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TITLE OF PROJECT: AGROMETEOROLOGICAL APPROACH TO CROP WATER USE EVALUATION FOR IMPROVED IRRIGATION EFFICIENCY

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Grant Project Officer:	Boaz Ayalon, Science Counselor, American Embassy, Tel Aviv
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Executive Summary

The purpose of the project was to develop a method for crop water use evaluation that would improve irrigation efficiency in the conditions of Kyrgyzstan and to transfer technology tested in Israel for implementation in Kyrgyzstan. The project required the purchase of Campbell Scientific, USA, automatic agrometeorological station (AMS) and sensors. Two scientists from Kyrgyzstan visited Israel to study the new technology, the software and the model of crop water evaporation developed by Prof. M. Fuchs. AMS was installed in an apple orchard of the Chui valley in Kyrgyzstan. A comparative analyze of irrigation scheduling methods in the apple orchard based on the lower limit of topsoil moisture content (local method by Ivanov) and on modeling using data obtained from AMS concluded that the second method is more reliable and accurate.

At first irrigation was conducted according to the limit of the topsoil moisture content using a gross norm 689 mm for six irrigations. Leaching below the root layer was 395.7 mm amounting to a loss of 56.7% the water resource. The AMS based model lead to 8 irrigations totaling 595.2 mm, with a leaching loss of 47.0 mm or 7.9%, saving 45.8 % of irrigation water and increasing apple fruit yield. The treated apple orchard produced on the average 31.7 tons/ha, for a total water use 826 mm and a planting density of 5×6 m. Specific water use was 26 mm/ton compared with 38-44 mm/ton obtained in the traditionally managed orchards. This comparison shows the benefits of the model's application to increased water use efficiency and production. Application to the main crops of Kyrgyzstan: corn, winter and autumnal wheat, sugar beet, alfalfa, and potato of these findings are very important for farmers, faced with agriculture reforms from centralized market oriented economy.

Research Objectives

This project was conducted because proper use of water resources in Kyrgyzstan as well as in Central Asia countries has vital importance. Israeli scientists in this field have a rich experience and achievements. For Kyrgyzstan it is also very important to increase crop yields. Technology transfer of modern irrigation methods and of crop production systems will solve agricultural reform problems in Kyrgyzstan. Results and achievements of this project would be useful for developing more complicated projects (S. Cohen, R.Sudhakara Rao, Y. Cohen, 1997). The Department of Science and new Technology of Kyrgyzstan is interested in continuation of this project and has provided additional finance support, but this support is very little because the Government has deficit of budget. Department of Water Economy supported this project and its results were included in the SIMIS project carried out in the Scientific and Research Institute for Irrigation under the directives of FAO. The Global Environmental Facilities (GEF), in frame of the Aral Sea project A1 fund, will also use skills and experiences acquired during the implementation of the project.

Methods and Results

1. Data, obtained by traditional methods
1.1. Specifications of the experimental plot
1.1.1. Location

The experimental orchard is located in Kok-Jar, 16 km of the southern outlying districts of Bishkek as in 1999. It is in foothill district at an altitude of 1000 m above a sea level, 30 km north of the high-mountainous glacier that rise to 4000 m altitude. The general slope of the orchard surface is within the limits of 0.05-0.07.

1.1.2. Climate

The analysis of the climatic factors obtained with the use of automatic meteorological station (AMS) in 2000, as well as in 1999, has shown the large variability climatic component. The main parameters of weather, air temperature and relative humidity fluctuate sharply during the season, from day-to-day and hourly. At the beginning of irrigation period, end of May, daily average air temperature changed from 16.3° up to 20.2°C. Within a day the temperature passed from 8°C minimum at night to a daytime maximum of 22°C. In June daily average temperature increased from 13.3 to 28.6°C from beginning to end of the month. Diurnal fluctuations were from 10-12°C at night and 27-30° during the day. July was warmer, with maxima daily average temperatures of 27.8°C, and minima of 15.8°C. Diurnal oscillations of temperature in the first decade were from 17.2°C at the night up to 33°C in daytime and from 16.5°C up to 29.7°C in the third decade. In August air temperature was more stable, ranging from 21.3°C to 28.0°C during the first, and from 17.9°C to 26.6°during the third decade. Corresponding diurnal variations were from 17°C at night to 30°C in daytime and from 12-14°C to 25-28°C. First two decades of September were warm with average temperature from 15.2°C to 22.9°C, and diurnal variations from 6-12°C at night to 22-25°C during the day. During the third decade, temperature dropped sharply from a range 11.2° -16.7°C in the beginning of decade down to 3.6° -13.8°C in the end. From 26.09, night temperature did not exceed 1.6-5.3°C, day's 8-20°C. The first of October active vegetation of the apple trees terminated and observations on AMS were stopped.

The humidity of air is subject to the large variations. In June the daily average humidity of air changed from 39.3 to 68.3 % for diurnal variations from 20 % up to 75 % from day to night, and up to 92 % during precipitation.

In July and August variation of diurnal humidity reached 11% and 72-93% for precipitation. The driest period was occurred at the end of the third decade of August. In August the daily variations of humidity have made from 22-39% up to 48-65% for clear weather and from 72 % up to 99 % for precipitation.

In September the humidity of air fluctuated from 28.0 % to 54.3 % in dry weather and from 63.0 to 94 % for precipitation. Within day it changed from 18-25% during day up to 55-73% at night increasing to 97-99 % during precipitation.

The wind for period of observations did not exceed a velocity 1.4-3.0 m/s and only from time to time for gusts reached 5-7 m/s. The main daily average parameters of the climatic factors are indicated in Appendix 1.

Intrusion of cold air masses from neighboring mountain glaciers imposes cultivation of regionally adapted apple tree varieties.

The vegetation duration of the orchard varies annually depending on the duration of the warm period of each year.

Vegetation in 2000 was favorable. However, in the beginning of May, blossoms suffered from cold temperatures down to 6°C and winds, lowering the proportion of apples graded "excellent" in the final yield.

1.1.3. Water-soil and surface data

The territory of the orchard is located on the piedmont deposit of the river Ala-Medin. Stony lands occupy 15 % of the territory. The soil type is serozem. In the loam soil forming a main part of the orchard, there are lenses and layers of sand, gravel giving a lighter mechanical structure to the soil.

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

To prevent erosive processes, soil between tree rows was sown with perennial grasses, pink clover, motley grass and wild grasses. The community of grasses is the natural consumer of moisture of the irrigated orchard. Therefore, for account of total water use by the orchard, it is necessary to take into account water use of grasses.

The general slope of district within the limits of 0.05-0.07 hinders surface watering of orchard. Watering was made on undeviating ring and half-ring furrow, as in 1999, sharply reducing a possibility of development of irrigation erosion for watering on steep slopes.

1.2. Water regime of the orchard

1.2.1. Terms and norms of watering

On April 2, 2000 soil moisture sampling were initiated at the site of AMS. Soil moisture to a depth of 1.5 m averaged 14.7 % or 80.6% of FC, or a water equivalent of 64 mm in 1.5 m of soil. Stored moisture was sufficient for normal development of the apple trees.

The first irrigation of 57.5 mm was applied at the start of AMS operation. At the time, the moisture content of the 1.5 m topsoil layer was 299.6 mm or 76.7 % of FC.

The following two watering were conducted on 08.06 and 20.06 with average gross norms 74.5 and 73.7 mm. Moisture contents before-watering were 73.4 and 85.1 % from FC (fig.1.1, for matching data of 1999 see fig.1.2.). The next two irrigations applied 74.5 and 54.2 mm on 05.07 and 20.07 at soil moisture contents 78.4 and 85.4 % from FC. The 6-th and 7-th irrigations on 10.08 and 28.08 applied 120.3 mm and 69.6 mm at moisture contents of 71.9 % and 80.5 % from FC to a profile depth of 1.5 m.

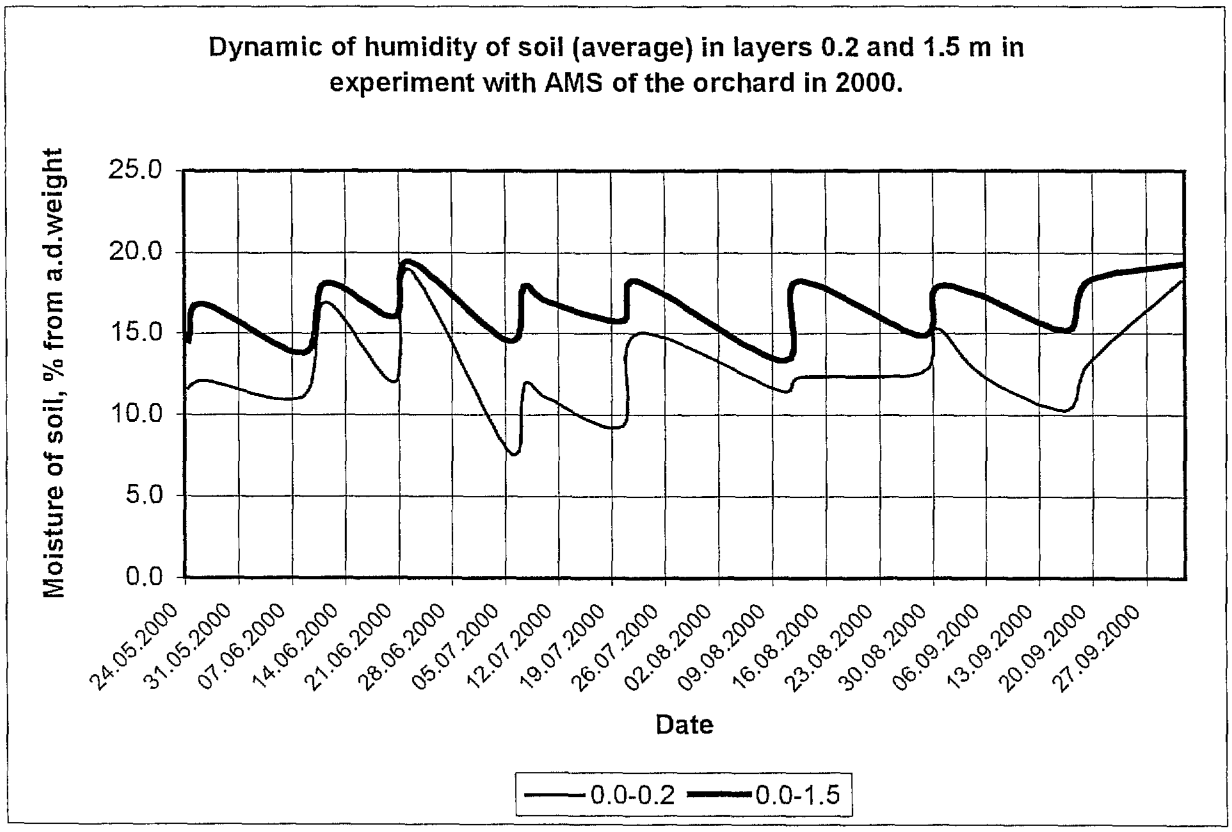

Fig. 1.1

Dynamic of moisture content of the 1 m top layer of soil in experiment B-1-1 of the apple orchard in 1999.

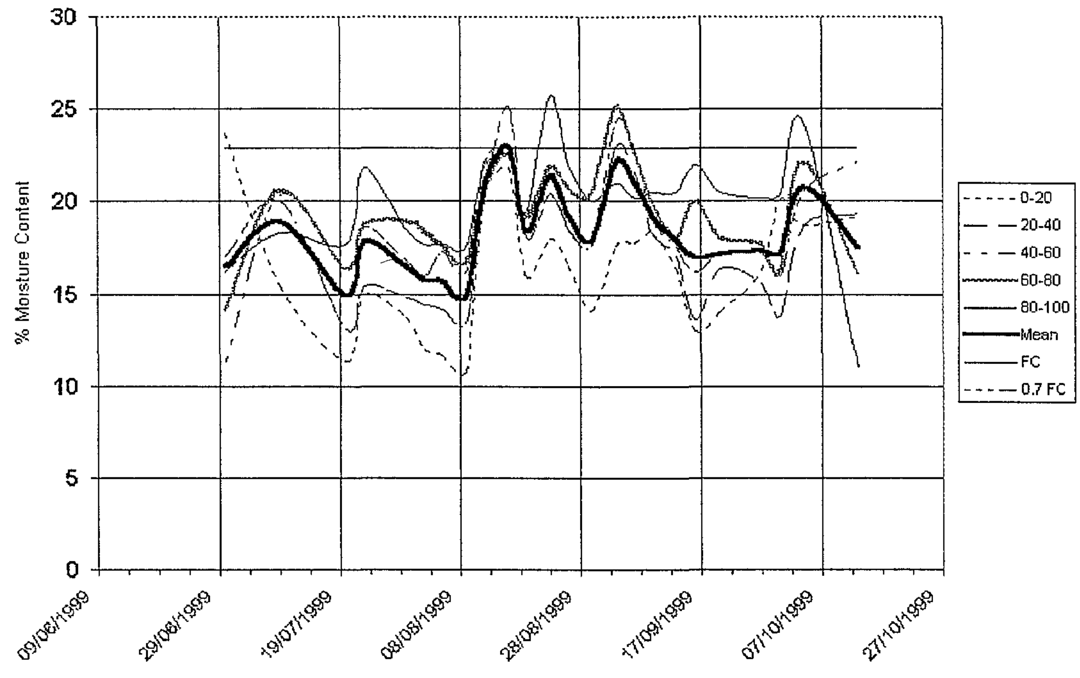

Fig.1.2

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

Dynamic of moisture content of the 1 m top layer of soil in experiment B-1-2 of the apple orchard in 1999.

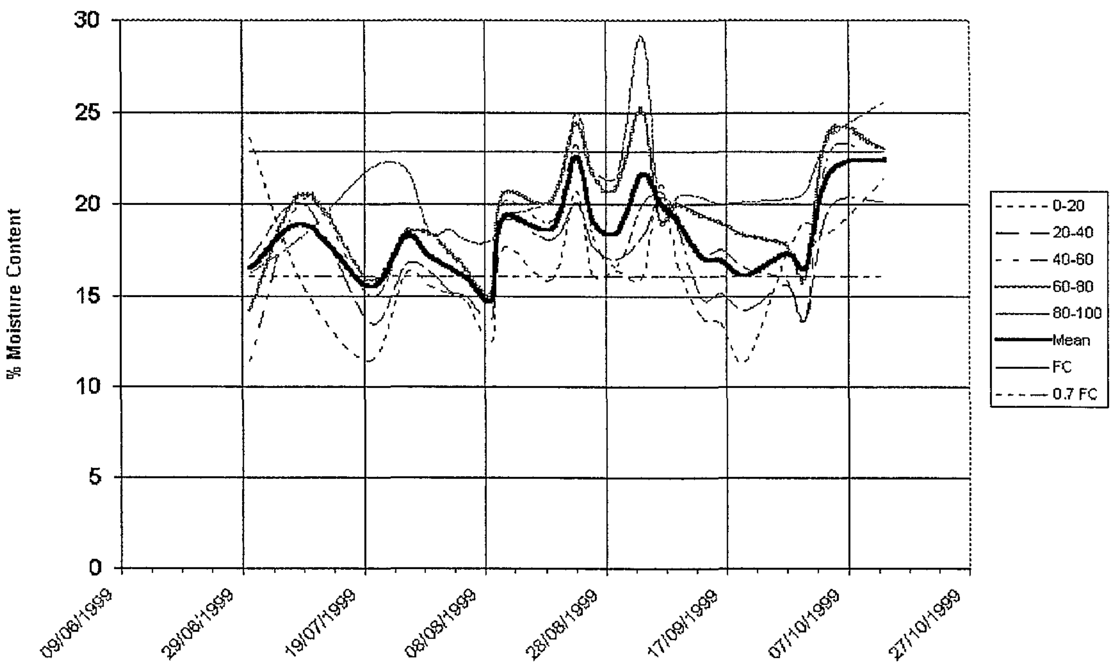

Fig. 1.3

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

Last irrigation was applied on 17.09, when the moisture content to a depth of 1.5 m was 299.1 mm or 82.2 % from FC on the average in both experiments.

Fall irrigation was not necessary because of abundant precipitation.

The eight irrigations during the vegetation season of the orchard applied 595.2 mm of water, of which 548.2 mm or 92.1 % were retained in the 1.5 m deep root zone and 47.0 mm or 7.9 % were lost by leaching. The water applications were conducted according to the water use estimated of the model. This procedure resulted in a very small loss by leaching below the root zone. Details of the water balance following the irrigation application are shown in table. 1.2.

Table 1.2

Detailed water balance of the soil to a depth of 1.5 m in experiments of 2000 (average)

Number of watering	Dates of watering	Stored water, mm		Net norm, mm	Irrigation gross norm, mm			Leaching	
		After watering	Before watering		AMS 1-1	AMS 1-2	Average	mm	% of gross norm
1	24.05	344.3	299.6	44.7	58.8	56.2	57.5	12.8	22.2
2	08.06	367.6	280.1	71.2	72.2	76.8	74.5	3.3	4.4
3	21.06	393.8	325.1	68.7	72.6	74.8	73.7	5.0	6.8
4	05.07	363.0	294.0	69.0	78.6	70.4	74.5	5.5	7.4
5	20.07	358.2	312.2	46.0	52.2	56.2	54.2	8.2	15.1
6	10.08	352.8	236.8	116.0	130.6	110.0	120.3	4.3	3.6
7	28.08	360.6	293.9	66.7	71.6	67.6	69.6	2.9	4.2
8	17.09	365.0	299.1	65.9	69.5	72.3	70.9	5.0	7.0
Total				548.2			595.2	47.0	7.9

1.2.2. Dynamic of moisture of soil for irrigation of orchard

Initial soil moisture was sampled at the second phase of apple tree development, blossom and beginning of flowering (12.04) before the first irrigation is shown in table 1.3.

For the experiment of 2000 irrigation scheduling was determined from the water depletion calculation of the model and AMS by keeping the moisture balance of the 0-1.5 m soil layer between 70% and 100 % of FC. The last irrigation and a 39.8 mm rainfall raised the average moisture content to 100 %, allowing to omit the irrigation for replenishing soil water storage.

Table 1.3

Moisture of soil and stocks of moisture on modeled layers in spring period and before the beginning of active vegetation of orchard in 2000 (average in experiment).

Horizons and settlement layers, M	Spring period (12.04)			Beginning active vegetation (24.05)		
	Moisture of soil, %		Stock of a moisture, mm	Moisture of soil, %		Stock of a moisture, mm
	From weights of absolutely dried soil	From FC		From weights of absolutely dried soil	From FC	
0.0-0.2	12.1	63.3	36.8	11.6	60.7	35.2
0.2-.04	14.9	77.6	41.4	11.4	59.4	31.7
0.4-0.6	17.7	89.4	50.0	14.5	73.2	40.9
0.6-0.8	18.5	96.3	52.6	16.5	85.9	46.8
0.8-1.0	12.2	80.2	38.0	13.8	90.8	45.6
1.0-1.2	11.8	77.6	36.8	16.5	84.2	48.6
1.2-1.5	15.7	80.1	63.0	17.5	94.5	49.4
0.2-0.6	16.3	83.6	91.4	13.0	66.7	72.6
0.2-0.8	17.0	87.8	144.0	14.1	72.7	118.6
0.0-1.0	15.1	81.4	218.8	13.6	73.5	200
0.0-1.5	14.7	80.6	318.6	14.5	76.7	299.6

The dynamic of moisture content in the soil down to 1.5 m depth in the orchard irrigated according to AMS (average of two replicates) is shown in fig.1.1 and table.1.4.

Table 1.4

Dynamic of soil moisture profile in the orchard irrigated according to AMS in 2000
% dry weight (average of two replicates)

Soil horizons, m	Dates									
	12.04 Spring selection	24.05 before watering N1	26.05 after watering N1	08.06 before watering N2	11.06 After watering N2	20.06 before watering N3	22.06 After watering N3	05.07 before watering N4	07.07 After watering N4	10.07 The control
0.0-0.2	12.1	11.6	12.1	11.1	16.9	12.0	18.9	7.7	11.9	11.0
0.2-0.4	14.9	11.4	16.8	11.4	17.9	14.1	19.0	12.6	17.6	16.3
0.4-0.6	17.7	14.5	18.1	13.0	19.2	16.2	19.3	14.9	19.2	16.3
0.6-0.8	18.5	16.5	19.8	16.7	19.2	16.9	20.1	13.9	20.6	18.1
0.8-1.0	12.1	13.8	15.9	12.1	16.4	16.7	19.8	18.2	20.8	18.8
1.0-1.2	11.8	16.5	18.9	16.0	19.4	17.9	19.3	17.4	19.1	19.3
1.2-1.5	15.7	17.5	16.2	16.6	19.7	18.1	19.5	16.7	16.1	19.5
0.0-1.5	14.7	14.5	16.8	13.8	18.1	16.0	19.4	14.5	17.5	17.0
0.0-0.2	9.. 3	15.0	11.4	12.3	12.6	15.3	12.4	10.3	13.2	18.2
0.2-0.4	11.0	16.9	11.2	16.6	12.2	18.0	14.2	13.3	17.3	19.8
0.4-0.6	16.4	20.1	12.0	19.0	16.2	19.8	18.8	14.2	19.2	19.8
0.6-0.8	17.6	20.1	14.1	21.7	17.9	19.2	20.5	15.1	20.1	20.4
0.8-1.0	18.9	21.8	16.2	22.2	16.6	20.2	21.3	17.9	21.3	21.6
1.0-1.2	18.7	19.7	14.2	19.5	16.2	18.9	19.3	18.0	17.9	19.0
1.2-1.5	12.2	13.5	14.0	16.3	12.3	13.7	14.9	17.5	18.7	17.2
0.0-1.5	15.8	18.2	13.3	18.2	14.9	17.8	17.3	15.2	18.2	19.3

1.2.3. Total water use of the irrigation orchard

In parallel with the experimental determination of total water use by the orchard, for monitoring, the water balance equation accounted analytically for water use during a time interval:

$$P + M + Zm + Zx - E - Ev - Mthru + \Delta Wh + \Delta Usur + Kh - Jh = 0,$$

Where:

P – sum of precipitation for the interval, mm;
M – irrigation norm for the same period, mm;
Zm and Zx – run-on from water leaking from main and supply channels upstream of the experimental plot (EP);
E – total water use, mm;
Ev – evaporation from ponded water on the soil or from sprinkled drops, mm;

Mthru –runoff of excess irrigation from the EP, mm;
ΔWh = Whbeg-Whend –moisture content change in the root zone h,

Whbeg and Whend –moisture content at the beginning and end of the interval,
Kh – replenishment of the root zone from the water table, mm;
Usur – run-on from upstream terrain, mm;
Jh – moisture leaching below the root zone, mm.

The supplying flumed channel is far from EP. Run-on of water leaks is insignificant. Therefore, the terms Zm and Zx of the equation in accounts can be omitted.

Excess runoff was excluded by the furrowing technique and the small amounts at each application.

Initial accumulation of moisture in early spring is excluded from water use, because the bookkeeping of water begun on May 25.

Evaporation of free water in buried half-ring furrow is negligibly small and can be discarded.

Water leaching below the root zone is given by the formula:

$$J_F = m_{gn} - m_{nt}, \qquad M_{nt} = W_{aw} - W_{bw}$$

Where:

M_{gn} - the irrigation gross norm for each watering, mm;
M_{nt} – the irrigation net norm, mm;
W_{aw} , W_{bw} – Water stored in soil after and before watering.
The equation of water balance for EP is:

$$W_{beg} + m + P - E - J_F - W_{end} = 0,$$

Accordingly the water use of tree and grass community was:

$$E = W_{beg} + m + P - J_F - W_{end},$$

The soil water balance to 1.5 m and the total water use of the orchard are presented in tables 1.5 and 1.6.

Table 1.5.

Periodic water balance of 1.5 m soil layer of irrigated orchard.

Date			Period, days.	Moisture storage, mm		Effective irrigation, mm	Production rain, mm	Total water use, mm					
								modeled			adjusted		
Initial	Final	Average		Initial	Final			For period	Daily average	Integrated	For period	Daily average	Integrated
25 05	08.06	31.05	15	299.6	280.1	44.7	13.0	77.2	5.15	77.2	77.2	5.15	77.2
09.06	20.06	14.06	12	280.1	325.1	71 2	3.0	29.2	2.43	106.4	38.2	3.17	115.4
21.06	05.07	28.06	15	325.1	294.0	68.7	4.6	104.4	6.96	210.8	69.6	4.64	185.0
06.07	10.07	08.07	5	294.0	360.0	69.0	0.1	3.1	0.62	213.9	59.2	6.84	244.2
11.07	20.07	15.07	10	360	312.2	-	4.2	52.0	5.20	265.9	40.3	40.3	284.5
21.07	10.08	31.07	21	312.2	236.8	46	3.6	125.0	5.95	390.9	74 3	3.55	359.0
11.08	28.08	19.08	18	236.8	293.9	116.0	5.6	64.5	3.58	455.4	79.0	4.39	438.0
29.08	05.09	01.09	8	293.9	346.0	66.7	0.0	14.6	1.75	470.0	46.5	5.81	484.5
06.09	16.09	11.09	11	346.0	299.1	-	0.0	46.9	4.26	516.9	32.5	2.95	517.0
17.09	01.10	24.09	15	299.1	381.9	65.9	39.8	22.9	1.53	539.8	23.0	1.53	540.0

Total water use from 25.05.00 till 01.10.00 or for 130 day, modeled and adjusted, was 539.6 mm and 540.0 mm. Initial daily average water use was 5.15 mm/day and varied from 2.95 to 4.64 mm during the irrigation period. Water use by vegetation during the autumnal period was 1.53 mm/day.

Water use during the phases if tree development changed at the beginning of leaf growth from 3.94 to 4.27 mm/day. At the start if the irrigation period, it became 5.4 to 6.44 mm/day, ending at 2.68 to 2.14 mm/day at the halt of the active vegetation.

Table 1.6

Soil water balance to 1.5 m depth of irrigated orchard at specified development phases

Phases of development	Date			Period, day	The stocks of a moisture, mm		Net irrigation, mm	Precipitation, mm	Total water use, mm					
									Modeled			Adjusted		
	Initial	Final	Average		Initial	Final			For period	Daily average	Integrated	For period	Daily average	Integrated
1. Fruit set, leaf growth –pruning redundant ovaries, shoot growth	25.05	20.06	07.06	27	299.6	325.1	115.9	16.0	106.4	3.94	106.4	115.4	4.27	115.4
2. Pruning redundant ovaries, shoot growth - beginning strengthened fruit growth	21.06	10.07	30.06	20	325.1	360.0	137.7	4.7	107.9	5.40	214.3	128.8	6.44	244.2
3. Beginnings of strengthened fruit growth beginning of fruit maturing	11.07	05.09	08.08	57	360.0	346.0	228.7	13.4	255.7	4.49	470.0	240.3	4.22	484.5
4. Beginning of fruit maturing end of active vegetation, harvest	06.09	01.10	18.09	26	346.0	381.9	65.9	39.8	69.8	2.68	539.8	55.5	2.13	540.0

1.3. Qualitative analysis of data and results of field modeling experiments

The qualitative analysis of data and results of modeling was made for periods of observations and phases of development of apple trees by comparing evaporability according to AMS data and observed water requirements of the orchard (table 1.7 and fig.1.4).

Table 1.7

Seasonal total water use during measurement intervals and ratio of accumulated modeled water use Eo over accumulated Ei evaporability of the irrigated orchard

Date of observations periods			Transpiration from AMS EP, mm		Total water use by orchard Ei, mm				Factor ratio				The lower threshold of moisture of soil for period, % FC
					Balance		adjusted,		Kpi		Kai		
Initial	Final	Average	On periods of observations, Eop	Integrated Eoi	On periods of observations Eip	Integrated Eis	On periods of observations Eap	Integrated E as	Eip Eop	Eis Eoi	Eap Eop	Eas Eoi	
25.05	08.06	31.05	66.90	66.90	77.2	77.2	77.2	77.2	1.15	1.15	1.15	1.15	74.39
09.06	20.06	14.06	54.71	121 61	29.2	106.4	38.2	115.4	0.53	0.88	0.70	0.95	86.25
21.06	05.07	28.06	77.38	198.99	104.4	210.8	69.6	185 6	1 35	1.06	0.90	0.93	78.17
06.07	10.07	08 07	29.46	228.45	3.1	213.9	59.2	244.2	0.10	0.94	2.00	1.07	91.64
11.07	20.07	15 07	43.25	271.70	52.0	265.9	40.3	284.5	1.20	0.98	0.93	1.05	85.17
21.07	10.08	31.07	101.60	373.30	125.0	390.9	74.3	359.0	1.23	1.05	0.73	0.96	71.7
11.08	28.08	19 08	79.38	452.68	64.5	455.4	79.0	438.0	0.81	1.01	0.99	0.97	80.32
29 08	05.09	01.09	32.45	485.13	14.6	470.0	46.5	484.5	0.45	0.97	1.43	1.00	93.26
06 09	16.09	11 09	42.51	527 64	46.9	516.9	32.5	517.0	1.10	0.98	0.76	0.98	81.94
17.09	01.10	24.09	30.33	557.97	22.9	539.8	23.0	540.0	0.75	0.97	0.76	0.97	98.11

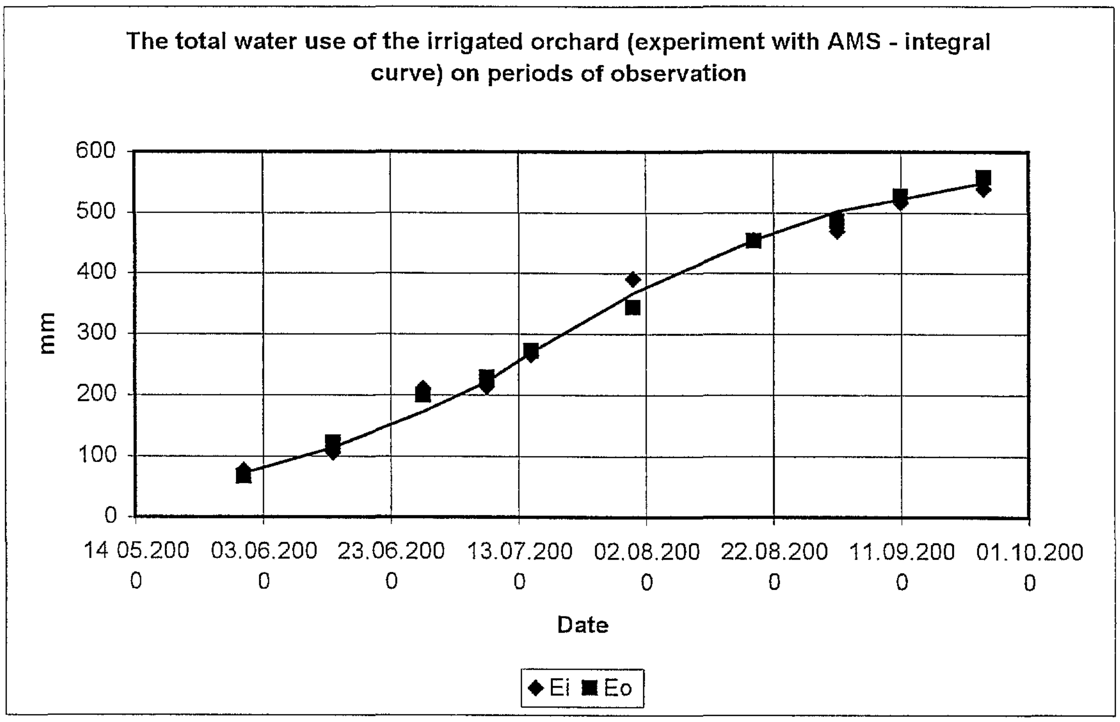

Fig. 1.4

In 2000, orchard water use determination begun at the start of the irrigation season. The dynamic analysis of factors Kpi and Kai shows that their magnitude changed with apple tree development and with meteorological conditions. In the beginning of the season, the threshold moisture content to operate irrigation was above 80 % FC, factors Kpi and Kai are fairly similar through the growth phases of the orchard during the irrigation season. At the end of the season the cold temperature slowed the water uptake resulting in a decrease of the factors. Factors were smaller when the threshold moisture content that triggered irrigation decreased.

1.4. Physiological and biological survey of main crops in conditions of the arid zone of Kyrgyzstan

For a theoretical evaluation of water use of the most significant agricultural crops (corn, sugar-beet, alfalfa, potato, spring and winter wheat) information about physiological development of plants and formed climate factors is collected from the last and existing statistics of data.

In particular, into a data bank is entered the following information.

- Date of planting
- Date of shoot emergence
- Date of leaf emergence
- Phase and period of development of plant
- Duration of a phase of development
- Date of harvesting
- Date of the last watering
- Irrigation amounts
- Planting density
- Average yield
- Height of plants; maximum
- Height of plants; average
- Heat requirement of plants in for vegetation period

The aforementioned information is in Appendix 2.

1.5. Productivity of orchard

The norm of irrigation, based on magnitude of total water use, received by model of Prof. M. Fuchs with use of data from AMS allowed the optimum water use of the orchard. This was a reason of the increased yield of apple fruit. Mixed apple orchard (varieties, Golden de Luxe, Excellent, Aport) gave an average yield of 31.7 tons/ha, for total water use of 826 mm and planting density of 5×6 m. Specific water use was 26 mm/tons, while in farms, where scheduling did not consider actinometrical and meteorological factors water use increased to 38-44 mm/tons. These data show the increase of irrigation efficiency and productivity that the AMS based model can provide.

2. Data obtained with the use of the model

Results of the models, obtained with the use of meteorological station are presented below.

Method of data processing is as follows:

1. Meteorological station, worked continuously, recording every 10 minutes the main climatic parameters (air temperature and relative humidity, direction and velocity of wind, solar radiation, precipitation);

2. Obtained data with the help of memory block are transferred from meteorological station to the computer and stored in a data bank;
3. From the data bank, the information for the selected days are transferred into the electronic table;
4. From the electronic table the information treated by an algorithm of Prof. M. Fuchs and the daily average climatic parameters and other additional information determined;
5. Obtained outputs reduced in the general table.

The results of climatic data processing are represented on a fig. 2.1. (Data of 2000).

In the 1999 qualitative analysis of data of the model was made with formulas of Ivanov, and Penman-Monteith. The climatic data obtained from automatic meteorological station, were substituted into the appropriate formulas, output was tabulated and seasonal results are plotted in fig.2.2.

Table 1.8

Total water use for orchard development phases of and cumulative water use, and ratio of water use Ei over modeled transpiration Eo

Phases of development	Date of periods of observation			The transpiration on AMS E_p, mm		Total water use by the orchard Ei, mm				Factor of ratio			
						Balance		Adjusted,		Kpi		Kai	
	Initial	Final	Average	On periods of observations Eop	Integrated Eoi	On periods of observations Eip	Integrated Eis	On periods of observations Eap	Integrated Eas	Eip/Eop	Eis/Eop	Eap/Eoi	Eas/Eoi
1.Fruit set, leafing, pruning of redundant ovaries, shoot growth	25.05	20.06	07.06	121.61	121.61	106.4	106.4	115.4	115.4	0.87	0.87	0.95	0.95
2. Pruning of redundant ovaries, shoot growth– Beginning of strengthened fruit growth	21.06	10.07	30.06	106.84	228.45	107.9	214.3	128.8	244.2	1.01	0.94	1.20	1.07
3. Beginnings of strengthened fruit growth beginning of fruit maturing	11.07	05.09	08.08	256.68	485.13	255.7	470.0	240.3	484.5	1.00	0.97	0.94	1.00
4. Beginning of fruit maturing, end of active vegetation, harvest	06.09	10.10	18.09	72.84	557.97	69.8	539.8	55.5	540.0	0.96	0.97	0.76	0.97

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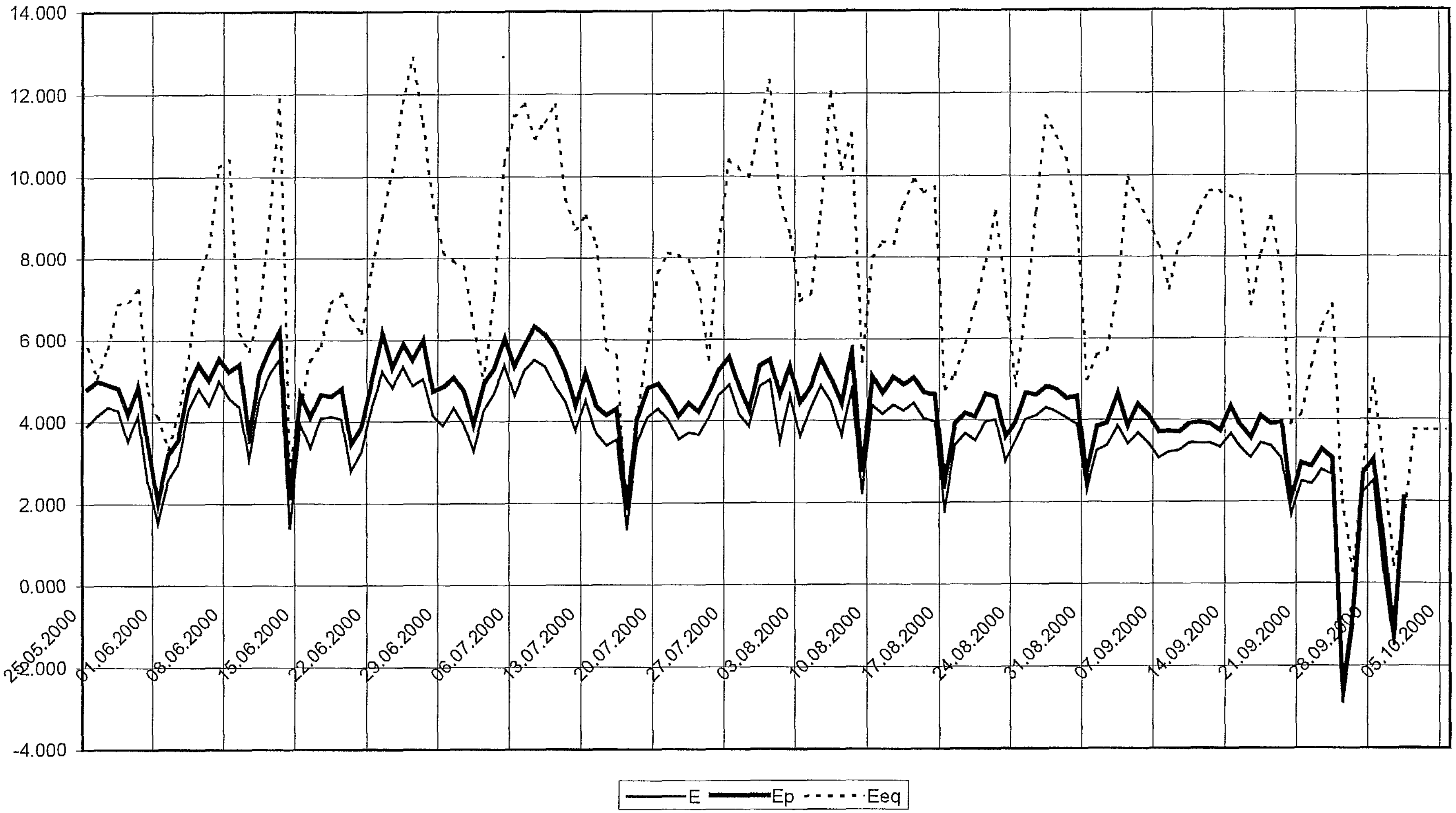
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E
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Eeq

Fig. 2.1

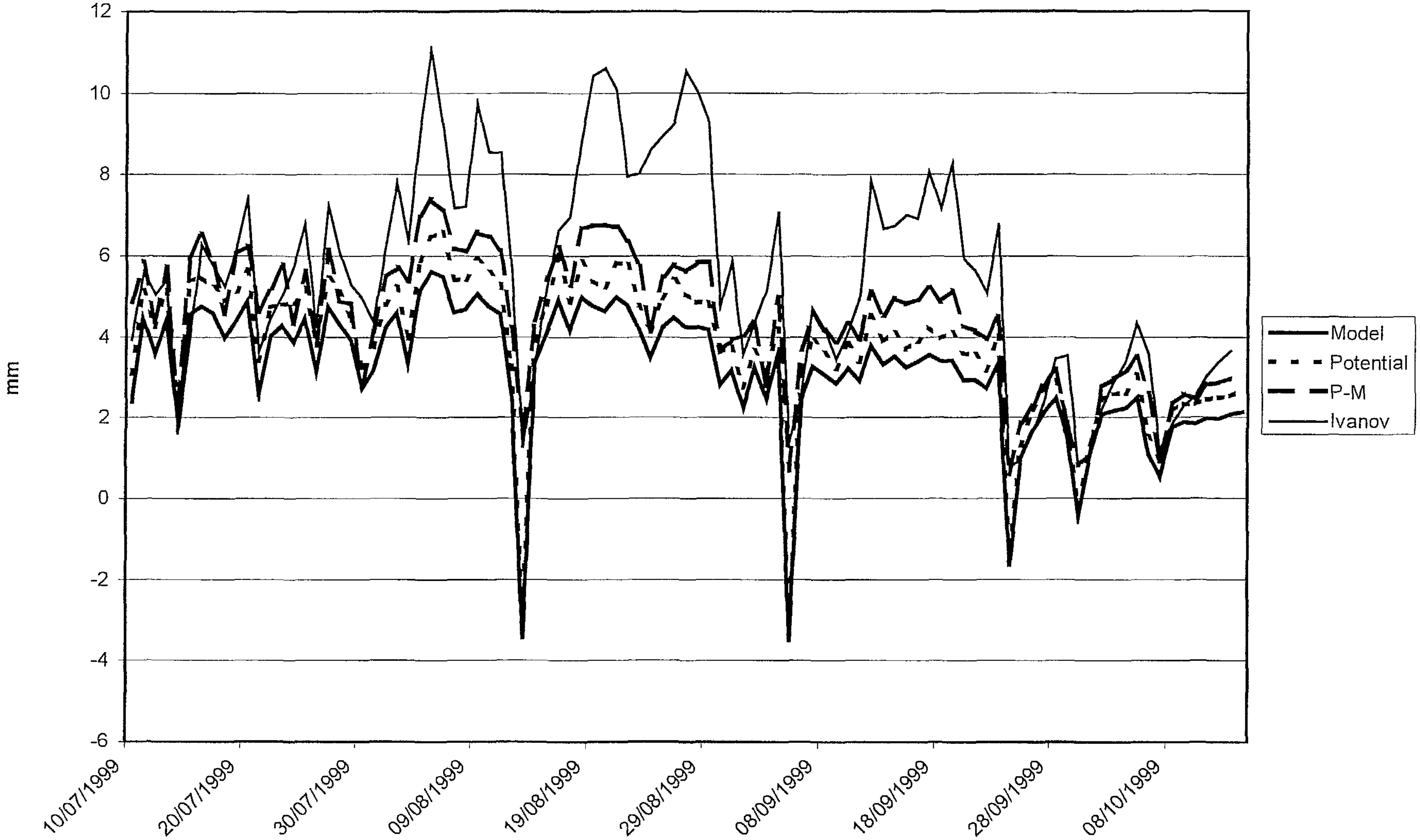

Fig. 2.2.
Comparison between potential, model, Penman-Monteith (P-M) and Ivanov calculations of apple orchard transpiration.

3. Conclusion

The comparison of methods for scheduling irrigation terms and show that the AMS based model provide the more reliable information.

Results of 1999 based on the limit of a moisture content determined a water use of 689 mm in six applications. The leaching amounted to 395.7 mm or 56.7%. In a 2000 scheduling used AMS data and the transpiration model. Water applied in 8 watering was 595 mm, from which leaching losses were 47 mm or 7.9%. The application AMS has allowed to save 45.8 % of the irrigation water.

Impact Relevance and Technology Transfer

Results of this project will be included to the tutorial program of the SIMIS (Scheme Irrigation Management Information System) project carried out in the Kyrgyz Scientific and Research Institute for Irrigation in frame of the World Bank loan organized for farmers and members of water users associations under observation of experts of FAO. At the same time a recommendation will be published for farmers about correct and accurate water regimes for the main crops in Kyrgyzstan. The experimental plot was situated on the orchard of the private farm "Eleman" and the owner was satisfied with results of research because he has received an unexpectedly higher yield in 2000. Neighbor farmers of the farm "Eleman" took an interest with results of the experiment and asked questions regarding the determination of the crop water requirements. Scientists recognized the farmers' urgent need for advice about modern technologies and scientific approaches for higher crop production. Experiences and skills have gained from this project will be useful for the GEF (Global Environmental Facilities) projects devoted to the problem of the Aral Sea basin.

During of implementation of the project four scientists acquired good skills in using of AMS and modeling of crop water regimes for efficiency irrigation water management developed in USA and Israel. Capacity of the laboratory was strengthened and six scientist and technicians studied computer and got AMS data processing skills. Staff of laboratory improved the knowledge in oral and written English. The laboratory has purchased an automatic meteorological station and sensors from Campbell Scientific, USA, four personal and two portable computers, Xerox, scanner, two mobile telephones and other laboratory and office equipment. The Institute opened new research directions and intends to expand the cooperation with USAID and Israel. For this purpose several project proposals are under preparation with Israeli scientists.

Project Activities/outputs

In June 1998 two scientists from Kyrgyzstan attended training and study sessions in Israel on crop production technologies developed in Israel and learned the modeling of crop water transpiration using of meteorological data collected by the Campbell Scientific weather station, so they can experiment in Kyrgyzstan on crop water use for improved irrigation efficiency.

They also observed application of the model cotton and maize experimental fields near Tel Aviv and an apple experimental orchard on the north of Israel.

In June 2000 Dr. J. Rahmanov attended Israel for coordination of project activities and discussion of the results obtained in 1999. During the visit of Dr. J. Rahmanov, coordination and terminology misunderstandings were clarified. The Annual Report was completed.

In November and December 2000 Dr. J. Rahmanov attended Israel for discussion of results of 2000 and completion of the Final Report. During the visit was organized a trip to the irrigation equipment factory "Netafim" in the south of Israel. Recently purchased frequency domain soil moisture probes were put in operation. Hook-up and wiring procedures were demonstrated. The data acquisition software was also tested in a set-up that simulates the equipment configuration to be used in Kyrgyzstan.

Future Work

Inspired with research results of 1999 and 2000 the Kyrgyzstan side intends to continue of field experiments and develop theoretical investigations. For this purpose, the Kyrgyz Institute will purchase Campbell Scientific soil moisture content probes to check and monitor the algorithm of irrigation water optimal management.

The objective of the study will be to verify the hypothesis about existence of an optimal management scheme for crop irrigation scheduling. We intend to develop software for an optimization algorithm based on the balance equation

$$E_{Fuchs}=W_{beg}+M+P-J_F-W_{end}, \quad (1)$$

Where $E_{Fuchs}=F_{Fuchs}(x,y,z,\ldots)$ a model prediction and $x,y,z,\ldots$ - meteorological parameters;

M - irrigation norm ;

P – precipitation ;

J_F – filtration;

W_{beg}, W_{end} – initial and final soil moisture contents. From (1) we will receive the equation:

$$dW/dt = E_{Fuchs}-M-P+J_F \quad (2).$$

Also we can defined

$$Y_{yield} = F(M) \quad (3),$$

Where, M–is a parameter of the management. From this equation we can find the constraints:

$$M_* \text{<or=} M \text{<or=} M^* \quad (4).$$

If T_0, T–the beginning and the end of the vegetation period than we can seek the minimum of the function

$$I= {}_{To}\int^{T} (k_1(M-M^{opt})^2+k_2(W_{end}-aFC)^2)dt \rightarrow \min \quad (5)$$

Where k_1 and k_2 – weight coefficients; and a=0.7, this coefficient has been used in experiments of 1999 and 2000 –70% of the Field Capacity (FC). In additional to the constraints (1), (2), (3) and (4), additional constraints parameters would be considered as they arise from the practical application of the experiment in field conditions.

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