Thesis of Doctoral (PhD) dissertation

THE EFFECT OF WATER SUPPLY ON THE DEVELOPMENT AND GROWTH OF GREEN BEAN SPECIES (*PHASEOLUS VULGARIS L.*) AND SWEET CORN HYBRIDS (*ZEA MAYS* L. CONVAR. SACCHARATA KOERN.)

Krisztina Molnár

Supervisor: Dr. Attila Csaba Dobos

UNIVERSITY OF DEBRECEN
Kerpely Kálmán Doctoral School

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1. PRELIMINARIES AND OBJECTIVES OF DOCTORAL THESIS

Today, extreme weather, decrease inaverage annual rainfall and increase in average temperatures make it difficult to ensure the amount of water necessary for optimum plant growth and development. The amount and distribution of rainfall is also highly variable between different areas and each year. Plant growth, development and yield are highly influenced by the interaction between the plant and the physical environment. The most important reasons for many plants' inhibited growth and yield loss are the variability in water can be accepted (*Boyer*, 1982).

The growth of plants is highly influenced by the water stress occurring during the development. The growth period is shortened if the amount of water less and can be extended in humid periods. The degree of impact depends on the amount of water that can be taken up, it can be different for each plant and variety (*Muchow*, 1985). The negative impact of water shortage on yield is closely related to the growth stage in which water stress has an impact on the plant, as well as the length and strength of this stress (*Salter and Goode*, 1967).

The high level of safe production and reducing yield fluctuation irrigation is required (*Erdészné*, 2008). The plant's water consumption varies considerably during the growing season, it is depend on the activity of the plant and environmental conditions as well (*Cselőtei et al.*, 1993). In irrigated conditions it is important to optimize the yield and water use. This may be achieve if we take into account at the timing of irrigation to the unavoidable water shortage periods coincide with the least sensitive growth stages (*Arora and Gajri*, 1998).

Particularly in case of a vegetable (eg. green beans, sweet corn) is required for the correct application of irrigation technology, where optimal water supply for plant is a basic requirement to ensure the efficient production.

The examination of water supply of arable and horticultural crops and the development of adequate water supply strategies for given plants are essential fo rthe cost-effective and safe crop production.

In my dissertation I define the optimal water supply conditions of cultivated green beans and sweet corn based on the parameters of crop growth and productivity and water use.

To achieve my aims I want to answer the following questions:

- how the water supply affects the development and productivity of the examined varieties and hybrids in different phenophases,
- how change the performance of green beans and sweet corn in the different treatments based on the examined parameters of crop growth and productivity,
- what kind of relationships are between crop growth parameters and yield characteristics in different stages of development,
- how changes the evapotranspiration during the growing season under different water supply,
- how the water supply affects water use of the species and hybrids.

2. RESEARCH METHODS

The field experiment was carried out between 2011 and 2013 in the demonstration garden of the Institute for Horticultural Sciences of the University of Debrecen, on chernozem soil. We established our experiment on small-plots in randomized complete block design and we sown the green bean and sweet corn seeds with three replications per treatment.

2.1. Species and hybrids of the experiment

Table 1: Green bean species involved in the experiments

Species	*Growing period*	*Colour of pods*	*Experiment time*
Serengeti	early	green	2011-2013
Pation	medium late	green	2011-2012
Cerdon	medium early	green	2013
Carson	early	yellow	2011-2013
Maxidor	midseason	yellow	2012-2013

Table 2: Sweet corn hybrids involved in the experiments

Hybrid	*Growing period*	*Colour of grain*	*Experiment time*
GSS 1477	***79 day***	golden yellow	2011-2013
Overland (GSS 3287)	***84 day***	medium yellow	2011-2013
GSS 2259 (Shinerock)	***87 day***	medium yellow	2011-2013

2.2. Weather of the experimental years

At the beginning of the growing season in 2011 the monthly mean temperature was warmer than the mean of 30-year across the country. In May due to a cooler period the temperature aligned with the average values. In June and August the temperature was 2 °C higher than the mean of 30-year. The high temperature values combined with low rainfall. During the growing season in July were more rain (138.4 mm), which were rainstorms.The lack of rain in the growing period was more than -100 mm anomaly.

As in the previous year, in 2012 was drought.Between June and August the mean temperature were 2-3 °C higher the mean of 30-year. Only in June was more rain (97.8 mm) than the mean of 30-year on the experimental area. The growing season has also ended with -85 mm anomaly.

In March of 2013 the mean temperature was below the mean of 30-year (5.2 °C), and in this month more than three times higher (104.4 mm) rain fell than the average (29 mm) in the experimental area. As in previous years, the monthly mean temperature of summer was 1-2 °C higher than the mean of 30-year. During the growing season only in May (74.4 mm) was more rain than the average. July was the driest months, ended with 54 mm rain deficit (*Figure 1, 2*).

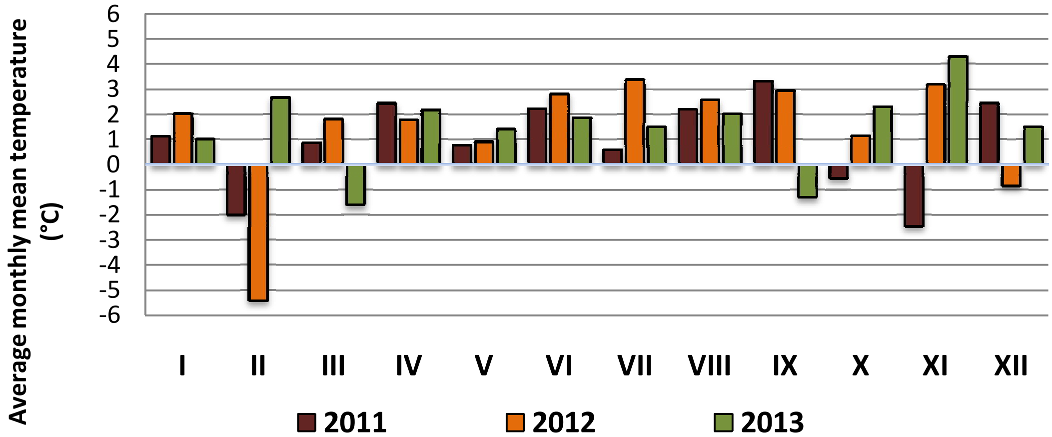


Figure 1: The temperature deviation of the30-year average in the experimental period (2011-2013)
(value of 0 means the 30-year average)

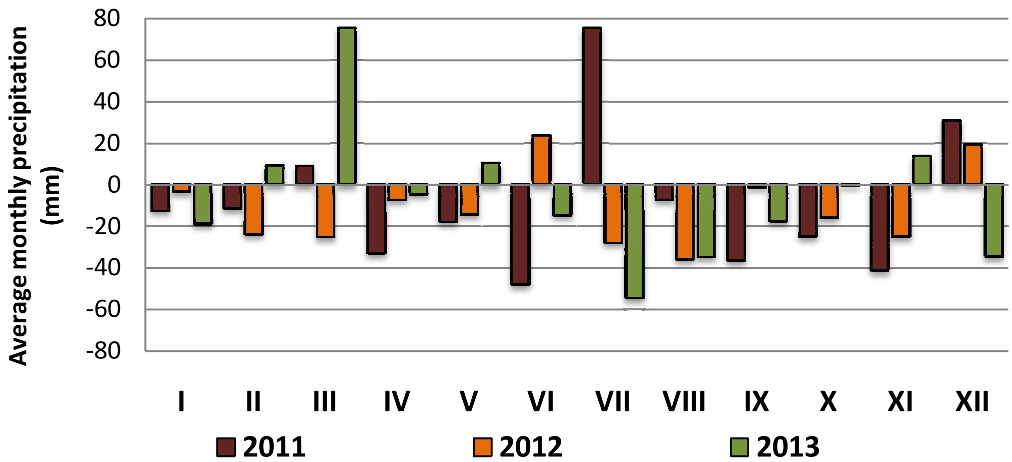


Figure 2: The average precipitation deviation ofthe 30-year average in the experimental period
(2011-2013)
(value of 0 means the 30-year average)

2.3. Irrigation treatments, assessment of water use

The aim of the experiment was to examine the effect of the water supply. So we determined the amount of irrigation water in different treatments by the daily data of meteorological station near the study area and we applied drip irrigation system. The firs treatment (full irrigation - Ö2) the amount of irrigation water was the evapotranspiration loss estimate by the Shuttleworth-Wallace method, in the second treatment (50% water deficit - Ö1) was the half of it. Without irrigation (Ö0) the plots were rain fed (*Table 3*).

Table 3: The amount of irrigation water in the treatments in 2011-2013

Year	**Green bean**		**Sweet corn**	
	Amount of irrigation water (mm)			
	50% water deficit (Ö 1)	**Full irrigation (Ö 2)**	**50% water deficit (Ö 1)**	**Full irrigation (Ö 2)**
2011	40	80	50	100
2012	43,5	87	62	124
2013	19,5	39	59	118

We modeled the change in crop water balance in space and time using MetAgro irrigation subsystem develpoed by the FAO recommendation (Allan et al., 1998).
In the treatments we determined the total water uptake of the growing season by actual evapotranspiration values. We characterized the water use (WUE) and irrigation water use efficiency (IWUE, $IWUE_2$) with yield produced per unit of water.

$$\mathrm{WUE} = \frac{\mathrm{yield\ (kgha^{-1})}}{\mathrm{ET\ (mm)}}$$

$$\mathrm{IWUE} = \frac{\mathrm{yield\ under\ irrigation\ conditions\ (kg\ ha^{-1})}}{\mathrm{amount\ of\ irrigation\ water\ (mm)}}$$

$$\mathrm{IWUE_2} = \frac{\mathrm{yield\ under\ irrigation\ conditions\ (kg\ ha^{-1})} - \mathrm{yield\ under\ rain\ fed\ conditions\ (kg\ ha^{-1})}}{\mathrm{amount\ of\ irrigation\ water\ (mm)}}$$

2.4. Measurements, examinations

We measured the parameters of growing and development in different phenophase on 10 plants per plots and in crops of plots. The parameters of fertility were measured after harvesting, the quality of yield were determined in laboratory.
We measured LAI, NDVI and SPAD values before flowering, during flowering and pod maturity in the case of green bean, and in 6-8 leaf stage, during tasseling and silking in the case of sweet corn.

2.4.1. Physiological experiment on plants (SPAD)

The chlorophyll content of the leaves was measured with *Minolta SPAD-502* portable chlorophyll meter.

2.4.2. Measurements in crops (LAI, NDVI)

The growth parameters of crops as leaf area (LAI= Leaf Area Index) we measured with *LI-COR LAI 2000* leaf area measurer and as spectral characteristic (NDVI= Normalized Difference Vegetative Index) we determined with *GreenSeeker Model 505* handheld crop sensor.

2.4.3. Measurements and examinations after harvesting

During harvesting we measured the yield parameters on 10 plants in every plots. We defined the yield and the amount of green biomass based on the yield of plots. The quality of yield were determined in laboratory.

2.5. Evaluation methods

The statistical evaluation was performed by using *Microsoft Excel and SPSS for Windows 16.0.* We used one-factor variance analyses (ANOVA) for the estimation differences of treatments, and Duncan's test or Games-Howell tests for simultaneous comparison of mean values, depending on the variance of the variables wasthe same or different. The regression analyses was used to reveal the relationships between the different parameters.

3. MAIN STATEMENTS OF THE THESIS

3.1. C*rop parameters in the experimental years*

3.1.1. Greenbean

3.1.1.1. Plant height

In 2011 every species were significantly higher in irrigation treatments (Ö1, Ö2), than in rain fed conditions. In 2012 there were significant difference between plant height in full irrigation (Ö2) and in rain fed (Ö0). In 2013 also growed better the plants in full irrigation (Ö2).

3.1.1.2. LAI

In our experiment we measured the leaf area 3 times in 2011 and 4 times in 2012 and 2013. The vegetative development of the plants was stronger in the irrigated treatments each year. In 2011 LAI values were from 4.63 to 5.76 m^2m^{-2} in irrigated treatments during pod maturity. During flowering the green been species had significantly higher leaf area index values in irrigation treatments, than in rain fed conditions (Ö0). In 2012, compared to the previous year, the photosynthetically active leaf area was smaller because of the moderate development in the drier growing season. Statistical differences between the treatments developed during pod maturity. In full irrigation (Ö2) LAI values were between 3,11-4,58 m^2m^{-2}. In three years, the lowest leaf area values were measured in 2013 (LAI maximum were 3,36-3,93 m^2m^{-2} in full irrigation), but the the growth dynamics of the species were similar. At the early growing species significant difference between LAI values of full irrigation (Ö2) and rain fed (Ö0) conditions was during pod binding. At midseason species the differences between the treatments were significant during flowering-pod binding.

3.1.1.3. NDVI

In our experiment we measured the NDVI values 3 times in 2011 and 4 times in 2012 and 2013. 2011 was unfavorable in precipitation for green bean development, the differences between the treatments were significant in the beginning of the measures. NDVI increased proportionally with water supply. During development these differences decreased, significant differences between NDVI of 50% water deficit (Ö1) and full irrigation (Ö2) disappeared for the duration of pod maturity. In rain fed conditions (Ö0) NDVI values were significantly lower.

In 2012 the effect of irrigation occured during flowering or pod binding at all varities. Carson and Pation responded as quickly as to irrigation. At the end of the vegetation period in 2013 the NDVI values of each species significantly lower in rain fed conditions (Ö0) than in irrigation treatments (Ö1, Ö2). Differences between treatments are the most pronounced in Carson and Serengeti.

3.1.1.4. SPAD

SPAD values of the treatments were measured on leaves before and during flowering, during pod binding and maturity in the three years. In 2011 the higher average SPAD values were in rain fed (Ö0), the lower were in irrigation treatments (Ö1, Ö2). The differences between rain fed and irrigated conditions decreased at each species after flowering. In 2012 the differences between the treatments were the most pronounced at Carson and Pation during pod binding, at Serengeti was this at pod maturation. In 2013 the differences between the treatments were the most pronounced at Serengeti during flowering. The average SPAD values of the other species were the same in irrigated treatments (Ö1, Ö2), and were lower than in rain fed (Ö0) conditions.

3.1.1.5. Evaluation of crop parameters

We have given points for crop condition based on the significant differences between measuring parameters. The species with highest significant values (a) gave the highest point (3). The species with significantly lower values gave one point less, the same result reached the same point.

Summerized the partial points in 2011 we determined that the species based on its crop condition have the same position in the hierarchy in treatments. Pation had the highest total points in all three treatments, the further order of decreasing condition is: Serengeti, Carson, Maxidor. In 2012 after summation of the partial points we determined that rain fed conditions was appropriate for developement of Serengeti and Carson, in 50% water deficit Pation had the best crop condition and in full irrigation Pation and Serengeti have tthe best values, but Carson develop well also. Maxidor was weak in every treatment. In 2013 based on the total points Maxidor had the best crop condition in rain fed treatement. The other three species have weak, but similar condition. In 50% water deficit Maxidor and Cerdon have the similar good crop condition, Serengeti and Carson have weaker than this. In full irrigation Carson had the lowest, Maxidor have the highest points. Cerdon and Serengeti points were similar and between the other two species' points.

3.1.2. Sweetcorn

3.1.2.1. Plant height

There were significant differences in plant height in treatments for all three hybrids in the experimental period. The lowest plants were in rain fed conditions (Ö0), the highest plants were in irrigation treatments (Ö1, Ö2). The highest of the three is GSS 2259, its plant height were 257-288 cm in full irrigation.

3.1.2.2. LAI

Based on the statistical evaluation in 2011 and 2012 there were not significant differences between treatments at 5% significance level in average LAI values of the the different developement stages (6-8 leaf stage, tasseling, silking) at GSS 1477. In 2011 LAI values in treatments of GSS 2259 and Overland had significant differenes during tasseling and silking. In 2012 significant differences of treatments at GSS 2259 and Overland were from 6-8 leaf stage till tasseling. Irrigation had an effect on LAI values only at Overland during silking and grain filling. In 2013 we measured LAI values in 4 times (6-8 leaf stage, tasseling, silking, grain filling) during the growing season. Because of the slow growth after emergence the development of the hybrids were the same. Overland had not developed as strongly as in previous years. Significant difference between the treatments were only at GSS 2259 and Overland during silking.

3.1.2.3. NDVI

In 2011 differences of NDVI values in the treatments were most pronounced during tasseling. In 2012 GSS1477 had the significantly higher NDVI values in 50% water deficit during silking, but GSS 2259 had the significantly higher NDVI values in full irrigation during silking. The 2013 year has started positively for the cultivation of corn, plant development was the most intense in 6-8 leaf stage. The amount of irrigation water till tasseling caused significant differences between rain fed and irrigation conditions (Ö1, Ö2).

3.1.2.4. SPAD

We began SPAD values measuring on the leaves of sweet corn in 2012. During tasseling the SPAD values of GSS 1477 were the highest in 50% water deficit and the lowest in full irrigation. The SPAD values of rain fed conditions did not differ significantly from irrigation treatments. SPAD values of GSS 2259 and Overland were similar in different water supply. During silking the three hybrids had significantly higher SPAD values in irrigation treatments (Ö1, Ö2) than in rain fed conditions. In

2013 the hybrids had the same react to irrigation. We measured the highest SPAD values in full irrigation. GSS 1477 and GSS 2259 had significantly higher SPAD values during silking and grain filling in full irrigation. Overland had the lowest average SPAD values in 50% water deficit in each phenophase.

3.1.2.5.Evaluation of crop parameters

We have given points for crop condition based on the significant differences between measuring parameters. The hybrid with highest significant values (a) gave the highest point (3). The hybrid with significantly lower values gave one point less, the same result reached the same point.

Because in 2011 the plant condition parameters in the treatments were no significant differences, so all three hybrids were evaluated one point, the plant body condition were the same. In 2012, to characterize the crop condition of the sweet corn hybrids we measured next to LAI and NDVI values we measured the SPAD values also. We determined based on the total points of crop condition that in rain fed conditions GSS 1477 and Overland, in full irrigation GSS 2259 had the best crop condition. The hybrids had similar crop condition in 50% water deficit. The total points in 2013 shown that in rain fed conditions Overland had the best condition, GSS 2259 had weaker, GSS 1477 had the weakest. In 50% water deficit GSS 2259 had the higher, GSS 1477 had the lower total score. In full irrigation Overland was the best, the other two hybrids were weaker, but had similar crop condition.

3.2. Yield parameters in the experimental period

3.2.1. Green bean

The water supply is heavily influenced by fertilization of green beans, which can be characterized by the number of standard and non-standard pods. During the harvest we measured fertility (numbers of standard and non-standard pods) and quality distribution of pods (weight of standard and non-standard pods) on the selected individuals of species in different treatments. To determined yield potential we defined the weight of standard and non-standard pods on plants, the yield of plots in t ha^{-1}.

The difference between the productivity parameters of species was significant at different levels. We have given points for productivity based on the significant differences between measuring parameters.

In the case of weight of standard pods and yield in t ha^{-1}the species with lower significant values (b,a) gave the higher point (2,3). In the case of weight of non-standard pods we gave points in reverse order: the species with lower significant values (b,c) gave the higher point (2,3), which had more yield (a) gave lower point (1). The species with significantly higher values gave one point less, the same result reached the same point. After a summary of the productivity parameters we determined which variety in which treatment was the best.

In 2011, after we summarized the part points based on significant differences we defined that the production of the plant is fully consistent with the crop condition. All thetreatment Pation with the best crop condition has made the best yields, the weakest was Maxidor. In the case of the other variety in rain fed conditions the hierarchy is the same as in crop condition: 2. Serengeti, 3. Carson. In 50% water deficit Carson and Serengeti had the same productivity, in full irrigation Carson had higher yield than Serengeti.

In 2012, after scoring productivity, we determined that Carson was the best in all three treatments. In rainfed conditions the other species had the similar productivity values.In 50% water deficit, after Carson, Pation with the best condition gave the higest total score, production of Maxidor and Serengeti is the same. In full irrigation Maxidor had the lowest points.

In 2013, after we gave points for green bean productivity parameters based on significan tdifferences we defined that in rain fed conditions Maxidor had the best crop condition and productivity. Productivity parameters of Carson and Cerdon were better, than Serengeti, despite of they had the same crop condition based on LAI, SPAD and NDVI values. In 50% water deficit Cerdon and Maxidor had the best adaptation to the circumstances, so they had the best in crop condition and productivity. The results of Serengeti and Carson were similar to their crop condition. In full irrigation Maxidor and Cerdon had the highest total score, Carson had better productivity than Serengeti.

In the case of green been the water supply, the air and soil temperature during pod maturity has an effect on nutrient uptake and utilization and through this on yield quality. In dry years the dry matter, protein and fiber content of green bean pods increase. The highest differences between the species were found in full irrigation. In 50% water deficit there were differences between the species only in proteint content.

The protein content of the species is the same in rain fed conditions, but Serengeti was the highest dry metter and fiber content.

3.2.2. Sweet corn

During harvesting we measured ear weight with or without husk, ear length and ear diameter and number of kernel rows.

The estimation of productivity we used ear weight with or without husk, net/gross ear weight, ear length and diameter, number of kernel rows and the yield in t ha^{-1} (weight without husk) of plots. The difference between the productivity parameters of species was significant at different levels.

We have given points for productivity based on the significant differences between measuring parameters. The hybrid with the lowest significant values gave the 1 point, the hybrid with significantly higher values gave 2 point. The hybrid with significantly the highest value gave 3 point. The same result reached the same point. After a summary of the productivity parameters we determined which hybrid in which treatment was the best.

In terms of productivity 2011 was the best for GSS 1477. In rain fed and full irrigation Overland could better adapt to different conditions than GSS 2259, in 50% water deficit they had the similar productivity. The meteorological conditions in 2012 was good for developement of GSS 2259. The water supply in 50% water deficit had better effect on Overland productivity, in full irrigation had better effect on GSS 1477 productivity. In 2013 Overland with good crop condition was the best productivity. In full irrigation GSS 2259 with weaker crop condition had the higher total score. In the case of GSS 1477 weaker crop condition caused weaker productivity.

The dry matter content was higher in rainfed conditions all threehybrids, the water supply had different effect of the sugar content of hybrids, the carotene content increased with water supply in direct proportion.

3.3. Relationshipsbetween development and productivity in different phenophase

3.3.1. Green bean

We determined the relationship between the yields and the studied parameters by linear regression at 5% significance level. On the basis of three years data there were average correlation between the amount of standard pods and LAI, NDVI or SPAD values during the development of green beans for each treatment (*Table 4*).

Table 4.Correlation between the measured parameters and yield of green bean (2011-2013)

	LAI - Standard pods ($t\ ha^{-1}$)			NDVI- Standard pods ($t\ ha^{-1}$)			SPAD- Standard pods ($t\ ha^{-1}$)		
	Ö0	**Ö1**	**Ö2**	**Ö0**	**Ö1**	**Ö2**	**Ö0**	**Ö1**	**Ö2**
Before flowering	0,183	**0,465**	**0,595**	0,230	0,268	0,071	0,318	**0,400**	0,314
Flowering	0,000	**0,429**	**0,430**	0,186	**0,640**	**0,608**	0,069	**0,464**	0,213
Pod binding	**0,461**	0,396	**0,499**	0,052	**0,544**	0,076	0,389	0,294	0,090
Pod maturity	0,065	**0,610**	0,135	**0,564**	**0,573**	0,257	0,020	**0,426**	0,295

Correlation at p=0,05 level, Ö0- rain fed, Ö1- 50% water deficit, Ö2- full irrigation

3.3.2. Sweet corn

Average and strong correlations between the ear weight without husk (tha^{-1}) of sweet corn versus leaf area, vegetation index or SPAD values were found in different development stages and treatments(*Table 5*).

Table 5. Correlation between the measured parameters and yield of sweet corn (2011-2013)

	LAI - Ear weight ($t\ ha^{-1}$)			NDVI - Ear weight ($t\ ha^{-1}$)			SPAD - Ear weight ($t\ ha^{-1}$)		
	Ö 0	**Ö 1**	**Ö 2**	**Ö 0**	**Ö 1**	**Ö 2**	**Ö 0**	**Ö 1**	**Ö 2**
6-8 leaf	**0,436**	0,385	**0,632**	**0,537**	**0,423**	**0,562**	**0,434**	**0,751**	0,322
Tasseling	0,076	**0,421**	0,292	0,178	0,349	0,356	**0,479**	**0,591**	0,339
Silking	**0,484**	**0,407**	0,284	**0,454**	0,268	**0,426**	0,270	**0,710**	**0,513**
Grain filling							0,105	0,162	0,349

Correlation at p=0,05 level, Ö0- rain fed, Ö1- 50% water deficit, Ö2- full irrigation

3.4. Changes of potential evapotranspiration in the growing season

3.4.1. Green bean

The potential evapotranspiration (ET) was the highest in full irrigation (Ö2) in every year. The MetAgro water balance model calculated 23-30% higher ET in 50% water deficit and 41-57 % higher ET values in full irrigation than under rain fed conditions in the 2011 and 2012 growing season in green bean plots.In the 2013 growing season due to the favorable temperature and precipitation conditions the differences between ET of treatments were more moderate (in 50% water deficit 14%, in full irrigation 22% higher ET than under rain fed conditions).

3.4.2. Sweet corn

In the examination period in full irrigation was the highest potential evapotranspiration (ET) also. At sweet corn ET calculated by the system were 9% higher in 50 % water deficit and 13% higher in full irrigation than in rain fed plots in 2011. In 50 % water deficit by 21%, in full irrigation from 40 to 42 % more water could transpired from plants than under rain fed conditions in 2012 and 2013.

3.5. Wateruse in the examination period

3.5.1. Green bean

The water use efficiency (WUE) of green bean was calculated as pod weight of plots (standard and non-standard) divided by seasonal ET. The irrigation water use efficiency (IWUE) was the ratio of yield in irrigated plots and total seasonal irrigation water applied, the irrigation effect ($IWUE_2$) was the yield difference between irrigated and rain fed treatments divided by amount of irrigation water.

We measured the highest average WUE in full irrigation in 2011 and 2013, and in 50% water deficit in 2012.We determined the irrigation water use efficiency in irrigated plots annually and by varieties. The higher irrigation water use efficiency (IWUE) and irrigation effect ($IWUE_2$) values of varieties were in 50% water deficit in every year.

Based on the average of three-year in 50% water deficit 9% decrease in WUE caused 19% yield reduction, under rain fed conditions 60% decrease in WUE caused 70% yield loss compared to the full irrigation WUE values.

We user linear regression to examine the relationship between water use and yield. Water use efficiency (WUE) and irrigation water use efficiency (IWUE, $IWUE_2$) values of green beans also showed positive correlation with the yield (*Figure 3*).

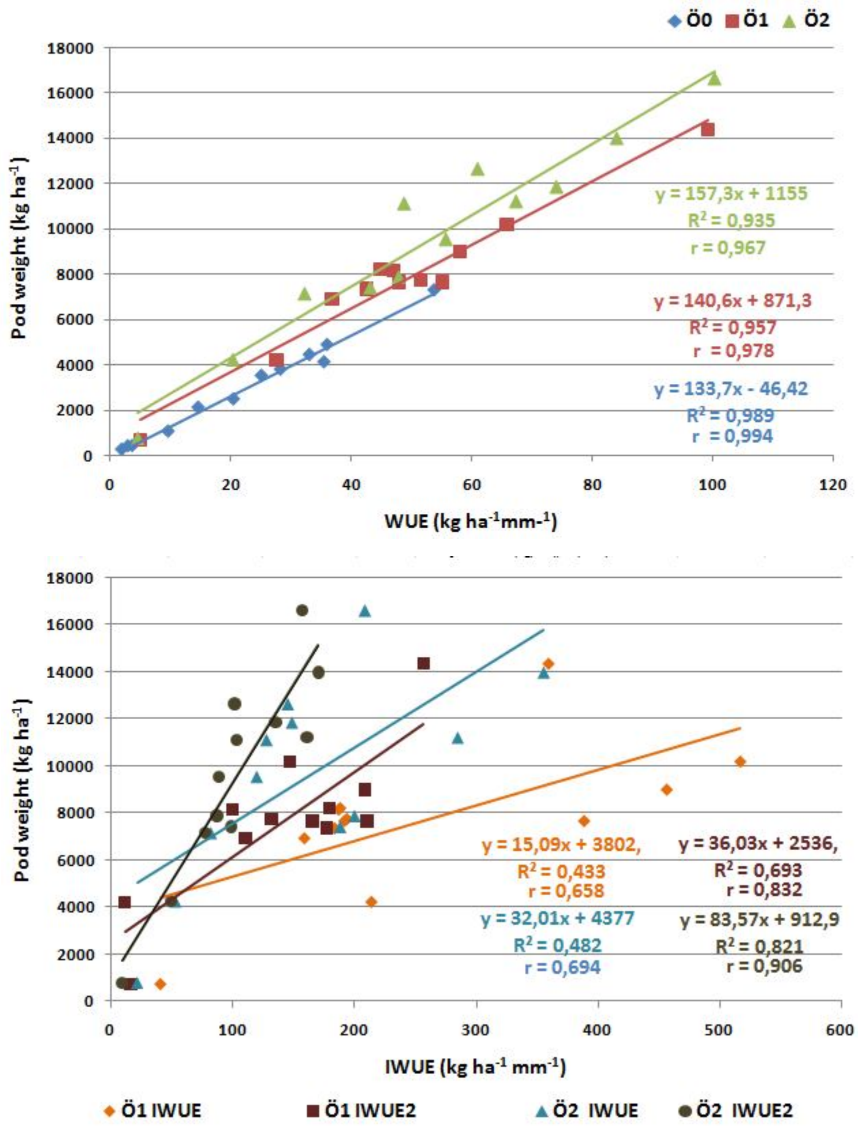


Figure 3: Relationships between pod weight and water use of green bean
(Ö0-rain fed, Ö1-50% water deficit, Ö2-full irrigation, WUE- water use efficiency, IWUE- irrigation-water use efficiency, IWUE2- irrigation effect)

3.5.2. Sweet corn

The water use efficiency (WUE) of sweet corn was calculated as ear weight without husk of plots divided by seasonal ET. The irrigation water use efficiency (IWUE) was the ratio of yield in irrigated plots and total seasonal irrigation water applied, the irrigation effect ($IWUE_2$) was the yield difference between irrigated and rain fed treatments divided by amount of irrigation water.

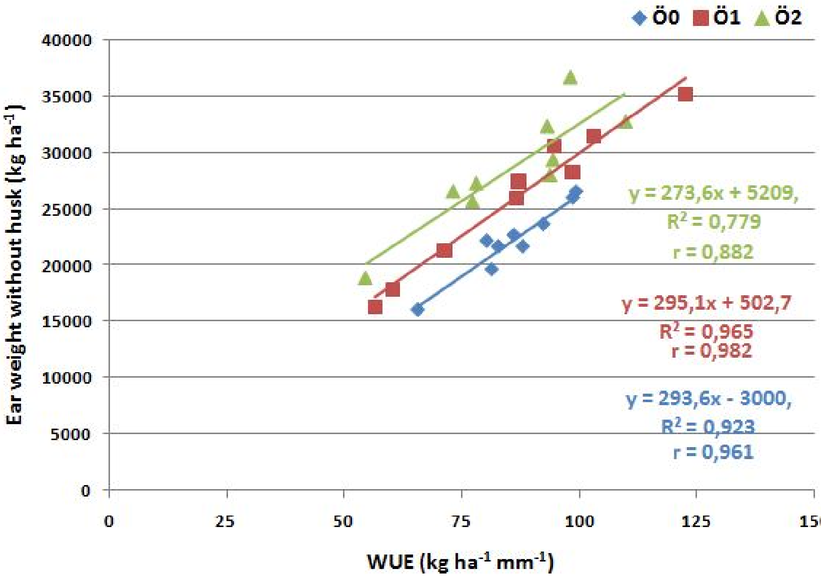
Sweet corn recovered most of the available water in 2011 and 2012 in 50% water deficit, and in 2013 under rain fed conditions based on the average water use efficiency of hybrids.

In irrigation treatements (Ö1, Ö2) we determined the irrigation water use efficiency by hybrids in each years. The averege irrigation water use efficiency (IWUE) of 50%

water deficit were 98% higher in 2011, 87% higher in 2012 and 55% higher in 2013 than in full irrigation. We observed similar, but moderate differences at the case of irrigation effect ($IWUE_2$).

There was little differences in average WUE values in the different treatments. Despite of it, the decreasing available water caused decreasing yield. The yield was 9% lower in 50% water deficit and 22% lower under rain fed conditions than in full irrigation.

Strong positive correlation was also found between the water use and yield, irrigation water use efficiency and yield of sweet corn (*Figure 4*).



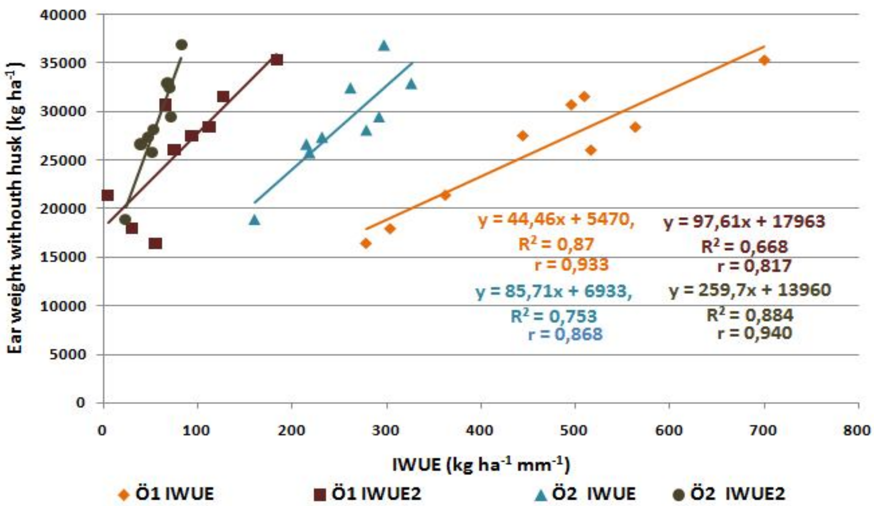


Figure 4: Relationships between ear weight and water use of sweet corn
(Ö0-rain fed, Ö1-50% water deficit, Ö2-full irrigation, WUE- water use efficiency, IWUE- irrigation-water use efficiency, IWUE2- irrigation effect)

4. NEW SCIENTIFIC RESULTS OF THE THESIS

- Water supply had significant effect on leaf area of green bean during pod binding and on spectral characteristics (NDVI, SPAD) during flowering and pod bindig. Water supply significantly influenced the leaf area of sweet corn during tasseling, the vegetation index during silking and SPAD values during silking and grain filling.
- Medium correlations between spectral characteristics (NDVI, SPAD) in different phenophase and yield of green bean and sweet corn provide an opportunity to predict the expected yield.
- Between irrigation-water use efficiency (IWUE) and yield was medium correlation at green bean and strong correlation at sweet corn. Based on these resulta we can determine the optimal water supply level for varieties and hybrids cultivation.
- Decreasing water use efficiency (WUE) cause significant (r=0,967-0,994) yield loss in the case of green bean, and moderate (r=0,882-0,982) yield loss in the case of sweet corn.

5. USABILITY OF THE RESULTS IN PRACTICE

- Water loss caused increasing dry matter, protein and fiber content of green bean pods. Among the varieties of green pods Serengeti is the most sensitive to water stress, its pods became hollow soon, but high protein content of pods give good food quality. The yellow pods Carson protein content is higher, but its more sensitive to water loss than Maxidor.
- Effect of irrigation on carotene content of sweet corn increased slightly, dry matter content of sweet corn decreases. GSS 1477 has the highest sugar-content in full irrigation. The sugar-content of GSS 2259 is the lowest in 50% water deficit. The sugar-content of Overland decreases with irrigation.
- Based on water use efficiency (WUE) and irrigation-water use efficiency (IWUE) Serengeti, Pation and Maxidor prefer 50% water deficit, Carson prefer full irrigation; GSS1477 sweet corn hybridis grateful for irrigation, GSS 2259 prefer full irrigation, Overland favor dry conditions.

6. REFERENCES

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7. PUBLICATIONS IN THE SUBJECT MATTER OF DISSERTATION

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PUBLICATIONS

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Doctoral School: Kerpely Kálmán Doctoral School of Corp Production, Horticulture and Regional Sciences

List of publications related to the dissertation

Foreign language international book chapter(s) (1)

1. Nemeskéri, E., **Molnár, K.**, Vig, R., Dobos, A., Nagy, J.: Defence Strategies of Annual Plants Against Drought.
   In: Advances in Selected Plant Physiology Aspects. Ed.: by Guiseppe Montanaro, Bartolomeo Dichio, Intech, Croatia, 133-158, 2012. ISBN: 9789535105572
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Hungarian scientific article(s) in Hungarian journal(s) (3)

2. **Molnár K.**, Vig R., Nemeskéri E., Dobos A.: A vízellátottság és az évjárat hatása eltérő genotípusú csemegekukorica (Zea mays L. saccharata Koern.) hibridek termőképességére.
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3. Dobos A., Vig R., **Molnár K.**, Nagy P.T.: Biotrágyák hatása a növényi kondícióra és a termésre.
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4. Vig R., Dobos A., **Molnár K.**, Nagy J.: Természetes alapanyagú lombtrágyák hatékonysága szabadföldi kísérletekben: I. Kukorica (Zea mays L.).
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5. Dobos, A., **Molnár, K.**, Nemeskéri, E., Vig, R.: The effect of water supply on the Normalized Difference Vegetation Index (NDVI).
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H- 4032 Debrecen, Egyetem tér 1. ¤ E-mail publikaciok@lib.unideb.hu

6. **Molnár, K.**, Vig, R., Dobos, A., Nemeskéri, E.: The crop condition and productivity of greenpea and green bean under extreme water supply.
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   DOI: http://dx.doi.org/10.1556/Novenyterm.59.2010.Suppl.4

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8. **Molnár, K.**, Dobos, A., Nagy, J., Nemeskéri, E., Dövényi-Nagy, T., Rácz, C., Bakos, K.L.: The effect of water supply on yield and water use of green bean.
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List of other publications

Hungarian scientific article(s) in Hungarian journal(s) (1)

9. Dobos A., Vig R., **Molnár K.**, Nagy J.: Természetes alapanyagú lombtrágyák hatékonysága szabadföldi kísérletekben:II. Burgonya (Solanum tuberosum L.). *Növénytermelés. 60* (1), 27-42, 2011. ISSN: 0546-8191.

Foreign language scientific article(s) in Hungarian journal(s) (1)

10. Vig, R., Dobos, A., **Molnár, K.**, Nagy, J.: The efficiency of natural foliar fertilizers. *Időjárás. 116* (1), 53-64, 2012. ISSN: 0324-6329.
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11. Rácz, C., Dobos, A.C., Nagy, J., Dövényi Nagy, T., **Molnár, K.**, Bakos, K.L.: Evaluation of the divergence between outputs of different evapotranspiration models. In: 13th ESA Congress Proceedings. Szerk.: Pepó Péter, European Society for Agronomy, Debrecen, [2] p., 2014.

Total IF of journals (all publications): 0.289
Total IF of journals (publications related to the dissertation): 0

The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of Web of Science, Scopus and Journal Citation Report (Impact Factor) databases.

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