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EFFECTS OF IRRIGATION AND FERTIGATION ON YIELD AND QUALITY PARAMETERS OF 'GALA' AND 'FUJI' APPLE

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Abstract

The climate change and growing production of crops increase the demand for the water and the efficient use of water in agriculture becomes more critical. This experiment presents the results of research in the orchard with different irrigation programs and fertigation on yield and quality parameters of the 'Gala' and 'Fuji' apple tree. Three irrigation programs were applied IR + F–full irrigation with fertigation; IR–full irrigation without fertigation; NON-IR – non-irrigation, only natural precipitations. There were no differences observed among these three irrigation programs for tree diameter, sugar content, starch content and fruits firmness ($P < 0.05$). Significant deficit of water was in program IR and NON-IR, at the length of annual growth, where the reduction was from from 680 mm to 440 mm at the 'GALA' variety. Statistically important differences between the irrigation variants were found out at the variety 'Fuji', in parametres yield, fruit weight and fruit diameter. Between programs IR + F and NON-IR was the difference of fruit weight 25.6 g (14.3 %) and of fruit diameter 4.5 mm (5.8 %).

Keywords: irrigation, fertilization, apple, 'Gala', 'Fuji'

INTRODUCTION

'Gala' and 'Fuji' are one of the most important apple cultivars highly demanded in the world apple industry. The apple cultivars in the 'Gala' group have a prominent place among the apple cultivars produced in the world. According to the estimations for 2020, it is envisaged that the place of 'Gala' in the ranking will remain unchanged (O'Rourke, 2016).

Since the effective root depths of new shapes of apple trees are short, the carrying out of such cultural practices, as irrigation and fertilization meticulously is quite important to increase the yield and water productivity (Ucar *et al.*, 2016). Apple orchards need to be supplied with all macro- and micronutrients (Bennewitz *et al.*, 2015; Bělíková *et al.*, 2016).

The climate change and growing production of crops increase the demand for the water and the efficient use of water in agriculture becomes more and more critical (Fallahi *et al.*, 2007).

Apple trees require irrigation to maintain high productivity and marketable fruit quality. Especially

in high-density apple orchards, irrigation is important because tree roots strongly compete for the water and nutrients. Irrigation show a very positive influence of yield and quality of apples, especially during the dry years (Veverka and Pavlačka, 2012). In many fruit-growing regions, mineral nutrients are applied through irrigation system (fertigation), which gives possibility to control precisely both, water and nutrient (Wojcik and Treder, 2006).

The drip irrigation system covers the water needs of plants and assures a good water balance which is favourable for growth and development of the plants. Moreover, this method saves at least 39% of water used compared to the full sprinkler system (Fallahi, 2017; Fallahi and Fallahi, 2017).

Merging new orchard designs with more efficient irrigation systems and nitrogen fertilization (N) can result in lower water consumption while producing higher quality fruit (Fallahi *et al.,* 2007; Neilsen *et al.,* 2008).

Many other authors concluded that this resulted in major water saving and improved fruit and yield quality (in case it did not improve the quality, it lowered it only very little). Those plants that were not watered, had only small loss of water during the storage. Trees receiving the full irrigation systems had lower fruit firmness reduction after storage than the treatments receiving deficit irrigation systems (Fallahi and Fallahi, 2017; Yildirim *et al.,* 2016; Naor *et al.*, 2008).

Very similar are the results of the nitrogen fertilization. They show, that after two years the fruit in the low irrigation treatments were significantly smaller, but firmer, with higher total soluble solids (11.8 °Bx) (Swarts *et al.,* 2016).

On the other hand, for example Leib *et al.* (2006) indicated that fruit size and yield of 'Fuji' apple in deficit irrigation were similar to those of partial root zone drying irrigation and conventional irrigation in the semi-arid climate of Washington State.

This experiment presents the results of the research in the orchard of different irrigation and fertigation on yield and some quality parameters of the 'Gala' and 'Fuji' apple tree.

The aim of this experiment was to study the level of impact of different irrigation and fertilization with regards to the storage of nutrients and water in the soil during the past years.

MATERIALS AND METHODS

The experiment was conducted at the orchards of Plantex, Ltd. (Latitude: 48°33′4.25″N, Longitude: 17°43′57.78″E) in the small town of Veselé, near city Piešťany, Slovakia, in the year 2017. The soils in the experimental area were classified as brown earth, medium-heavy type. The results from the agrotechnical experiments of soils are following: pH 7.2 (neutral), content of phosphorus 142.0 mg/kg^{-1} (medium), potassium 441.0 mg/kg^{-1} (high), magnesium 391.0 mg/kg^{-1} (high), calcium 3737.0 mg/kg^{-1} (high). The climate of Slovakia (experimental area) can be classified as Cfb climate; a warm temperate humid climate. Annual precipitation varies from 550 up to 600 mm. The average annual air temperature ranges from 9 to 10 °C. The altitude of the experimental area is 161 meters above sea level. The 14-year-old 'Gala, Schniga' and 'Fuji, Kiku 8' apple trees grafted on M9 rootstock were used in the study. Trees were trained as spindle bush. The tree row was maintained by herbicides and the alleyways consisted of mown turf grass. The trees were planted with 3.6 × 1 m. Each row consisted of one variant with ten adjacent trees in the middle of the row.

Irrigation and fertigation programs

A year ahead of the experiment, irrigation and fertilization were carried out in a standard way, regular for the firm, so all the variants could unite. Irrigation water was obtained from the hydrant near to the experimental area. In the irrigation system, drippers, each with a discharge of 2 l.h^{-1} and a space of 750 mm, were placed one row above the trees on the construction.

Three irrigation programs were applied during the whole growth season: variant IR + F – full irrigation with fertigation; IR – full irrigation without fertigation; program NON-IR–non-irrigation, only natural precipitations. The overall irrigation dose is described in Tab. I. Information on irrigation were collected from the automatic irrigation system and information about precipitations from the meteostation of the firm. The fertilizers used were from the company 'Haifa Chemicals' (Israel), specifically: Ammonium sulfate, Chelated Iron 6% EDDHA, Humifirst, KNO_3 Multi K, K_2SO_4 Solupotasse, MKP. The irrigation and fertilization regime were operated by the automatic irritation system and adjusted accordingly to the respective employee. All trees in variant received the same amount of water.

Vegetative growth, yield and fruit quality

Tree diameter: measuring of the tree diameter was carried out before the beginning of the vegetation in the spring, and after the end of vegetation. The point of measurement was 0.8 meter above the soil surface.

Lengths of year growth: all one-year shoots from three trees per variants were measured after the end of vegetation period.

Yield and fruit quality: fruit of selected five trees from each variant were harvested, weighted, measured and analysed. The harvest date was determined on the basis of changes of fruit skin colour ('Gala', 28 August 2017) and starch degradation ('Fuji', 25 October 2017). Fruit of commercially important diameters, 55–90 mm were harvested.

Flesh firmness: this was set as an average of two opposite sides values measured by penetrometer mounted on a rigid, rigid drill stand with 11 mm tip after removing the peel.

I: *Values of the irrigation dose during the season*

Month	A) full irrigation with fertigation (mm)		B) full irrigation without fertigation (mm)		C) non-irrigation, only natural precipitations (mm)
	Gala	Fuji	Gala	Fuji	
January	0	0	0	0	14.6
February	0	0	0	0	32.0
March	0	0	0	0	28.8
April	165	129	154	118	45.2
May	115	118	115	118	26.5
Jun	148	137	137	120	50.7
July	232	241	193	204	52.5
August	230	216	190	188	102.7
September	28	28	28	28	74.4
October	0	0	0	0	29.2
November	0	0	0	0	53.6
All together	869	918	776	817	510.2

The sugar content: was measured on the laboratory optical ABBE refractometer (°Bx).

The starch conversion code: was measured by the iodine test according to the colouring and further comparison with the appropriate table (CTIFL, 2002).

Fruit weight and diameter: all the harvested fruits from the trees were weigh by the electronic platform scale type CAS DB2 and then further averaged. The averages of the harvested fruits were measured in the plastic box.

Statistical analysis

The data were analysed together for both varieties. Two-factor ANOVA with interaction was used ($P < 0.05$). Statistical analyses were performed by the software "Statistica 12.0" (StatSoft Inc., USA).

RESULTS AND DISCUSSION

Tree diameter

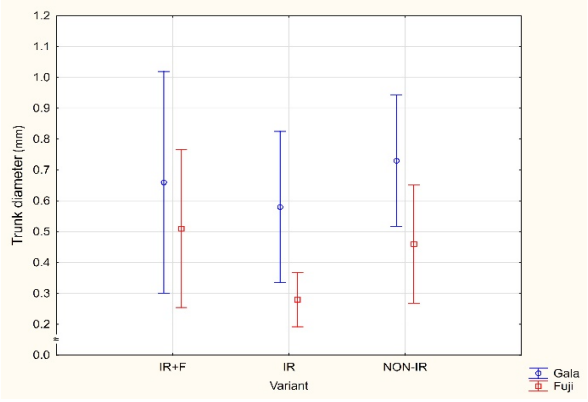
For the apple variety 'Gala', the largest trunk increments for vegetation were measured at variant NON-IR trees. Variant IR + F had smaller absolute increments. In variants of irrigation and between the measured varieties, there were no statistically significant differences (Fig. 1). Campi and García (2011) quoted the largest trunk increase at variant IR + F, by 11%, which is almost three times than our result. The reason for the difference can be a higher dose of nitrogen and different climatic and soil conditions. At variant NON-IR, the author gave the runk increment almost the same. In the 'Fuji' apple variety, the results were reversed.

Length of annual growth

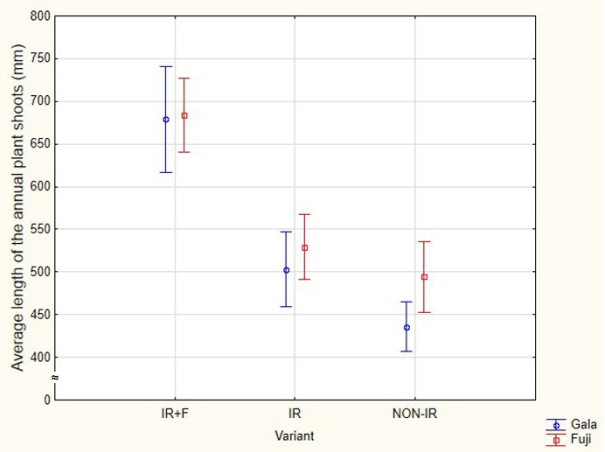
Accordingly, to the expectations, significantly, the highest average annual length of the shoot had treatment with variant IR + F. Statistically insignificant was the difference between IR and NON-IR (Fig. 2).

Sugar content

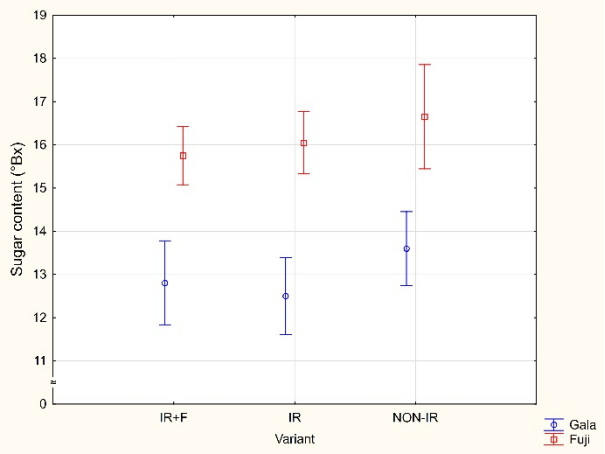
In the 'Gala' variety, the highest average sugar content was at the variant NON-IR with 13.55 °Bx, followed by the variant IR + F with 12.8 °Bx and



1: *Trunk diameter increment per variety and variant*



2: *Average length of the annual plant shoots*

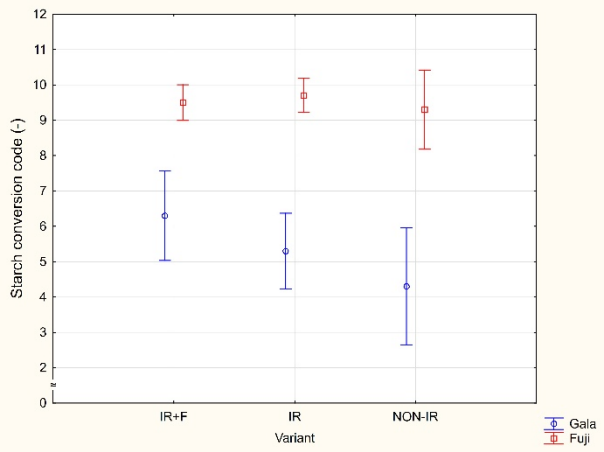


3: *Sugar content per variety and variant*

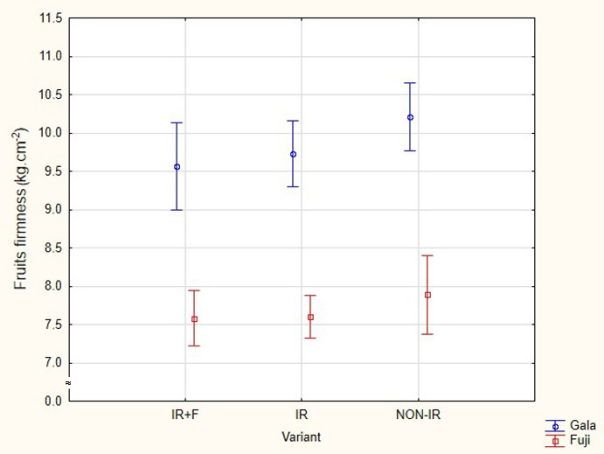
variant IR with 12.5 °Bx. The differences between variants were proven and the differences between the varieties are caused by the specific variety and the date of harvest (Fig. 3). Swarts *et al.* (2016) show a very similar sugar content as in our experiment. The higher sugar concentration in fruit variant NON-IR is, according to authors, caused by smaller fruits. In the 'Fuji' variety, the highest average sugar content was in variant NON-IR, 16.55 °Bx. Variant IR had an average sugar content of 16.05 °Bx and variant IR + F of 15.75 °Bx. Fallahi (2017) reports sugar content around 16 °Bx in their work. However, the order of the variants indicates the opposite, which justifies the climatic conditions of the given year. Wilcke (2005) reports optimum sugar content in fruit at harvest maturity of 12.5 °Bx for the 'Gala' variety and 14 °Bx for the 'Fuji' variety. This demand was achieved by both varieties and all three variants in the experiment.

Starch conversion code

The lower the starch value is, the more mature the apple and the higher the number of the degradation pattern is. Wilcke (2005) mentions an ideal starch degradation pattern ins between 5 to 7 for the 'Gala' variety and in between 4 to 6 for the 'Fuji' variety. In the 'Gala' variant IR + F, the average starch degradation pattern was 6.4, variant IR had an average starch degradation pattern 5.3 and variant NON-IR 4.3. This means, that the fruits in variant NON-IR were not yet mature. Similar results are reported by Swarts *et al.* (2016). The harvest of the 'Fuji' variety was done quite late for time reasons, but the difference across variants is still visible. The highest starch value contains variant NON-IR in the variety 'Fuji', which is same as in the 'Gala' variety. The highest starch degradation pattern of the average starch content had variant IR (9.7). Subsequently, variant IR + F had 9.5 and variant NON-IR 9.3. Wilcke (2005) states, that for the 'Fuji' variety, the most appropriate starch degradation pattern is between 4 and 6. That means that in our case, the apples were harvested over ripped. Fallahi *et al.* (2018) state at the harvest maturity the starch degradation pattern is 4.0 in variant IR + F, 4.3 in variant NON-IR. This means that all variants were harvested mature. With the 'Gala' variety (Fig. 4), there is slight trend of differences between the varieties, but in general, these differences are statistically not important.



4: *Starch conversion code per variety and variant*



5: *Fruits firmness per variety and variant*

Fruits firmness

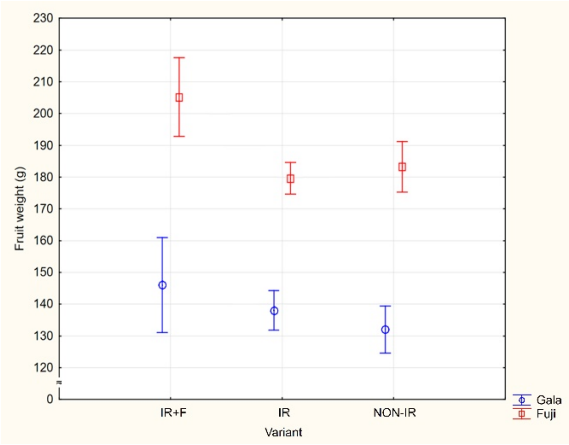
For the firmness of the apples, the rule is simple–the softer, the more mature. Average firmness of the 'Gala' variety in variant IR + F was 9.56 kg.cm^{-2}, variant IR had an average firmness a bit higher (9.73 kg.cm^{-2}) and variant NON-IR had the highest firmness 10.21 kg.cm^{-2}. Wilcke (2005) gives the most appropriate firmness for harvest maturity at 8 kg.cm^{-2}. Swarts *et al.* (2016) indicate firmness in variant IR + F the same as recommended by Wilcke (2005) for harvest maturity. Differences in firmness are due to the different climatic conditions. However, the differences between the variants are the same as in the experiment.

The average firmness of the 'Fuji' variety was the smallest at the variant IR + F (7.58 kg.cm^{-2}), then variant IR (7.6 kg.cm^{-2}) and variant NON-IR (7.98 kg.cm^{-2}). Wilcke (2005) reports an optimal firmness at harvest maturity of 6 kg.cm^{-2}, while Fallahi *et al.* (2010; 2018) reports a firmness of 7.3 kg.cm^{-2} in variant IR + F. According to Yildirim *et al.* (2016), irrigation reduced the fruit flesh firmness, which confirms our results (Fig. 5). Similarly, to the results of Starch conversion code, these results are not proved by any statistic.

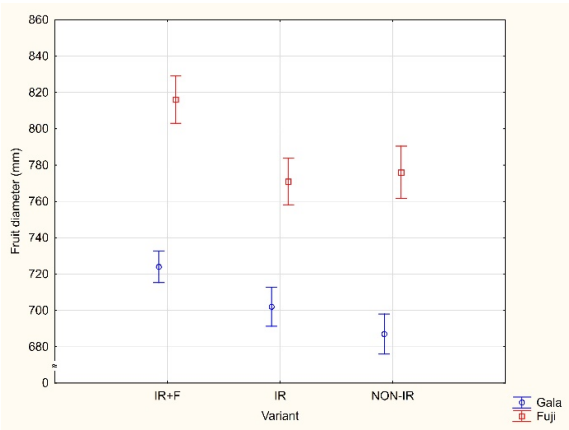
Fruit weight

In the 'Gala' variety, the average fruit weight was: in variant IR + F 146 g, in variant IR 138 g and in variant NON-IR 132 g. Blažek (2001) and Campi and García (2011) report that the difference between non-irrigated and irrigated fruits with fertigation is between 15 and 30%. However, the experiment shows a difference of only 10%. According to Robinson (2006) the reason for this difference is the residual nutrient supply in the soil of the previous vegetation.

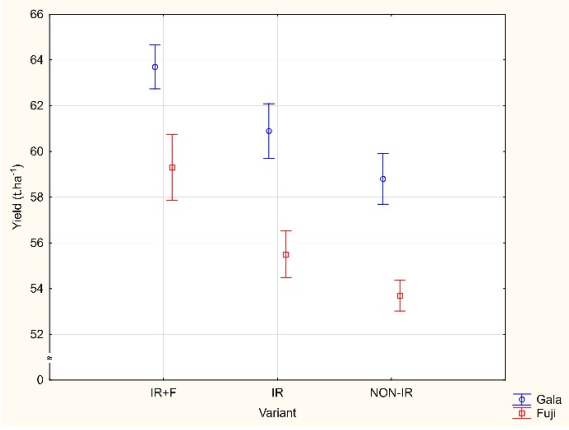
The average 'Fuji' fruit weight is one quarter higher than the 'Gala' variety. Variant IR + F had an average fruit weight of 205.2 g, variant NON-IR 183.2 g, and variant IR 179.6 g, event at this fruit variety, the difference of 15 and 30% was not confirmed between non-irrigated apples and apples irrigated with fertigation, as Blažek (2001) states. The measured difference was 11%. Fallahi (2017) reports weight in variant IR + F 256 g, which is almost 50 g more. The reason for this difference is apparently different cloud and clone. Statistically important difference was found out only at ther variant IR + F and only at the variety Fuji (Fig. 6).



6: *Fruit weight per variety and variant*



7: *Fruit diameter per variety and variant*



8: *Effects of different irrigation treatments on yield*

Fruit diameter

The fruit diameter of variety 'Gala' was in variant IR + F 72.4 mm, in variant IR 70.2 mm and in variant NON-IR 68.7 mm. Campi and García (2011) report almost the same diameter of the varieties in variant IR + F. In the variant NON-IR, they report smaller diameter of the apples – approximately 6 mm smaller. Yildirim *et al.* (2016) report, at the very similar climate conditions and as well after the first year of the experiment, almost the same diameters of the apples.

The fruit diameter of variety 'Fuji' was in variant IR + F 81.6 mm, and then in variant NON-IR 77.4 mm. The smallest diameter was at the variant IR 77.1 mm. The main reason for these results was probably not appropriate selection of the apples in May. Due to that, there are more apples on the tree, but with the shorter diameter as well as with

the lower weigh. Fallahi and Fallahi (2017) report the biggest diameter of the fruits in variant IR + F, which is 85.1 mm, and the smallest diameter in variant NON-IR, which is 69.8 mm.

The results of fruit diameter copy the results of fruit weight (Fig. 6 and 7). Moreover, statistically important difference was found out only at the variant IR + F and only at the variety 'Fuji'.

Yield

The total yield of the 'Gala' was 105% higher in the IR + F and 103% higher in the IR variant than in the NON-IR. The total yield of the 'Fuji' was 105% higher in the IR + F and 104% higher in the NON-IR variant than in the IR. Statistically important difference was found out at the variety 'Fuji' (Fig. 8).

Yildirim *et al.* (2016), Ucar *et al.* (2016) claim, that the total tree yield increased with irrigation level and are the same as authors Veverka and Pavlačka (2012) claim. The difference during the four years experiment between the variants IR + F and NON-IR was at the level 50%. On the other hand, Zegbe *et al.* (2007) claim, that the fruit yield at harvest was the same for the treatments.

CONCLUSION

The results obtained so far indicate the effect of the evaluated supplemental drip irrigation on the growth and the cavitative parameters of 'Gala' and 'Fuji' apple varieties. When evaluating the truncated strains where their diameter was determined, the values in all experimental variants were equalized without statistically significant differences. The annual plant shoots were the largest in full irrigation with fertigation variant in 'Fuji' variety and were 67 mm, their lowest values were in non-irrigation variants, in the 'Gala' variety they were only 43 mm. A significant qualitative indicator, when it comes to fruits, is the sugar content. The highest amount was determined for both varieties without irrigation, where the values varied between 13.5–16.5 Bx. For the market as well as for the farmers, the average weight of the fruit plays an important role. This was highest at the full irrigation with fertigation variant and was in 'Gala' variety 146 g and in 'Fuji' 205 g. The weight of fruits is directly connected with their total yield, which was the highest at the full irrigation with fertigation. The total yield of the 'Gala' variety was 64 $t.ha^{-1}$ and of 'Fuji' 59 $t.ha^{-1}$.

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