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Sustainable Crop Management through Optimization of Plant Density and Potassium Fertility in Sugar Beet (*Beta vulgaris* L.)

A. Mahdavi Damghani
Assistant Professor of Agroecology, Environmental Sciences Research Institute, Shahid Beheshti University
M. Nassiri Mahallati
Associate Professor of Agronomy, College of Agriculture, Ferdowsi University, Mashhad
A. Koocheki
Professor of Agronomy, College of Agriculture, Ferdowsi University, Mashhad

Abstract
The influence of plant density and potassium fertilizer levels on the root yield and quality of sugar beet (*Beta vulgaris* L.) was examined in a field study in 1999. The experimental design was a split plot with four completely randomized replications. Plant density was the main plot factor with three levels (80,000, 100,000 and 120,000 plants/ha) and potassium fertilizer was the subplot, also with three levels (40, 80 and 120 kg/ha potassium in form of potassium sulphate). Infection of the soil by beet nematode (*Heterodera schachtii*) dramatically affected root and sucrose content whereby the grand mean of root sucrose was 11.3%. Plant density and potassium fertility both had a significant effect on root yield. The highest root yield was obtained in 80,000 plants/ha and yield decreased with increasing crop density. Root yield increased with an increase in potassium application. Plant density had no significant effect on the qualitative indices of sugar beet, but the highest sucrose content and net sugat yield was obtained at the lowest potassium level. Plant density and potassium fertility had no significant effect on root potassium, sodium, nitrogen and Na/K ratio. A significant plant density by potassium fertility interaction was observed for root yield, gross and net sugar content. However, it was not significant for sucrose percent, white sugar content and root potassium, sodium and Na/K ratio.

Keywords: Sugar Beet, Plant Density, Potassium.

مدیریت پایدار تولید چغندر قند با بهینه‌سازی تراکم گیاهی و کود پتاسیم

عبدالمجید مهدوی دامغانی
دکترای کشاورزی، استادیار پژوهشکده علوم محیطی، دانشگاه شهید بهشتی
مهدی نصیری محلاتی
دکترای کشاورزی، دانشیار دانشکده کشاورزی، دانشگاه فردوسی مشهد
علیرضا کوچکی
دکترای کشاورزی، استاد دانشکده کشاورزی، دانشگاه فردوسی مشهد

چکیده
به منظور ارزیابی اثرات تراکم گیاهی و کود پتاسیم بر خصوصیات کمی و کیفی چغندر قند، آزمایشی در سال ۱۳۷۸ در مزرعه تحقیقاتی دانشکده کشاورزی دانشگاه فردوسی مشهد انجام گرفت. در این آزمایش، سه سطح تراکم گیاهی (۸۰، ۱۰۰ و ۱۲۰ هزار بوته در هکتار) و سه سطح کود پتاسیم (۴۰، ۸۰ و ۱۲۰ کیلوگرم در هکتار کود پتاسیم به صورت سولفات پتاسیم) به صورت آزمایش کرت‌های خردشده در قالب طرح بلوک‌های کامل تصادفی با چهار تکرار مورد ارزیابی قرار گرفت. به دلیل آلودگی نسبتاً شدید خاک مزرعه آزمایشی به نماتد چغندر قند، عملکرد کمی و کیفی به شدت تحت تاثیر قرار گرفت، به‌طوری که میانگین کل عیار قند در این آزمایش تا ۱۱/۳ درصد کاهش یافت. نتایج آزمایش نشان داد که عملکرد ریشه تحت تاثیر تراکم گیاهی و کود پتاسیم قرار گرفت. بیشترین عملکرد ریشه (۵۰/۳ تن در هکتار) در تراکم ۸۰ هزار بوته در هکتار به دست آمد و با افزایش تراکم گیاهی، عملکرد به دلیل کوچک شدن غده‌ها کاهش یافت.. با افزایش پتاسیم، عملکرد ریشه افزایش یافت و بیشترین عملکرد ریشه در بالاترین سطح کود پتاسیم مشاهده شد که احتمالاً دلیل آن افزایش مقاومت به نماتد در اثر مصرف کود پتاسیم بود. در این مطالعه شاخص‌های کیفی چغندر قند تحت تاثیر تراکم کاشت قرار نگرفت، اما تاثیر پتاسیم بر میزان عیار و عملکرد خالص قند معنی‌دار بود. بیشترین عیار (۱۲/۳۲) و عملکرد خالص قند (۳/۹۸ تن در هکتار) در تیمار ۴۰ کیلوگرم کود پتاسیم مشاهده شد و با افزایش میزان کود پتاسیم از عیار و عملکرد خالص قند کاسته شد که این امر احتمالاً به دلیل افزایش ناخالصی‌های ریشه بود. اثر متقابل تراکم گیاهی و کود پتاسیم بر عملکرد ریشه معنی‌دار بود و بیشترین عملکرد در تراکم ۱۰۰ هزار بوته در هکتار و ۱۲۰ کیلوگرم پتاسیم در هکتار به دست آمد. اثر متقابل تراکم گیاهی و پتاسیم بر عیار قند و میزان ناخالصی‌های ریشه معنی‌دار نبود.

کلیدواژه‌ها: چغندر قند، تراکم گیاهی، کود پتاسیم.

Introduction

Sugar is a main human nutritional requirement and plays an important role in supplying human energy. Sugar beet is considered a crop with a high efficiency value of transforming solar radiation into dry matter, higher than durum wheat but lower than maize and sorghum (Rinaldi and Vonella, 2006). Most sugar is obtained from sugar cane and sugar beet and the latter provides about 36% of total global sucrose consumption (Poehlman, 1987). In Iran, annual sugar consumption is reported to be 1.5 million ton of which 40-50 percent is imported.

Plant density is an important factor in crop productivity. Since plant density directly affects the quantitative and qualitative characteristics of sugar beet (Eckhoff *et al.*, 1991; Lauer, 1995; Wang *et al.*, 1995), determining the optimum density at which both high root yield and sucrose content can be achieved is a necessity. Leaves are the source of sugar production in sugar beet. The Optimum leaf area, which is a determinant of root yield, is affected by plant density (Dragovic *et al.*, 1996). Variations in seed germination rate and soil moisture content as well as weeds, diseases and pests can all decrease the final plant density in the field and diminish the yield. Hence, managing crop density during the growing season is an important key to successful sugar beet production. Suzuko *et al.* (1977) reported that the recommended crop density was 60,000 before 1948. Once the role of white sugar (recoverable sugar) content in final sugar quality had been discovered, higher densities which result in producing smaller roots with fewer impurities were recommended. Herron *et al.* (1964) showed that the optimum sugar beet density is 85,000-100,000 plants/ha. Other researchers reported densities of 110,000-120,000 plants/ha to be the best crop densities. Fornstrom and Jackson (1983) proved a positive correlation between plant density and root yield. Ghaemi (1993) reported that the highest and lowest yields were obtained, respectively in the 80,000 and 120,000 plants/ha crop densities in Iran. The results of Zeiger (1983) demonstrated that plant density in the range of 40,000 to 100,000 plants/ha did not affect the yield. Marschner (1989) argued that, in general, too low or too high plant densities (less than 50,000 and more than 100,000 plants/ha, respectively) would decrease root yield in sugar beet.

Sugar concentration, both the gross and net sugar content of beet root, is also affected by plant density (Eckhoff *et al.*, 1991). Since sucrose production in beet is a function of root yield and the recoverable sugar content, crop density which is a determining factor for these variables would affect sucrose production (Carter, 1986). Furthermore, extracting high quality sugar requires that impurities (Na, P and non-protein N) remain in low concentrations, because each unit of these impurities causes 1.5 to 1.8 unit sucrose losses in molasses (Eckhoff *et al.*, 1991). Regulating plant density can minimize the level of impurities in beet root (Yanagisawa, 1989).

Potassium is an essential cation in crop production. Potassium is involved in carbohydrate metabolism (Malakuti and Riazi Hamedani, 1991), sugar formation and translocation from leaves to the storing root (Cook and Scott, 1993) and plant resistance to pests and diseases (Munson, 1985). It is a general belief that in arid and semi-arid regions, there is no need for potassium fertilizer application because of sufficient potassium reservoirs in the soil and no leaching. In sugar beet production in Iran, however, it seems that potassium fertilizing should be carried out for two reasons. First, the concentration of potassium in sugar beet leaves is ten times higher than in the roots (Mahn *et al.*, 2002). As the leaves are not returned to the soil in most farming systems in Iran but are used for livestock feeding, soils usually experience potassium deficiency in the long term. In addition, Armstrong *et al.* (1999) showed that each ton of sugar beet root removes 1.75 kg potassium (2.1 kg $K2O$) from the soil. Second, soil erosion which is a serious problem in our agroecosystems is a main factor in potassium loss in soils (Sparks and Martens, 1980).

Reports on the effect of potassium on beet root indicate that potassium increases yield and quality in sugar beet. Results from Saftner and Dae (1983) showed that potassium application increased root yield by 25%. Bringer (1987) demonstrated that, in 16 studies, using potassium oxide fertilizer resulted in higher sucrose content without any decrease in syrup purity. In another study, applying 255 kg/ha potassium fertilizer increased root yield by 2.5-4.5 ton/ha (Davis, 1955). Doubling the fertilizer application, however, had not any significant effect on yield.

It is thought that the number and distribution of plants per unit area, as well as appropriate fertilization are central challenges in the production process of all field crops (Pospišil *et al.*, 2000). The objective of this study was the evaluation of the effects of crop density and potassium fertility management as well as their interactions on root yield and quality of the sugar beet.

Materials and Methods

The study was conducted in 1999 at the research farm of the College of Agriculture, Ferdowsi University of Mashhad (latitude 15.36, longitude 28.59 and altitude 985m). The soil was a clay loam (Calciothrid and Fine loamy, mixed.mesic Xerollic). The result of soil test is shown in Table 1.

Since potassium fertility was one of variation sources in the experiment, a field which had not received any potassium during last ten years was selected. The autumn and spring plow was carried out and 120 kg/ha urea and 350 kg/ha ammonium phosphate was applied before planting. Seeds (Cultivar 7233) were planted on April 22nd. After thinning in early June, 100 kg/ha urea was added to the plots.

The experimental design was a split plot with four completely randomized replications. The main plot had three levels of crop density (80,000, 100,000 and 120,000 plants/ha) and the subplot had three levels of potassium fertilizer (40, 80 and 120 kg/ha K, in the form of potassium sulphate). The main and subplots were 8×11^{m} and 8×3.3^{m}, respectively. Weeds were controlled by hand weeding. Larva of *Agrotis segetum* was observed on late May and controlled using Carbaryl. The soil was infected by the sugar beet nematode (*Heterodera schachtii*) which reduced drastically the yield and sugar content of roots.

During the growth season, samples were taken at 20 day intervals in a 0.33 m^2 area in each plot to determine the leaf area index, shoot/root ratio and dry matter. Growing Degree Days (GDD) was used to estimate the growth and development of crop during the growing season applying following equation:

$$\text{Daily GDD} = ((T_{max} + T_{min})/2) - T_{base}$$

Where T_{max} is the daily maximum air temperature, T_{min} is the daily minimum air temperature, and T_{base} is the GDD base temperature for the crop.

Table 1. Soil test results of the experimental field in depth of 0-30^{cm}.

Na	K	Ca	Mg	PO4	NO3	Organic N
9	4.5	23.1	4.32	0.64	0.67	3.53

Unit: mg in 100 gr. Soil

Leaf area was measured using an LAmeter. Plants were harvested on October 27th and root yield was determined. 20 kg root from each plot was selected and the sucrose content, molasses sugar, root potassium, sodium, nitrogen and Na/K ratio, white sugar content (WSC), gross white sugar content (GWSC) and net white sugar content (NWSC) were determined using a Betalyzer. Data were analyzed by MSTAT-C and Excel packages.

Results and Discussion

As mentioned before, the field was infected with the beet nematode which causes serious yield and sugar losses. The mean sucrose content in the study was 11.3%.

1- Plant Density

The highest root yield was observed in the 80,000 plants/ha plots (50.3 ton/ha, Figure 1). The difference in root yield with the other two densities was not significant. Results of root yield in the present study are consistent with other reports from Iran. Ghaemi (1993) showed that the highest yield at four densities (60,000, 80,000, 100,000 and 120,000) was obtained at the 80,000 plants/ha density and yield was decreased by increasing crop density. Reducing root yield by increasing crop density can be attributed to smaller root size (Yonts and Smith, 1997). Although the number of plants increased at higher densities, it seems that this could not compensate for the reduction in the size of roots. Because there is a negative correlation between root size and sugar content, and increasing the number of plants per area which causes smaller roots, total sugar production increase up to densities of 100,000 plants/ha (Ulrich, 1959). Marschner (1989) and Minx (1984), however, reported that higher densities produced roots that were too small and have little recoverable sugar (Yonts and Smith, 1997). In addition, increasing density caused the overlapping of leaves which results in less radiation inception (Cook and Scott, 1993), and so increasing plant density will not result in increased yield. The growth analysis showed that the highest LAI was observed in 80,000 plants/ha (Figure 2) which also produced the highest root yield and this indicates the best radiation use at this density.

The qualitative indices of beet root were not affected by plant density. Sucrose content in 80,000, 100,000 and 120,000 plants/ha were, respectively, 12.21, 10.65 and 10.84%. Cook and Scott (1993) showed that the planting density had no significant effect on sucrose content and this is consistent with other reports (Lauer, 1995, Smith and Martin, 1977). Plant density also had not significant effect on the K, Na, N and Na/K ratio of roots. This may be due to the ability of sugar beet to take in a constant level of nutrients over a range of planting densities (Lauchli and Pfluger, 1978). Smith and Martin (1977) argued that nutrient accumulation in roots is a function of soil nitrogen content rather than crop density.

2- Potassium Fertilization

The highest root yield was obtained by the application of 120 kg potassium fertilizer (Figure 3). This can be attributed to the role of potassium in disease resistance (Shepherd *et al.*, 1959). It can be concluded that potassium increased resistance to nematodes and prevented further yield losses. Munson (1985) reported that application of potassium fertilizer in nematode infected soybeans resulted in increasing the yield by 400-940 kg/ha compared with soybeans received no potassium fertilizer.

Potassium had no significant effect on sucrose content but the highest white sugar content (8.37%) and net white sugar content (3.98 ton/ha) was observed in 40 kg/ha potassium (Figures 4 and 5). As the highest root yield was obtained by using 120 kg/ha potassium fertilizer and the highest white sugar content was observed in 40 kg/ha, it can be concluded that the role of potassium was more important in white sugar content than in root yield. So, the highest net white sugar content was observed with 40 kg/ha potassium fertilizer.

The effect of potassium on root nitrogen, potassium, sodium and the Na/K ratio was not significant. Because of the high level of sodium in the soil and intake by the roots, sugar beet had a weak response to potassium. Miltchewa (1977) showed that potassium had no effect on the chemical composition of sugar beet root.

3- Interaction of Plant Density and Potassium Fertilization

The interaction of plant density and potassium fertilization on root yield was significant. The highest yield was obtained in 100,000 plants/ha with 120 kg/ha potassium application (51.2 ton/ha), while the lowest one was observed in 100000 plants/ha with 40 kg/ha potassium fertilizer (43.3 ton/ha). The reason for the low yield in the latter may be due to increasing the crop density to 100,000 plants/ha which probably reduced the root size and the increased plant number per area could not compensate for it. In addition, low levels of potassium might result in the lowest resistance to nematode and high yield losses.

The highest net white sugar content was observed

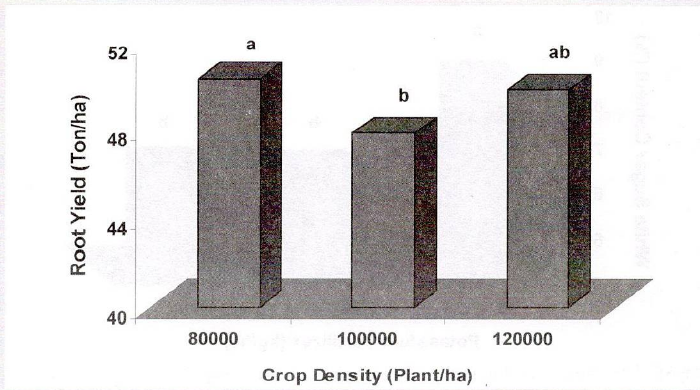

Figure1. Effect of crop density on sugar beet root yield.

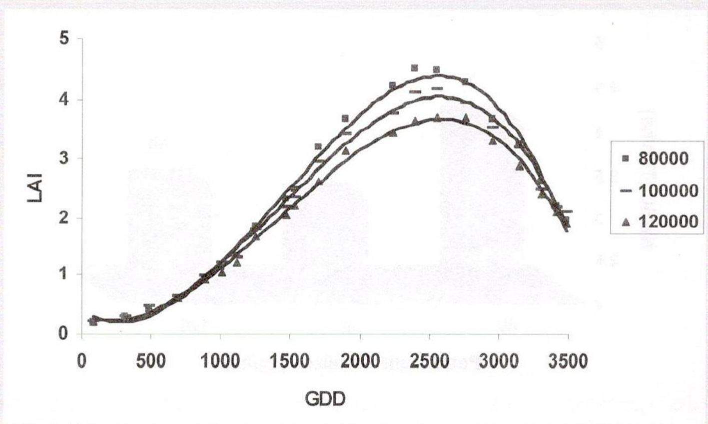

Figure 2. Leaf Area Index (LAI) as affected by plant density during growing season.

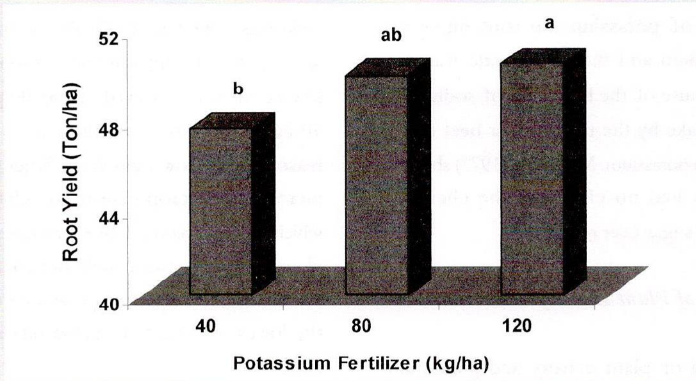

Figure 3. Effect of potassium fertility on sugar beet root yield.

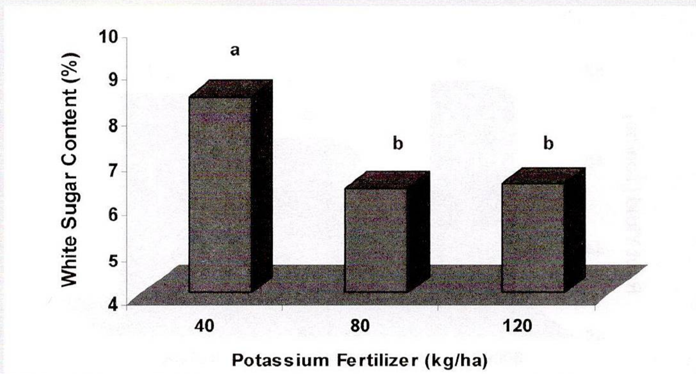

Figure 4. Effect of potassium fertilizer rates on White Sugar Content (WSC). WSC is the difference of total sucrose content and the molasses sugar.

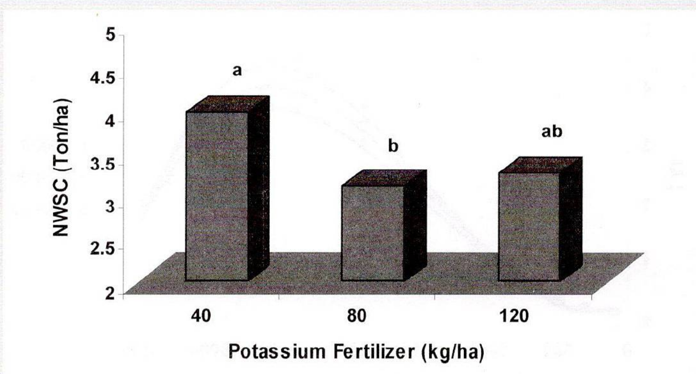

Figure 5. Effect of potassium fertilizer rates on Net White Sugar Content (NWSC). NWSC is root yield multiply by WSC.

in 80,000 plants/ha with 40 kg/ha potassium fertilizer (4.95 ton/ha). As the highest root yield was produced at the lowest density (Figure 1) *and* the highest net white sugar content (NWSC) was recorded at the lowest level of potassium application (Figure 5) and, as NWSC is the function of root yield and white sugar content, it is acceptable that the combination of these two measures produce the highest NWSC.

Conclusions

Sustainable agriculture requires maximization of the efficiency of utilization of plant nutrients and minimization of those losses that cause unwanted environmental consequences (Vos, 1996). On the other hand, some researchers demonstrate that growth and yield production of sugar beet depends primarily on site and climatic effects and the influence of agronomic practices is much lower (Kenter *et al.*, 2006). However, since applying potassium fertilizer as a nutrient management tool has a significant effect on the yield and quality of sugar beet and regulating crop density as an agronomic practice resulted in considerable changes in yield and sugar production in the present study, it may be concluded that determination of the optimum nutrient application rate should be considered in these cropping systems. Applying an optimum rate of potassium will help in the successful production of sugar beet in the studied area. Choosing the best plant density also results in optimal resource utilization and efficiency. The following studies should focus on the relation and interactions between potassium and other cations, especially sodium. Also, anatomical studies to evaluate the effect of agronomic practices including crop density management on root and root cell size is suggested.

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