Response of pear trees to different fertilization treatment

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During 2015 and 2016 we investigated the influence of different organic (cattle manure, Humus Vita Stallatico (HVS)), organo-mineral (Multi Comp Base (MCB)) and mineral fertilizers (calcium ammonium nitrate (CAN), compound (NPK) and natural zeolite (Agrozel) as a soil conditioner on the yield and fruit physico-chemical properties of pear cv. 'Williams' grafted on quince BA.29 rootstock. Results showed that fertilizers, years and their interaction significantly changed the evaluated properties. Yield per tree and hectare was the highest with compound NPK application and the lowest in the control variant. Fruit weight (FW) was higher when NPK was used in comparison with the Agrozel application and the control variant. Manure, CAN, NPK and HVS induced similar and higher fruit length (L) than control, whereas NPK induced higher fruit diameter (D) than manure, Agrozel, CAN applications and control with no significant differences between them. Agrozel and NPK induced similar and higher fruit shape index (sphericity) values in comparison with manure and CAN application. Soil application of NPK induced higher surface area than Agrozel and control. Fertilizers did not affect flesh firmness (FF). Soil application of manure, MCB, NPK and HVS increased soluble solids content (SSC) in comparison with other treatments, whereas the highest acidity was observed in the control variant. Agrozel induced the highest pH juice, invert sugars (IS) and sweetness index (SI). The best ripening index (RI) was found with NPK fertilization. Total sugars (TS) and sucrose (SC) contents were the highest in the MCB variant. Generally, fruit physical and chemical properties were better in the first year of the investigations. However, the significant interaction fertilizer × year indicates that some fertilizers did not show a consistent effect in certain years.
Keywords: fertilization, fruit physico-chemical properties, *Pyrus communis* L., productivity

Reaktionen von Birnbäumen auf unterschiedliche Düngebehandlungen. In den Jahren 2015 und 2016 untersuchten wir den Einfluss verschiedener organischer (Viehmist, Humus Vita Stallatico (HVS)), organisch-mineralischer (Multi Comp Base (MCB)) und mineralischer Düngemittel (Calciumammoniumnitrat (CAN), Compound-Dünger (NPK) als auch von natürlichem Zeolith (Agrozel) als Bodenverbesserer auf den Ertrag und die physikalisch-chemischen Eigenschaften von Früchten der Birnensorte 'Williams', veredelt auf der Quittenunterlage BA.29. Die Ergebnisse zeigten, dass Düngemittel, Jahr und deren Wechselwirkung die bewerteten Eigenschaften signifikant veränderten. Einzelbaum- und Hektarerträge waren bei der Compound-NPK-Applikation am höchsten und bei der Kontrollvariante am niedrigsten. Das Fruchtgewicht (FG) war bei NPK-Applikation höher als bei der Agrozel-Anwendung und der Kontrollvariante. Mist, CAN, NPK und HVS induzierten ähnliche und höhere Fruchtlänge (L) als die Kontrolle, während NPK einen höheren Fruchtdurchmesser (D) induzierte als Mist, Agrozel und Kontrolle, wobei keine signifikanten Unterschiede zwischen ihnen auftraten. Agrozel und NPK induzierten ähnliche und höhere Fruchtform-Indices im Vergleich zu Mist- und CAN-Anwendung. Die Bodenapplikation von NPK bewirkte eine größere Oberfläche als Agrozel und die Kontrolle. Düngemittel beeinflussten die Fruchtfleischfestigkeit (FF) nicht. Die Bodenausbringung von Mist, MCB, NPK und HVS erhöhte den Gehalt an löslichen Feststoffen (SSC) im Vergleich zu anderen Behandlungen, während die höchste Acidität in der Kontrollvariante beobachtet wurde. Agrozel zeigte die höchsten Werte für pH, Invertzucker (IS) und Süßigkeitsindex (SI) im Saft. Der beste Reifungsindex (RI) wurde bei der NPK-Variante gefunden. Die Gehalte an Gesamtzucker (TS) und Sucrose (SC) waren in der MCB-Variante am höchsten. Im Allgemeinen waren die physikalischen und chemischen Eigenschaften der Früchte im ersten Untersuchungsjahr besser. Die

signifikante Wechselwirkung Dünger × Jahr weist jedoch darauf hin, dass einige Dünger in bestimmten Jahren keine konsistente Wirkung zeigten.
Schlagwörter: Düngung, physikalisch-chemische Eigenschaften von Früchten, *Pyrus communis L.*, Produktivität

Pear (*Pyrus communis* L.) is a well-appreciated and widely grown fruit type worldwide. World production in 2019 amounted to 23.73 million tons and was realized from ≈1.4 million hectares (FAOSTAT, 2020). This fruit species is primarily grown due to its high usable value, first of all as fresh fruit and then processed into a variety of products. That is due to the great content of the so-called primary and secondary metabolites which are important for human nutrition and health (Hudina and Stampar, 2005; Milošević et al., 2020). Serbia has very suitable natural conditions for pear growing. However, they have not been used optimally, which is confirmed by large fluctuations in the quantity and quality of fruit from year to year. In 2018, only 53.905 t were produced with approximately 4.982 ha of harvest area (FAOSTAT, 2020). According to this source, Serbia is ranked 23rd in the world by annual pear production. In the structure of fruit species in this country, it ranks second behind the apple in the pome fruit group, that is, third behind the plum and apple in the overall structure.

Success in fruit production is conditioned not only by the choice of cultivar and rootstock, the system of cultivation and suitable ecological factors, but also the system of care measures, where fertilization is particularly important. Plant nutrition is one of the key factors influencing the yield and quality of crop plants. All essential elements play a vital role in deciding growth and development of plants (Rathore, 1991). For a particular nutrient, there exists a relationship between its concentration in the soil as well as in plants and yield as well as quality attributes of fruits. This serves as a guide to obtain maximum productivity and quality of fruits. Brunetto et al. (2015) found a relationship of available nutrients with yield and quality of pear. However, little is known concerning the nutritional requirements of pear (Wooldridge, 1993), and results are sometimes contradictory and depend on several factors such as cultivar and rootstocks tested, environmental conditions and cultural practices in general (Jordão et al., 2008).

Numerous authors have engaged in the problems of fruit nutrition. When it comes to pear, most researchers have studied the impact of different types of fertilizers and application time as well as the amount and ratio of nutrients added on productivity and fruit quality attributes (Ystaas, 1980; Brunetto et al., 2015; Sete et al., 2019). In general, orchard fertilization is a pre-harvest factor that affects productivity and fruit quality and has to be performed very carefully since, after harvest, fruit quality cannot be improved (Crisosto et al., 1997). Since acidic soils are predominant in Serbian fruit orchards (>60 %), fertilization of fruit trees, including pears, obviously requires new management practices (Milosevic and Milosevic, 2009). These authors also reported that Serbian fruit growers primarily use complex NPK fertilizer (15:15:15) in late autumn, N mineral fertilizers (CAN and/or urea) in early spring (before onset of vegetative cycle), and sporadically farmyard manure as a source of organic matter during autumn or winter whereas micronutrients are applied when there are deficits.

Recently, natural zeolite, commercially named "Agrozel", alone or when mixed with N, P, K and/or manure is applied in late autumn in some Serbian fruit plantations. Application of natural zeolites to soils increases their electrical conductivity, and as a result it increases nutrient retention capacity and usually increases soil pH (soil conditioner) (Torii, 1978). It was verified that when mixed with N, P and K compounds, natural zeolite enhances the action of such compounds as slow-release fertilizers (Williams and Nelson, 1997), both in horticultural and extensive crops. Zeolite contains the most important plant nutrients such as N and K, and also Ca, Mg and micronutrients (Polat et al., 2004). This compound may also improve the physical properties of soils including water retention and its release in drought conditions (Xiubin and Zhanbin, 2001). Data from literature indicate that natural zeolites improve growth and development of fruit trees and their application results in a yield increase (Torii, 1978; Milošević and Milošević, 2013).

The practice of fertilization may affect fruit quality from morphological, physical, chemical and organoleptic points of view (Brunetto et al., 2015). However, actual fruit nutrition strategies worldwide are subtle and based on the fact that only the missing elements need to be added to the plants. Earlier, excessive fertilization was rather common, especially in horticultural farming, with fertilizer cost accounting for almost 10 % of variable costs (Huett and Dirou, 2000; Paunović et al., 2018). In addition to the financial aspect, excessive fertilization has been associated with the contamination of soils, water and fruit, as well as with increased pest and disease incidence (Marschner, 1995).

For these reasons, the main goal of this study was to investigate the influence of different organic, mineral and organo-mineral fertilizers on productivity and fruit physico-chemical properties of the pear *cv*. 'Williams' grafted on quince BA.29 and grown under western Serbian environmental conditions.

Materials and methods

Plant material and field experiment

The research was carried out in a private commercial pear orchard during 2015 and 2016. The orchard was located in the Trbušani village (43°55' N; 20°19' E, 256 m a.s.l.) near Čačak city (western Serbia) and was established in autumn 2009. The *cv*. 'Williams' grafted onto quince BA.29 rootstock was used as the plant material. The planting distance was 4.0 m × 1.5 m which corresponds to a density of 1667 trees/ha. Trees were trained to a slender spindle.

Standard cultural practices were used (pruning, soil management, pest and disease protection, weed control with Glyphosate as a total systemic herbicide, drip irrigation). Orchard floor management involved grass cover between the rows and 1 m-wide herbicide strips in the tree rows.

The soil treatment involved the application of the organic fertilizer - mature cattle manure from a local farm with 0.5 % total N (N_{TOT}), 0.3 % P_2O_5, 0.6 % K_2O and 25 % organic matter on dry weight (4.2 kg/m^2) and HVS (0.07 kg/m^2), mineral fertilizers - CAN (0.03 kg/m^2) and compound NPK (10:30:20) (0.04 kg/m^2), MCB as a multi-nutrient organo-mineral fertilizer (0.03 kg/m^2) and natural zeolite commercially named "Agrozel" - product of the Institute for Technology of Nuclear and Other Mineral Raw Materials from Belgrade (1 kg/m^2). Manure, HVS, NPK, MCB and Agrozel were given in autumn 2014 and 2015, while CAN was given in early spring 2015 and 2016. All fertilizers were applied every year.

MCB (Haifa Chemicals Ltd., Haifa, Israel) is a multi-nutrient fertilizer in form of NPK + MgO + microelements + humic acid. It contains 14 % N, 13 % P, 20 % K, 2.1 % MgO, 0.01 % Cu, 0.05 % Mn, 0.05 % Zn, 0.01 % B and humic acid, which covers granules and has high biological value. HVS (FOMET SPA, San Pietro di Morubio, Italy) fertilizer powder is obtained solely by mixing the selected fertilizer (horses + cows) that has been subjected to a fermentation process over 8 to 10 months. It contains 25 to 28 % organic carbon, 43 to 48 % humified organic matter, 9 % fulvic acid, 10 % humic acid and over 4 billion beneficial microorganisms per g of fertilizer. Fertilizer treatments were conducted in a randomized complete block design with six trees per cultivar-fertilizer combination in four replicates (n = 24). A total of 192 trees were included in the trial alongside with the untreated control.

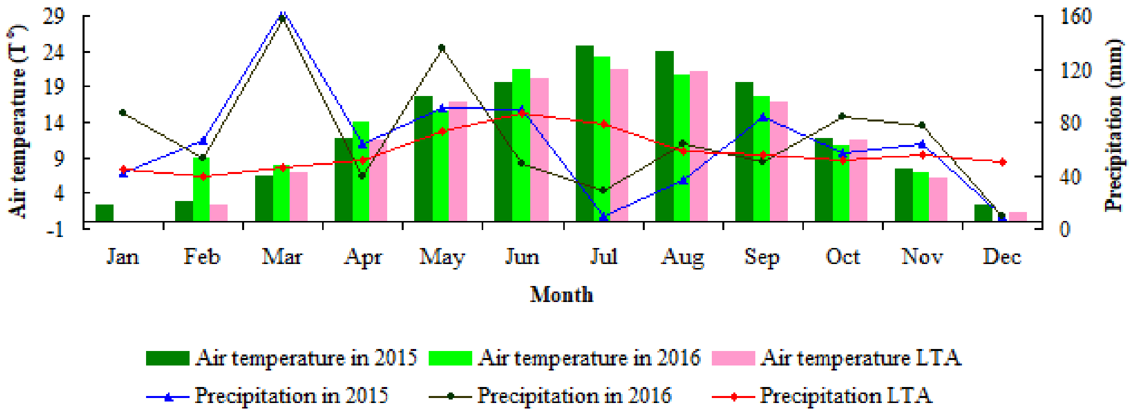

Fig. 1: Weather parameters (air temperature and precipitation) during the experimental period (LTA = long-term average ; 45 year-average, i.e. 1965 to 2010 period)

Weather conditions and soil characteristics

Data about weather conditions (Fig. 1) during the trial were obtained from the Republic Hydro-meteorological Bureau in Belgrade, Serbia (http://www.hidmet.gov.rs). In the experimental years, mean annual air temperatures were 12.5°C and 12.2°C, respectively. Long-term average (LTA) (45-year average, i.e. 1965 to 2010 period) for annual air temperature was 11.3°C. The average air temperature for the vegetative cycle in 2015 (18.4°C) was higher than in 2016 (17.6°C) and the LTA (17.0°C). The annual sum of precipitation in 2015 and 2016 were 777.7 mm and 834.6 mm, respectively, which was much higher than the long-term average (691.5 mm). The sum of precipitation for the vegetative cycle in 2015, 2016 and LTA were approximately 432.5 mm, 450.8 mm and 456.0 mm, respectively. Since there is an irrigation system in the orchard, temperatures in relation to the amount of precipitation could have had a greater impact on the examined properties.

Soil characteristics were analyzed prior to establishment of the experiment. Soil is an alluvial deposit. Soil pH in water suspension was 6.58 units. The contents of organic matter and N_{TOT} were 1.62 % and 0.24 %, respectively. The contents of available P_2O_5 and K_2O were above the optimal level for pear growing under Serbian conditions (5 to 8 mg P_2O_5 and 15 to 20 mg K_2O; Milošević, 1997), and amounted 40 mg per 100 g on dry soil basis each.

Measurements of yield and fruit quality attributes

Yield per tree (kg) of each cultivar-fertilizer treatment and control treatment was measured using an ACS electronic scale (Zhejiang, Jinhua, China). Yield per unit area (t/ha) was calculated.

Twenty fruit per treatment in four replicates (n = 80) were randomly hand-picked at full maturity. The FW was measured using a technical balance KERN FCB (Kern & Sohn GmbH, Belingen, Germany). The L and D (both in mm) were determined using a Starrett 727 digital clipper (Starrett, Athol, MA, USA). The FF was determined using a Bertuzzi FT-327 penetrometer (Facchini, Alfonsine, Italy). Sphericity and fruit surface area were calculated using the formulas proposed by Mohsenin (1986). The measurements of the physical properties of pear fruit were performed immediately after harvesting.

All chemical analyses were done on the whole frozen fruit, previously collected at full maturity, in four replications with six fruit per replication (n = 24) per each fertilizer treatment and control. Collected fruit were chopped and frozen (-18°C) before chemical analysis. The SSC (°Brix) was assessed with a hand refractometer Milwaukee MR 200 (ATC, Rocky Mount, USA) at 20 ºC. The TA (% of malic acid) was determined by potentiometric titration with 0.1 mol/L NaOH up to pH 8.1. The pH of the fruit juice was tested by a Consort c860 pH meter (Mettler Toledo, Lester, UK). The RI was calculated as the SSC/TA ratio.

The contents TS and IS were determined volumetrically using the Luff-Schoorl method (Egan et al., 1981). The SC was calculated according to the relationship: SC = (TS – IS) × 0.95. Results were expressed in % of fresh weight. The SI was calculated as the TS/TA ratio.

Statistical analysis

Differences between data were separately determined by two-way analysis of variance (ANOVA) using the GenStat software package (VSN International, Harpenden, UK). Means were compared with the LSD test at $P \leq 0.05$.

Results and Discussion

Table 1: Yield per tree and unit area of pear *cv*. 'Williams'; data are the mean ± SE for two consecutive years

Parameter	Yield per tree (kg/tree)	Yield per ha (t/ha)
Fertilizer (A)		
Manure	3.25 ± 0.32 c	5.42 ± 0.54 c
Agrozel	3.32 ± 0.37 c	5.39 ± 0.60 c
CAN	3.76 ± 0.60 bc	6.26 ± 1.00 bc
MCB	4.73 ± 0.73 b	7.88 ± 1.22 b
NPK	6.16 ± 1.05 a	10.26 ± 1.75 a
HVS	4.58 ± 4.45 b	7.63 ± 0.74 b
Control	2.13 ± 0.24 d	3.54 ± 0.39 d
Year (B)		
2015	3.14 ± 0.22 b	5.20 ± 0.36 b
2016	4.83 ± 0.44 a	8.06 ± 0.73 a
ANOVA		
A	*	*
B	*	*
A × B	*	*

Means in same columns followed by different letters differ significantly at $P \leq 0.05$ according to LSD test.
Asterisks in columns indicate significant differences between means at $P \leq 0.05$ according to *F* test.

Yield per tree and unit area (ha)

On the basis of our results presented in Table 1, it can be said that fertilizers applied to soil, year and their interaction had a significant effect on the yield which is in agreement with data previously obtained by Dar et al. (2015). Due to soil in our trial contained medium contents of organic matter and N_{TOT} and an excessive amount of available P_2O_5 and K_2O, compound NPK induced the highest yield per tree (6.16 kg) and logically per hectare (10.26 t), followed by MCB (4.73 kg and 7.88 t), HVS (4.58 kg and 7.63 t) and CAN (3.76 kg and 6.26 t). However, effects of MCB, HVS and CAN on yield were statistically similar. The lowest yield was found in the control variant (2.13 kg and 3.54 t). Our results are supported by data of Hussain et al. (1997), who noted that NPK fertilizers significantly increased pear yield. Namely, fertilizers that contain high amounts of N, P, K improved productivity due to their physiological role in the formation and development of bearing potential, fruit set, fruit size and resistance to drought stress (Ubavić et al., 2001). In addition, Mohammed et al. (2010) noted that chemical fertilizers promoted better yield in pear trees than organic fertilizers, including manure. It is obvious that manure and/or Agrozel alone did not have the capacity to increase yield comparable to other fertilizers, probably due to environmental conditions and short experimental time. Previous reports have demonstrated that organic fertilizers alone need a long time in achieving crop yields equal to or higher than chemical fertilizers (Hargreaves et al., 2008; Polat et al., 2010; Song et al., 2010). Similar behavior of Agrozel alone applied to soil was previously determined in apple (Milosevic and Milosevic, 2009) and apricot (Milošević and Milošević, 2013). On this line, Khan and Sharma (2018) reported that the effectiveness of mineral fertilizer is greatly enhanced when it is applied along with farmyard manure, which may be because the organic matter helps in retaining N in the root zone and making the P and K available to the plant.

In the current study, a significantly higher yield per tree and per unit area was registered in 2016 (4.83 kg and 8.06 t) compared to 2015 (3.14 kg and 5.20 t). Year-by-year yield variations in pear were also previously reported (Gill et al., 2017). The second year of the experiment was rainier than the first, so that could be the reason that those fertilizers caused better yields in 2016. However, the existence of an interaction between the main effects indicates that some fertilizers did not increase yield in the second year of the experiment. This phenomenon primarily relates to manure and Agrozel, which had a stronger effect on the yield in 2015 than in 2016. In this respect, several studies noted that the impacts of fertilization on yield depend on many factors such as cropping method, tree age, plant material, i.e. scion/rootstock combination, the time of treatment, nutrients applied, the occurrence of stress factors - drought, excess water, root damage, etc. (Wociór et al., 2011).

Generally, our results for yield per tree and yield per hectare (Table 1) were lower than those presented in literature for the same cultivar (Dar et al., 2012; Hudina and Stampar, 2005). Very low yields can be associated with rainy and cold weather during flowering in both years, which caused poor fertilization and fruit set (data not shown). In general, honey bees rarely visit pear flowers due to their unpleasant smell (Milošević, 1997) unlike to other fruit types such as raspberry, blackberry, plums, apple, sour and/or sweet cherry.

Table 2: Main physico-mechanical properties of pear fruit *cv*. 'Williams'; data are the mean ± SE for two consecutive years

Parameter	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)	Sphericity	Surface area (cm²)	Flesh firmness (kg/cm²)
Fertilizer (A)						
Manure	181.4 ± 9.08 ab	90.06 ± 2.40 a	65.41 ± 1.18 b	0.809 ± 0.009 b	167.22 ± 6.38 ab	1.45 ± 0.16 a
Agrozel	168.0 ± 8.80 b	86.48 ± 3.09 ab	64.61 ± 0.93 b	0.841 ± 0.024 a	160.39 ± 6.30 b	1.35 ± 0.22 a
CAN	177.0 ± 15.13 ab	89.82 ± 3.52 a	65.44 ± 1.52 b	0.814 ± 0.013 b	167.84 ± 8.89 ab	1.40 ± 0.19 a
MCB	178.4 ± 11.10 ab	89.22 ± 1.93 ab	66.61 ± 0.75 ab	0.826 ± 0.008 ab	169.67 ± 4.58 ab	1.51 ± 0.03 a
NPK	194.2 ± 11.82 a	89.69 ± 2.64 a	68.83 ±1.25 a	0.840 ± 0.010 a	177.98 ± 7.36 a	1.48 ± 0.14 a
HVS	185.4 ± 12.67 ab	89.93 ± 3.32 a	66.62 ± 1.63 ab	0.821 ± 0.008 ab	171.30 ± 9.43 ab	1.66 ± 0.14 a
Control	162.2 ± 13.37 b	85.51 ± 2.51 b	63.93 ± 1.03 b	0.822 ± 0.010 ab	157.34 ± 5.63b	1.55 ± 0.17 a
Year (B)						
2015	200.3 ± 3.95 a	94.24 ± 0.70 a	67.81 ± 0.55 a	0.804 ± 0.003 b	180.27 ± 2.53 a	1.78 ± 0.05 a
2016	155.8 ± 3.91 b	83.10 ± 0.82 b	64.03 ± 0.56 b	0.845 ± 0.006 a	154.51 ± 2.54 b	1.19 ± 0.05 b
ANOVA						
A	*	*	*	*	*	*
B	*	*	*	*	*	*
A × B	*	*	*	*	*	*

Means in same columns followed by different letters differ significantly at $P \leq 0.05$ according to LSD test.
Asterisks in columns indicate significant differences between means at $P \leq 0.05$ according to F test.

Fruit physical properties

Fruit weight is a very important qualitative characteristic that affects the yield as well as consumer acceptance (Durmaz et al., 2010). Data in Table 2 show that fertilizers and years as single factors and their interaction significantly changed fruit weight of 'Williams' pear. Compound NPK caused higher FW (194.2 g) compared with both Agrozel (168.0 g) and control (162.2 g) treatments but similarly affected this property with other fertilizers. It appears that all fertilizers containing macro- and microelements and organic matter in the present trial have improved the fruit weight of this cultivar, which was reported earlier (Fawzi et al., 2010; Shen et al., 2016). The control variant (without fertilizer application) did not have the capacity to increase FW. In addition, Agrozel alone without mixture with any essential nutrients had no effect on this property as compared to the control. The behavior of Agrozel applied to the soil and its effect on FW is in accordance with its role described in earlier studies on pome (Milošević and Milošević, 2009) and stone fruit types (Milošević and Milošević, 2013; Milošević et al., 2013). Bussi et al. (2003) recorded that increasing N rates resulted in bigger fruit, which partially confirmed our results. On the other hand, Crissosto et al. (1997) noted that excess N does not increase fruit size and production. Hence, it can be said that fertilizer's effect on the FW is contradictory. High dissimilarity between results obtained by the above authors might be due to diverse agro-climatic conditions, the cultivar factor *per se* (genotype), cropping method and tree age (Wociór et al., 2011). Our range values for FW of 'Williams' are in agreement with data previously reported by Milošević (1997).

Length (L) and diameter (D) define the final shape of the fruit and also the appearance of the fruit sought by the consumer (Di Vittori et al., 2018). Available data indicate that L and D of pear fruits vary greatly and ranged from 61 to 91 mm and 59 to 78 mm, respectively (Karadeniz and Sen, 1990). According to research carried out by Nenadović-Mratinić et al. (2007), the average fruit length of 'Williams' fruit was 92.8 mm. Data in Table 2 show the superior and statistically similar influence of NPK (68.83 mm), MCB (66.61 mm) and HVS (66.62 mm) on the fruit D. On the other hand, application of manure (65.41 mm), Agrozel (66.41 mm) and CAN (65.44 mm) had no statistically significant effect on D as compared to the control (63.93 mm). Gill et al. (2012) also found that various nutritional treatments significantly improved L as compared to the control. Gobara (1998) and Ubavić et al. (2016) reported that fertilization with K and N increased fruit size and other physical properties, which confirmed results in our trial, since NPK fertilizer had high positive effects on fruit dimensions (Table 2). It is well documented that N affects the protein synthesis and consequently the growth of the fruit, while K favorably affects photosynthesis, elongation and cell division (Buskienė and Uselis, 2008).

The sphericity of the fruit is a physical trait that is important in assessing the size of the sample in respect to designing machines and certain processes in the processing of fruit (Nunak and Suesut, 2007). This trait depends on fruit type, cultivar, but also on environmental conditions, cultural practices, position of the fruit on the canopy itself and the stage of maturity (Milošević et al., 2012). In the present study, Agrozel (0.841) and NPK (0.840) induced higher sphericity values than manure (0.809) and CAN (0.814) (Table 2). Nevertheless, all sphericity values obtained in the current study indicate the typical fruit shape of the 'Williams' pear.

The surface area of fruits is an important physical property for the food and processing industries (Mohsenin, 1986). This feature is also significant in physiological, entomological and phytopathological studies where it serves to evaluate the damage resulting from a physiological disorder or pathogen attack (Bovi and Spiering, 2002). It is clear from the data in Table 2 that application of NPK (177.98 cm^2) had a higher impact on surface area related to Agrozel (160.39 cm^2) and control (157.34 cm^2). Our results for pear surface area were lower than those of Ozturk et al. (2009) who stated a range between 182.42 cm^2 and 227.71 cm^2. In addition to affecting quality, FF is a very important indicator of maturity status (Kawamura, 2000). When it comes to FF, it was not significantly affected by fertilizers (Table 2). Some authors also previously noticed that fertilization did not affect FF of pear (Raese and Staif, 1989). Kiprjanovski and Ristevski (2009) argue that fruits should be harvested in the optimal stage of ripeness, as this is the only way to produce fruit of adequate strength. Fruit firmness values higher than 5.5 kg/cm^2 always result in unacceptable quality (Crisosto et al., 2005).

Regardless of the year effects in our work, the higher values of FW (200.3 g), L (94.24 mm), D (67.81 mm), surface area (180.27 cm^2) and FF

(1.78 kg/cm^2) were recorded in 2015. Conversely, for the fruit sphericity, significantly higher values were found in 2016 (0.845) than in 2015 (0.804). However, interaction fertilizer × year for all fruit physical traits were statistically significant (Table 2). This leads us to the observation that the nutrients did not exhibit similar behavior during the two years of testing, because there was a deviation from the general tendency. Namely, the FW and both fruit linear dimensions were higher in the first year when CAN and NPK were applied and in the control, while other fertilizers had a similar effect on these properties in both years of the experiment. In terms of sphericity, only manure, Agrozel and NPK caused higher values in the second year of the experiment, whereas other treatments and control caused a similar fruit shape in both years. Regarding the influence of the interaction fertilizer × year on the surface area and FF, only the application of MCB and control caused similar values in both years. This points to the complex nature of the formation of the final physical properties of the pear fruit because it participates in this process through other factors (climatic conditions, growing technology as well as the number and position of the fruit in the tree), not only from fertilizers and years as previously reported (Milošević et al., 2015).

Soluble solids content, acidity, juice pH and ripening index

Regarding SSC and TA, significant and consistent differences were found between fertilizers through two years of study (Table 3). These findings confirm previous reports showing that fertilization changed SSC and TA (Jordão, 2008; Milošević et al., 2015). Several fertilizers such as manure (15.03 °Brix), MCB (15.40 °Brix), HVS (15.00 °Brix) and NPK (15.09 °Brix) influenced higher and similar SSC related to Agrozel (14.82 °Brix) and CAN (14.45 °Brix) application and control (14.71 °Brix). Between Agrozel and CAN treatments and control, differences were not significant. Several authors reported that fertilization with a high dose of N decreased SSC (Crisosto et al., 1997) whereas fertilization with K fertilizers increased the content of this phytochemical (Bussi et al., 2003; Havlin et al., 2007), which confirmed our results. Also, Asma et al. (2007) reported that K application had more effect on SSC than N and/or P application. The minimum SSC to harvest for European pears is 10 %; however, this parameter is not very trustable because crop load and climatic conditions could influence it (Marini, 2009). No statistical differences in SSC were observed depending on the year (Table 3). However, this tendency relates only to Agrozel, CAN and control, because other treatments caused significant differences in SSC per years.

Table 3: Chemical properties of pear fruit *cv*. 'Williams'; data are the mean ± SE for two consecutive years.

Parameter	Soluble solids content (ºBrix)	Titratable acidity (%)	pH juice	Ripening index
Fertilizer (A)				
Manure	15.03 ± 0.20 a	0.85 ± 0.05 b	3.69 ± 0.04 c	17.77 ± 1.15 d
Agrozel	14.82 ± 0.20 b	0.60 ± 0.01 d	4.20 ± 0.02 a	24.74 ± 0.45 b
CAN	14.45 ± 0.24 b	0.71 ± 0.04 c	3.88 ± 0.09 bc	20.27 ± 0.44 c
MCB	15.40 ± 0.33 a	0.73 ± 0.05 c	3.78 ± 0.02 c	20.98 ± 0.99 c
NPK	15.09 ± 0.20 a	0.54 ± 0.01 e	3.92 ± 0.01 b	27.99 ± 0.58 a
HVS	15.00 ± 0.29 a	0.61 ± 0.02 d	3.97 ± 0.05 b	24.67 ± 0.76 b
Control	14.71 ± 0.24 b	0.93 ± 0.09 a	3.47 ± 0.02 d	15.82 ± 0.69 e
Year (B)				
2015	14.85 ± 0.21 a	0.60 ± 0.02 b	3.75 ± 0.05 b	16.82 ± 0.52 a
2016	15.01 ± 0.29 a	0.82 ± 0.06 a	3.93 ± 0.08 a	12.99 ± 0.95 b
ANOVA				
A	*	*	*	*
B	ns	*	*	*
A × B	*	*	*	*

Means in same columns followed by different letters differ significantly at $P \leq 0.05$ according to LSD test.
Asterisks in columns indicate significant differences between means at $P \leq 0.05$ according to F test.
ns: not significant

TA was also affected by fertilizers, year and interaction fertilizer × year (Table 3). The highest TA was found in the control variant (0.93 %) and the lowest in the variant with NPK soil application (0.54 %). Some authors reported that an increased level of K application results in reduced acid content of fruit because a high K level in tissues provokes neutralization of organic acids (Pattee and Teel, 1967). It is well-known that acidity plays an important role in the perception of fruit quality because acid content balances fruit taste (Schmitzer et al., 2011) and high acid content often reduces fruit quality. The content of acids in pears is low when compared to apples and therefore has less influence on the aroma. In pears, SSC a has a more significant influence on aroma than acids (Vangdal, 1985). In the present study, all fertilizers significantly decreased fruit acidity which is in agreement with the results of Hudina and Stampar (2002) and Song et al. (2012) who noted similar tendencies but higher TA contents than those obtained in our study. It seems that the geographic region with specific weather conditions also plays an important role in biosynthesis of compounds that determine the TA. Pear fruit were more acidic in 2016 (0.82 %) compared to 2015 (0.60 %). Crisosto et al. (1997) stated that the accumulation of acids in the fruit was higher in the colder and rainier period before and during harvest which was the case in our trial in 2016 (Fig. 1). However, the interaction fertilizer × year indicates that this tendency was supported by the soil application of manure and MCB and control, whereas other fertilizers caused similar fruit acidity in both years of investigations. Data in Table 3 show the strong influence of fertilizers on juice pH. The highest pH of fruit juice was found with the Agrozel application (4.20), and the lowest in the control variant (3.47). Observed by years, the higher juice pH value was in the second season (3.93) compared to the first (3.75). However, the interaction fertilizers × year showed that only the application of CAN and NPK significantly supported this tendency, while other fertilizers showed similar impact on juice pH. In a study of Hudina and Stampar (2005), the juice pH of 'Williams' rated from 4.1 to 4.2 independently from the treatment which is similar to our results. In general, pH increases as acidity decreases and vice versa although this relationship can depend on aspects like buffering capacity (Boulton et al., 1999).

The relationship between SSC and TA (SSC/TA ratio or RI) plays an important role in consumer acceptance of fruits (Crisosto et al., 2005). In the current study, the lowest RI value was observed in the control variant (15.82), and the highest in NPK application (27.99) probably due to its impact on low acidity, and relatively high SSC (Table 3). These results are in agreement with a previous study on apricot (Bussi et al., 2003). The ideal pear SSC and acidity content for consumer acceptance is SSC>14 % and TA ≈ 1.8 % (Kader, 1999), which was the case in our study for all treatments (Table 3).

In terms of year, the RI value was much higher in the first year of the trial (16.82) compared to the second (12.99), which may be related to the lower fruit acid content in 2015. However, interaction fertilizer × year showed that only manure application and control variant supported this tendency, whereas other fertilizers induced similar RI values in both years. These data are in agreement with results of Milošević et al. (2015) who reported a similar phenomenon in pear.

Table 4: Content of total sugars, invert sugars, sucrose and sweetness index values of pear fruit *cv*. 'Williams'; data are the mean ± SE for two consecutive years.

Parameter	Total sugars (%)	Invert sugars (%)	Sucrose (%)	Sweetness index
Fertilizer (A)				
Manure	7.53 ± 0.00 c	6.79 ± 0.00 b	0.60 ± 0.001 e	8.90 ± 1.33 d
Agrozel	9.09 ± 0.01 b	7.56 ± 0.01 a	1.44 ± 0.001 c	15.17 ± 1.04 a
CAN	7.54 ± 0.96 c	6.28 ± 0.01 b	1.19 ± 0.005 d	10.57 ± 0.91 c
MCB	10.17 ± 0.01 a	7.54 ± 0.00 a	2.63 ± 0.005 a	13.86 ± 0.31 b
NPK	7.32 ± 0.00 c	4.92 ± 0.00 d	1.42 ± 0.001 c	13.58 ± 1.13 b
HVS	6.94 ± 0.00 d	5.00 ± 0.00 c	1.84 ± 0.001 b	11.41 ± 0.63 c
Control	5.15 ± 0.00 e	5.02 ± 0.01 c	0.12 ± 0.005 f	5.54 ± 0.77 e
Year (B)				
2015	8.93 ± 0.50 a	7.10 ± 0.35 a	1.52 ± 0.18 a	15.11 ± 0.84 a
2016	6.64 ± 0.40 b	5.08 ± 0.26 b	1.45 ± 0.36 b	8.71 ± 0.60 b
ANOVA				
A	*	*	*	*
B	*	*	*	*
A × B	*	*	*	*

Means in same columns followed by different letters differ significantly at $P \leq 0.05$ according to LSD test.
Asterisks in columns indicate significant differences between means at $P \leq 0.05$ according to *F* test.

Sugars and sweetness index

Data in Table 4 reveal that applied fertilizers significantly modified sugars content and sweetness index in 'Williams' pears. The highest values of TS and SC contents in fruit were observed under MCB treatment (10.17 % and 2.63 %, respectively). Content of IS was the highest with Agrozel (7.56 %) and MCB (7.54 %) applications with no significant differences between them. As expected, the poorest values of TS (5.15 %), IS (5.02 %), SC (0.12 %) and SI (5.54) were observed in the control variant. Interestingly, HVS treatment induced a low value of IS (5.00 %) similar to control. Compared to other fertilizers, MCB as a complex organo-mineral fertilizer contains humic acid and more nutrients in addition to N, P, K, especially Mg and microelements. As known, Mg is an important component of chlorophyll (Dimassi-Theriou and Bosabalidis, 1997) so Mg status may directly affect the content of starch and sugars in the leaves as well as in the fruit (Tewari et al., 2006). Multiple studies have shown a relationship between available N and K versus SSC i.e. sugars in diverse fruit types such as strawberries (Wang and Lin, 2002), chokeberries (Skupien and Oszmianski, 2007), dates (Al-Kharusi, 2009,), apricots (Milošević et al., 2013) and grapes (Christensen et al., 1994), as well as the potential influence of other trace elements. Several authors reported that K originating from single or complex foliar or soil fertilizers increased sugar contents (Liwerant, 1960; Lalatta, 1975; Lester et al., 2010). On this line, Hudina and Stampar (2005) noted that the foliar fertilization with P and K in pear fruit of *cv.* 'Williams' resulted in higher quantities of glucose, sorbitol and soluble solids. In general, all sugar contents in our study were in agreement with data presented previously by Niketić-Aleksić (1988) for pears under Serbian conditions. In our work, differences between years in sugar contents and SI were significant which is in agreement with results of Alizadeh et al. (2015) who reported that internal fruit quality generaly depends on the cultivar, but climate, i.e. weather conditions preceding the harvest, had a significant impact. According to data in Table 4, higher values were observed in the first season of the trial probably due to better weather conditions in this year (Fig. 1). Namely, the contents of TS, IS, SC and SI value in 2015 were 8.93 %, 7.10 %, 1.52 % and 15.11, respectively. Hudina and Stampar (2005) and Dar et al. (2012) reported that besides cultivar and climate, rootstock, canopy management, fertilization and other pre- and postharvest cultural practices have less importance for fruit internal quality.

The balance between sugars and acids (sweetness index) is very important in achieving the harmonious taste of fruits (Hudina and Stampar, 2005; Chen et al., 2006). In the present study, the high value of TS in the Agrozel variant (9.09 %) and relatively low content of TA (0.60 %), resulted in a situation that pear fruit had the highest SI value (15.17) when they were fertilized with this soil conditioner. Other authors also reported that different fertilization methods had a more significant impact on the intrinsic quality (SSC, sugars, TA, TS/TA ratio) of pear (Shen et al., 2016; Yinghuan et al., 2018).
The statistically significant interaction fertilizer × year in our study confirms the complex nature of accumulation of sugars in pear fruit because certain fertilizers and control did not show a stable effect in both years of investigation (Table 4). Namely, unlike as with all applied fertilizers, TS and IS were higher in the second season in the control variant , whereas only the application of Agrozel caused significantly larger differences in the SI values between years.

Conclusions

The results of this study showed that a two-year soil treatment with five different fertilizers (cattle manure, HVS, CAN, NPK, MCB) and one soil conditioner (Agrozel) significantly influenced yield and main fruit quality properties compared to the control variant (without fertilization). The capacity of their influence varied. Compound NPK (15:15:15) generally induced the best values of yield, fruit physical properties, SSC and RI whereas promoted the lowest acidity. Fertilizers that contain macro- and microelements and organic matter, i.e. MCB and HVS, appear to have improved many of the parameters, especially yield, fruit physical properties, SSC and sugars content. Application of CAN as N fertilizer caused moderate yield and acidity, good fruit size and poor SSC and sugar contents. Manure as organic fertilizer and Agrozel as a soil conditioner and fertilizer, need time to decompose in the soil so it may be advisable to test their effect on certain traits after a longer time in the future. The year alone and interaction of fertilizer × year also affected all the properties evaluated, which indicates a strong influence of weather conditions on the one and the synergistic effect of season and fertilizer on the other hand. Based on the obtained results, for similar soil and climatic conditions, we recommend the use of complex NPK mineral fertilizer or organo-mineral fertilizers such as CVC and MCB as an alternative. Leaf chemical analysis is necessary as a supplement to soil chemical analysis in order to more accurately and correctly determine the type and rate of fertilizer and also time of application. Finally, before summarizing the performance of any fertilizer, a more years of investigation are needed, and very often this evaluation cannot be generalized and applied due to various environmental conditions and cultural practices used.

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Conflict of interests

The authors declare that they have no competing interests.

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