1}$ respectively), which also exhibited significant differences from EF5 and EF6 (Table 3). The highest dry leaf yield (1,400 kg ha$^{-1}$) was observed at EF7, significantly outperforming EF6, EF5, and EF4. Additionally, dry leaf yields from EF3 (1,240 kg ha$^{-1}$), EF2 (930 kg ha$^{-1}$) and EF1 (750 kg ha$^{-1}$), were significantly higher than those of EF4 (630 kg ha$^{-1}$) and EF5 (530 kg ha$^{-1}$), which recorded the lowest yields. These results are consistent with several studies highlighting the importance of proper management practices in achieving high yields in stevia cultivation. Under conditions of limited rainfall, regular irrigation is crucial. Stevia requires irrigation at least once a week, depending on the farmer's equipment and the plant's developmental stage (Mengesha et al., 2014; Hossain et al., 2017). Kharwade and Shedge (2016) observed a dry biomass yield of 4,100 kg ha$^{-1}$ with drip irrigation and proper fertilization, further supporting the role of irrigation in maximizing stevia productivity. The crop is highly sensitive to water stress, as emphasized by Singh et al. (2010), who noted that inadequate watering significantly reduces leaf biomass and steviol glycoside content. Similarly, Midmore et al. (2012) demonstrated that maintaining soil saturation at 80% of total field capacity significantly enhances stevia leaf yield.

The results of our study align with those of Angelini et al. (2018), who reported dry leaf yields ranging from 1,200 to 1,500 kg ha$^{-1}$ under optimal irrigation and soil management in Mediterranean climatic conditions. Additionally, the time of planting plays a critical role in optimizing production. Khan et al. (2012) found that planting stevia on April 1 resulted in the highest dry leaf yield per plant (3.38 g$^{-1}$), compared to a significantly lower yield of 0.4 g$^{-1}$ when planting was delayed to July 1. Zaman et al. (2015) reported similar findings, observing a significant decrease in yields when planting in non-calcareous soils was delayed beyond May. In our study, early planting at EF3 and EF7 (May 22) contributed to higher biomass and leaf yields, while delayed planting on other fields limited their potential. These results emphasize the importance of combining early planting with efficient irrigation practices and proper soil management to maximize stevia productivity. The results of biometric measurements and the achieved yields by localities are presented in Table 4.

Table 4. Results of biometric measurements and achieved yields by localities

| Locality | L1 | L2 | L3 |
|---|---|---|---|
| Rooth length (cm) | 14.2$^{a}$ | 11.3$^{b}$ | 13.6$^{a}$ |
| Plant height (cm) | 58.3$^{b}$ | 59.2$^{b}$ | 76.7$^{a}$ |
| Yield of dry biomass (kg ha$^{-1}$) | 3,115$^{a}$ | 2,450$^{b}$ | 3,250$^{a}$ |
| Yield of dry leaves (kg ha$^{-1}$) | 840$^{b}$ | 875$^{b}$ | 935$^{a}$ |

The root length varied significantly among the localities. L1 and L3 exhibited statistically similar root lengths (14.2 cm and 13.6 cm, respectively), both of which were significantly higher than the root length recorded at L2 (11.3 cm). For plant height L3 recorded the tallest plants (76.7 cm), significantly surpassing L1 (58.3 cm) and L2 (59.2 cm), which did not differ statistically from each other. Dry biomass yield was statistical significantly higher at L3 (3,250 kg ha$^{-1}$) and L1 (3,115 kg ha$^{-1}$), compared with L2 (2,450 kg ha$^{-1}$). Dry leaf yield followed a similar trend, with L3 producing the highest yield (935 kg ha$^{-1}$), significantly greater than L1 (840 kg ha$^{-1}$) and L2 (875 kg ha$^{-1}$), which did not differ significantly.

**Conclusion**

The results of one-year investigation revealed significant variability in stevia yield across experimental fields and localities. The highest dry biomass yield (4,400 kg ha$^{-1}$) was recorded at EF3 (v. Dolno Vranovci), followed by EF7 (3900 kg ha$^{-1}$, v. Kruseani) and EF1 (3580 kg ha$^{-1}$, v. Zleovo respectively), showing significant differences with other fields ($p < 0.05$). In terms of dry leaf, the highest yield (1,400 kg ha$^{-1}$) was observed at EF7 (v. Kruseani), with statistical differences with EF6, EF5, and EF4. Among the localities, L3 (Pelagonija locality) exhibited the highest dry biomass yield (3,250 kg ha$^{-1}$) and dry leaf yield (935 kg ha$^{-1}$), outperforming L1 and L2.

These findings suggest that stevia can achieve substantial productivity under appropriate conditions, including optimal irrigation and soil management. However, as this was a single-year investigation, the results should be interpreted with caution. Long-term studies across multiple seasons and locations are necessary to assess the stability of yields and the economic viability of stevia as an alternative crop having in mind its perennial nature. Only with additional data can stevia's potential for sustainable cultivation and its suitability as a profitable crop be reliably recommended.

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## Stevija kao alternativna kultura za proizvodnju duvana u RS Makedoniji

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**Sažetak:** Reforma Zajedničke poljoprivredne politike (ZPP) za sektor duvana u Evropskoj uniji ima za cilj postepeno ukidanje subvencija za uzgoj duvana, što će značajno uticati na duvansku industriju u Republici Severnoj Makedoniji. Kao odgovor na ove promene, jedna od predloženih strategija adaptacije je uzgoj alternativnih kultura kako bi se održao nivo zaposlenosti i konkurentnost tržišta sa novim proizvodima. Stevija (Stevia rebaudiana Bertoni) je istraživana kao potencijalna alternativna kultura koju bi lokalni poljoprivrednici mogli usvojiti. Poljski eksperimenti su sprovedeni tokom 2019. godine na tri lokaliteta (L1 – L3) na sedam eksperimentalnih polja (EP1 – EP7). Rezultati su pokazali da je EP3 ostvario najveći prinos suve biomase od 4,400 kg/ha, kao i EP7 i EP1 (3900 kg ha$^{-1}$ i 3580 kg ha$^{-1}$, respektivno), sa značajnim razlikama u odnosu na ostala polja ($p < 0.05$). Najveći prinos suvih listova (1,400 kg ha$^{-1}$) utvrđen je na EP7, sa statističkim razlikama u odnosu na EP6, EP5 i EP4. Među lokalitetima, prinos suve biomase bio je statistički značajno veći na L3 (3,250 kg ha$^{-1}$) i L1 (3,115 kg ha$^{-1}$) u poređenju sa L2 (2,450 kg ha$^{-1}$). Prinos suvih listova pratio je sličan trend, gde je L3 proizveo najveći prinos (935 kg ha$^{-1}$), statistički značajno veći od L1 (840 kg ha$^{-1}$) i L2 (875 kg ha$^{-1}$). Iako su neki rezultati, kao što je prinos suve biomase obećavajući, ukupni rezultati dobijeni iz jednogodišnjeg istraživanja nisu dovoljni da bi se stevija u ovom trenutku preporučila kao održiva alternativa za duvanske regione zemlje.

**Ključne reči:** stevija, duvan, biomasa, list, prinos