Sugar Beet N Fertilization Management

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Sugar beet fertilization is a very complex agrotechnical measure for farmers. The main reason is that technological quality is equally important as sugar beet yield, but the increment of the root yield does not follow the root quality. Technological quality implies the concentration of sucrose in the root and the possibility of its extraction in the production of white table sugar. The great variability of agroecological factors that directly affect root yield and quality are possible good agrotechnics, primarily by minimizing fertilization. It should be considered that for sugar beet, the status of a single plant available nutrient in the soil is more important than the total amounts of nutrients in the soil. Soil analysis will show us the amount of free nutrients, the degree of soil acidity and the status of individual elements in the soil so that farmers can make a compensation plan. An estimate of the mineralizing ability of the soil, the N min, is very important in determining the amount of mineral nitrogen that the plant can absorb for high root yield and good technological quality.

sugar beet root yield | root quality | amount of nitrogen | vegetative growth | soil analyses

1. Introduction

Sugar beet (*Beta vulgaris* L. subsp. *vulgaris* var. *altissima* Döll.) and sugar cane (*Saccharum officinarum* L.) are the plants that are mostly grown in the world as raw materials for processing into sugar. Sugar cane cultivation for sugar production began in India in 2000 BC, while sugar beet is a relatively young plant and has been grown since the late 18th century. Sugar beet is biologically adapted to the temperate climate zone and is grown in the area from 30° to 60° north latitude and from 25° to 35° south latitude. Nowadays, sugar beet accounts for 20% of world sugar production, while the remaining 80% of sugar is from sugar cane [1]. The most suitable geographical conditions for beet growing are found where the soil is deep, friable, well drained and contains a certain proportion of lime. Sugar beet is usually cultivated as a rotation crop. Even though there is a need for agrotechnical measures, it would be interesting to try the adoption of conservation tillage, which provides considerable environmental benefits while improving soil fertility [2][3][4][5][6]. Sugar beet yields under reduced tillage are similar to those of beets grown in plowed soil when the N application increases [7].

The sugar content in sugar beet root is usually 13–20% [8][9]. The total biomass of the sugar beet plant is divided into root and leaf dry matter. According to Hoffmann and Kenter [10], sugar beet root yield has increased in the past decades by 1.5% per year, but the sugar content has increased at the expense of the plant canopy (or leaf dry matter). More than 98% of total root sugar is sucrose, fructose and glucose in very small amounts [11].

Sugar beet fertilization significantly impacts yield formation and sugar beet root quality. Nitrogen is probably the most studied nutrient for sugar beet because N is the most limiting nutrient directly related to sugar beet yield and quality. Many researchers reported that N fertilization greatly influences excessive N fertilization, resulting in more lush development of the leaves and crowns, root maturity is slowed down, and the sugar content in the root is lower. In addition, root quality may be reduced due to the increased content of melas-forming elements [12][13][14][15].

As one of the main building blocks, nitrogen has a special significance in plants because it is an integral part of proteins from which protoplasm, cells and plant tissues are formed [16][17]. In addition, N is the main yielding element in plant production. The range of N concentration in the leaf blade of sugar beet is from 2.2 to 3.5% and in the leaf stalk from 1.0 to 1.5% [18]. Sugar beet needs a large amount of N as a nutrient. The amount of N applied to the soil should be performed according to the chemical and microbiological properties of the soil. Furthermore, weather conditions should be considered to avoid unused amounts of N by plants that will, due to extreme instability of this nutrient, move into the deeper layers of the soil and bring about groundwater eutrophication [19][20]. Moreover, excessive amounts of N fertilizers negatively affect the content of melas-forming substances and primarily alpha-amino [21][22][23].

2. Nitrogen Fertilization Influence on Vegetative Growth

Malnou et al. [16] point out that it is desirable for sugar beet to reach 85% of the canopy, which covers the soil, as soon as possible to maximize the use of solar radiation, while Jaradat and Rinke [24] point out that newer genotypes can achieve up to 90% soil coverage. According to a two-year study in Germany (Göttingen), Hoffman and Kluge-Severin [25] state that under temperate climatic conditions, sugar beet as a spring crop absorbed only 24% of the incoming radiation in May and up to 83% in June.

The most intense leaf formation in European production area is from the beginning of June, when sugar beet leaves close the rows and last until mid-July [26]. After that, the plant forms leaves of smaller dimensions, and the leaves gradually die off by the end of the vegetation. The growth of sugar beet roots through vegetative stages has a linear trend, and the largest root growth occurs from mid-July to mid-August.

The leaf rosette of sugar beet reaches its maximum at the end of July and the beginning of August, while toward the end of the vegetation, it gradually decreases [6][27]. According to Kristek and Liović [28] and Jelić et al. [29], in agroecological conditions of southeast Europe, the largest daily increase in sugar beet leaves is from mid-June to mid-July.

Manderscheid et al. [30] state that a higher amount of N (126 and 156 kg ha^{-1} N) compared to a smaller one (63 and 78 kg ha^{-1} N) resulted in an increase in fresh leaf mass and an increase in individual leaves through the vegetation (11th, 16th, 26th and 31st leaf), while statistically significant differences were not found between different N fertilizations and the number of sugar beet leaves. Lüdecke [31] states that the development of sugar beet in conditions of reduced N supply at the beginning of vegetation is the same because beets have enough N available. The author emphasizes that sugar beet matures earlier in conditions of lower N supply, and phenotypically, the leaves are lighter in color, while the root lags behind in growth.

Newer genotypes have erect leaves that allow growth in a smaller vegetation area [32]. Vukadinović et al. [33] point out that hybrids with more upright leaves tolerate shading better, i.e., they can be grown in higher density. In addition to the above, in terms of photosynthesis, Müller-Linow et al. [34] emphasize the importance of the vertical distribution of leaves, i.e., the angle at which the leaves are located on the rosette of sugar beet.

In spring sowing, the dying of sugar beet leaves is more intense after July. Kenter et al. [35] point out that air temperature and radiation have a very significant impact ($p < 0.001$) on the growth of sugar beet leaves in the first 65 days after sowing (early June) by growing sugar beet at 27 locations in Germany.

In the phase of intensive leaf growth (mid-June to the end of July), the total leaf area of one plant is 2000 to 6000 cm^2 [12][27][36], while the optimal leaf area index (LAI) of sugar beets in this period is from 3 to 4 m^2 m^{-2} [12][37][38][39][40]. With the optimal leaf area index of sugar beet (3 to 4 m^2 m^{-2}), the outer leaves use almost all of the sun's energy. If the LAI is higher than optimal, the photosynthesis of the lower leaves is reduced, the crop is not drought resistant and has a greater need for nutrients. Manderscheid et al. [30] emphasize the importance of N fertilization and state that depending on N fertilization, a different number of dry sugar beet leaves was found in August and September. Furthermore, the authors point out that sugar beet had an average of 1.58 dry leaves in late June and early July, 5.58 in August and 9.55 dry leaves in the second half of September.

Sugar beet also absorbs the ammonium form of N (NH_4^+) well, which, due to physiological processes within the root cells, can negatively affect the sugar content in the root, breaking it down or preventing the synthesis of sucrose. Therefore, in the spring, before sowing and in the feeding of sugar beet, fertilizers that have an ammonium form of N, such as urea ($CO(NH_2)_2$, 46% N) and UAN (urea + NH_4NO_3 + water, 30% N), should be avoided. This is confirmed by Brentrup et al. [41] who stated that the yield of sugar beet when applying 115 kg ha^{-1} N in the form of calcium ammonium nitrate (CAN) was 47.7 t ha^{-1}, and the yield of sugar was 8.49 t ha^{-1}, while with the same amount of N from urea, root yield was lower at 44.2 t ha^{-1} and sugar yield at 7.31 t ha^{-1}.

3. Sugar Beet N Fertilization Management

Draycott [42] points out that in many European countries, it is the practice to add all the N needed to achieve maximum sugar beet yields in the spring in the amount of 30 to 40 kg ha^{-1}, which should be added before sowing, while the rest is added in top dressing in phase 2–4 leaves.

The greatest need of sugar beet for nutrients is in the phase of intensive leaf growth (from early June to mid-July). Sugar yield is linearly related to dry matter yield and total N uptake. However, Last et al. [43] point out that increasing N above 200 kg ha^{-1} of N does not increase sugar yield, and the maximum sugar yield over six years of research was obtained by applying 125 kg ha^{-1} N or less.

Starke and Hoffmann [44] state that the differences in the share of root dry matter depending on N fertilization were not very pronounced, and according to the results of their research, the average share of root dry matter was 22.5%, with fertilization of 150 kg ha^{-1} N 23.6%, while at an even higher amount of N than 300 kg ha^{-1}, dry matter was reduced to the level of the control treatment (22.5%). According to another study, Starke and Hoffmann [45] point out the positive effect of N on the dry matter yield of sugar beet leaves. Namely, the authors conclude that with higher fertilization, with as much as 300 kg ha^{-1} N, the yield of leaf dry m

4. Nitrogen Use Efficiency (NUE) in Sugar Beet Production

Increasing nitrogen use efficiency can be achieved by using the right combination of nutrients, fertilizing at the right time and avoiding nutrient loss [46]. Nitrogen is a very mobile element and can be lost in several ways. Losses are often in the air volatile but also as leaching in the deeper layers of the soil by rainfall and groundwater. Both cases cause economic losses but also environmental problems. Nitrogen losses are affected by nitrogen form (nitrate, ammonium or urea), as well as soil properties (pH, texture, temperature, moisture, cation exchange ability, organic matter) and fertilizer management (time and dosage) [47][48].

Another important approach to sugar beet production is organic farming. Organic farming is one of the most important agricultural practices focused on food safety and biodiversity. This means producing food from a healthy environment of land, plants and animals. Organic fertilizers, genetically modified organisms, pesticides and other synthetic chemicals are not used in organic production. Organic agricultural production reduces human impact on the environment, improves soil quality in the long run and contributes to increasing biodiversity [49].

5. Influence of Soil Type and N Fertilization on Sugar Beet Yield and Quality

The sugar beet production should always note that the land and weather conditions determine the framework and implement agrotechnical measures for the production level. Sugar beet can use large quantities of N, and the optimal amount moves within narrow limits. With an increased supply of N for the same root yield, beets can adopt up to 70% more N from the required amounts, negatively impacting root quality. Due to these facts, N fertilization should be done only to replenish stocks in the ground. As N in the soil occurs in the organic and mineral form, determining the stock of plants' available N represents a problem, and because of the great variability in the soil, the problem is the time of soil sampling for analysis. Sugar beet depends on several factors, such as soil and weather, plant distribution in the field and number per unit area, a form of added N [50], as well as the fact that beets absorb uneven N throughout different growth phases in vegetation.

Today, people apply N based on the established stocks of N min in the soil before tillage and pre-sowing fertilization when fertilizing sugar beet. Early determination of N fertilization assumes the impossibility of accurately predicting N's mobilization (subsequent delivery) from organic matter soil, since the period elapsed between the optimal fertilization period and harvest period is extremely long. This is important because the yield and quality of beets also depend on the availability of N during the second half of the vegetation. In practice, N fertilization is very often the cause of bad production results. In this research, the aim was to determine the effect of early N addition in the form of urea and increased fertilization through yield fertilization and root quality. Precipitation and air temperature over the season significantly affect N fertilization and achieved production results. Kristek et al. [51] point out that soil type and especially N application time significantly affect yield elements and sugar beet root quality. Sugar beet prefers the nitrate form of N(NO_3^-), so top dressing in production is usually performed in the phase 3–4 of leaves with mineral fertilizer calcium ammonium nitrate (CAN), which contains 27% N.

6. Cercospora Leaf Spot and N Fertilizers

Fertilization generally and high amounts of N fertilizers favor the development of the disease of the crops, affecting the plant's disease risk either directly or indirectly through changes in the community structure or nitrogen [52][53][54][55].

The CLS is the most detrimental disease of sugar beet in temperate climates worldwide [56][57], which affects the above-ground parts of plants, including seeds. Symptoms are observed on older leaves in the form of gray spots inside and with a brown edge. The infected leaves become necrotic and eventually fall to the ground but remain attached to the root head. According to Kristek et al. [32], the damage caused by *Cercospora beticola* Sacc. reduces the photosynthesizing surface of the leaves. The yield of sugar beet root may be reduced up to 60% and sucrose content by 3–7%. These decrements in sugar beet root quality ultimately lead to a 42% reduction in technological sugar yield [58][59][60] up to 50% [61].

Ontario [62] suggests that the N application rate could reduce the need for fungicide applications to control Alternaria leaf blight and Cercospora leaf spot diseases in the field-grown carrots because lower N treatments resulted in fewer live leaves per plant at harvest. Makheti Mutebi and Atieno Ondede [63] found that for mulberry (*Morus alba* L.), plant fertilization amount of 200 kg ha^{-1} N is an effective approach for suppressing Cercospora leaf spot of mulberry and can be recommended to the farmers.

7. Leaf N Content

The N concentration in the sugar beet plant depends on the amount of N in the soil. Draycott and Chirstenson [13] state that in the phase of fully expanded leaves, the N concentration in a sugar beet plant can range from 1.0 to 3.5%, in the root from 0.5 to 0.8%, in the leaf blade from 2.2 to 3.5% and in the stalk from 1.0 to 1.5%, but that in soils where beets are grown for a long time, there is N in the soil either in excessive or insufficient amounts and, therefore, N concentrations may be outside the specified limits.

Draycott and Chirstenson [13] state that the dry matter of sugar beet leaves at harvest contains about 0.3% phosphorus, 3% potassium, 2.5% sodium and 0.4% magnesium, while the dry matter of the root contains about 0.1 phosphorus, 0.8% potassium and 0.1% sodium. Furthermore, according to the experience in France and Great Britain, the authors state that at the time of the largest leaf area (July and August), the above-ground mass of sugar beet has the highest amount of phosphorus, from 20 to 25 kg ha^{-1} P_2O_5, while in the root, the amount of phosphorus increases during vegetation and at the time of extraction can be up to 40 kg ha^{-1} P_2O_5.

Leaf blades and petioles of healthy sugar beet plants contain a large amount of N in the nitrate form. The lowest concentration of any nutrient can change a little with sugar beet variety, climate or soil conditions, moisture stress, disease, etc. Bilir and Saltalı [64] state that different N fertilization can greatly influence nitrate concentration in the sugar beet leaves, which needs to be analyzed if the leaves are used as animal fed.

8. Sugar Beet Root Quality

Sugar beet fertilization is specific in relation to other field crops. As crop which have high yield, technological quality is also expected to be high. Proper fertilization management includes several essential questions, such as which fertilizer to apply, what amount of nutrients, in what ratio and when to apply them. With increasing rates of N, there is an increased content of α-amino N and another non-sugar matter at the root, which is unfavorable, reflecting sugar crystallization during processing.

Last et al. [50], during a six-year field study (1973–78), examined the impact of ammonium nitrate fertilization (0, 41, 82, 124, 166 and 207 kg N ha^{-1}) and irrigation on the yield and quality of sugar beet. The authors stated that in the arable soil layer, the optimal concentration of N min was about 40 mg kg^{-1} N soil during May. Later in the growing season, N greatly increased dry matter, and root yield was also reflected in sugar yield. Sugar beet root yield linearly increase in relation to accumulation of dry matter. However, from the data of several experiments, increasing in N resulted in higher root yield in most cases, but on the contrary, higher N rate even decreased sucrose content in the root.

References

1. Bruhns, J.; Baron, O.; Maier, K. Sugar Economy Europe 2004; No. Ed. 50; Verlag Dr. Albert Bartens KG: Berlin, Germany, 2003.
2. Jug, D.; Jug, I.; Brozović, B.; Vukadinović, V.; Stipešević, B.; Đurđević, B. The role of conservation agriculture in mitigation and adaptation to climate change. Poljoprivreda 2018, 24, 35–44.
3. Kristek, S.; Brkić, S.; Jović, J.; Stanković, A.; Ćupurdija, B.; Brica, M.; Karalić, K. The application of nitrogen-fixing bacteria in order to reduce the mineral nitrogen fertilizers in sugar beet. Poljoprivreda 2020, 26, 65–71.
4. Stošić, M.; Brozović, B.; Vinković, T.; Ravnjak, B.; Kluz, M.; Zebec, V. Soil resistance and bulk density under different tillage system. Poljoprivreda 2020, 26, 17–24.
5. Rašovský, M.; Pačuta, V.; Černý, I.; Ernst, D.; Michalska-Klimczak, B.; Wyszyňski, Z. Monitoring of Influence of Biopreparates, Weather Conditions and Variety on Production Parameters of

Sugar Beet. Listy Cukrov. A Řepařské 2021, 137, 154.

6. Varga, I.; Lončarić, Z.; Pospišil, M.; Rastija, M.; Antunović, M. Dynamics of sugar beet root, crown and leaves mass with regard to plant densities and spring nitrogen fertilization. Poljoprivreda 2020, 26, 32–39.
7. Jurišić, M.; Radočaj, D.; Plaščak, I.; Rapčan, I. A Comparison of Precise Fertilization Prescription Rates to a Conventional Approach Based on the Open Source GIS Software. Poljoprivreda 2021, 27, 52–59.
8. Antunović, M.; Varga, I.; Stipešević, B.; Ranogajec, L. Analýza chorvatského cukrovarnického sektoru a produkce cukrové řepy. Listy Cukrov. A Řepařské 2021, 137, 383–386.
9. Ernst, D.; Černý, I.; Pačuta, V.; Zapletalová, A.; Rašovský, M.; Skopal, J.; Vician, T.; Šulík, R.; Gažo, J. Yield and Sugar Content of Sugar Beet Depending on Different Soil Tillage Technologies. Listy Cukrov. A Řepařské 2021, 137, 319–324.
10. Turesson, H.; Andersson, M.; Marttila, S.; Thulin, I.; Hofvander, P. Starch biosynthetic genes and enzymes are expressed and active in the absence of starch accumulation in sugar beet tap-root. BMC Plant Biol. 2014, 14, 104.
11. Hoffmann, C.M.; Kenter, C. Yield potential of Sugar beet—Have we hit the ceiling? Front. Plant Sci. 2018, 9, 289.
12. Franzen, D.W. Delineating nitrogen management zones in a sugarbeet rotation using remote sensing—A review. J. Sugar Beet Res. 2004, 41, 47–60.
13. Draycott, A.P.; Christenson, D.R. Nutrients for Sugar Beet Production: Soil-Plant Relationships; CABI: Wallingford, UK, 2003.
14. Jaćimović, G.; Marinković, B.; Crnobarac, J.; Bogdanović, D.; Kovačev, L.; Danojević, D. Influence of fertilization and nitrate-nitrogen position in soil profile on the sugar beet root yield and quality. J. Agric. Sci. 2008, 53, 83–90.
15. Kristek, S.; Kristek, A.; Evačić, M. Influence of nitrogen fertilization on sugar beet root yield and quality. Cereal Res. Commun. 2008, 36, 371–374.
16. Malnou, C.S.; Jaggard, K.W.; Sparkes, D.L. A canopy approach to nitrogen fertilizer recommendations for the sugar beet crop. Eur. J. Agron. 2006, 25, 254–263.
17. Pospišil, M. Ratarstvo II. Dio—Industrijsko Bilje; Zrinski: Čakovec, Croatia, 2013.
18. Lundegårdh, H. Plant Physiology; Oliver and Boyd: Edinburgh, UK; London, UK; T. & A. Constable Ltd.: Edinburgh, UK, 1966.
19. Hoffmann, C.M.; Kluge-Severin, S. Growth analysis of autumn and spring sown sugar beet. Eur. J. Agron. 2011, 34, 1–9.

20. Pevalek-Kozlina, B. (Ed.) Fiziologija Bilja; Profil International: Zagreb, Croatia, 2003.
21. Klotz, K.L.; Finger, F.L. Impact of temperature, length of storage and postharvest disease on sucrose catabolism in sugarbeet. Postharvest Biol. Technol. 2004, 34, 1–9.
22. Tarkalson, D.D.; Bjorneberg, D.L.; Camp, S.; Dean, G.; Elison, D.; Foote, P. Improving nitrogen management in Pacific Northwest sugarbeet production. J. Sugar Beet Res. 2016, 53, 14–36.
23. Carter, J.N.; Traveller, D.J. Effect of time and amount of nitrogen uptake on sugarbeet growth and yield. Agron. J. 1981, 73, 665–671.
24. Jaradat, A.A.; Rinke, J. Modeling sugar content of farmer-managed sugar beets (Beta vulgaris L.). Commun. Biometry Crop Sci. 2012, 7, 23–34.
25. Hoffmann, C.M.; Kluge-Severin, S. Light absorption and radiation use efficiency of autumn and spring sown sugar beets. Field Crops Res. 2010, 119, 238–244.
26. Kristek, A.; Halter, J. Djelovanje vegetacijskog prostora na porast lišća šećerne repe i prinos korijena. Agron. Glas. 1988, 2–3, 79–94.
27. Stanaćev, S. Šećerna Repa; Nolit: Beograd, Serbia, 1979.
28. Kristek, A.; Liović, I. Ritam rasta šećerne repe u uvjetima 1987. godine. Poljopr. Aktualnosti 1988, 30, 173–185.
29. Jelić, S.; Antunović, M.; Bukvić, G.; Varga, I.; Iljkić, D. Impact of plant density on growth, yield and quality of sugar beet. Listy Cukrov. A Řepařské 2019, 135, 107.
30. Manderscheid, R.; Pacholski, A.; Weigel, H.J. Effect of free air carbon dioxide enrichment combined with two nitrogen levels on growth, yield and yield quality of sugar beet: Evidence for a sink limitation of beet growth under elevated CO2. Eur. J. Agron. 2010, 32, 228–239.
31. Lüdecke, H. Šećerna Repa; Poljoprivredni Nakladni Zavod Zagreb: Zagreb, Croatia, 1956.
32. Kristek, A.; Kristek, S.; Varga, I.; Drmić, Z. Rezultati u proizvodnji šećerne repe u zavisnosti od izbora hibrida i broja tretiranja fungicida. Poljoprivreda 2015, 21, 15–22.
33. Vukadinović, V.; Jug, I.; Đurđević, B. Ekofiziologija Bilja. In Poljoprivredni Fakultet u Osijeku; Sveučilište Josipa Jurja Strossmayera u Osijeku Zebra: Vinkovci, Croatia, 2014.
34. Müller-Linow, M.; Pinto-Espinosa, F.; Scharr, H.; Rascher, U. The leaf angle distribution of natural plant populations: Assessing the canopy with a novel software tool. Plant Methods 2015, 11, 11.
35. Kenter, C.; Hoffman, C.M. Seasonal patterns of sucrose concentration in relation to other quality parameters of sugar beet (Beta vulgaris L.). J. Sci. Food Agric. 2006, 86, 62–70.
36. Drachovská, M.; Sandera, K. Fysiologie Cukrovky; Nakladatelství Československé Akademie věd: Prague, Czech Republic, 1959.

37. Märländer, B.; Hoffmann, C.M.; Koch, H.J.; Ladewig, E.; Merkes, R.; Petersen, J.; Stockfisch, N. Environmental Situation and Yield Performance of the Sugar Beet Crop in Germany: Heading for Sustainable Development. J. Agron. Crop Sci. 2003, 189, 201–226.
38. Tóth, M.; Pokrivčák, J.; Smutka, L.; Dvořák, M.; Pulkrábek, J. Economic aspects of sugar beet production and biodiversity: Effects of ban on neonicotinoids use. Listy Cukrov. Řepařské 2022, 138, 116–120.
39. Pospišil, A.; Pospišil, M. The Effect of Organic Fertilizers on the Spelt Yield and the Yield of its Components. Poljoprivreda 2021, 27, 37–43.
40. Tan, Z.X.; Lal, R.; Wiebe, K.D. Global soil nutrient depletion and yield reduction. J. Sustain. Agric. 2005, 26, 123–146.
41. Issukindarsyah, I.; Sulistyaningsih, E.; Indradewa, D.; Putra, E.T.S. The Effect of Ammonium Nitrate Ratio and Support Types on the NPK Uptake and Growth of Black Pepper (Piper nigrum L.) in Field Conditions. Poljoprivreda 2021, 27, 25–33.
42. Draycott, A.P. Sugar Beet; Wiley-Blackwell: Hoboken, NJ, USA, 2008.
43. Last, P.J.; Draycott, A.P.; Messem, A.B.; Webb, D.J. Effects of nitrogen fertilizer and irrigation on sugar beet at Broom's Barn 1973–8. J. Agric. Sci. 1983, 101, 185–205.
44. Starke, P.; Hoffmann, C.M. Yield Parameters of Beta Beets as a Basis to Estimate the Biogas Yield; Nutzung von Zuckerrüben für die Biogaserzeugung–Definition der Qualität sowie ertragsrelevante Parameter von Rübe, Blatt und Schossern; Institut für Zuckerrübenforschung: Gottingen, Germany, 2014; Volume 42.
45. Starke, P.; Hoffmann, C.M. Yield parameters of Beta beets as a basis to estimate the biogas yield. Sugar Ind. 2014, 139, 169–176.
46. Yadav, M.R.; Kumar, R.; Parihar, C.M.; Yadav, R.K.; Jat, S.L.; Ram, H.; Meena, R.K.; Singh, M.; Birbal; Verma, A.P.; et al. Strategies for improving nitrogen use efficiency: A review. Agric. Rev. 2017, 38, 29–40.
47. Melino, V.J.; Tester, M.A.; Okamoto, M. Strategies for engineering improved nitrogen use efficiency in crop plants via redistribution and recycling of organic nitrogen. Curr. Opin. Biotechnol. 2022, 73, 263–269.
48. Stevanato, P.; Chiodi, C.; Broccanello, C.; Concheri, G.; Biancardi, E.; Pavli, O.; Skaracis, G. Sustainability of the sugar beet crop. Sugar Tech 2019, 21, 703–716.
49. Atlason, R.S.; Lehtinen, T.; Davíðsdóttir, B.; Gísladóttir, G.; Brocza, F.; Unnþórsson, R.; Ragnarsdóttir, K.V. Energy return on investment of Austrian sugar beet: A small-scale comparison between organic and conventional production. Biomass Bioenergy 2015, 75, 267–271.

50. Last, P.J.; Draycott, A.P. Growth and yield of sugar beet on contrasting soils in relation to nitrogen supply: II. Growth, uptake and leaching of nitrogen. J. Agric. Sci. 1975, 85, 27–37.
51. Kristek, A.; Kristek, S.; Antunović, M.; Varga, I.; Katušić, J.; Besek, Z. Utjecaj tipa tla i gnojidbe dušikom na prinos i kvalitetu korijena šećerne repe. Poljoprivreda 2011, 17, 16–22.
52. Veresoglou, S.D.; Barto, E.K.; Menexes, G.; Rillig, M.C. Fertilization affects severity of disease caused by fungal plant pathogens. Plant Pathol. 2013, 62, 961–969.
53. Huber, D.M.; Haneklaus, S. Managing nutrition to control plant disease. Landbauforsch. Volkenrode 2007, 57, 313.
54. Long, D.H.; Lee, F.N.; TeBeest, D.O. Effect of nitrogen fertilization on disease progress of rice blast on susceptible and resistant cultivars. Plant Dis. 2000, 84, 403–409.
55. Liu, X.; Lyu, S.; Sun, D.; Bradshaw, C.J.; Zhou, S. Species decline under nitrogen fertilization increases community-level competence of fungal diseases. Proc. R. Soc. B Biol. Sci. 2017, 284, 20162621.
56. Skaracis, G.N.; Pavli, O.I.; Biancardi, E. Cercospora leaf spot disease of sugar beet. Sugar Tech 2010, 12, 220–228.
57. Schmittgen, S. Effects of Cercospora Leaf Spot Disease on Sugar Beet Geno-Types with Contrasting Disease Susceptibility. Ph.D. Thesis, Universitäts-und Landesbibliothek der Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany, 2015.
58. Vereijssen, J. Cercospora Leaf Spot in Sugar Beet. Epidemiology, Life Cycle Components and Disease Management. Ph.D. Thesis, Wageningen University, Wageningen, The Netherlands, 2004.
59. Vereijssen, J.; Schneider, J.H.; Termorshuizen, A.J. Root infection of sugar beet by Cercospora beticola in a climate chamber and in the field. Eur. J. Plant Pathol. 2005, 112, 201–210.
60. Vukčević, R. Nova primena aviometode na zaštiti šećerne repe od cerkospore. Agron. Glas. 1964, 14, 245–256.
61. Westerveld, S.M.; McKeown, A.W.; McDonald, M.R. Relationship between nitrogen fertilization and Cercospora leaf spot and Alternaria leaf blight of carrot. HortScience 2008, 43, 1522–1527.
62. Makheti Mutebi, C.; Atieno Ondede, D. Effect of nitrogen nutrition on the intensity of Cercospora leaf spot of Mulberry. Int. J. Hortic. Sci. Technol. 2021, 8, 335–342.
63. Bergmann, W. Nutritional Disorders of Plants: Visual and Analytical Diagnosis; Jena Gustav Fischer Verlag: New York, NY, USA, 1992.
64. Grzebisz, W.; Przygocka-Cyna, K.; Łukowiak, R.; Biber, M. An evaluation of macronutrient nutritional status of sugar beets in critical stages of growth in response to foliar application of

multi-micronutrient fertilizers. J. Elem. 2010, 15, 493–507.