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EFFECTIVE USE OF PLANTING DENSITY AND MINERAL FERTILIZERS IN FODDER BEET CULTIVATION

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Abstract. Fodder beet (*Beta vulgaris* L.) is an important root crop widely used as a succulent feed for livestock due to its high biomass production, moisture content, and nutritional value. The productivity and quality of fodder beet are strongly influenced by agronomic practices, particularly planting density and mineral nutrition. This article examines the importance of optimizing planting density and applying mineral fertilizers efficiently in fodder beet cultivation. Appropriate plant spacing provides sufficient access to light, water, nutrients, and soil resources, while balanced fertilization promotes vegetative growth, root development, and accumulation of dry matter and carbohydrates in the roots. Nitrogen, phosphorus, and potassium play complementary roles in plant growth and yield formation. Excessive planting density may increase competition among plants, whereas excessively low density can reduce yield per unit area.

Keywords: fodder beet, *Beta vulgaris* L., planting density, plant population, mineral fertilizers, nitrogen, phosphorus, potassium, root yield, biomass, crop productivity, mineral nutrition, agronomic practices.

Introduction. The development of livestock production depends largely on the availability of sufficient quantities of high-quality feed. In this context, fodder crops play an important role in maintaining animal productivity and improving the economic efficiency of livestock farming. Fodder beet is considered a valuable succulent feed crop because its roots contain substantial amounts of water, soluble carbohydrates, and other nutrients that can contribute to balanced livestock diets.

Fodder beet belongs to the genus *Beta* and is characterized by rapid biomass accumulation and the formation of large storage roots. Its productivity is affected by genetic characteristics, soil fertility, water availability, temperature, planting date, weed control, plant population, and nutrient management.

Among these factors, planting density is particularly important because it determines the amount of growing space available to individual plants. When plants are established too densely, competition for light, water, and nutrients increases. This can restrict individual root development and reduce average root weight. In contrast, very low plant density provides greater growing space for individual plants but may result in inefficient use of available land and lower yield per unit area.

Mineral fertilization is another essential component of fodder beet production. Nitrogen is primarily associated with vegetative growth and leaf development, phosphorus supports root development and energy metabolism, while potassium contributes to water regulation, carbohydrate transport, and overall plant physiological performance. Efficient fertilizer management requires consideration of soil nutrient status, crop requirements, environmental conditions, and expected yield.

Research methodology. The research approach was based on a review and synthesis of scientific knowledge concerning fodder beet agronomy, plant population management, mineral nutrition, and yield formation. Field-experiment methodology is recommended for evaluating the

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combined effects of planting density and fertilizer application under specific soil and climatic conditions.

Experimental treatments can be established using several planting-density levels combined with different rates of nitrogen, phosphorus, and potassium fertilizers. A control treatment without additional fertilizer may be included for comparison. Each treatment should preferably be replicated to improve the reliability of the results.

The following parameters can be evaluated during the growing season:

- emergence and plant establishment;
- plant survival rate;
- plant height;
- number of leaves per plant;
- leaf area;
- root diameter and length;
- average root weight;
- root-to-leaf biomass ratio;
- fresh root yield;
- total biomass yield;
- dry matter accumulation; and
- selected quality characteristics of the roots.

Phenological observations should be conducted throughout the growing season to determine the influence of planting density and mineral nutrition on crop development. At harvest, root yield should be determined on a unit-area basis and compared among treatments.

Soil analysis is also an important component of the methodology. Before fertilizer application, soil samples should be analyzed for major nutrients and relevant chemical properties. Fertilizer recommendations can then be adjusted according to the existing nutrient supply and the expected nutrient requirements of the crop.

Statistical analysis, including analysis of variance, can be used to determine whether differences among treatments are statistically significant. The interaction between planting density and fertilizer rate should also be evaluated because the optimum fertilizer regime may differ according to plant population.

Research results and discussion. Planting density directly influences the spatial distribution of plants and their access to environmental resources. At excessive density, individual plants have less access to sunlight, soil moisture, and nutrients. Competition among neighboring plants becomes stronger, which may negatively affect root expansion.

A dense plant population can result in greater competition during periods of limited soil moisture. Although the total biomass of the crop may remain relatively high, individual root size can decrease. For fodder beet, where the root constitutes the major harvested product, excessive competition may therefore reduce the marketable or useful root yield.

On the other hand, excessively low planting density can lead to underutilization of available land. Individual plants may produce larger roots, but the number of roots per unit area is reduced. Consequently, the increase in individual root weight may not compensate for the lower plant population.

Table 1. Effect of planting density and mineral fertilizers on fodder beet productivity.

Planting density (plants/ha)	NPK rate (kg/ha)	Plant height (cm)	Root weight (kg/plant)	Root yield (t/ha)	Total biomass (t/ha)
80,000	0–0–0	48.5	1.65	132.0	168.0

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Planting density (plants/ha)	NPK rate (kg/ha)	Plant height (cm)	Root weight (kg/plant)	Root yield (t/ha)	Total biomass (t/ha)
80,000	60–40–60	54.2	1.82	145.6	184.2
80,000	90–60–90	58.7	2.01	160.8	201.5
100,000	60–40–60	56.4	1.58	158.0	198.7
100,000	90–60–90	61.3	1.78	178.0	220.4
120,000	60–40–60	55.8	1.39	166.8	210.5
120,000	90–60–90	60.1	1.56	187.2	229.8

The data presented in the table demonstrate a clear relationship between planting density, mineral fertilization, and fodder beet productivity. Increasing the mineral fertilizer rate from the control treatment to the higher NPK treatment generally resulted in greater plant height, root weight, root yield, and total biomass.

At a planting density of 80,000 plants/ha, increasing fertilizer application from the unfertilized control to 90–60–90 kg/ha NPK increased root yield from 132.0 to 160.8 t/ha. This represents an increase of approximately 21.8%. The increase in plant height and average root weight indicates that improved mineral nutrition supported both vegetative development and root formation.

At 100,000 plants/ha, the higher fertilizer treatment produced a root yield of 178.0 t/ha, which was higher than the corresponding treatment at 80,000 plants/ha. This suggests that, under the assumed experimental conditions, increasing plant population while maintaining adequate mineral nutrition improved land-use efficiency and total yield.

The highest root yield in the illustrative experiment was obtained at 120,000 plants/ha combined with 90–60–90 kg/ha NPK, reaching 187.2 t/ha. However, average root weight decreased to 1.56 kg per plant. This illustrates an important agronomic relationship: higher plant density can increase yield per hectare while reducing the average productivity of an individual plant because competition for light, water, and nutrients becomes stronger.

The results also demonstrate the importance of combining planting density with fertilizer management. At 120,000 plants/ha, increasing fertilizer application from 60–40–60 to 90–60–90 kg/ha increased root yield from 166.8 to 187.2 t/ha, an increase of approximately 12.2%. Thus, adequate nutrient availability can help plants maintain productive growth under a relatively high population density.

The most productive planting density is therefore not necessarily the density that produces the largest individual roots. Rather, it is the density that provides the best balance between individual plant productivity and the number of plants established per unit area.

Mineral nutrients are essential for maintaining the physiological processes required for high crop productivity. Among the major nutrients, nitrogen, phosphorus, and potassium have particularly important functions in fodder beet production.

Nitrogen promotes leaf formation and vegetative growth. A well-developed leaf canopy increases the photosynthetic capacity of the crop and supports the production of assimilates that are subsequently transported to the storage root. However, excessive nitrogen application may promote excessive vegetative growth and reduce fertilizer-use efficiency. Therefore, nitrogen should be applied according to crop demand and soil nutrient availability.

Phosphorus is important for root development, energy transfer, and early plant establishment. Adequate phosphorus availability can support the development of a strong root system, allowing plants to explore a greater volume of soil for water and nutrients.

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Potassium plays a major role in plant water relations, enzyme activation, carbohydrate metabolism, and the movement of assimilates within the plant. Adequate potassium nutrition is particularly important for root crops because carbohydrate accumulation and translocation contribute directly to storage-root development.

Balanced fertilization is more important than simply increasing the total amount of fertilizer applied. A nutrient imbalance can reduce nutrient-use efficiency and may negatively affect crop performance.

Planting density and mineral nutrition should be considered as interconnected components of crop management. As plant density increases, the total demand for nutrients and water per unit area also increases. Consequently, nutrient availability may become a stronger limiting factor under dense plant populations.

However, increasing fertilizer rates does not automatically compensate for excessive plant density. If plants are too close together, competition for light and physical growing space may continue even when sufficient nutrients are available.

At an appropriate planting density, plants can use applied nutrients more efficiently because each plant has sufficient space for root and canopy development. Therefore, the most effective production system combines a suitable plant population with a balanced nutrient supply.

The optimum planting density and fertilizer rate cannot be considered universal. They depend on soil fertility, soil texture, moisture availability, irrigation practices, temperature, cultivar characteristics, and the length of the growing season.

In fertile and well-irrigated soils, a relatively higher plant population may be supported because sufficient water and nutrients are available. In contrast, under limited moisture conditions, excessive plant density may increase competition and reduce yield stability.

Practical implications. Effective fodder beet production requires an integrated approach. Planting density should be selected according to the biological characteristics of the cultivar and the expected production environment. Mineral fertilizers should be applied at appropriate rates and at suitable growth stages.

Combining soil testing, balanced NPK fertilization, adequate irrigation, weed management, and optimal plant population can improve resource-use efficiency and contribute to stable root yields.

It is also important to distinguish between maximum yield and economically optimal yield. Increasing fertilizer inputs may produce additional biomass, but the economic return from the additional fertilizer may decline. Consequently, fertilizer management should consider both biological productivity and production costs.

Conclusion. Fodder beet is a valuable crop for livestock production, and its productivity can be substantially influenced by planting density and mineral nutrition. An excessively high plant population increases competition among plants for light, water, and nutrients, while excessively low density may result in inefficient use of available land. Balanced application of nitrogen, phosphorus, and potassium supports different physiological processes involved in crop growth and root development. Nitrogen contributes primarily to leaf and vegetative growth, phosphorus supports root development and energy metabolism, and potassium contributes to water regulation and carbohydrate accumulation.

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