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Impact of quantity and intensity of rainfall on soil water content in an orchard located in the central part of Poland

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Abstract: The measurement of water used by plants is a decisive factor for calculation of irrigation rates, and generally the need of irrigation. Quantity, intensity and seasonal distribution of precipitation have an indubitable impact on soil moisture. Precipitation water could be used by plants only when percolates into soil and is retained as capillary water. Unfortunately, in case of excessive amount or intensity of rain, part of water percolates below the root system range or runs off at soil surface. During three years of experiment (1995-1997) quantity and intensity of precipitation were observed and weekly measurements of soil moisture at different orchard layouts were done. On the basis of collected data, the analyses of impact of quantity and intensity of precipitation on soil moisture changes in orchard were conducted. The results indicate low efficiency of small rains (smaller than daily potential evapotranspiration). Relatively small efficiency was found also for stormy rains, whose contribution to the total amount of precipitation during vegetative period was from 20 % up to 36 %. Efficiency of precipitation depended also on initial soil moisture, which was the reason of high differences in influence of precipitation amounts on changes of water content in soil profile in irrigated and non-irrigated orchards.

Key words: *precipitation efficiency; soil water content; TDR; orchard*

INTRODUCTION

The measurement of crop evapotranspiration is essential for evaluating irrigation needs. The determination of soil water balance is one of the most widely used methods for their evaluation. Precipitation is the major input to the soil water balance in temperate zones. Its amount, intensity and temporal distribution have a indubitable influence on soil moisture. According to DRUPKA (1993), the most useful rainfalls for plants are those with very low intensity and small drops, of intensity not higher than 2-3 $mm \cdot h^{-1}$. BAC and ROJEK (1979) increase this threshold to 4 $mm \cdot h^{-1}$. Excessive amounts or intensity of precipitation can cause the surface runoff or percolation below the root system range (BALLIF, 1995). According to ŚWIĘCICKI (1981) in Polish orchards the runoff is caused by rains with intensity over 10 mm·h^{-1}.

Very small rains do not influence soil moisture. According to CHUDECKI *et al.* (1971), 2.5 mm daily rainfalls have no significant impact on soil moisture. ŚWIĘCICKI (1981) says after RODE (1963), that even daily precipitation up to 5 mm does not influence the plants growth. Part of such a rain evaporates immediately, and part moistens only shallow soil layer and does not reach the root system. According to DRUPKA (1976) effective rainfall is the precipitation which influences soil water status, and only precipitation higher than daily values of potential evaporation should be taken into consideration.

All above considerations could be discussed within the framework of widely accepted models of water distribution in atmosphere-soil-plant system, and particularly the formula of soil water balance (KĘDZIORA, 1995). For analyses of influence of precipitation on changes of soil water content in accordance to such models, however, the number of various observations is essential to allow description of changes and interaction of all elements. When the experiment is planned to represent many crops, soil types, cultivation technologies and when the final conclusions are requested to be practically useful, large number of observed parameters is not economically justified. In such a case, the simplification of water balance formula is advisable to reduce variety of required observations and to allow at least for indicating (but still useful in irrigation practice) evaluation of precipitation efficiency.

The aim of experiment was to evaluate dependence of soil water content in irrigated and non-irrigated orchards upon the total amounts and intensity of precipitation.

MATERIAL AND METHODS

EXPERIMENTAL SITE AND PLANT MATERIAL

The experiment was conducted at Research Institute of Pomology and Floriculture in Skierniewice in 1995-1997 years. Because of anticipated small number of heavy rains and rainstorms during experimental period, sufficient number of data was obtained by enlarging number of crop/cultivation combinations. The cultivars, rootstocks and models of orchard were selected torepresent current trends in horticulture. Eleven combinations of different age, planting density and canopy size were selected. Each combination was irrigated with part of trees serving as non-irrigated control. Sweet cherries (one combination) were irrigated by means of micro jets, while drip irrigation systems were installed at all other combinations of apples, plums and sour cherries. Orchard was planted on grey-brown podzolic soil with loamy subsoil. Moisture contents for different pF values are presented in Table 1.

Table 1. Soil moisture (% vol.) at different levels of water potential pF

Soil layer cm	Density g·cm^{-3}	pF 2	pF 2.85	pF 3.2	pF 4.2
15-20	1.55	22.23	18.75	16.95	13.78
40-45	1.62	27.55	24.5	22.9	19.65

2.2. MEASUREMENT OF METEOROLOGICAL VARIABLES AND SOIL WATER CONTENT

Each year from the beginning of May until the end of September the followi[ng] meteorological measurements were made: total precipitation and its intensity, wi[nd] speed, air temperature and relative humidity, and solar radiation. The measureme[nts] were made with an automatic meteorological station METOS (produced by Pes[sl], Austria) at 12 minutes intervals. On the basis of the collected data, potential evap[o]transpiration was calculated by METOS software using the Penman equation in t[he] following form (modification of formula presented by DOORENBOS and PRUI[TT] (1977):

$$ET_o = \frac{\Delta}{\Delta+\gamma}R_n + \frac{\gamma}{\Delta+\gamma}0{,}26(1+\frac{u}{100})(e_a - e_d)$$

where:

ET_o – potential evapotranspiration, mm·day^{-1},
Δ – slope of saturation vapour pressure curve, mbar·K^{-1},
γ – psychrometric constant = 0.66 mbar·K^{-1},
R_n – net radiation balance calculated as the sum of measured values, W·m^{-2} c[ol]lected every 12 minutes,
u – wind velocity at 2 m height, km·day^{-1},
e_a – mean saturation vapour pressure at a given air temperature, mbar,
e_d – saturation vapour pressure at dew point, mbar.

To allow the calculation of soil water balance for the irrigated and non-irriga[ted] plots, measurements of soil water content were made once a week using the TRA[SE] meter at 20, 40 and 60 cm thick soil layers (below soil surface) in four repetitions [in] each experimental plot. Soil moisture meter TRASE (produced by Soilmoisture, US[A]) is a time domain reflectometry (TDR) type equipment, and allows fast and accu[rate] measurement of average moisture (in % of volume) of a defined soil layer.

The changes of soil water content (*CSWC*, mm·week^{-1}) were calculated us[ing] simplified equation:

$$CSWC = SWC_f - SWC_i$$

where:

SWC_f – final soil water content (after weekly period), converted from TDR measurement (for an evaluated soil layer) to an equivalent "mm" value,

SWC_i – initial soil water content for evaluated soil layer, mm.

2.3. GENERAL CHARACTERISTICS OF PRECIPITATION DURING EXPERIMENTAL PERIOD

The temporal distribution of precipitation for each year is presented in Table 2. Total rainfalls for years 1995 and 1997 were only slightly different from multi-year average. Using the classification described by KACZOROWSKA (1962) these two years were "normal", while 1996 year was "wet". The temporal distribution of precipitation differed between years. Year 1997 was specific, because total precipitation from May until July was high and equaled to 302 mm, while from August to October it was 25 mm only. Individual years differed also in the total number of rainy days (in the May-September period).

Table 2. Distribution of precipitation in Skierniewice for 1995-1997 years and mean distribution for period 1951-1970, mm

Years	Months												Sums	
	J	F	M	A	M	J	J	A	S	O	N	D	M-S	J-D
1995	22	33	38	58	53	63	51	48	75	10	49	30	290	530
1996	21	20	140	40	81	67	169	51	76	17	27	2	444	711
1997	79	44	19	31	106	63	132	9	13	3	14	42	323	555
1951-70*	21	26	23	34	58	65	93	60	43	29	41	31	319	524

* according to KRUSZE (1984)

3. RESULTS AND DISCUSSION

3.1. EFFECTIVE RAINFALL JUDGEMENT

Not every precipitation is important for the proper irrigation scheduling, since not every one affects the soil water content. Only the rainfall which changes soil moisture can be considered effective. Table 3 shows numbers of rainy days, number of days when daily precipitation was higher than potential evapotranspiration (ET_o), and number of days with precipitation exceeding 5 mm. Collected data show distinct differences between number of rainy days for individual years. From May to September 1997 the number of rainy days was the lowest (41), and twice lower than for 1996.

Table 3. Number and percentage contribution of rainy days depending on adopted efficiency criterion (for the periods May-September)

Years	Number of rainy days					
	Total		> ET_o (acc. DRUPKA, 1976)		> 5 mm (acc. ŚWIĘCICKI, 1981)	
	number	%	number	%	number	%
1995	53	100	39	74	23	43
1996	82	100	55	67	26	32
1997	41	100	28	68	21	51

Adopting different criteria for effective rainfall judgement resulted in large differences between counted numbers of days with effective rainfall. The days with precipitation higher than ET_o made 67 % to 74 % of all rainy days (depending on year), while the days with precipitation higher than 5 mm made only 32 % to 51 % of all rainy days.

Also the comparison of total effective precipitation (Fig. 1) shows great differences between the two above criteria. Total contribution of daily rainfalls higher than ET_o was relatively uniform between years and made 88 % of total precipitation in 1995, 96 % in 1996, and 91 % in 1997 year. The contribution of rainfalls higher than 5 mm varied much more and made 75 % of total precipitation in 1995, only 49 % in 1996, and as much as 90 % in 1997. Especially low contribution of precipitation over 5 mm in "wet" 1996 year was caused by very great number of days with precipitation below 5 mm (56 days), of which days part happened in sequences. According to DRUPKA (1993) this type of precipitation is very effective for plants. Recapitulating, the effective rainfall judgement depends not only on amount of daily precipitation, but also on air temperature and total precipitation in several consecutive days.

Long-lasting low intensity precipitation increases air humidity, moistens leaves, diminishes temperatures of air and plants, and additionally significantly reduces the quantity of solar radiation. All these parameters have significant impact on reducing plant transpiration, which decreases expenditures of soil water. In orchards where capillary retention from soil water has significant influence on water content increase in the root zone layer, the reduction of transpiration can have indirect effect on soil water content. Short, low intensity rain in a hot sunny day, certainly does not impact soil water content, but moistens (for a short time) the leaves only. KĘDZIORA (1995) claims after Zinke, that interception capability (i.e. keeping water on the leaves surface) can reach even 2 mm. According to ŚWIĘCICKI (1981) yearly interception of deciduous trees can reach up to 15-20 % of yearly total precipitation. All these notices concern single small precipitation. CHUDECKI *et al.* (1971) and DRUPKA (1976) claim that all rains up to 2.5 mm could be concerned as not significant. This seems to be more appropriate than 5 mm level. However, mentioned above (after DRUPKA, 1976) criterion of effective rainfalls as those higher than daily potential evapotranspiration appears optimal, because each daily precipitation higher than daily evaporation from soil and plants surface is a receipt for soil water balance.

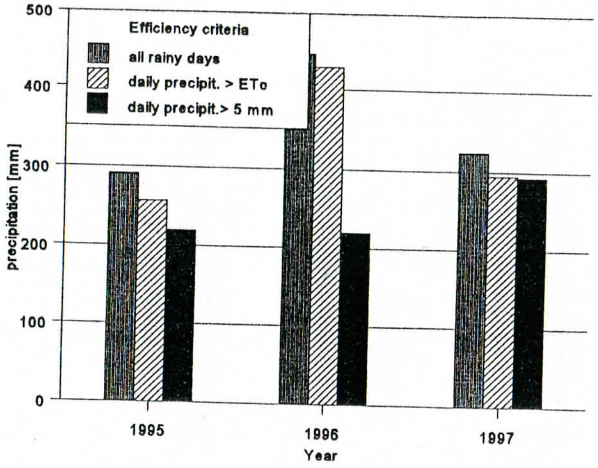

Fig. 1. Total amounts of precipitation (for periods May-September) depending on selected efficiency criterion

3.2. IMPACT OF HIGH RAINFALLS ON SOIL WATER CONTENT

High rainfalls are very significant for correct calculation of water receipts. According to BAC *et al.* (1998) daily precipitation over 20 mm causes significant surface runoff and deep percolation. Conducted measurements showed the occurrence of such precipitation in every year of experimental period (Table 4). Extremely high precipitation appeared in rainy period of 1997 year, when four days occurred with daily rainfall over 20 mm.

Table 4. Maximum amounts of single and daily precipitation (mm), and numbers of days with total daily precipitation over 20 mm

Parameter	1995	1996	1997
Maximum amount of single precipitation, mm	18.4	25.5	20.0
Maximum amount of daily precipitation, mm	21.0	79.8	36.6
Numbers of days with daily precipitation >20 mm	1	3	4

On the basis of measured moisture contents for different pF values (Table 1) the quantities of water available for some significant levels of soil water potential were calculated (Table 5). Assuming, that the soil layer 0-60 cm is the most important fo fruit trees, the total amount of available water in that layer is about 50 mm. Wate shortages in which the soil moisture content is below the permanent wilting point ar uncommon in Polish climatic conditions. In practice, water deficits do not usually ex ceed 30 mm. With properly scheduled irrigation, the water deficits do not excee growth inhibition level (pF 2.85). Thus, in orchards with soil characteristics similar t those presented in Table 1, soil moisture deficit for 0-60 cm layer should not excee 20 mm. That means that precipitation exceeding this amount is not important for pla use of water. Young orchards or bushes with shallow root systems will have an eve lower threshold.

Table 5. Soil water amounts (% vol.) depending on the range of its availability for plants

Soil layer cm	Very easy available water	Easy and very easy available water	Available water
15-20	3.48	5.28	8.45
40-45	3.05	4.65	7.9
Average	3.27	4.97	8.18

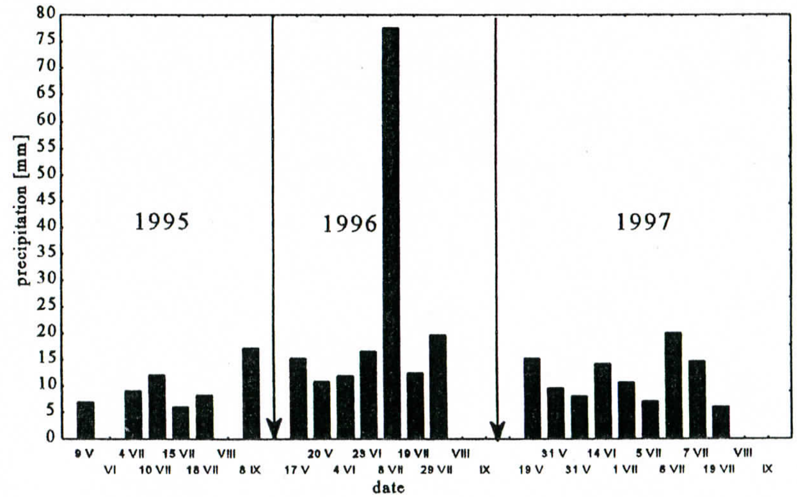

Fig. 2. Occurrence and amounts of rainstorms in 1995-1997 years

This conclusion is confirmed by DRUPKA (1976), who reports that light soils are unable to absorb more than 31 mm of precipitation, and heavy soils more than 40 mm. During the period investigated the highest daily precipitation occurred in 1996 and was equal to 80 mm, much more than the calculated maximum soil moisture deficit levels. Thus, practically large parts of such rainfall did not supply the root system zone, and should be considered as an input to the soil water balance. In 1997 maximum daily precipitation was also high and equaled to 36.6 mm.

Rainfall of low intensity and short duration usually does not cause surface runoff but intense precipitation (especially rainstorms – with intensity over 10 $mm \cdot h^{-1}$) does cause runoff, and thus reduces water income. Heavy rains (with intensity 5-10 $mm \cdot h^{-1}$) and rainstorms made very significant contribution to the total precipitation during measurement period, especially in July of 1995 and 1996 (Table 6).

The analysis of distribution, amount and intensity of precipitation shows, that summarized precipitation amounts should not be indiscriminately added to soil water content equations. This hypothesis was confirmed by relationship functions between weekly sums of precipitation and soil water balance values (Fig. 3). As the normal precipitation all rainfalls except rainstorms were assumed. All data collected between May and September for the three years of experiment were used. Fig. 3 shows that the polynomial regressions differ for different soil layers with the change of soil water content equal to zero for weekly total precipitation of approximately 18 mm. Thus, with maximal efficiency of precipitation, average orchard evapotranspiration was about 2.6 mm (18/7) per day during evaluated period.

Table 6. Percentage contribution of heavy rains and rainstorms for separate months from May until September of each year

Year	May		June		July		August		September	
	type of precipitation									
	heavy rain*	rain-storm	heavy rain	rain-storm	heavy rain	rain-storm	heavy rain	rain-storm	heavy rain	rain-storm
1995	0	12.7	25.4	6.8	27.8	51.4	0	0	22.9	0
1996	31	13.4	11.9	17.6	8.5	65.5	10.3	0	18.9	0
1997	32.5	9.2	18.6	22.8	6.6	29.8	0	0	80	0

* – heavy rain – intensity 5-10 $mm \cdot h^{-1}$, rainstorm – intensity over 10 $mm \cdot h^{-1}$

Efficiency of different levels of precipitation depends on the depth of soil layer chosen for calculating changes of soil water content. The precipitation efficiency for 0-20 cm layer decreases when weekly precipitation is over 21 mm. Weekly precipitation over 27 mm was more efficient for 0-60 cm layer than for 0-40 cm layer. This

practically means that weekly precipitation below 27 mm did not raise the soil moisture at 40-60 cm layer (calculated as a difference between 0-60 and 0-40 cm layers).

The impact of rainstorms on soil water content was analysed in a different way. The relationship between changes of soil water content and precipitation was evaluated using only these weekly sums of precipitation, when rainstorms occurred, and they made at least 80 % of total precipitation amount. The obtained regression shows low efficiency of rainstorms. The highest efficiency among different soil layers was obtained for 0-60 cm layer, and is presented as the separate regression line in Fig. 3. This is consistent with the observations of ŚWIĘCICKI (1981) and KĘDZIORA (1995) that rainstorms have lower significance for plant water management.

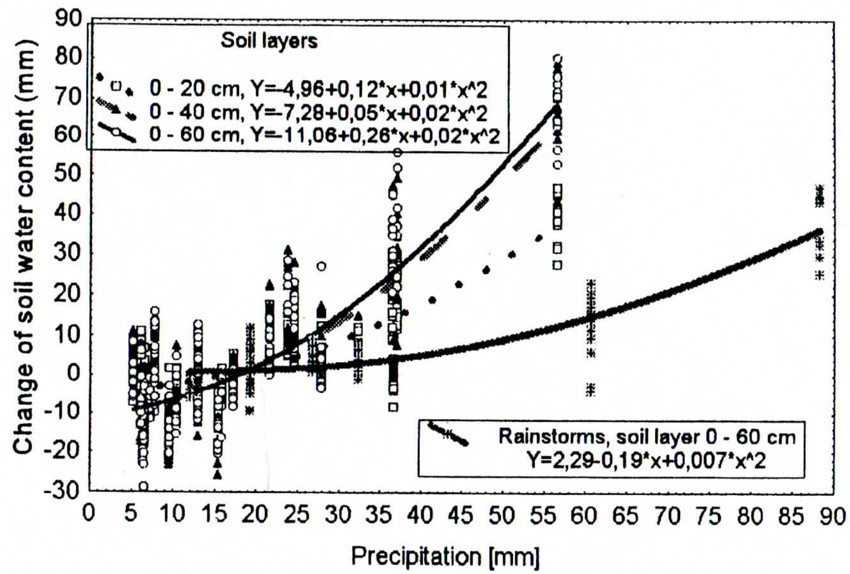

Fig. 3. Influence of amount and type of rainfall on soil water content in non-irrigated orchards

Precipitation efficiency depends also on initial soil moisture. The limited soil water holding capacity in irrigated orchards caused different precipitation efficiencies in irrigated and non-irrigated orchards (Fig. 4). At weekly precipitation over 25 mm, moisture of soil layers 0-40 cm and 0-60 cm increased more in non-irrigated orchards, but at weekly precipitation below 25 mm higher efficiency was observed in irrigated orchards. The latter phenomenon can be explained by positive effect of higher initial moisture of soil surface layer, because in non-irrigated orchards the soil surface dries (in drought periods) so much that its infiltration during small rainfalls is reduced. Soil profile in irrigated orchards has generally much lower water holding capacity comparing to non-irrigated orchards, causing large losses of water after heavy rains.

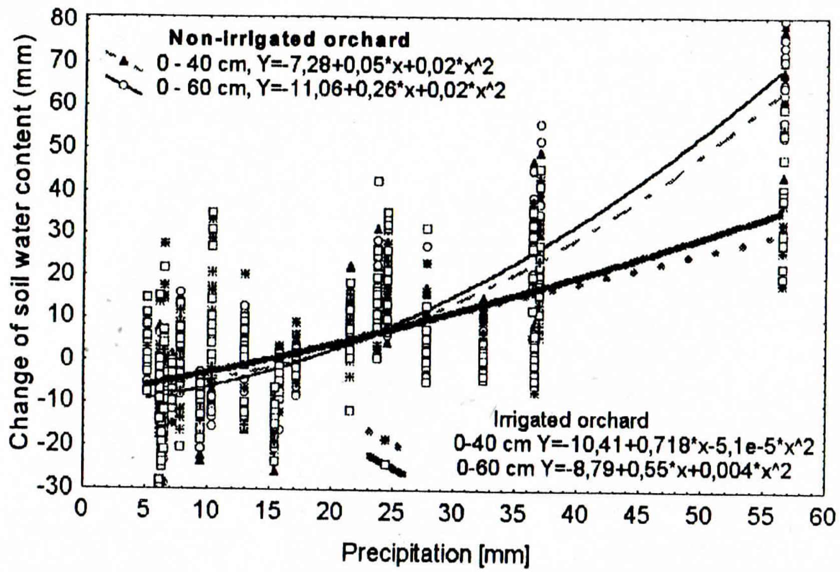

Fig. 4. Influence of precipitation amount on soil water content in irrigated and non-irrigated orchards

CONCLUSIONS

The described above impact of low precipitation on soil moisture and microclimate of cultivated areas confirms DRUPKA's (1976) suggestion, that precipitation is effective when exceeds potential evapotranspiration.

In case of heavy rains exceeding the amounts of very easy accessible soil water (in accounted soil layer), the predicted soil water content should increase only by this part of water, which refills soil water to the level of field water holding capacity. This is one of the reasons, apart from surface runoff, of much lower efficiency of rainstorms comparing to efficiency of other rainfalls.

It was found that the influence of precipitation on soil water content increases with the thickness of accounted soil layer. However, the higher initial soil moisture in irrigated orchards caused lower efficiency of rainfall (for layers 40 or 60 cm thick).

High diversity of acquainted data suggests low scientific applicability of presented simple inductive models (Fig. 3. and 4.). However, original experiment was planned as a preliminary study being helpful for irrigation practice in orchards.

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STRESZCZENIE

Wpływ ilości i intensywności opadów na zmiany wilgotności gleby w sadzie w centralnej Polsce

Pomiar zużycia wody przez rośliny uprawne ma decydujące znaczenie dla określenia wielkości i celowości nawadniania. Ilość i intensywność oraz rozkład opadów mają niewątpliwy wpływ na wilgotność gleby. Woda opadowa może być wykorzystywana przez rośliny tylko wtedy gdy wsiąknie do gleby i jest w niej retencjonowana jako woda kapilarna. Niestety, w przypadku obfitości lub nadmiernej intensywności opadów część wody może przesiąkać poza zasięg systemu korzeniowego lub odprowadzana jest z pola poprzez spływ powierzchniowy. W trakcie trzyletnich badań (1995-1997) prowadzono pomiary wielkości i intensywności opadów oraz cotygodniowe pomiary wilgotności gleby w różnych nasadzeniach sadowniczych. Na podstawie otrzymanych wyników przeprowadzono analizę wpływu wielkości i intensywności opadów na zmiany wilgotności gleby w sadzie. Wyniki tych analiz wskazują na

małą efektywność opadów niskich (poniżej wysokości dziennej ewapotranspiracji potencjalnej). Stosunkowo małą efektywnością charakteryzują się także opady burzowe których udział w całkowitej ilości opadów w okresie wegetacji stanowił aż 20 do 36%. Efektywność opadów zależna była także od początkowej wilgotności gleby, co było powodem znacznych różnic we wpływie wielkości opadów na zmiany bilansu wodnego profilu glebowego sadów nawadnianych i kontrolnych.

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