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Executive Summary

The presented report is devoted to check of suitability of the agricultural meteorology approach to the evaluation of water use by plants in conditions of a mountain-foothill zone of a Chu valley of Kyrgyzstan.

The practical appeal of the agricultural meteorology approach is to allow defining water use of plants from the measured climatic parameters (temperature and relative humidity of an air, velocity and direction of a wind. solar radiation and precipitation). Therefore, the arduous measurement of moisture content using auger core soil samples during the vegetation period is not required.

The climatic parameters were determined immediately on an experimental plot (a apple-tree orchard at the village Kok-Zjar 10 km to the south of Bishkek) with the help of an automatic weather station of firm "Campbell Scientific". The obtained data were further processed on the personal computer.

In the report the data about the disposition of the experimental plot, surface and soil structure are presented. Orchard cultivation in a mountain-foothill district is explained and the concept of orchard plant community is given. The climatic condition and their characteristics for a mountain-foothill zone are indicated.

The report focuses on a water dosage for the experimental plot. Soil moisture was determined every 3 -5 days, to a depth of 1 m. According to these data six watering kept soil moisture in the 0.7 m top soil layer at least moisture capacity (FC), after the final autumnal watering. The field data established total irrigation water use of the apple-tree orchard.

The data obtained in the experimental plot assessed the qualitative and quantitative suitability of the agrometeorological approach for evaluating water use by plants. They were used for extensive applications.

Comparisons of water use estimates obtained by different techniques were made. The agricultural meteorology approach proved reliable in the conditions of the mountain-foothill zone of the Chu valley of Kyrgyzstan.

Section 1

A. Research Objectives

The purpose of the research is to establish the applicability of the agrometerorological approach for evaluating plant water use to increase irrigation efficiency in the conditions of the Kyrgyz Republic.

B. Research Accomplishments

Work carried in Kyrgyzstan

1. Data obtained by traditional methods

1.1. Specifications of the experimental plot

Location: The experimental plot is located 10 km from southern part of Bishkek at the village Kok-Jar on the foothill of Ala-Too at an altitude of 1000 m above the sea level, 30 km of the south of the plot the high-mountain glaciers at an altitude of about 4000 m. The plot is in a young apple orchard. The surface of the plot has the advanced microcontour. The general slope of the surface is within the range of 0.05-0.07 (fig. 1.1).

Climate: The analysis of the climatic factors obtained with the help of the Automatic Meteorological Station (AMS) in 1999, shows the large variability of the climatic component. The main parameters of weather - temperature and relative humidity of an air, changed sharply both within months and day. So, in the warmest month - July, the daily average temperature of the air changed from 17.2° up to 23.6°C. Diurnal oscillation was from 15°C at night to 30°C during daylight. In August abundant precipitation - 31.9 mm per day, lowered daily average temperature to 26.5-27.9°C. Diurnal oscillation were between minima of 9-15°C at night, and maxima of 20-29°C during daylight. September was colder. Maximum daily average temperature reached 21.9°C, and minimum was 9.3°C. Diurnal fluctuations of temperature during the first decade were from 7.2°C at the night to 26°C in daylight and from 6.5°C up to 27.7°C during the third decade at the time of leaf drop.

The humidity of the air fluctuated. In July the daily average humidity of the air changed from 42.1 to 84.0 %. Diurnal oscillations were from 35 (daylight) to 82 % (night) and increased to 92 % during precipitation. In August diurnal oscillation of humidity reached 55.7 %, from 28.1 % to 83.8 % during precipitation. The driest period was during the second and beginning of the third decade, with diurnal oscillations of humidity 20-22% to 55-72% for the clear weather and from 55 % up to 97 % during rain. In September the humidity of the air was changed from 33.4 % up to 88.6%. Within day it changed from 21-24% in the day time, till 65-68% in night, being lifted during falling precipitation up to 97-99%.

The wind for the period of observations did not exceed the velocity 3.4-4.0 meter per second (m/s) and only from time to time for bursts of wind reached 6-7 m/s. The main daily average parameters of the climatic factors are indicated in Appendix 1.

Cold airmass intrusions from nearby glaciers during night allow possible to growing only adapted apple-trees. Yet, their flowers and ovaries are damaged by the sharp temperature variations. The duration of the vegetation period of the apple orchard depends on the temperature of the warm period of each year. In this respect 1999 was most unfavorable. At the beginning of May, when apple-trees were in blossom, snow chilled the flowers and prevented fruit set.

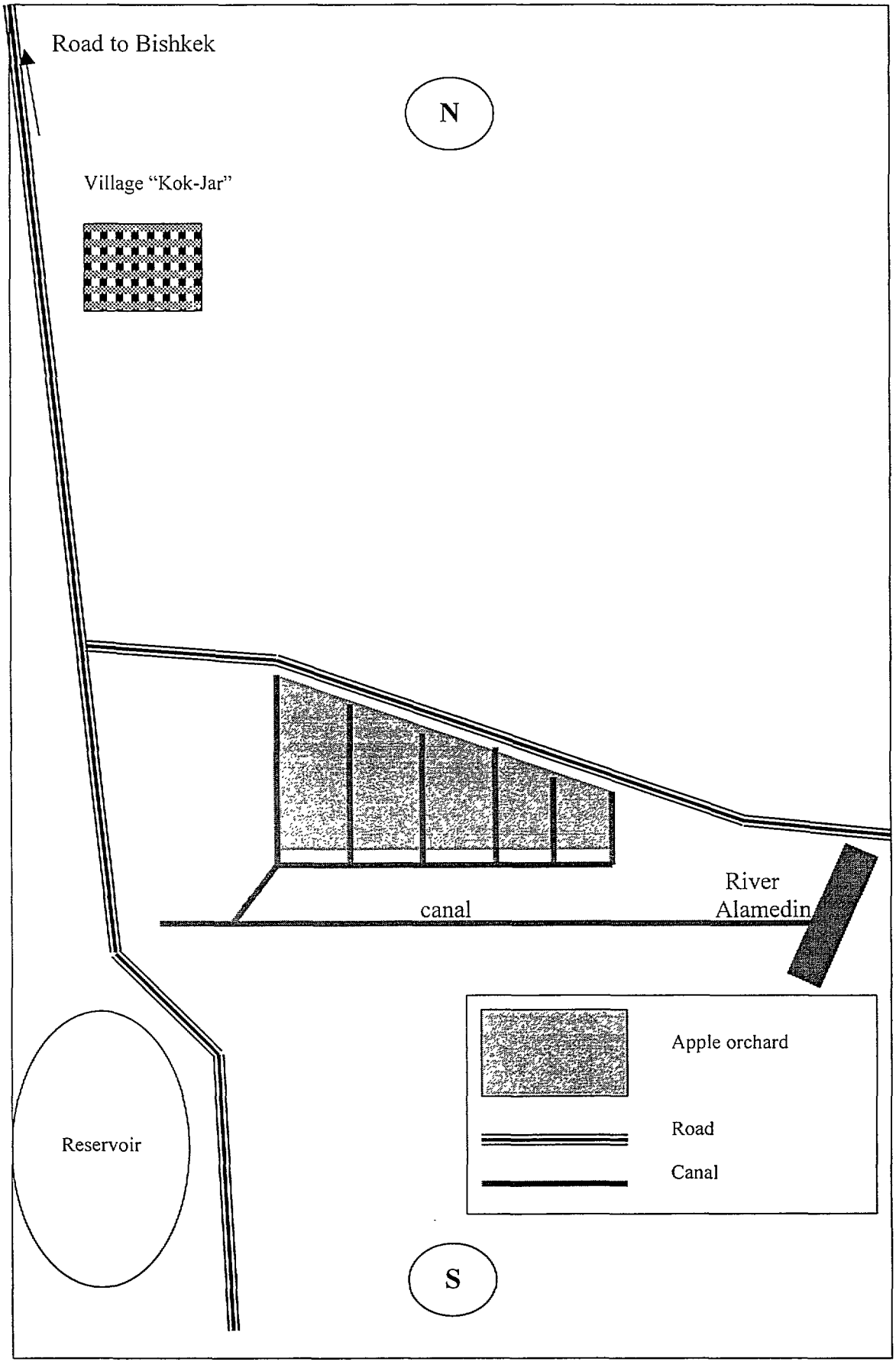


Fig. 1.1. Scheme of disposition of the experimental plot

Water-soil and topography: The orchard is located on the alluvial cone of the river Alamedin. Stony grounds occupy a significant part (up to 15 % of territory). The soil type is sierozem. The main part of the orchard is clay. Lenses of sand and gravel form the coarser soil layers.

The water-physical properties of the soil, moisture content at Field Capacity (FC) and water deficit (W_{def}) in mm of water at the moisture content that is critical to plant growth, were mapped according to contour lines (Table 1.1).

Table 1.1 Hydraulic properties of the apple orchard soil.

Soil horizon, m	Moisture content at-Field Capacity (β_{FC}) %	Volumetric mass, t/m^3, d	Critical moisture content		Deficit of a soil moisture	
			Fraction of γ_{FC}	% Moisture content $\beta_{kr°}$	% Moisture content β_{def}	mm of water, W_{def}
0-20	21.3	1.36	0.65	13.84	7.46	20.3
20-40	21.3	1.36	0.65	13.84	7.46	20.3
40-60	23.6	1.32	0.71	16.76	6.84	18.1
60-80	24.5	1.29	0.72	17.64	6.86	17.7
80-100	23.7	1.31	0.71	16.83	6.90	18.1
0-100	22.88	1.33	0.69	15.78	7.10	94.5

Perennial grass planted between rows (pink clover, mixed grass including wild grass) prevented topsoil erosion. The grass uses irrigation water. Therefore, the total water requirement of the orchard must account water consumption by the grass. The grass also provides much needed forage for cattle owned by orchard-farmers. It is not possible to separate the water use of the apple trees and the grasses.

The weak general slope of the surface within the limits 0.05-0.07 makes difficult surface watering of orchard. Ring watering and half-ring furrows sharply reduced the risk of run-off erosion.

1.2. The water regime of the apple orchard

1.2.1. Terms and dosages of watering

In both variants of the experiment 70 % depletion from FC in the 1-m topsoil layer S served as criterion to trigger watering. At the AMS site, the first soil moisture sampling occurred on 30.06.99. The moisture content of the soil was 15.5 % from absolute-dry soil or 72.0 % from FC. The stored moisture amounted to 219.5 mm. The moisture deficit was 85 mm. Because of absence of an irrigation network in the orchard, the watering was not made. On 08.07.99, the orchard received 72.5 mm of water. Precipitation from 28.06 till 07.07, totaling 37.5 mm complemented the water supply to exceed the deficit. Stored moisture prior to AMS installation amounted to 251.4 mm or 82.5 % from FC.

The next two irrigations occurred on 22.07 and 08.08 with the average gross dosages of 78.5 and 207.0 mm when depletion reached 66.7 and 64.9 % of the initial moisture content of the soil. Two subsequent irrigations with 95.5 and 92.5 mm were made on 20-21.08 and 02.09 when depletion reached 81.0 and 79.7 %. Irrigation dosages were calculated from the cumulated evaporation. The last irrigation of the vegetation season occurred on 03.10 when average moisture deficit in the 1-m topsoil layer reached 225.6 mm or 74.06 % from FC in both experiments. Post seasonal irrigation with 200.0 mm was given on 10-12.10 to increase average moisture the top 1-m layer of soil to 87.5 % of FC.

Irrigation during the vegetation season consisted of six applications with a gross amount of 689.0 mm, of which 293.3 mm or 43.3 % were absorbed in the top 1-m layer of soil. Consequently a significant amount of water leached below the 1-m soil layer. The vol-

ume of deep percolation amounting to 50-65% of irrigation gross dosages provides a water reserve for use by secondary and tertiary roots that can reach depths of 9 m and more.

The account of irrigation net dosages and leaching volume for 1 meter layer of soil is indicated in table 1.2.

Table 1.2. Account of irrigation net dosages and leaching volume for 1 m of layer of soil for watering of the apple orchard in 1999 (average in experiment).

№ of watering	Date of watering	Stock of a moisture, mm		Net dosage, mm	The irrigation gross dosage, mm			Leaching	
		After watering	Before watering		B-1-1	B-1-2	Average	Mm	% From irrigation gross dosage
1	08.07	251.6	219.5	32.1	65	80	72.5	40.4	55.7
2	22.07	240.6	203.1	37.5	75	82	78.5	41.0	52.2
3	10.08	265.6	197.8	69.8	170	244	107	137.2	66.3
4	21.08	293.5	246.7	46.8	87	104	95.5	48.7	51.0
5	02.09	291.9	242.6	49.3	95	90	92.5	43.2	46.7
6	03.10	283.4	225.6	57.8	142	144	144	85.2	59.6
The sum				293.3			689	395.7	56.7

1.2.2. Dynamic of moisture content of soil for irrigation of the apple orchard

Before starting the field experiment the farmer irrigated the orchard. Soil moisture was measured before the beginning of the experimental irrigation on three test plots in triple replicates. In experiment B-1 soil tests were taken two days after a "flood irrigation" with a small water dosage wetting the soil to a depth of 0.5 m. The moisture content of soil in the upper horizon reached 111.3 % of field capacity and was only 48.3 % in the 0.4-0.6 m horizon (fig. 1.2). In experiment B-2, one week after the first watering, soil moisture in the layer 0.0-0.2 m was 71.8 % of field capacity, 64.4 % in the layer 0.2-0.4 m, down to 48.2-49.1 % in the deeper layers (fig.1.3).

In experiment B-3, where the orchard was never watered, the soil dried severely, precipitation allowing moisture to reach 63.4 % of field capacity in upper 0.2 m layer and only 35.9 % in the layer 0.6-0.8 m (Table 1.3.)

Table 1.3. Moisture content of the 1 m soil layer and storage of moisture before the beginning of watering of the apple orchard in experiment of 1999.

Horizon, m	Experience B-1			Experience B-2			Experience B-3		
	Soil moisture content, %		Stored moisture, mm	Soil moisture content, %		Stored moisture, mm	Soil moisture content, %		Stored moisture, mm
	Weights of absolute-dry soils	Relative to field capacity		Weights of absolute-dry soils	Relative to field capacity		Weights of absolute-dry soils	Relative to field capacity	
0.0-0.2	23.7	111.3	64.4	15.3	71.8	41.6	13.5	63.4	36.7
0.2-.04	17.1	80.3	46.6	13.7	64.4	37.3	10.0	46.9	27.2
0.4-0.6	11.4	48.3	30.0	11.6	49.1	30.6	9.4	39.8	24.8
0.6-0.8	14.1	57.5	36.4	11.8	48.2	30.4	8.8	35.9	22.7
0.8-1.0	16.2	68.3	42.4	13.9	58.6	36.4	9.7	40.9	25.4
0.0-1.0	16.5	72.1	219.5	13.3	58.4	176.3	10.3	45.3	136.8

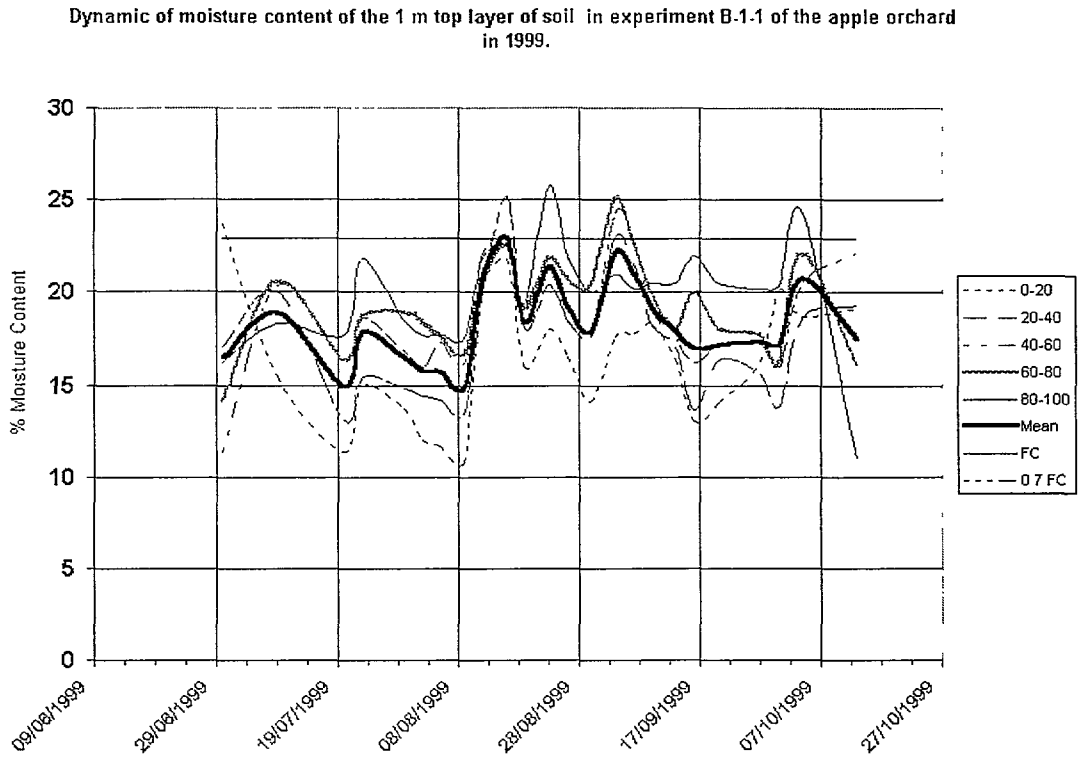


Fig. 1.2. Dates of watering: 1 - 08/07, 2 – 22/07, 3 – 10/08, 4 – 21/08, 5 – 02/09, 6 – 03/10.

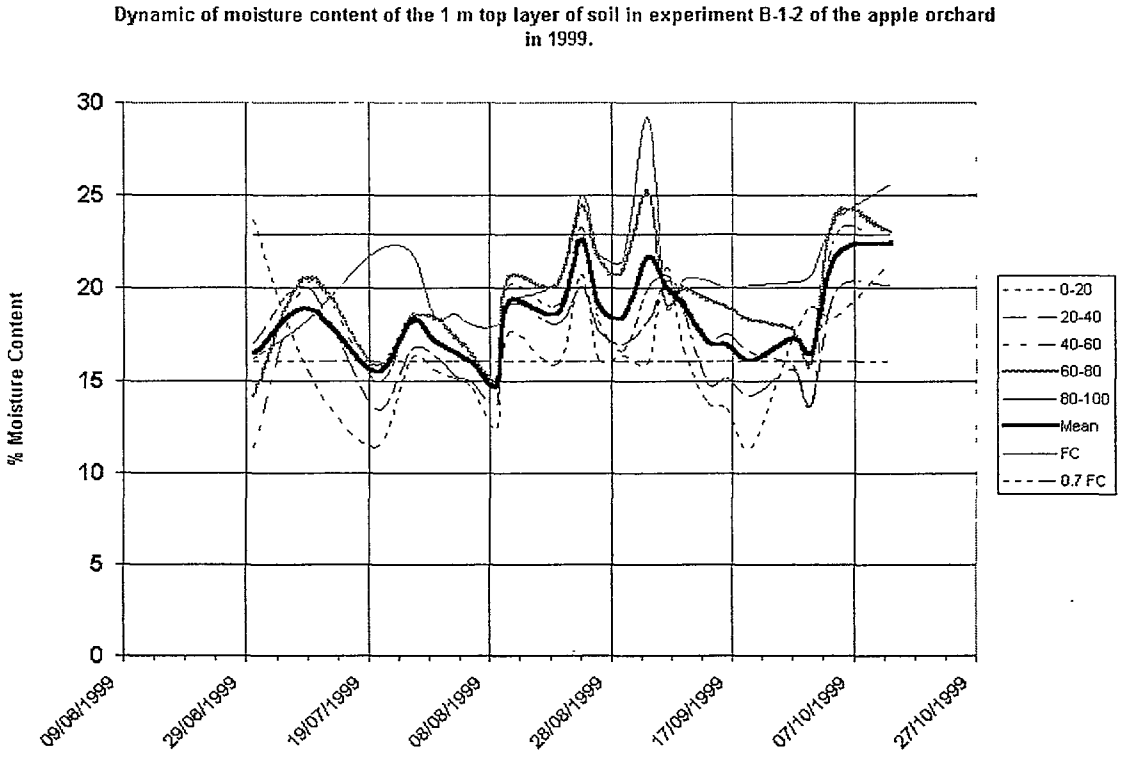


Fig. 1.3 Dates of watering: 1 – 08/07, 2 – 23/07, 3 – 10/08, 4 – 21/08, 5 – 10/09, 6 – 10/10

High moisture content in the layer 0.8-1.0 m of the irrigated experiments was unexploited moisture accumulation from the previous autumn-winter-spring precipitation. So, unsystematic irrigation could decrease efficiency of stored soil moisture use.

To avoid drought stress of the apple trees the first 2 watering the trigger threshold moisture content in the 1m layer was raised to 65-70 %, but the resulting moisture content reached only 79.0-82.6 % of field capacity owing to the dryness of the upper horizons. Moisture accumulation in the middle and lower horizons of soil reached 84-92% of FC. Later water applications were according to data received from AMS. Average moisture content of soil in 1 m of layer was kept at the level 80 % of FC before watering and 95-100 % after. Moisture content of soil in the lower horizons was not lowered below 85-90 % of FC and increased to 110-115% of FC after watering.

Irrigation with deep ring furrows transferred the main stocks of moisture under appletrees from the upper horizons down to 0.4 m, decreasing evaporative moisture loss from the soil surface and water supply to the grass. In the deeper layers more moisture became available for use by the trees.

From the middle of September to the beginning of October the orchard was not watered, but the moisture in middle and lower horizons of the root zone remained high enough within the limits of 72-76 % . At this time high layers of soil had dried down to 48-50 % of FC.

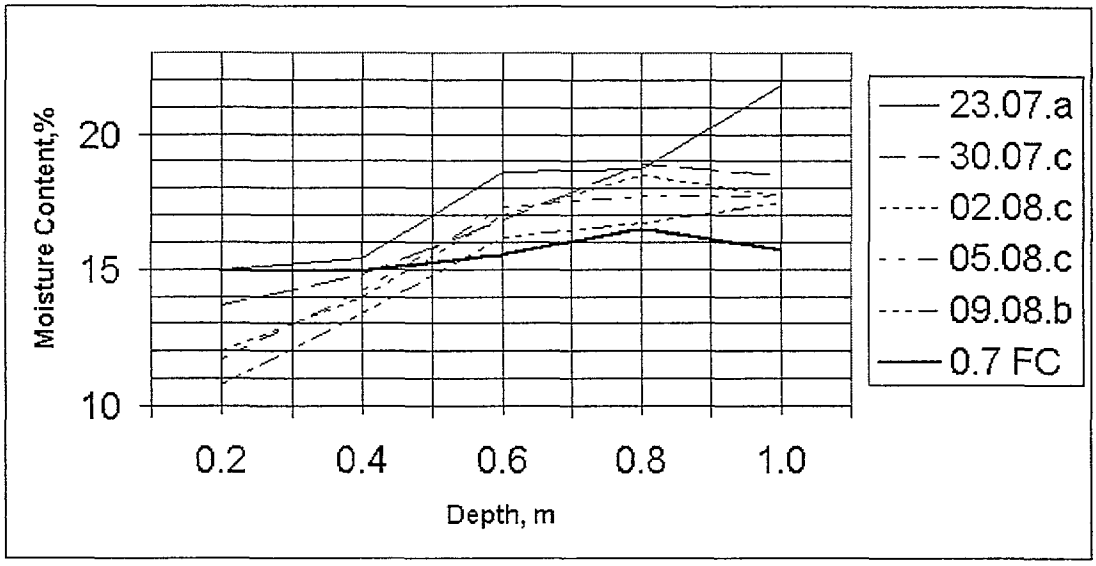
The last watering during the vegetation season increased average moisture content to 91-95% of FC, and lifted it above 100% in low layers. Autumn watering increased moisture to 100 % of FC (Appendix 2).

The periodic moisture content measurements in intervals between watering (3-4 days) showed that the moisture from the different horizons of the root zone was not depleted uniformly. In the summer period from 23 July to 9 August in experiment B-1-1, the moisture was consumed uniformly from all horizons to 1-m depth. In the autumn from 6 September, moisture removal from horizon 0.8-1.0 m was stopped. Here moisture content remain constant to the end of the month (Fig.1.4, 1.5 and Appendix 2). Therefore, we concluded that trees did not consume moisture from this horizon. During this period, night air temperature dropped sharply down to 5-6°C and leaves turned yellow. It is possible to judge, that from this period vegetation of the orchard terminated. The moisture from the higher horizons was consumed mainly by grasses (Table 1.4).

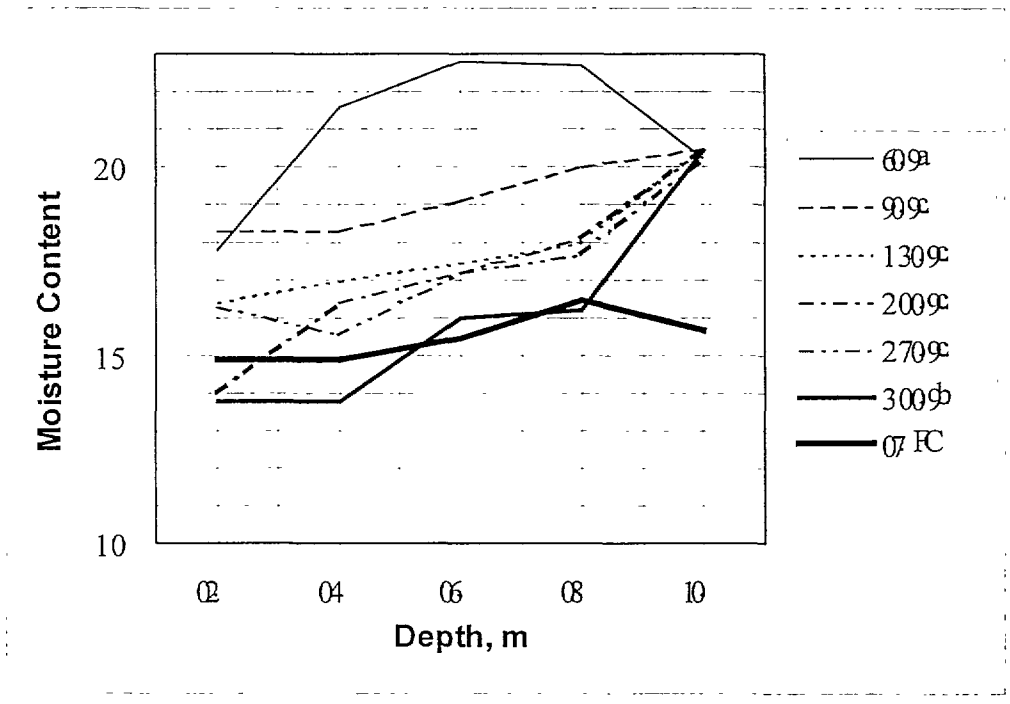
Table 1.4. Dynamic of moisture content of soil horizons for the irrigated apple orchard in experiment B-1-1 and B-1-2 with AMS

Horizon of soil, m	Periods, dates of moisture content measurements and parameters											
	Summer					Autumn						
	23.07, after watering	30.07, monitoring	02.08, monitoring	05.08, monitoring	09.08, before watering	06.09, monitoring	09 09, monitoring	13.09, monitoring	16.09, monitoring	20.09, monitoring	27.09, monitoring	30.09, before watering
Experience B-1-1												
0.0-0.2	15.0	13.7	12.0	11.7	10.8	17.8	18.3	16.4		14.0	16.3	13.8
0.2-0.4	15.4	14.8	14.4	14.2	13.4	21.6	18.3	17.1		16.4	15.6	13.8
0.4-0.6	18.6	16.8	17.0	17.3	16.2	22.8	19.1	17.5		17.2	17.2	16.0
0.6-0.8	18.7	18.9	18.5	17.7	16.7	22.7	20.0	10.8		18.1	17.7	16.2
0.8-1.0	21.8	18.5	17.7	17.7	17.5	20.2	20.5	20.5		20.5	20.2	20.4
Experience B-1-2												
0.0-0.2	16.2	15.5	15.1	14.6	12.5	21.1	16.7	13.8	13.5	11.4	17.4	19.0
0.2-0.4	16.7	16.3	15.3	14.9	13.7	20.4	18.7	14.8	15.1	14.2	15.6	13.7
0.4-0.6	18.1	17.3	16.3	15.8	14.8	20.7	19.4	17.2	17.5	16.5	15.8	13.3
0.6-0.8	18.4	18.4	17.4	16.4	15.1	19.2	20.0	19.4	19.0	18.3	17.8	16.6
0.8-1.0	22.0	18.4	18.6	18.0	18.0	19.0	20.5	20.4	20.0	20.2	20.3	20.7

Dynamics of moisture content of a 1 m of layer of soil in experiment with S for the apple orchard on average variants of experiment are indicated in fig. 1.6 and in Appendix 2.



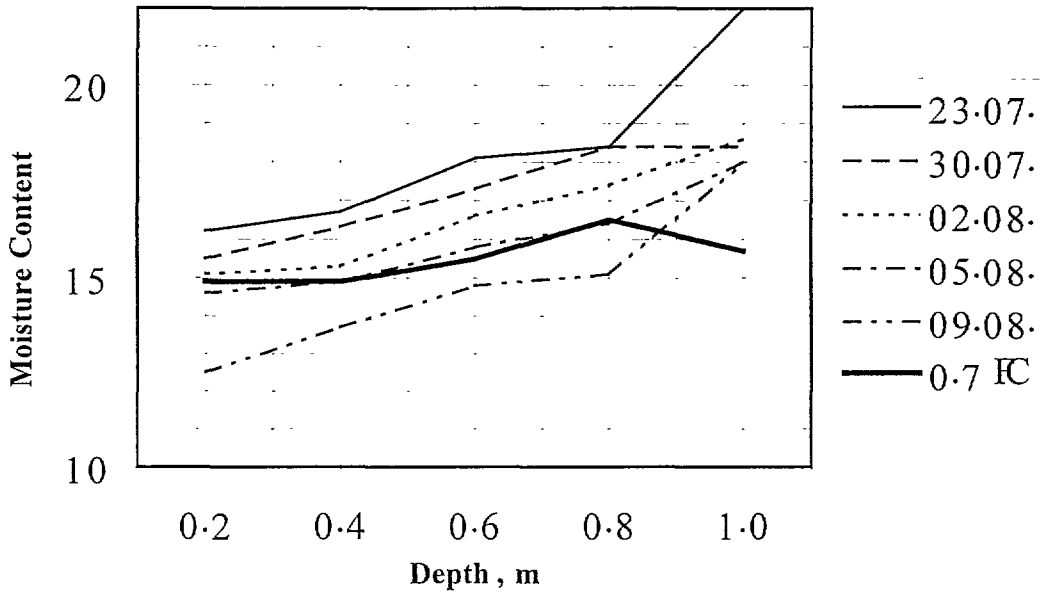
Summer



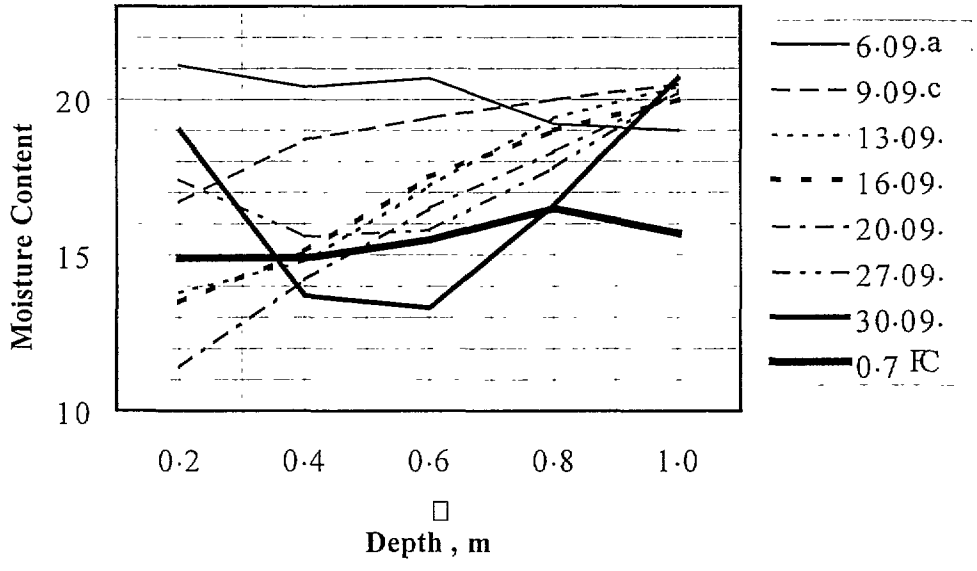
Autumn

P - after watering, c - control take of soil samples, b - before watering

Fig. 1.4. Dynamic of soil moisture content on horizons in period between watering in July and September for irrigation of the apple orchard (experiment B-1-1)



Summer



a - after watering, c - control take of soil samples, b - before watering
Autumn
Fig. 1.5.

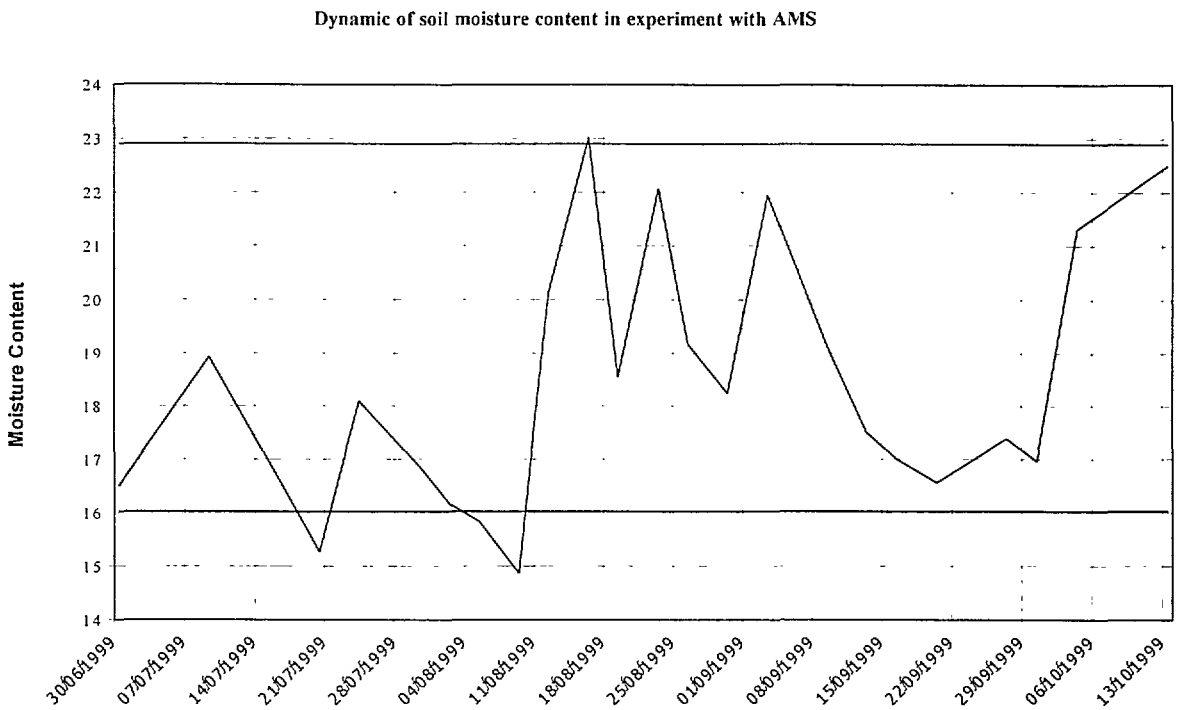


Fig. 1.6.

1.2.3. Total water requirement of an irrigated apple orchard

The complete water balance of the experimental plot (EP) for a given time interval is:

$$P + M + Z_m + Z_x - E - E_B - M_{dum} + W_h + U_s + K_h - J_h = 0,$$

Where,

P precipitation for the interval, mm;
M irrigation (watering) dose for the interval, mm;
Z_m and Z_x seepage of water from main and secondary channels located above EP;
E total water requirement, mm;
E_B evaporation from a water surface of "flood irrigation" or from sprinkler spray, mm;
M_{dum} dumping of redundant irrigation water out of EP, mm;
$W_h = W_h - W_{hk}$ change of moisture storage in the rooted layer of soil, W_h and W_{hk}, moisture storage at the beginning and end of the interval;
K_h rise of ground water into the root zone, mm;
U_s surface water (thawed) production, mm;
J_h leaching below root zone, mm.

As supply channels are far from the EP seepage terms Z_m and Z_x are neglected. The dumping of redundant irrigation water was measured as part of irrigation dosages, not as a separate term. The water table was below 20m and its contribution to the root zone was negligible. Surface storage contribution in early-spring is excluded because the water balance started on 30 June. Evaporation from the furrows is also negligible.
Leaching was determined by formula:

$$J_F = m_{br} - m_{nt}, \quad m_{nt} = W_{af} - W_{bef}$$

where,

m_{br} the irrigation gross dosage, was from the management of each watering, mm;

m_{nt} the irrigation net dose, mm;

W_{af} W_{bef} istored soil moisture after and before watering.

With the above assumptions, the water balance for EP simplifies to:

$$W + m + P - E - J_F - W_k = 0,$$

The l water requirement of the trees and grasses is:

$$E = W + m + P - J_F - W_k,$$

The results are in table 1.5.

Table 1.5. Account of water balance 1 m of layer of soil of irrigated apple orchard on periods of observations

Date			Interval, days	Stock of moisture, mm		Irrigation net dosage, mm	Precipitation, mm	Total water requirement, mm					
								Modeled			Adjusted,		
Initial	Final	Average		Initial	Final			For period	Daily average	Integrated	For period	Daily average	Integrated
30.06	20.07	10.07	20	219.5	203.1	32.1	50.9	99.4	4.97	99.4	99.4	4.97	99.4
20.07	30.07	25.07	10	203.1	224.2	38.6	6.7	24.2	2.42	123.6	18.1	1.81	117.5
30.07	02.08	01.08	3	224.2	214.9	0	0.7	10.0	3.33	133.6	17.5	5.83	135.0
08.08	05.08	03.08	3	214.9	210.5	0	5.4	9.8	3.27	143.4	8.5	2.83	143.5
05.08	09.08	07.08	4	210.5	197.8	0	0	12.7	3.18	156.1	20.0	5.00	163.5
09.08	19.08	14.08	10	197.8	246.7	70.4	37.8	59.3	5.93	215.4	38.5	3.85	202.0
19.08	26.08	23.08	7	246.7	255.0	46.9	0	38 6	5.51	254.0	52.0	7.42	254.0
26.08	30.08	28.08	4	255.0	242.6	0	0	12 4	3.10	266.4	28.0	7.00	282.0
30.08	06 09	03.09	7	242.6	273.3	49.3	34.4	53 0	7.57	319.4	36.2	5.14	318.2
06.09	09.09	08.09	3	273.3	254.7	0	1.8	20.4	6.80	339.8	26 8	8.03	345.0
09.09	13.09	11.09	4	254.7	232.9	0	0	21.8	5.30	361.6	13 8	3.45	358.8
13.09	16.09	14.08	3	232.9	226.2	0	0	6.7	2.23	368.3	7.2	2.40	366.0
16.09	20.09	18.09	4	226.2	220.2	0	0	6.0	1.50	374.3	6.0	1.50	372.0
20.09	27.09	24.09	7	220.2	231.3	0	9.2	8.1	1.16	382.4	10.0	1.43	382.0
27.09	30.09	28.09	3	231.3	225.6	0	0	5.7	1.57	388.1	6.0	2.00	388.0
30.09	13.10	06.10	13	225 6	267.0	57.9	16.7	33.2	2.55	421.3	9.0	6.69	397.0

The water requirement from 30.06.99 till 13.10.99 or for 104 days was 421.3 mm, indicated 397.0 mm. Daily average water requirement changed from 4.97 mm/day at the beginning of the first interval to 2.42 and 3.33 mm before the next watering. Demand increased from a up to it was increased from 3.10 in the beginning of August to 7.57 mm/day in the middle of September. In the autumn, the water requirement reduces to 1.16-1.57 mm/day.

For characteristic of intensity of increase of process evapotranspiration of the irrigated orchard by results of water-balance accounts in the increasing total constructs an integrated curve of total evaporation of community of plants of the apple orchard (fig.1.7).

Seasonal evapotranspiration has three phases:

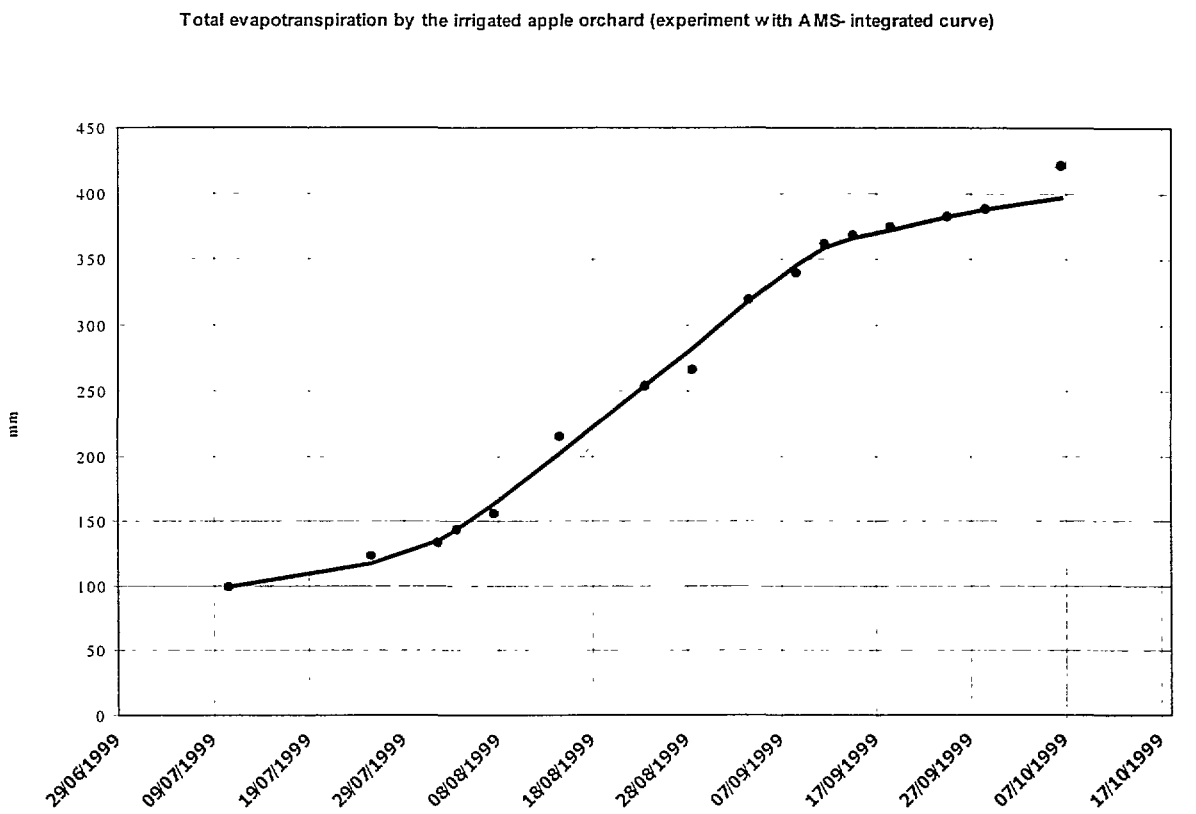


Fig. 1.7.

- The initial phase of water use with gradual increase of requirement by plants. Phase is finished in the first transitional period from 31.07 till 07.08;
- Phase of a rather stable evapotranspiration - till 07.09, from 08.09 till 15.09 - second transitional period;
- Phase of sharp decrease of water requirement with of the autumn.

1.3. Qualitative analysis of data AMS

The qualitative analysis of evaporability data were compared to field observations in the experiment (Table 1.6.)

The ratios of determined water requirement by a orchard over evaporability during intervals between observations (Kip = Eip/Eop) and accumulated (Kii = Eii/Eoi) were obtained. The K factors changed with the development of the plant community in the irrigated orchard, and depended on the moisture stock in the soil. The factors were stable down to a soil moisture content of 80 % FC. Further decrease of the soil moisture to 66.88% FC reduced the factors sharply to 0.123. Maintaining the lower threshold of soil moisture content between 65 and 70 % FC settled K_{ip} around 0.220-0.229, and K_{ii} = 0.258-0.248 and K_{ip} = 0.211-0.214. Rewatering to 80 % FC and above promoted water use and increases the factor 0.548. Later, cooling and fruit maturation, leaf yellowing reduced water use. The factors fell to 0.290 and 0.395 and to 0.260 and 0.102.

Table 1.6. Results of the periodical observations of total water use Ei in comparison with AMS evaporability Eo..

Date of periods of observations			Evaporability on AMS Eo, mm		Total water requirement by a orchard Ei, mm				Factor of ratio		The lower level of moisture content of soil for period, % FC
					Balance		Indicated,				
Initial	Final	Average	On periods of observations Eop	Integrated Eoi	On periods of observations	Integrated	Integrated E_{ii}	On periods of observations Eip	K_{ii}	K_{ip}	
01.07	20.07	10.07	262.6	262.6	99.4	99.4	99.4	99.4	0.387	0.387	82.18
20.07	30.07	25.07	175.7	438.3	18.1	117.5	121.0	21.6	0.276	0.123	66.62
30.07	02.08	01.08	40.9	479.2	17.8	135.0	130.0	9.0	0.271	0.220	70.57
02.08	05.08	03.08	58.9	538.1	8.5	143.5	143.5	13.5	0.267	0.229	69.13
05.08	09.08	07.08	94.6	632.7	20.0	163.5	163.5	20.0	0.258	0.211	64.93
09.08	19.08	14.08	182.4	815.1	38.5	202.0	202.5	39.0	0.248	0.214	81.00
19.08	26.08	23.08	170.4	985.5	52.0	254.0	257.0	54.5	0.261	0.320	83.71
26.08	30.08	28.08	54.9	1040.4	28.0	282.0	280.0	23.0	0.269	0.419	79.65
30.08	06.09	03.09	81.0	1121.4	36.2	318.2	321.5	41.5	0.287	0.512	97.10
06.09	09.09	08.09	39.2	1160.6	26.8	345.0	343.0	21.5	0.295	0.548	83.62
09.09	13.09	11.09	55.7	1216.3	13.8	358.8	360.0	17.0	0.296	0.305	76.46
13.09	16.09	14.09	44.6	1260.9	7.2	366.0	366.0	6.0	0.290	0.134	74.28
16.09	20.09	18.09	64.5	1325.4	6.0	372.0	374.0	8.0	0.282	0.124	72.31
20.09	27.09	24.09	68.7	1394.1	10.0	382.0	382.0	8.0	0.274	0.116	75.94
27.09	30.09	28.09	26.0	1420.2	6.0	388.0	385.0	3.0	0.271	0.115	74.06
30.09	13.10	06.10	98.2	1518.4	9.0	397.0	395.0	9.0	0.260	0.102	93.06

2. Data obtained by technique of Israel

2.1. Processing of data received by meteorological station

The climatic data received with automatic meteorological station, were treated as follows:

1. meteorological station, working continuously, recorded every 10 minutes the main climatic parameters (air temperature and relative humidity, direction and velocity of wind, solar radiation, precipitation);
2. The obtained data with the help of memory block were transferred from meteorological station to the computer and stored in a data bank;
3. From the data bank, the information for the certain day was selected and was transferred into the electronic table;
4. From the electronic table the information was treated by an algorithm of Prof. M. Fuchs and the daily average climatic parameters were determined in addition;
5. The obtained output were reduced in the general table.

2.2. Qualitative analysis of data

The qualitative analysis of data of the model is made with the help of formulas of Ivanov, and Penman-Monteith. The climatic data obtained with the help of automatic meteorological station, were substituted into the appropriate formulas, the output was tabulated. The seasonal results are plotted in Fig. 2.1.

The curves show good concordances between the modeled transpiration that takes into the resistance of the stomates, the potential transpiration (assuming optimal water supply) and the conventional Penman-Monteith method. The Ivanov formula overestimates the crop water use.

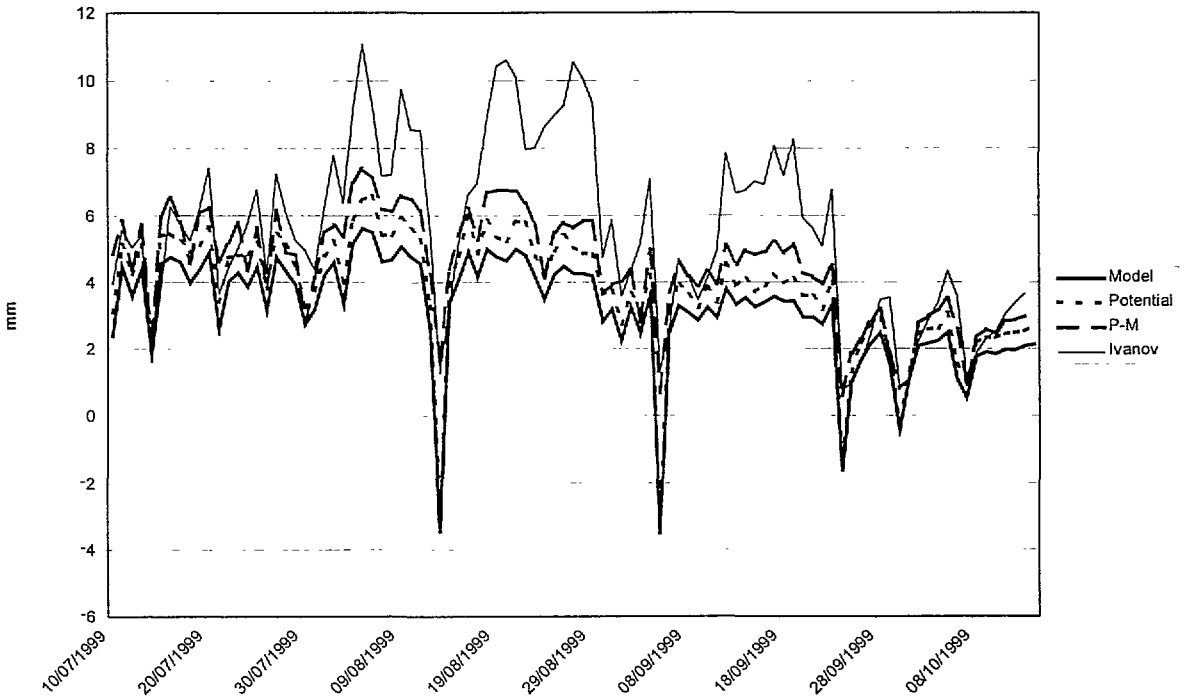


Fig. 2.1. Comparison between potential, model, Penman-Monteith (P-M) and Ivanov calculations of apple orchard transpiration.

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Work carried out in Israel

3.1 Linkage with the work in Kyrgyzstan

The application of the transpiration model presented in Fig. 2.1 assumes that the availability of soil moisture during an irrigation cycle is constant. It is known that soil water depletion during the irrigation interval lessens the water uptake capability of plants. The Israeli research team undertook to investigate this issue and to formulate the findings with parameters entering the transpiration model. This work was carried out on maize as specified in the research proposal, but the results are compatible after parameter adjustment with the research conducted in the Kyrgyz apple orchard.

3.2 Stomatal response of maize to water stress

3.2.1 Introduction

The transpiration model based on the combination approach (Monteith, 1964) introduces the physiological control of water vapor flow in the leaves by a leaf resistance parameter. To adjust for deficit moisture supply from the soil, the leaf resistance increases. In the original formulation of the model, this resistance referred to a lumped resistor representing the foliage, hooked-up in series with the aerodynamic resistance of the atmospheric surface layer. Experimental investigation of the foliage resistance required an inversion of the transpiration model and independent measurements of the transpiration (Van Bavel, 1967). Yet, the relation to direct measurements of the stomatal resistance on leaves remained undefined.
A sub model with identifiable parameters about the mechanism regulating stomatal opening is needed to render the model operational. As light is the main environmental factor, to which stomatal aperture responds it is reasonable to parameterize the relation between incoming photosynthetically active radiation (PAR) and stomatal resistance. Previous research with cotton (Petersen et al., 1991) has shown that moisture stress changed the value of the coefficients in the mathematical function relating leaf resistance to PAR. The current project refines this finding by establishing directly the effect of a soil water deficit on these coefficients.

3.2.2 Methods

A series of stomatal resistance measurements under various conditions of the soil moisture deficit in the soil was made to deal with this problem in two 1000 m^2 plots receiving drip irrigation. The actual transpiration was measured with the heat pulse method. Potential transpiration was computed from the model assuming zero stomatal resistance. The daily value of the actual to potential transpiration ratio was calculated. In the dry treatment a drop to 60% of the initial value immediately after the last irrigation triggered a new water application restoring 60% of the accumulated soil water deficit. In the wet treatment the irrigation triggering value was a 20% drop of the ratio with a full return of the total water depletion. A steady state porometer (LI-1600) measured stomatal resistance. The porometer bears a quantum sensor for *PAR* (LI-190) to measure incident *P*hotosynthetically *A*ctive *R*adiation on the leaf. The measurements were taken on the abaxial and adaxial faces of the leaf. During a measurement the leaf remained in its original position. A time domain reflectometer (TDR) monitored soil moisture content in three replicates at the following locations: depth - 0.05, 0.35, 0.50 m, distance from dipper line - 0.15, 0.30, 0.45 m.

3.2.3 Results and discussion

The diurnal values of the resistances were plotted against incident PAR during several drying cycles. The results are summarized in Table 1. The mathematical form of the relation be-

$$r_L = \frac{r_{L\min}}{1 + \frac{S_{ph}}{PAR}}$$

tween measured resistance and incident PAR followed an inverse hyperbolic function:

here $r_{L\,\min}$ represents the minimum leaf resistance and S_{ph} is the value of PAR for which the actual resistance is twice the minimum value.

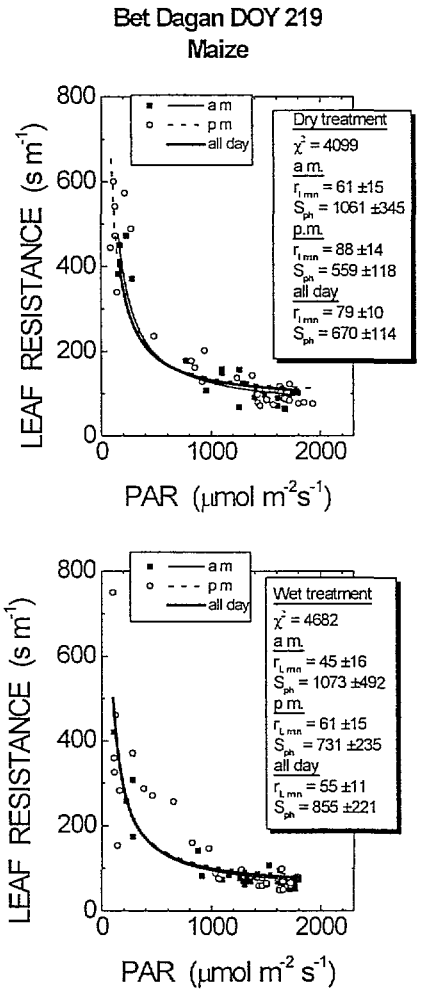

Figure 1. Relation between leaf stomatal resistance and incident photosynthetically active radiation measured during a day immediately following an irrigation.

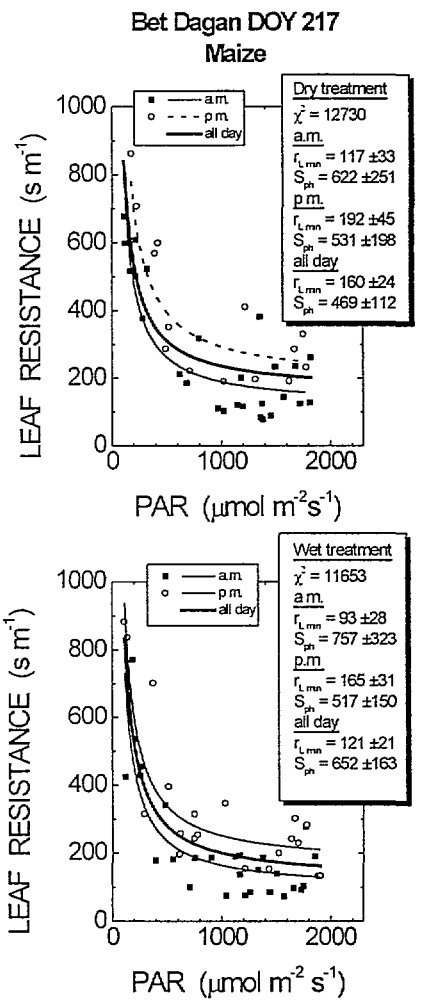

Figure 2. Relation between leaf stomatal resistance and incident photosynthetically active radiation measured during a day with large soil moisture deficit.

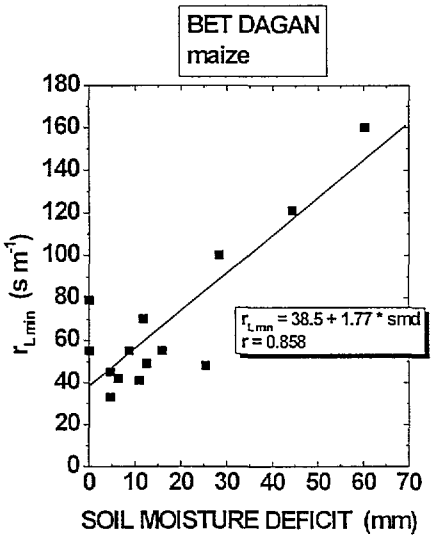

Figure 3. A linear function accounts for the increase of minimum leaf resistance with soil moisture deficit.

Figures 1 and 2 illustrate this relation for two conditions of the soil water status. In Figure 1 a recent irrigation has restored soil moisture to field capacity in the root zone. The soil moisture deficit is low. The parameters of the mathematical functions in the two treatments are similar, with a minimum resistance of the order of 60 s m^{-1}. Figure 2 represents conditions of a large soil moisture deficit. The minimum resistance reaches 120 s m^{-1} in the wet treatment and 160 s m^{-1} in the dry treatment. Yet in the course of the day, the decrease of moisture content due to water uptake causes an increase of the minimum resistance from morning to afternoon. The relative change of resistance with PAR appears independent of the soil moisture condition. The diurnal difference increases as soil moisture deficit increases. Although the value of Sph varies between data sets, the change is not associated with soil moisture. Therefore, in the application of the model this parameter takes on a constant value of 740 μmol m^{-2} s^{-1}.

The leaf resistance increases linearly with soil moisture deficit (Fig. 3). The least square fit of the linear coefficient and offset shown in Figure 3 were used to update the stomatal function in the transpiration model. In the current version this update is manual once a day. The diurnal change of the minimum resistance at a high soil moisture deficit may impose a modification of the model for use in cases of severe deficit irrigation.

3.2.4 References

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Table 1. Soil moisture deficit increases the minimum leaf resistance ($r_{L\ min}$) and the sensitivity of stomatal response to photosynthetic light (S_{ph}). At a high moisture deficit, the stress condition appears as increase of minimum leaf resistance in the afternoon.

DOY	Treatment	Soil moisture deficit (mm)	a.m.		p.m.		all day	
			$r_{L\ min}$	S_{ph}	$r_{L\ min}$	S_{ph}	$r_{L\ min}$	S_{ph}
198	dry	8.7	51 ± 13	425 ± 182	59 ± 19	617 ± 295	55 ± 11	441 ± 143
	wet	6.4	47 ± 19	575 ± 360	49 ± 24	1106 ± 665	42 ± 15	841 ± 404
200	dry	20.9	29 ± 34	1688 ± 2305	38 ± 36	2186 ± 2266	28 ± 25	2364 ± 2241
	wet	18.6	10 ± 19	2708 ± 5532	44 ± 15	951 ± 372	26 ± 11	1517 ± 697
203	dry	4.6	42 ± 6	357 ± 173	42 ± 5	718 ± 162	45 ± 3	311 ± 60
	wet	4.6	31 ± 6	638 ± 210	31 ± 7	935 ± 400	33 ± 5	636 ± 159
205	dry	12.5	36 ± 38	1516 ± 1810	47 ± 50	1950 ± 2355	49 ± 30	1355 ± 975
	wet	11.0	1 ± 28	38414	54 ± 40	1757 ± 1528	41 ± 23	1487 ± 961
207	dry	28.3	36 ± 34	1604 ± 1765	181 ± 38	370 ± 1434	100 ± 25	638 ± 238
	wet	25.4	26 ± 13	1787 ± 1058	88 ± 15	558 ± 125	48 ± 10	1026 ± 249
217	dry	60.3	117 ± 33	622 ± 251	192 ± 45	531 ± 198	160 ± 24	469 ± 112
	wet	44.4	93 ± 28	757 ± 323	165 ± 31	517 ± 150	121 ± 21	652 ± 163
219	dry	0.0	61 ± 15	1061 ± 345	88 ± 14	559 ± 118	79 ± 10	670 ± 114
	wet	0.0	45 ± 16	1073 ± 492	61 ± 15	731 ± 235	55 ± 11	855 ± 221
222	dry	15.9	53 ± 11	612 ± 226	60 ± 12	610 ± 171	55 ± 8	667 ± 142
	wet	11.9	60 ± 10	472 ± 124	75 ± 10	295 ± 53	70 ± 7	331 ± 45

C. Scientific Impact of Collaboration

1. On June 1, 1999 we received the money for the project continuation.
2. In June, 1999 we installed the meteorological station "Campbell Scientific", USA and involved Dr. Sergei Pismennyi to the project activities.
3. In October 1999 we dismounted the weather station for storage in the laboratory.

D. Description of Project Impact

The project results in the near future will be useful for farmers engaged with the apple orchards. The results and methodology will be used in the framework of the SIMIS project funded by a World Bank loan under the supervision of FAO.

E. Strengthening of Developing Country Institutions

1. Purchase of the equipment (weather station) for the field experiments.
2. Purchase of the office computer and other equipment for laboratory and field experiments.
3. Training in Windows, Spread Sheet and development of software for further improving of the data processing.
4. Training in modeling of crop water requirement.
5. Training in carrying out of the field experiments with use of new equipment and local methods.

For the progress of the project implementation it is necessary:

- to purchase of the portable computer;
- to purchase of new equipment for more complicated research experiments;
- to train of the use a new equipment from USA.

F. Future work

Because the long time required for the initial organization and purchasing of the equipment, a decision about necessity for the changing of the crop and the extension of the project terms of the implementation has been made by both collaborative Israel and Kyrgyzstan sides.

Reasons:

- The experimental site was not sufficiently protected against thieves and too expensive for providing of the field experiments. Very high trend of inflation and transport expenses.
- Apple orchard is an important crop in Kyrgyzstan.

The implications of the information provided by the model can be made relevant to other crops that are grown in irrigated districts. Research to implement the findings of this project to these other crops requires the development of a data set on the phenology, vegetative and generative development of these plants. It requires surveying and mapping the relevant climatic parameters, and establish a suitable network of automatic meteorological stations capable of providing rapidly irrigation scheduling advice to farmers.

Section 2

A. Managerial Issues

At the begining of 1999 the bank system was unstable in Kyrgyzstan and the money for the project was received only in June, but currently the situation is better.

C. Budget

It is necessary to enter the new items of the budget: local transportation, local and international travel.

E. Request for Tel Aviv, A.I.D. or BOSTID Actions

We also wish to receive a subgrant for carrying out of an additional experiment on the foothills of Ala-Too near glaciers. Local conditions of soil and water quality are favorable for experimental work. The proximity of the presidential skiing resort ensures good security and energy supply. We will submit a project proposal for this purpose.