Influence of fertigation on generative potential and pomological properties of different apple cultivars

Uticaj fertirigacije na parametre generativnog potencijala i pomološke osobine različitih sorti jabuke

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Abstract

The paper presents an investigation into the influence of fertigation on generative potential parameters and pomological properties of apple fruits. The study was done in apple orchard of Fruit Research Institute Čačak (Serbia) over two-year period (2009–2011) on three cultivars ('Morens Jonagored', 'Gloster' and 'Granny Smith'). Fertigation included fertilizers NPK 16:8:32, NPK 12:0:43 and PGPR – inoculum of diazotrophic bacterium *Klebsiella*. Results of the study suggest that fertigation with 12:0:43 NPK fertilizer had the most pronounced effect on all generative potential parameters, except abundance of flowering (initial fruit set – 3.71; final fruit set – 3.31). Similarly, this fertilizer had the same effect on all yield parameters in the apple cultivars studied, i.e. yield per tree – 9.60 kg/tree, yield per unit land area – 24.40 t/ha, cumulative yield – 19.20 kg/tree, cumulative yield 48.00 t/ha and yield efficiency – 0.77 kg/cm^2. Mineral fertilizer NPK 16:8:32 gave the highest abundance of flowering (4.51). In terms of pomological properties the applied fertilizers had a significant effect on fruit weight (239.05 g), soluble solids content (14.78%) and ripeness degree (4.75).

Keywords: apple, fertigation, yield

Rezime

U radu su prikazani rezultati proučavanja uticaja fertirigacije na parametre generativnog potencijala i pomološke osobine ploda jabuke. Proučavanje je sprovedeno u zasadu jabuke Instituta za voćarstvo Čačak (Srbija), tokom dvogodišnjeg perioda (2009-2011) na tri sorte ('Morens Jonagored', 'Gloster', 'Granny Smith'). Fertirigacijom su primenjena tri đubriva (NPK 16:8:32; NPK 12:0:43 i PGPR - inokulum diazotrofne bakterije *Klebsiella*). Rezultati istraživanja ukazuju da je najizraženiji uticaj fertirigacije na sve ispitivane osobine generativnog potencijala, izuzev intenziteta cvetanja, zabeležen primenom mineralnog đubriva formulacije NPK 12:0:43 (intenzitet zametanja - 3,71; intenzitet održanih plodova - 3,31). Navedeno đubrivo je isti uticaj ispoljilo i u pogledu svih parametara prinosa proučavanih sorti jabuke (prinos po stablu - 9,60 kg/stablu; prinos po jedinici površine - 24,40 t/ha; kumulativni prinos 19,20 kg/stablu; kumulativni prinos 48,00 t/ha; specifični prinos 0,77 kg/cm^2). Najviši intenzitet cvetanja zabeležen je primenom mineralnog đubriva NPK 16:8:32 (4,51). U pogledu pomoloških osobina, primenjena đubriva su značajno uticala na masu ploda jabuke (239,05 g), sadržaj rastvoljivih suvih materija (14,78 %) i stepen zrelosti (4,75). Najizraženiji efekat je zabeležen u varijanti sa NPK đubrivom formulacije 16:8:32.

Ključne reči: jabuka, fertirigacija, prinos

Detaljan rezime

Poslednjih godina, voćarska praksa podržava novije koncepte u đubrenju, koji se zasnivaju, prvenstveno, na primeni sporodelujućih i tečnih đubriva. Primena sporodelujućih đubriva bazira se na potpunijem zadovoljenju bioloških zahteva gajenih vrsta, što se pozitivno odražava, ne samo, na ekonomske, već i na ekološke aspekte proizvodnje. Najsavremeniji pristup u ishrani voćaka vezuje se za fertirigaciju, odnosno primenu vodno rastvorljivih đubriva preko irigacionih sistema. S tim u vezi u ovom radu je prikazan uticaj fertirigacije na parametre generativnog potencijala (intenzitet cvetanja, zametanja, održanih plodova, kumulativni i specifični prinos) različitih sorti jabuke (‘Morens Jonagored’, ‘Gloster’, ‘Granny Smith’).

Proučavanja su sprovedena u proizvodnom zasadu jabuke Instituta za voćarstvo Čačak (Srbija) tokom perioda 2009–2010. godine (zasad je podignut 2006. godine). Ogledom su bile obuhvaćene tri sorte jabuke (‘Morens Jonagored’, ‘Gloster’, ‘Granny Smith’), okalemljene na podlozi M 9. Sadnice jabuke su posađene na rastojanju 4 x 1 m po sistemu slučajnog blok rasporeda u tri ponavljanja sa po 30 stabala, na zemljištu tipa degradirana smonica. Istraživanja su sprovedena primenom 3 tretmana fertirigacije. Primenjena su mineralna NPK đubriva različite formulacije, tj. 16:8:32 i 12:0:43, i mikrobiloško đubrivo PGPR koje predstavlja čistu kulturu *Gram*-negativne diazotrofne azotofiksirajuće bakterije *Klebsiella planticola.*

Intenzitet cvetanja, zametanja, masa ploda i sadržaj rastvorljivih suvih materija bili su najizraženiji u varijanti sa NPK mineralnim đubrivom formulacije 16:8:32. Najveći uticaj na povećanje intenziteta održanih plodova, visinu ploda, širinu ploda i stepen zrelosti ispoljilo je NPK mineralno đubrivo formulacije 12:0:43.

Najveći uticaj na sve parametre generativnog potencijala (intenzitet cvetanja, intenzitet zametanja, intenzitet održanih plodova, visina ploda, širina ploda, masa ploda, sadržaj rastvorljivih suvih materija, stepen zrelosti) izuzev prinosa, ispoljila je sorta ‘Morens Jonagored’. U pogledu prinosa (kg/stablu; kumulativni prinosi; specifični prinos) superiornost je ispoljila sorta ‘Gloster’.

Introduction

Over the past years, fertigation has been a regular agro-technical measure, given its superiority over the other forms of fruit plant nutrition. According to Miller et al. (1981), fertigation is based on its pronounced capacity to supply plants with actually available nutrients whose availability is independent of chemical processes in soil. Fertigation eliminates fluctuation of humidity in soil, which results in enhanced plant development and higher yields **(**Baryosef, 1999; Tojnko and Čmelik, 2004; Kipp, 2005), as well as in maximum performance of fruit bearing capacity (Mohamedharoon, 1991; Udayasoorian and Prabakaran, 2010). High fertilizer uptake efficiency provided by this nutrition method (about 67 %) ensures minor environment pollution, which conforms to the trends of modern agricultural production (Hagin and Lovngart, 1996; Fukuda et al., 1999).

High cropping and quality of apple fruits are primarily governed by genotype, as well as by growing technology, soil management, and physical, chemical and biological properties of soil. Gaining and maintaining optimal growth and cropping balance requires appropriate combination of pomotechnical practices and plant nutrition methods. According to Stiles and Reid (1991), from physiological, economical and ecological aspects, the absence of deficiency symptoms in an orchard, or any toxicity manifestations related to excessive application of fetilizers, is not necessarily the indicative of optimal nutrition regime in an orchard. Therefore maintenance of optimal nutrition system should involve monitoring of different growth parameters in an orchard, particularly from growing period onset until fruit-bearing phase, which should also include regular control of soil fertility and leaf diagnostics (Miller, 2002).

In recent time, plant growth promoting rhizobacteria (PGPR) have been used as an alternative and/or complement to incorporation of mineral fertilizers to ensure essential plant nutrients supply. According to Brown (1995), PGPR-induced yield increase may be due to the microorganisms-produced compounds whose activity is largely analogous to that of plant hormones. Through the free N2 fixation occurring throughout their life activity, PGPR (Boddey and Dobereiner, 1995) leave readily available nutrients and enhance growth regulators content, e.g. indolacetic acid, giberillic acid, cytokinins and ethylene (Arshad and Frankenberger, 1993; Glick, 1995).

In order to gain high yields while at the same time observing sustainable production requirements we considered it beneficial to investigate the effect of fertigation-applied mineral fertilizers and biofertilizers on parameters of generative potential as well as on quality of apple fruits.

Material and methods

Plant material and growth conditions

The research was conducted in seasons 2009–2010 in a commercial apple planting of Fruit Research Institute, Čačak, Serbia (43^{o} 53' N latitude, 20^{o} 20' E longitude, 225 m altitude). The orchard was established in spring 2006 on a south-east exposed terrain. The trial included apple cultivars ‘Morens Jonagored’, ‘Gloster’ and ‘Granny Smith’ grafted on M 9 rootstock. The trial was set up at a randomized block design (4 x 1 m planting distance), in three replications with 30 trees each. The soil is degraded clay.

The experimental soil was slighty acid reaction (pH in 1nKCl = 6.45), moderate supplied with organic matter (4.37% humus) and well supplied with plant available P and K (AL-method: mg 100 g^{-1} of soil = 21.0 P_2O_5 and 25.7 K_2O). The inter-raw space was mulched during growing period, whereas intra-raw space was treated with herbicides (Bingo-0.4%).

Treatments

The investigations included three fertigation treatments (I – NPK 16:8:32, II – NPK 12:0:43, III – PGPR, and the control (IV – irrigation). PGPR is a pure culture of Gram-negative diazotrophic nitrogen-fixing bacteria *Klebsiella planticola* (Emtsev, 2000) obtained from the microorganisms collection of Microbiology Laboratory, Faculty of Agronomy, Čačak. Bacteria titer in the inoculum ranged from 20–40 x $10^6/cm^3$.

Fertilizers were applied via a trickle irrigation system at a 0.3% concentration on 30 mm water (30 l/m^2) by using Venturi tube. Trees were treated three times over growing period, i.e. June 17, July 9, August 14 (2009) and July 1, July 22 and August 12 (2010). Irrigation terms were based on precipitation and soil humidity data by using Watermark tensiometer.

Generative potential parameters and pomological properties of fruits

Generative potential of apple fruits was studied during growing period onset and after June drop. It included the assessment of abundance of flowering, initial fruit set, final fruit set (0–5) and yield (physiological ripeness phase). Yield measurements included determining yield per tree (kg/tree), yield per unit land area (t/ha), cumulative yield per tree (kg/tree), cumulative yield per hectare (t/ha) and yield efficiency – yield/trunk cross-sectional area (kg/cm^2).

Trunk diameter was measured 10 cm after grafted union and trunk cross-sectional area was calculated.

Pomological properties of fruits (fruit weight, width and length) involved the examination of 25 fruits in three replications. Fruit weight (g) was checked by 'Metler' technical scale (± 0.01 accuracy). Fruit size, expressed in mm, was measured by 'Inox' vernier scale (± 0.05 mm accuracy). Soluble solids content (%) was determined in the phase of physiological ripeness of fruits by 'Carl Zeiss' binocular refractometer, while ripeness degree involved iodine-starch method.

Statistical analysis

Experimental data were subjected to analysis of variance (ANOVA) using the MSTAT-C statistical computer package (Michigan State University, East Lansing, MI, USA). Dunett's test at $p \leq 0.05$ and $p \leq 0.01$ was used for mean separation of experimental data related to application of fertilizers. The Duncan's Multiple Range Test ($p \leq 0.05$) was used for mean separation of data referring to the application of cultivars as well as year.

Results and discussion

Results of the investigation into the generative potential in the studied fertigation-treated apple cultivars are shown in Table 1.

Table 1. Generative potential parameters in apple cultivars studied (2009–2010)

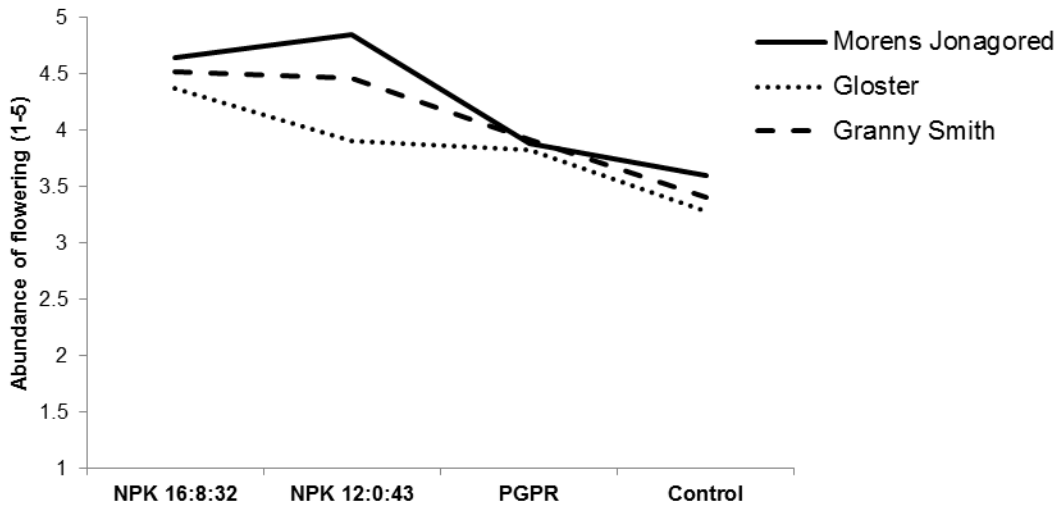
Factor		Abundance of flowering (1–5)	Initial fruit set (1–5)	Final fruit set (1–5)	Yield	
					kg/tree	t/ha
Fertilizer (A)	NPK 16:8:32	4.51±0.11**	3.58±0.10**	3.02±0.17**	9.42±1.26**	22.99±3.13**
	NPK 12:0:43	4.41±0.14**	3.71±0.15**	3.31±0.13**	9.60±1.43**	24.00±3.57**
	PGPR	3.88±0.18ns	3.23±0.21**	2.84±0.19**	8.05±1.18**	20.13± 2.95**
	Control[1]	3.43±0.26	2.53±0.23	2.19±0.18	6.35±0.96	15.88±2.40
Cultivar (B)	Morens	4.25±0.15a	3.44±0.15a	2.94±0.17a	10.94±0.43b	26.93±1.11b
	Jonagored					
	Gloster	3.85±0.17c	3.03±0.19c	2.78±0.19b	12.03±0.84a	30.06±2.10a
	Granny Smith	4.10±0.20b	3.31±0.18b	2.80±0.14b	2.10±0.21c	5.25±0.53c
Year (C)	2009	3.45±0.14b	2.80±0.16b	2.58±0.15b	6.65±0.62b	16.63±1.56b
	2010	4.66±0.06a	3.72±0.08a	3.10±0.10a	10.06±0.99a	24.87±2.48a
ANOVA						
A		**	**	**	**	**
B		**	**	**	**	**
C		**	**	**	**	**
A × B		**	**	**	**	**
A × C		**	**	**	**	**
B × C		**	**	**	**	**
A × B × C		**	**	**	**	**

- A, B and C stand for fertilizers, apple cultivars and years of study, respectively.
- ** in columns stand for the significant differences between P<0.05 and P<0.01 means, based on Dunnet's test and results of ANOVA (F test); ns – not significant.
- Means in rows referring to cultivars (B) and years (C), denoted with the same small letter, mark no justifiable differences for P<0.05 based on Duncan Multiple Range test.

Analysis of variance of the studied generative potential parameters suggests a marked effect of fertilizer applied, cultivar, year of study as well as of all interactive factors on the parameters above.

In comparison with the control, the highest abundance of flowering in our study (Fig. 1) was observed in apple trees treated with 16:8:32 NPK (4.51±0.11), the lowest being in the one involving PGPR (3.88±0.18). According to Mišić (2002), intensity of flower buds differentiation depends on type, content, and nutrients (N/K) ratio.

Fig. 1. Abundance of flowering (A×B)



The identical trend was observed in terms of the other generative potential parameters, i.e. initial fruit set, final fruit set, yield per tree and unit land area (Fig. 2, 3, 4, 5).

Fig. 2. Initial fruit set (A × B)

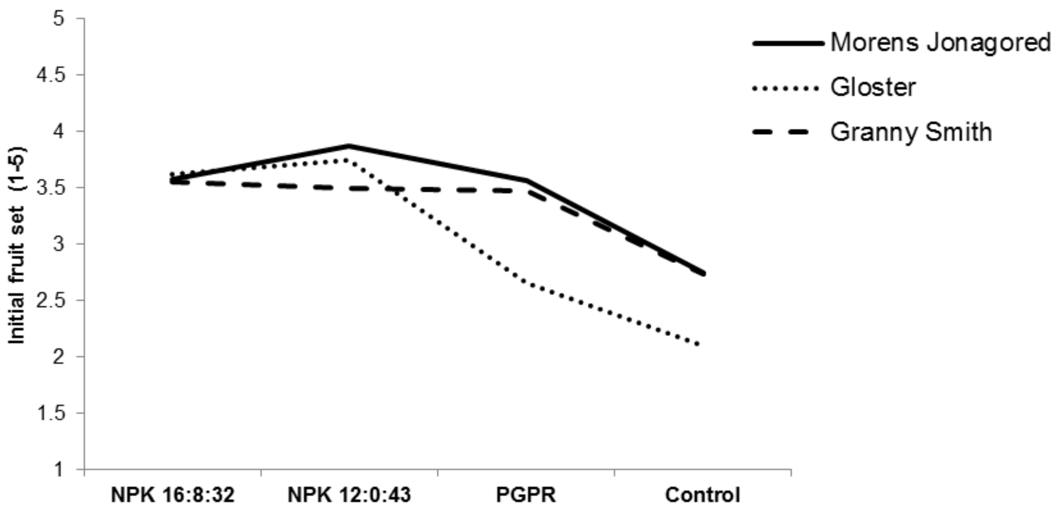


Fig. 3. Final fruit set (A × B)

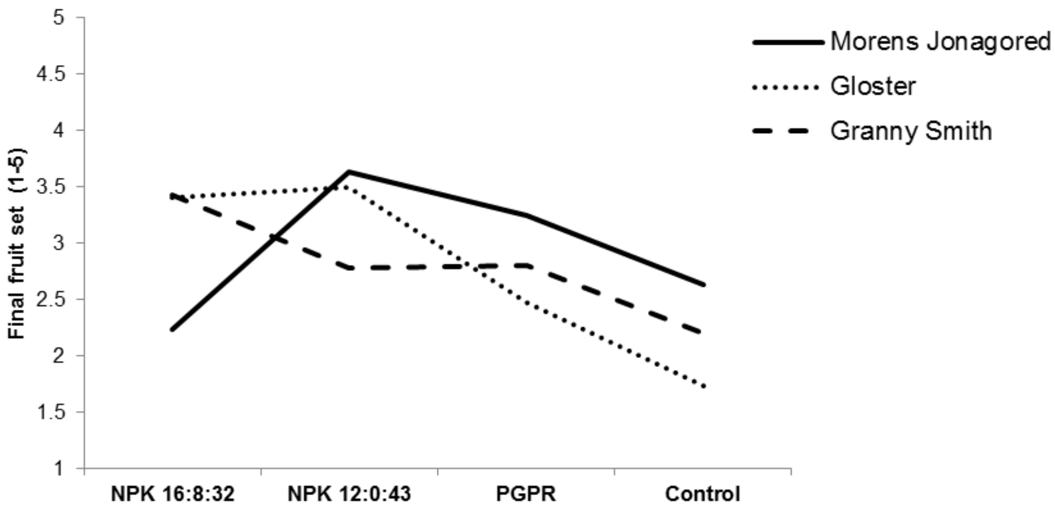


Fig. 4. Yield per tree (A × B)

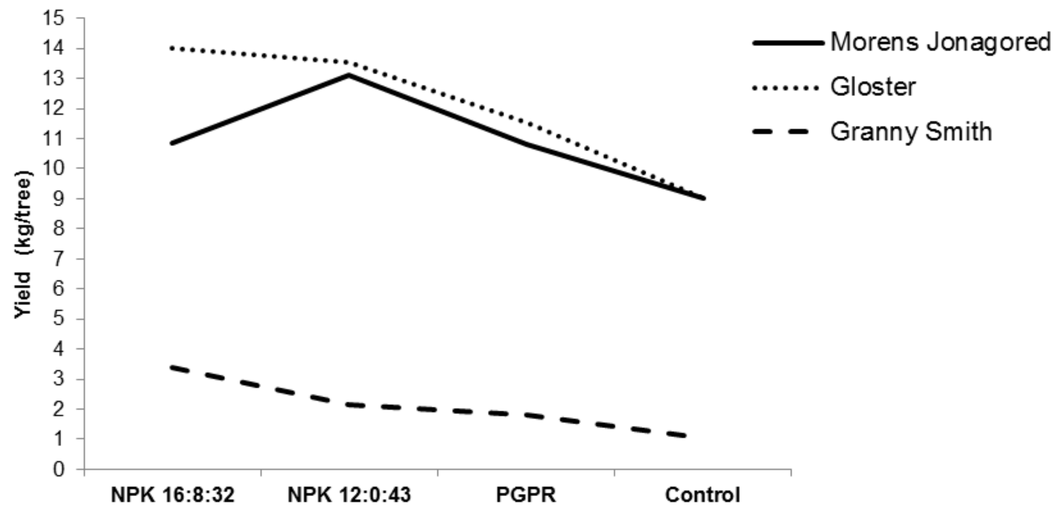
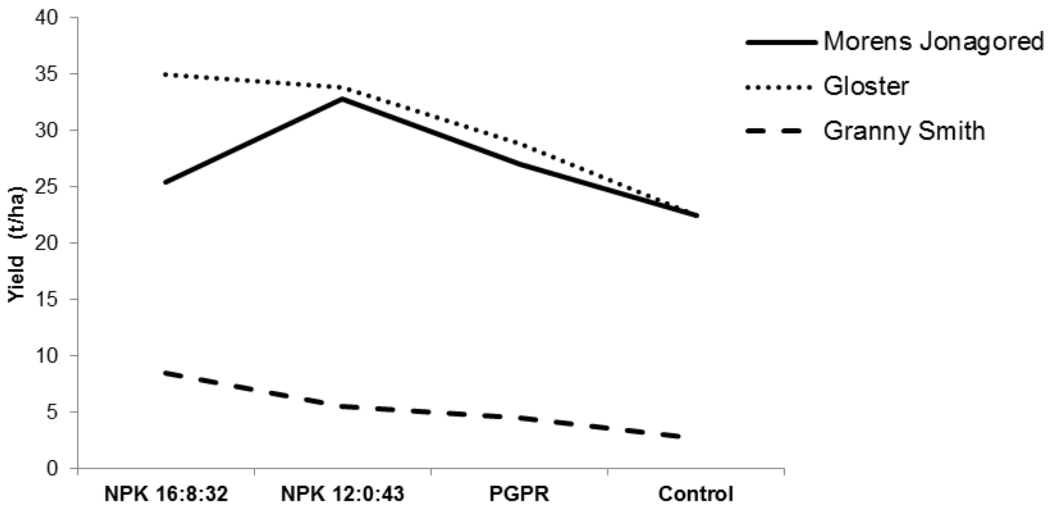


Fig. 5. Yield per unit area (A × B)



According to Rakićević et al. (2011), applied fertigation enhanced yield per tree in 'Idared' and 'Wilmuta' by 42.7% and 27% respectively, and increased yield per unit land by 50.0%. In contrast, Dolega and Link (1998) report on the absence of positive effects of fertigation on apple yield. In our study, the highest values of the parameters studied were evidenced in the variant of treatment involving 12:0:43, the lowest being obtained with PGPR.

With regard to the abundance of flowering, initial fruit set and final fruit set examined among different genotypes, it is 'Morens Jonagored' that exhibited the best performance (4.25±0.15; 3.44±0.15; 2.94±0.17), while the lowest values of respective parameters were recorded in 'Gloster' (3.85±0.17; 3.03±0.19; 2.78±0.19). As regards yield per tree and unit land area, the results suggest superiority of 'Gloster' (12.03±0.84 kg/tree; 30.06±2.10 t/ha) and the poorest performance of 'Granny Smith' (2.10±0.21 kg/tree; 5.25±0.53 t/ha). Given that boron (B) content plays an important role in pollination process, this phenomenon is most likely the consequence of the low level of the element. Similarly, Nyomora et al. (2000) reported that although genetic factors account for most of the potential of the pollenizer, other variables, including mineral nutrition of the plant, may influence pollen quality and its subsequent performance.

All the generative potential parameters of the studied apple cultivars were significantly higher in the second year of study (2010). By studying the effect of nitrogen and complete NPK fertilizer on growth and production of apple cultivar 'Gala', Treder (2006) observed a considerably higher effect of complete NPK on yield, also in the second year of study.

Table 2 presents the two-year (2009–2010) results of the study on pomological properties of fruits in the apple cultivars examined.

Table 2. Pomological properties of fruits in apple cultivars studied (2009–2010)

Factor		Fruit height (mm)	Fruit width (mm)	Fruit weight (g)	Soluble solids (%)	Ripeness degree
Fertilizer (A)	NPK 16:8:32	71.92±1.07 ns	81.45±1.02 ns	239.05±8.17 **	14.78±0.57 **	4.75±0.38**
	NPK 12:0:43	72.07±1.04 ns	82.07±0.95 ns	223.59±1.23 ns	13.90±0.29 **	4.42±0.45**
	PGPR	71.95±0.99 ns	81.41±1.11 ns	195.41±1.28 ns	13.11±0.30 **	4.21±0.48**
	Control[1]	69.59±1.17	80.40±1.18 ns	199.05±4.21	12.48±0.40	2.96±0.17
Cultivar (B)	Morens Jonagored	70.55±1.02 a	82.42±0.98 a	217.41±7.13 a	15.10±0.39a	5.85±0.35a
	Gloster	72.08±0.95 a	80.49±0.88 a	223.57±7.56 a	12.33±0.30c	2.93±0.21c
	Granny Smith	71.51±0.83 a	81.08±0.86 a	201.84±1.20 a	13.26±0.21b	3.48±0.13b
Year (C)	2009	70.74±0.79 a	80.79±0.78 a	211.21±9.55 a	13.65±0.21 a	4.36±0.22a
	2010	72.02±0.73 a	81.89±0.70 a	217.34±4.85 a	13.48±0.40 a	3.80±0.35b
ANOVA						
A		ns	ns	**	**	**
B		ns	ns	ns	**	**
C		ns	ns	ns	ns	**
A × B		ns	ns	ns	**	**
A × C		ns	ns	ns	**	**
B × C		ns	ns	ns	**	**
A × B × C		ns	ns	**	**	**

- A, B and C stand for fertilizers, apple cultivars and years of study, respectively.
- ** in columns stand for the significant differences between P<0.05 and P<0.01 means, based on Dunnet's test and results of ANOVA (F test); ns – not significant.
- Means in rows referring to cultivars (B) and years (C), denoted with the same small letter, mark no justifiable differences for P<0.05 based on Duncan Multiple Range test.

Analysis of variance points to a substantial influence of fertilizer type on fruit weight, soluble solids and ripeness degree. The studies on fertigation carried out by Sozzi et al. (1985) suggest similar results in terms of soluble solids content (Idronova 21:7:14) on qualitative properties of 'Stark Redgold' nectarine. In the study, they also observed a substantial influence of genotype on soluble solids content and ripeness degree. Year of study, as the third factor examined, had a major impact only on ripeness degree. A marked influence of the interaction was evidenced only in soluble solids and fruit ripeness degree. Besides, interaction effects were only observed on soluble solids content and fruit ripeness degree (Fig. 6, 7).

Fig. 6. Soluble solids content (A × B)

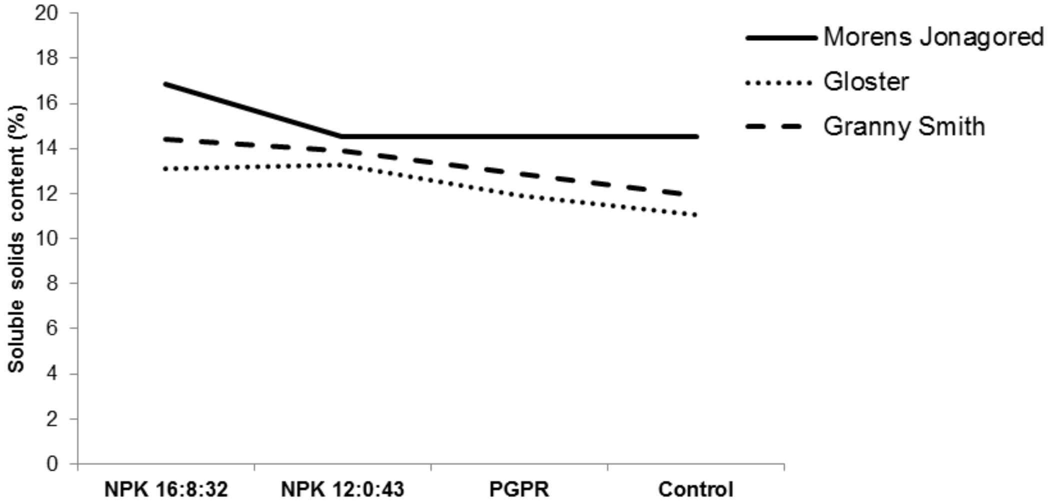
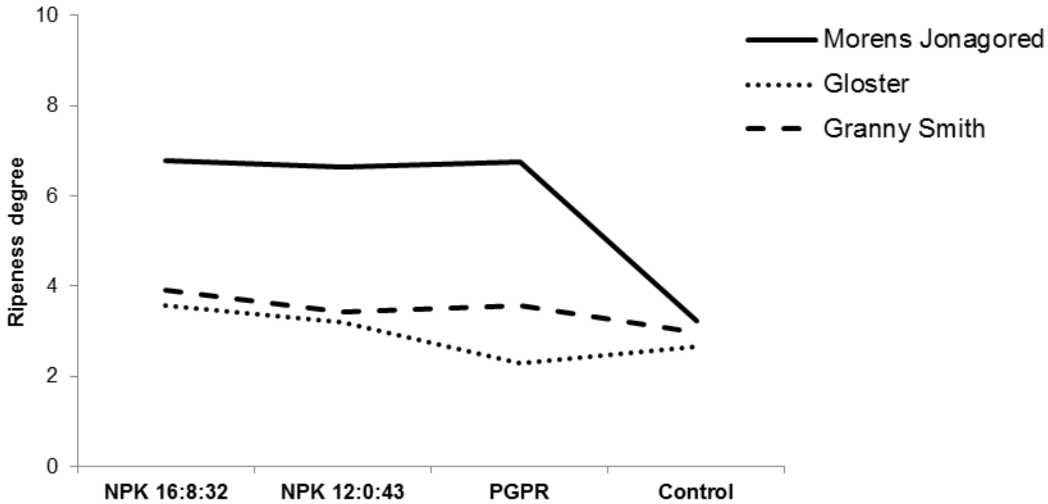


Fig. 7. Ripeness degree (A × B)



Compared to the control, the highest fruit weight, soluble solids content and fruit ripeness degree were observed in the variant of treatment involving 16:8:32 NPK fertilizer (239.05±8.17; 14.78±0.57; 4.75±0.38), whereas the lowest were in the treatment involving PGPR (195.41±1.28; 13.11±0.30; 4.21±0.48).

Regarding the influence of genotype specificities, the results analysis pertaining to soluble solids and fruit ripeness degree point to the superiority of ‘Morens Jonagored’ (15.10±0.39; 5.85±0.35), as contrasted to the poorest performing ‘Gloster’ (12.33±0.30; 2.93±0.21). Some studies on fertigation yield suggestion that besides its positive effect on production it also enhances some parameters of quality of apple fruits (Fukuda et al., 1999; Malaguti et al., 2002).

Concerning year of study, substantial differences in terms of pomological characters were observed only in fruit ripeness degree, the value being significantly higher in the first year of study (2009).

Table. 3. Cumulative and yield efficiency in apple cultivars studied

Factor		Cumulative yield		Yield efficiency
		kg/tree	t/ha	kg/cm^2
Fertilizer (A)	NPK 16:8:32	18.80±3.53*	47.00±8.83*	0.75±0.13**
	NPK 12:0:43	19.20±4.06**	48.00±10.14**	0.77±0.14**
	PGPR	16.10±3.38ns	40.25±8.44ns	0.63±0.10*
	Control[1]	12.70±2.77	31.73±6.91	0.47±0.09
Cultivar (B)	Morens Jonagored	21.85±1.17a	54.63±2.93a	0.84±0.04a
	Gloster	24.05±2.18a	60.11±5.45a	0.90±0.08a
	Granny Smith	4.20±0.60b	10.50±1.51b	0.23±0.02b
ANOVA				
A		**	**	**
B		*	*	**
A × B		ns	ns	ns

- A, B and C stand for fertilizers, apple cultivars and years of study, respectively.
- ** in columns stand for the significant differences between P<0.05 and P<0.01 means, based on Dunnet's test and results of ANOVA (F test); ns – not significant.
- Means in rows referring to cultivars (B) and years (C), denoted with the same small letter, mark no justifiable differences for P<0.05 based on Duncan Multiple Range test.

In terms of yield, the results shown in Table 3 infer a marked effect of both fertilizer and cultivar specificities. Regarding the fertilizers effect, the comparison of fertigation variant and the control one points to statistically significant differences in respect of cumulative yield, and negligible differences between PGPR variant and the control. Results of investigation of yield efficiency suggest statistically significant differences in all variants of treatment involving fertigation-applied fertilizers, compared to the control.

The results pertaining to tree production suggest identical influence of genotype specificities on all yield parameters (Table 3), the highest being in 'Morens Jonagored' (21.85±1.1754-kg/tree; 63±2.93 t/ha; 0.84±0.04 kg/cm^2) and the lowest in 'Granny Smith' (4.20±0.60-kg/tree; 10.50±1.51t/ha; 0.23±0.02kg/cm^2).

Conclusion

In terms of generative potential of fruits, fertigation is considered an influential factor which is to a great extent governed by selected fertilizer.

It was 16:8:32 NPK fertilizer that had the greatest effect on abundance of flowering, fruit set, fruit weight and soluble solids in cultivars examined, whereas 12:0:43 NPK fertilizer had a major influence on the increase in final fruit set, fruit width and length, and fruit ripeness degree. The latter had the same effect on all the examined yield parameters (kg/tree; t/ha; cumulative yield; yield efficiency).

It was 'Morens Jonagored' that was to the highest degree influenced by fertigation in respect of all the parameters of generative potential (abundance of flowering, initial fruit set, final fruit set, fruit width and length, fruit weight, soluble solids, fruit ripeness degree) except for yield. In terms of yield (kg/tree; cumulative yield; yield efficiency) the best performing cultivar was 'Gloster'.

Fertigation had a higher effect on all the parameters in the second year of study, except for soluble solids and fruit ripeness.

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