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MICRO IRRIGATION SCHEDULING OF APPLE ORCHARDS

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EXECUTIVE SUMMARY

During the four year of work the following was accomplished:

1. Planning of the project at the first year. Mutual learning and familiarization of the investigators with Khyrghiz agronomy and conditions from one side and modern irrigation scheduling and agro-physical research methods from the other side.
2. Acquisition and shipping of the irrigation and control equipment to Cholpon Ata. Initial hands-on training of the Khyrghiz PI was done in MIGAL at 1995.
3. Physical and methodical implementation of the field experiment at the experimental farm:

- Automated weather station was installed and activated for general meteorological observations and for calculation of reference evapotranspiration
- Farm water supply was adapted for pressurized irrigation
- Microirrigation equipment installed and activated. Local personnel familiarized and trained in the operation of the systems and the experimental instrumentation and in computerized documentation and data processing.

4. Irrigation experiments commenced at mid May and ended end September each year of 1996, 97 and 98 seasons.

The following results were obtained:

- The meteo-station functioned well through all three seasons and provided the reference ET for irrigation scheduling. Observations compared favorably with adjacent Cholpon-Ata conventional meteorological station.
- Irrigation system functioned properly, though it was operated by manually set metering valves, because of electrical failures that ruined the Motorola IRRINET controller.
- Light interception of the orchard was about 20 - 25% of the incoming radiation. Irrigation was scheduled as 40% from full cover reference daylight ET taking in account orchard geometry.
- Neutron probe soil water monitoring and fruit growth curves indicated that the basic scheduling was correct, thus verifying the reference ET evaluation concept and algorithm.
- Tree variability in the orchard was one of the limiting factors to reach more sharp and definitive conclusions.
- Local conditions limited yield determination to a sampling process, not enabling final yield harvest or fruit quality evaluation.

5. The investigators and research personnel of the KSIRI and the Cholpon Ata experimental farm strengthened their research capabilities in Agrometeorology, Biophysics and Irrigation Science, in theoretical knowledge and in application of modern instrumentation and computerized data processing.. Israeli scientists tested reference ET evaluation methods developed under Mediterranean conditions in high altitude Central Asian climate.

6. The technology was presented to the farmers and other decision-makers. Broader implementation will be expected when the Issyk-Kul Lake Hollow farm economy will adjust to the post agrarian reform era.

Section I.

A. Research Objectives.

The aim of research is to evaluate microirrigation scheduling and application methods for apple orchards under high altitude, cold climate, light soil and intermittent summer rain conditions.

Specific objectives of the program are:

1. To Apply and test combined meteorological and plant data based irrigation scheduling in apple orchards, under Yssyc-Kul Lake Hollow conditions.

2. To adapt microirrigation technologies to apple orchards at the Yssyc-Kul Lake Hollow area.

B. Research Methods and Results

B.1 First stage: Installation and testing.

Irrigation equipment was installed during April 1996. Experimental treatments were started in spring 1996. J. Tsipris was participated in the installation and initialization stage at end April, M. Meron was in the site at the end of May to participate at the begin of the experimental and treatments. During this period a knowledge exchange and advanced technology familiarization program was accomplished as follows:

- Irrigation control and monitoring and irrigation scheduling method were tested.
- Automatic weather station, communication links and a Personal Computer was assembled, programmed and tested in experimental site in Kyrghyzstan.
- Field experiment methods were discussed in-depth and final program was developed.
- A comprehensive program on advanced irrigation and research technologies included:

◊ Operation and programming of MOTOROLA IRRINET irrigation control.
◊ Operation and programming of the Campbell CR10 weather station.
◊ CR10 weather data processing, ET calculation from weather data.
◊ Familiarization with the irrigation equipment operation and troubleshooting.
◊ Operation of the new TROXLER Neutron probe.
◊ Operation, data acquisition and processing of electronic ceptometers.
◊ PC Spreadsheet calculations, graphing and word processing skills.

B.2 Field experiments - Materials and Methods

A microirrigation experiment was initiated in the Yssyk-Kul Government Horticultural Introduction Experimental Station, at Cholpon Ata, near Yssyk-Kul Lake in a 10 year old apple orchard , under the auspices of the Khyrghiz Scientific and Research

Institute of Irrigation (KSRII). Total area of orchard is 68 ha; area of experimental plot is 0.8 ha. Variety of apple is "Kooper zanzi", with planting scheme 3x5 m.

The experiment consists of nine treatments in a random block factorial design of six replicates, total of 54 plots of 6-8 trees, as detailed in Table 1.

Table 1: Experimental treatments number designations in micro irrigation of apple orchards at Cholpon Ata, 1996.

Irrigation (% PET * 0.4)	Drip - single lateral	Drip- double laterals	Micro- Sprinklers
70	1	4	7
100	2	5	8
130	3	6	9

Single and double drip laterals of Model RAAM 3.6 l/hr self regulating emitters, 0.75 m. apart (NETAFIM) were installed in April 1996 for drip irrigation. DANPAL Model 8855 self-regulating micro sprinklers of 37 l/h, one sprinkler per tree, were installed at that time for micro-sprinkler irrigation. Mains and water supply to the experimental site were laid out in Summer1995.

Three irrigation regimes were imposed, 70%, 100% and 130% of the calculated potential ET * 0.4. Irrigation amounts were calculated from hourly meteorological data by a light interception factored Penman formula:

$$ET = LI * \gamma/(\gamma+\Delta)*R_n *3600/latent + VPD*\Delta /(\gamma+\Delta)*f(w), \qquad (1)$$

where:

ET	potential evapotranspiration, mm/hour;
R_n	net radiation, W/m², calculated from global radiation;
LI	light interception by canopy, nondimensional, fragment of 1;
VPD	vapor pressure deficit (kPa);
γ	psychrometric constant (kPa/°C);
Δ	slope of saturated vapor pressure curve (kPa/°C);
w	wind speed (m/s);
f(w)	wind function, 0.034+0.054*w for daytime or 0.125+0.382*w for night;
latent	specific vaporization heat (J/kg).

To measure the necessary variables for ET calculation (radiation, air temperature, relative humidity and wind speed), the Campbell Scientific CR10 automatic weather station was assembled and deployed in the experimental farm. It was used with communication and processing equipment and supplied with the following sensors:

LI-COR 200S Radiometer
Vaisala 50Y RH/Temperature Sensor
RM Young 30002 Wind velocity and direction sensor
Thermocouples for soil and other temperature measurements
Texas Electronics 625MM Rain gauge.

Data processing was done on a PC, with Campbell Model PC208 data processing software and additional software and routines developed by the Khyrghiz team under the program while staying in Israel.

The actual amount of irrigating water necessary for one experimental plot ("norm") was calculated by formula:

$$m = k * F * (\Sigma ET - \Sigma P), \qquad (2)$$

where:

m	the upper defined "norm" (litre/treatment);
k	imposed coefficient (0.7, 1.0 or 1.3 depending on treatment);
F	treatment area (m^2), including all replicates;
Σ ET	sum of hourly daylight ET for calculation period (mm);
Σ P	total rain for calculation period (mm).

The irrigation was performed when Σ (ET-P) was greater than 4 mm because of irrigation efficiency considerations. Light interception coefficient by canopy (LI in (1)) was assumed equal to 0.4 for all treatments during all period of irrigation.

Neutron probe was used to monitor soil water dynamics. 36 access tubes were inserted in a distance of 0.24 m from the tricklers or 0.60 m from the micro sprinklers. Before tubes installation, soil volumetric weight was determined in three layers of soil (0-25, 25-50 and 50-75 cm) by sampling and drying a known volume of soil. In the time of access tube insertion, the soil water content was determined by sampling and drying the same three layers of soil for each tube and multiplying w/w water content with the volumetric weight to obtain v/v water content. At the same time neutron probe counts were taken also to obtain the neutron probe count - soil water content relation. After that, neutron probe measurements were performed once a week.

Canopy cover was defined as 1 - K_{av} , where K_{av} is the average value of Photosynthetic Active Radiation (PAR) measured below the canopy on the soil surface, divided by the PAR measured outside the canopy in the sun. Both PAR in shadow and in the sun was determined twice in the growth season in cloudless days about midday with a Decagon Devices ACCU-PAR ceptometer. Out of total 36 experimental plots 18 were selected, including all 9 treatments for measurements; the distance between trees within the row (3 m) was divided to 3 strips of 0.8 m (length of the ceptometer) and measurements were done with the ceptometer held parallel to the row along the strips into the alley between the rows, in increments of 0.20 m both sides of the row until fully sun lighted ground was met.

Fruit growth rate was chosen as a direct method to estimate crop response to irrigation. At begin of the season, two trees were chosen from each plot in four out of six replicates (i.e., 2 trees * 4 replicates * 9 treatments = 72 trees). Ten apples were marked in each tree for size measurement. The measurements began on July 9 and were performed once a week till October 1. The circumference of the apple was measured using a tape measure with accuracy of 1 mm. In volume calculation a spherical approximation of the apple volume was used. A variety specific circumference - volume calibration was performed the second season.

Yields were estimated from the final fruit volume measurements by determination the "average apple" (an apple with average circumference) in replicate and weighing this apple, then calculating:

a) Total weight of apples from each tree (number of apples on that tree * average weight of one apple);

b) Average yield from one tree;

c) Cumulative yield from replicate (average yield from one tree * 7 trees in replicate). This particular method was used because of local difficulties to reach harvest with all the fruit intact on the trees.

B.3 Field experiments - Results and Discussion.

Meteorological Measurements.

The meteostation operated well and properly from it's installation to the end of the season. A brief description of the representative meteorological conditions in the test site from May 96 to October 96 is given in figures 1. and 2. Average daily temperatures were around 15°C most of the summer with some hotter days in August, but maxima never reached above 30°C. Frost came in at begin October, and indicated the end of the season.

Figure 1. Average, Min and Max Temperatures at Cholpon Ata (Experimental-Station) Summer 1996

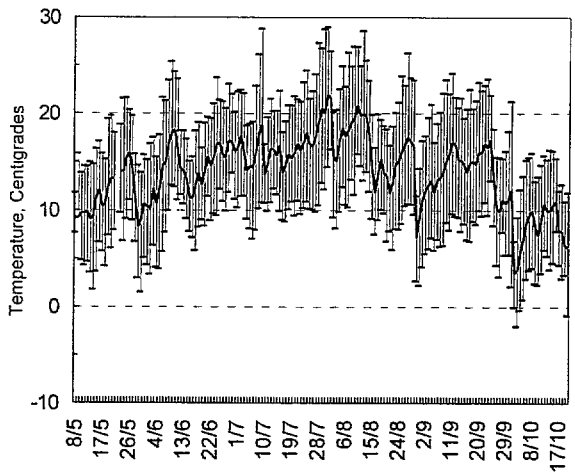
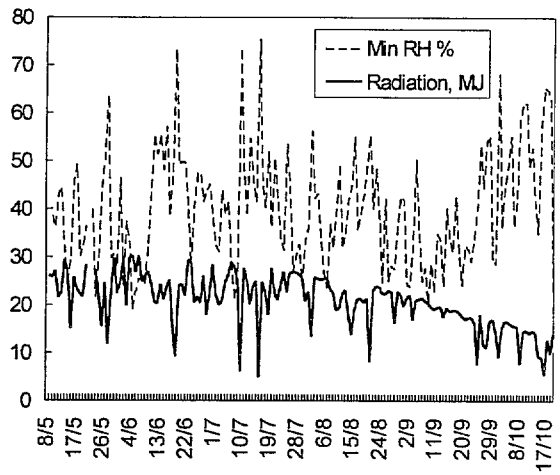


Figure 2. Global Radiation and Min RH at Cholpon Ata (Experimental Station) Summer 1996



Global radiation reached above 30 MJ/m^2 in June and declined as expected with the summer. Drops below the maximum indicate cloudy days, and deep drops below occur on rainy days, as can be seen also at the RH minima.

Table 2. Potential Evapotranspiration (PET) and precipitation in Cholpon Ata Experimental State Farm 1996-1998

		Month					Vegetation	June-
		May	June	July	Aug	Sep	period	August
PET	1996	52.7	123.8	133.2	124.6	64.4	499.0	381.6
mm	1997		125.9	148.2	107.8		381.9	381.9
	1998		74.4	116.8	93.1	52.3	336.6	284.3
0.4 PET	1996		54.1	57.8	54.5	28.0	219.0	166.4
mm	1997	23.9	55.4	65.2	47.4		168.0	168.0
	1998		29.7	46.7	37.3	20.9	134.6	113.7
Precipitation	1996		32.5	23.0	26.8	1.8	87.3	82.3
mm	1997	3.2	2.4	19.5	51.1		73.0	73.0
	1998		7.5	24.7	50.7	26.1	109.0	82.9

Potential daytime evapotranspiration for fully covered, well water reference crop (Table 2) ranged between 284 to 382 mm for June-August (3-4.1 mm/day). Irrigation requirement based on 0.4 PET for small trees was about 1.25 -1.85 mm/day. Seasons of 1996 and 97 were similar in PET and higher than 1998. Rain patterns were similar in 1996 and 97, and differed from 1997, so the difference is not related to rain.

Table 3. Calculated Potential Evapotranspiration and 3000 cm^2 Pan Evaporation

		Month						June-
		May	June	July	Aug	Sep	Oct	August
PET(mm)	1996	52.7	123.8	133.2	124.6	90.6	37.9	381.6
	1997		125.9	148.2	107.8	55.6		381.9
	1998		74.4	116.8	93.1	59.6	40.8	284.3
Pan	1996	109.7	153.9	188.5	196.6	152.2	95.5	539
	1997				141.1	68.5		
	1998		95.8	124.1	67.2			287.1
Pan/PET	1996	2.08	1.24	1.42	1.58	1.68	2.52	1.41
	1997				1.31	1.23		
	1998		1.29	1.06	0.72			1.02

Comparison to the evaporation Pan located at the Cholpon Ata Village main meteostation (Table 3.) shows the same tendency, however the conversion coefficients from Pan to PET are very different. Seasonal totals of PET and rain for the Village and the Experimental Station indicate the order of magnitudes of potential irrigation needs.

While daytime PET is a reference for full cover, well watered crop, without any further coefficients, Pan ET needs at least two coefficients: one to account for night evaporation (plants usually close stomata in dark) and another for the difference in surface resistance between plant canopy and free water.

Irrigation.

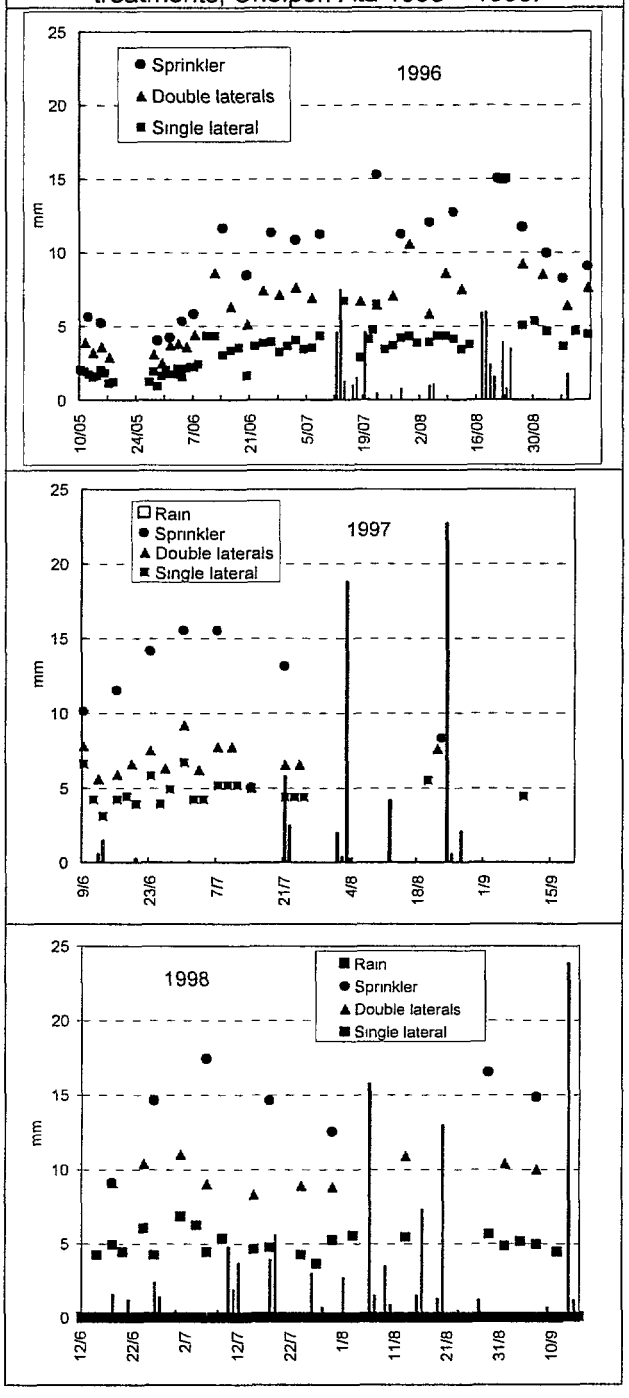
Seasonal irrigation applied in all the treatments, in three seasons is shown in Table 4. Irrigation needs for a young orchard with widely spaced, small trees, like the one in the experiment, were found quite small, between 100 - 200 mm/season. There was no stored water in the soil from the winter, because by local customs, the space between the rows is used in the spring for forage grass cropping.

Table 4. Seasonal irrigation amounts (mm) in Apple irrigation at Cholpon Ata 1996-98

Year	Single lateral			Double laterals			Mini sprinklers		
	130%	100 %	70%	130%	100 %	70%	130%	100 %	70%
1996	256	201	145	236	185	134	239	187	135
1997	173	133	93	169	130	91	89	127	165
1998	136	104	73	130	97	70	129	100	70

The course of irrigation and rain through the season for the 100% treatments is shown in Figure 4.

Figure 4. Irrigation scheduling of 0.4 PET treatments, Cholpon Ata 1996 – 1999.



Soil water content.

Neutron probe counts for 1996 to 98 are presented in figures 5-7. Calibration attempts were ultimately judged unsuccessful because of difficulties to determine actual bulk density in each sampling location. Accordingly soil water content trends, as influenced by the treatments, can be analyzed, but no water balance can be calculated. Trends along the first season (Figures 5.a and 5.b) were indicative of soil moisture changes as a result of irrigation. Under 70% irrigation with **single laterals** the soil became dry with time, 100% and 130% irrigation kept the soil in wet conditions. Under **double laterals** the tendency was of increasing wetness along the season, and with increasing irrigation. However this was partly caused because of placing both laterals close to the neutron probe access tube, instead only one. Considering this effect, the increasing wetting tendency with increasing irrigation from 70% to 130% may still indicate that the 100% treatment is close to the expected water use. Under **micro-sprinklers** the soil dried out gradually along the season, slower with 130% irrigation and faster with 70% irrigation. Part of the effect can be related to the water losses into the air under sprinklers, and the access tubes have been located somewhat too far from the sprinklers, as indicated from after season excavations.

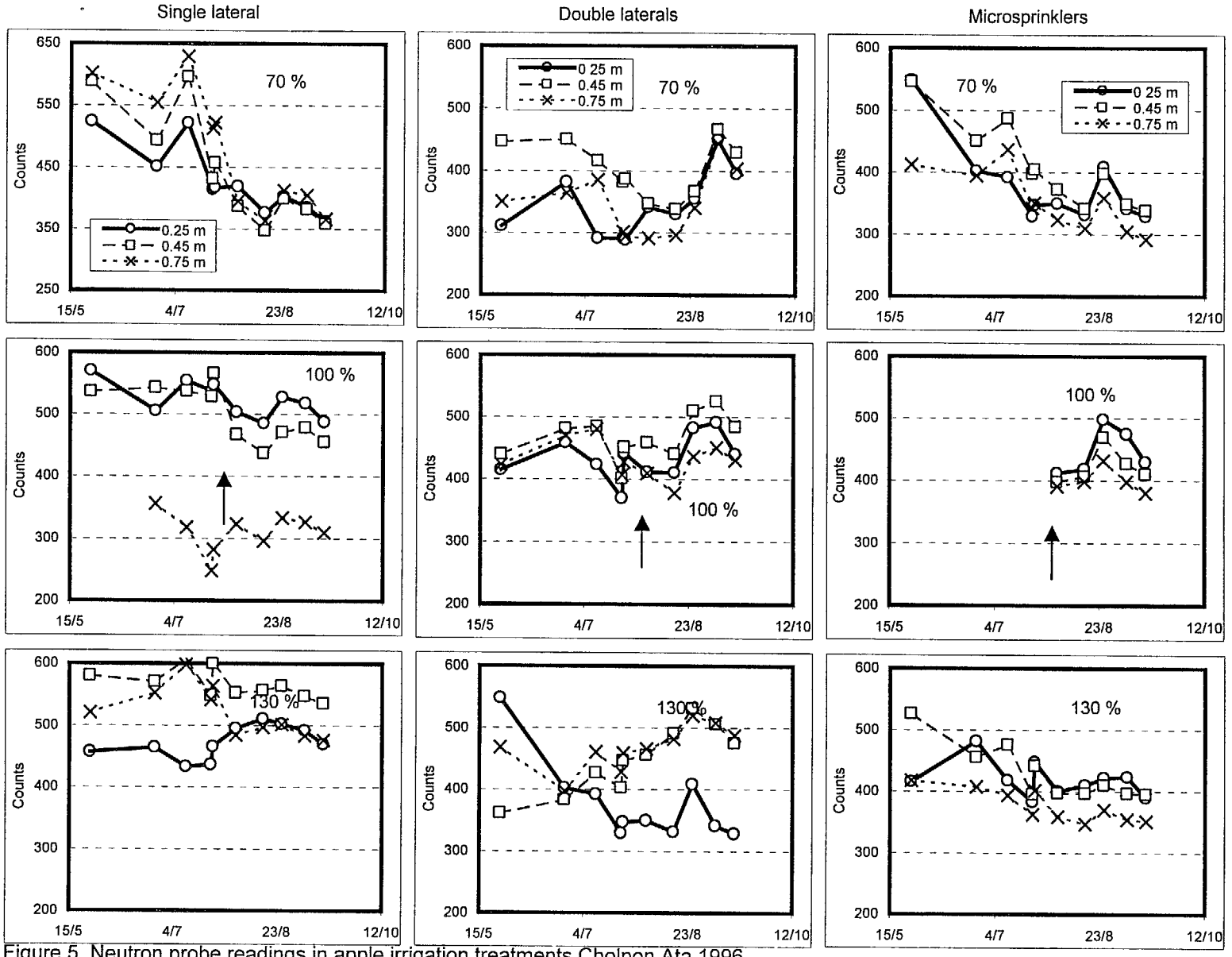


Figure 5. Neutron probe readings in apple irrigation treatments Cholpon Ata 1996

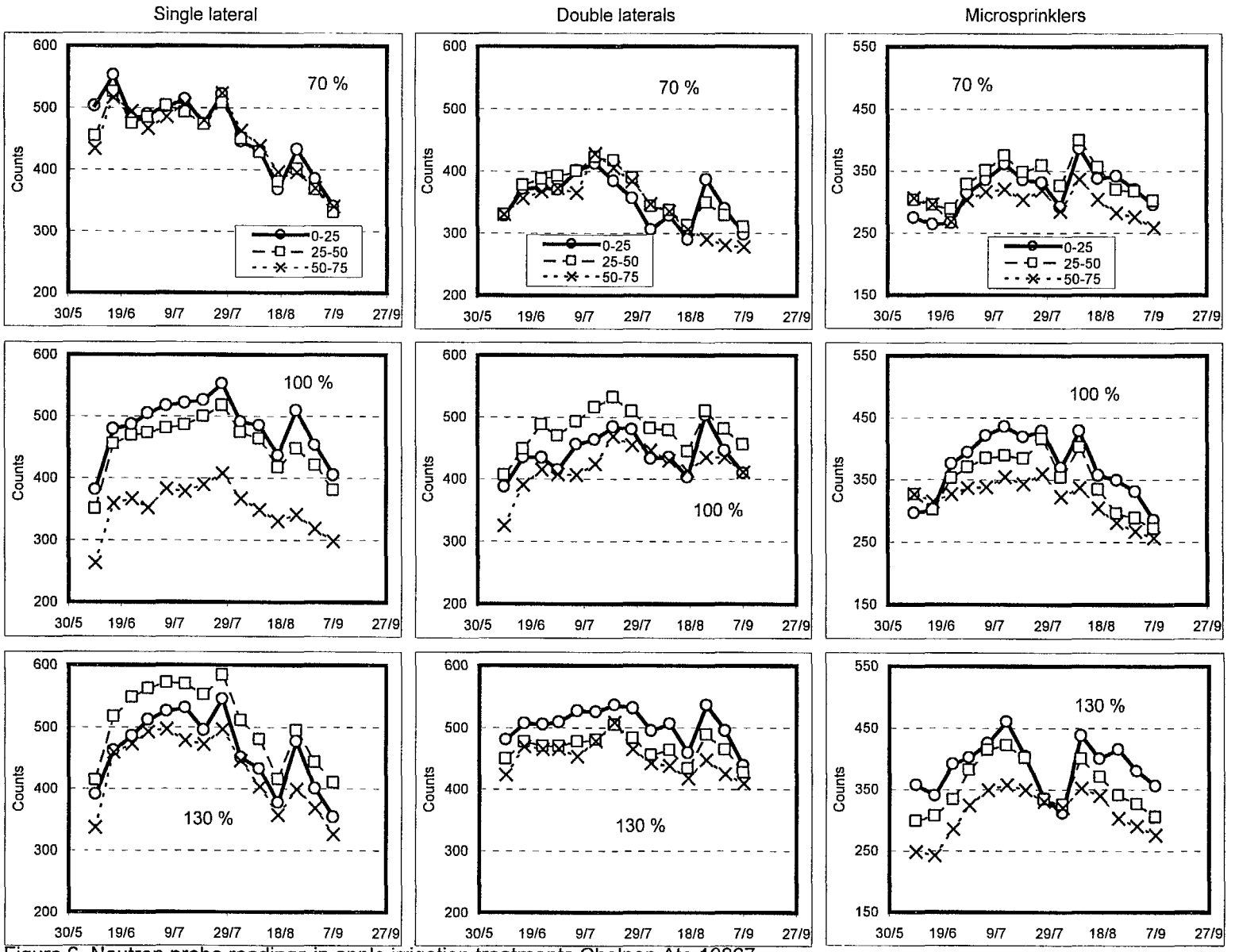


Figure 6. Neutron probe readings in apple irrigation treatments Cholpon Ata 19967

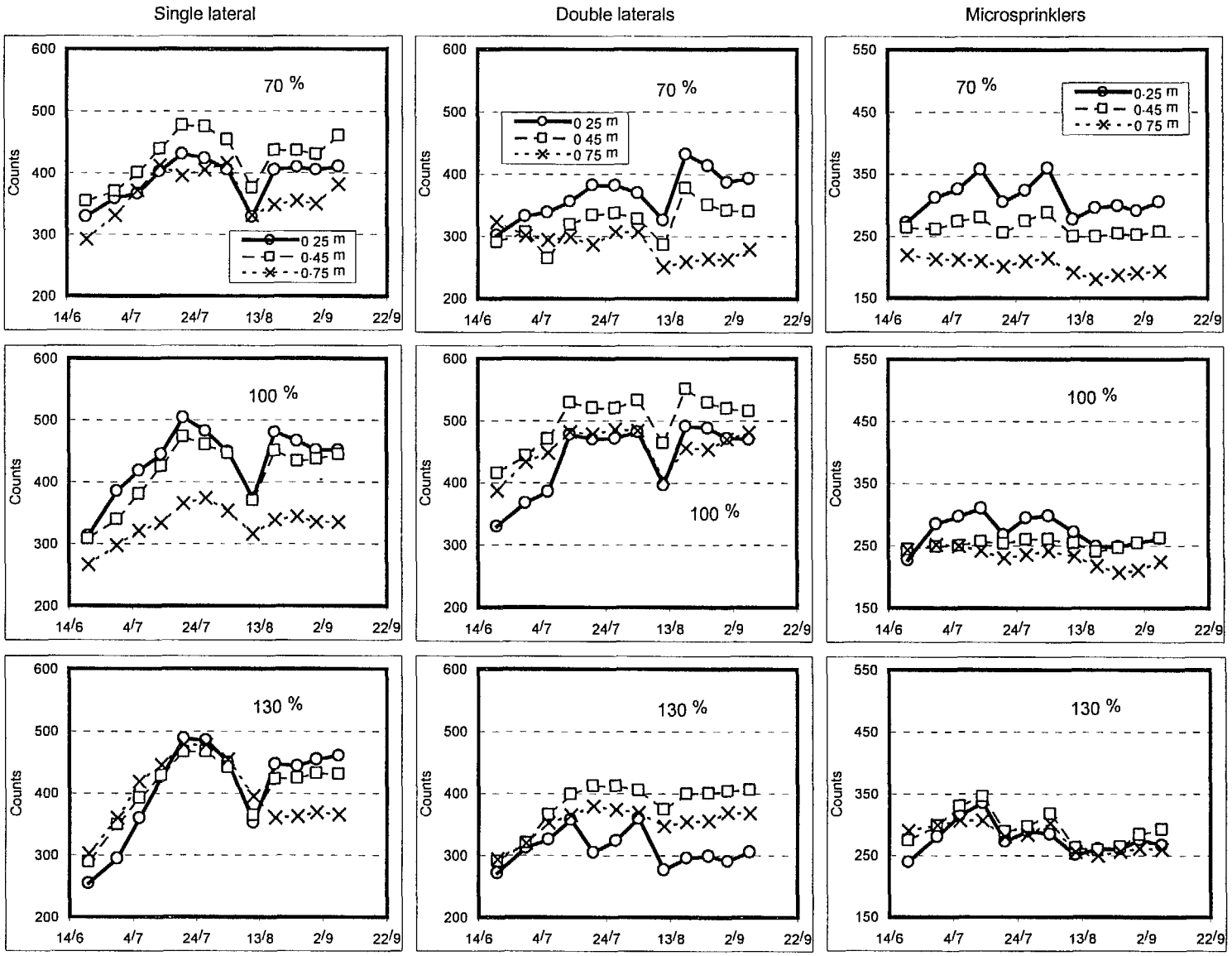


Figure 7. Neutron probe readings in Apple irrigation treatments, Cholpon Ata 1998

The overall picture of changes in soil water content indicates that the irrigation was near correct to replace evapotranspiration losses.

Neutron probe count trends along the second season (Figure 6) were indicative of soil moisture changes as a result of irrigation, however only at the **double laterals** irrigation the 70% treatment showed distinct counts decline with time. Under **micro-sprinklers** an irrigation problem occurred mid season. This years neutron probe data were less indicative that of 1996, and the overall impression is that 70% treatments were a little under-irrigated, but almost ample.

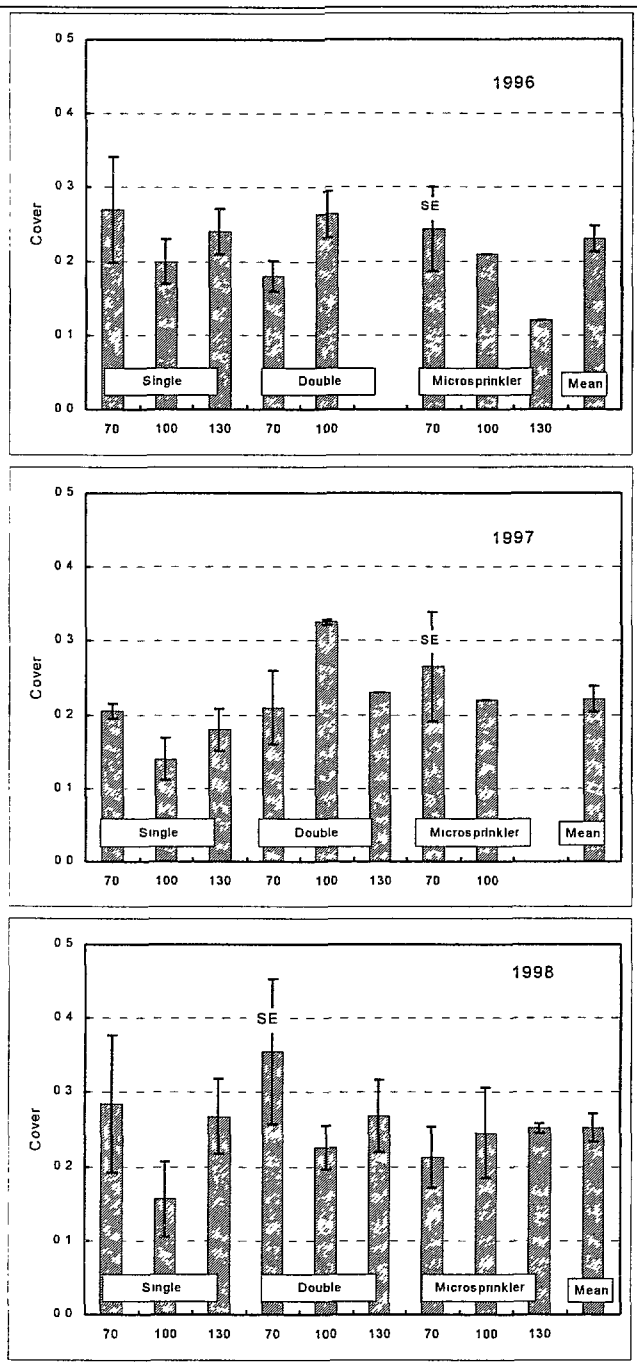


Figure 8. Light interception in microirrigation of apples Cholpon Ata 1996-98

The overall picture of changes in soil water content indicates that the irrigation was a little too high at the first part of the season and less than correct to replace evapotranspiration losses at the second half of the season, maybe because of incorrect estimation of the rainfall.

In the third season (Figure 7) there are little indications in the neutron probe measurements, and the impression is of over irrigation, without regard to the treatment designation. The irrigation needs and PET in the 1998 season were quite low, so over irrigation, even in such low amounts is a possibility.

Canopy size and crop cover.

Summary of light interception measurements in all three seasons are given in Figure 8.
Analysis of variance showed no significant differences between treatments, sampling dates, or irrigation methods. There is no consistency of tree sizes and treatments from season to season. The average light interception is in the range of 22%-26%. That would imply an LI factor of less than 0.4 to use in equation 1 in flat canopy, field crops. In orchards light interception alone cannot describe the transpiration envelope of the tree row. In our experiments in Israel we found lately that in 2.5x4.5 tree spacing, 25% LI corresponds to PET coefficient of 0.4 to 0.5. This later finding supports our initial estimate of crop cover for irrigation scheduling.

In 1996 the ground between the trees was covered with grass, and that might have introduce an additional factor in crop cover estimation. Better weed control of the space between the rows was done in the next two seasons, with herbicides supplied from Israel.

Plant responses.

. Fruit size growth curves for the treatments are shown in Fig. 9. The results are somewhat confusing since all the three possible response types are represented:

- **Correct irrigation:** In double laterals 1996, and single laterals 1997, 100% and 130% irrigation fruit grows faster than 70%, indicating stress irrigation at lower water application, no gain in fruit size 100% and up.
- **Under irrigation:** In single laterals 1996 and micro sprinklers 1998, only at 130% irrigation the fruit growth rate is higher than at both lower amounts, indicating the same stress at 100% and 70%.
- **Over irrigation:** In sprinkler irrigation 1996 and 1997 the 100% treatment makes fruit grow faster, implying water shortage stress at 70% and over watering stress at 130%.

At most of the cases 70% irrigation treatments produced smaller fruit and slower fruit growth, so disregarding two cases, fruit growth results support the notion that the basic scheduling was correct.

A closer look into the graphs shows that there is a correspondence between initial fruit size and the final growth pattern. There is some difficulty to select sampling sites to balance carefully the natural variability in the orchard at fruit marking time.

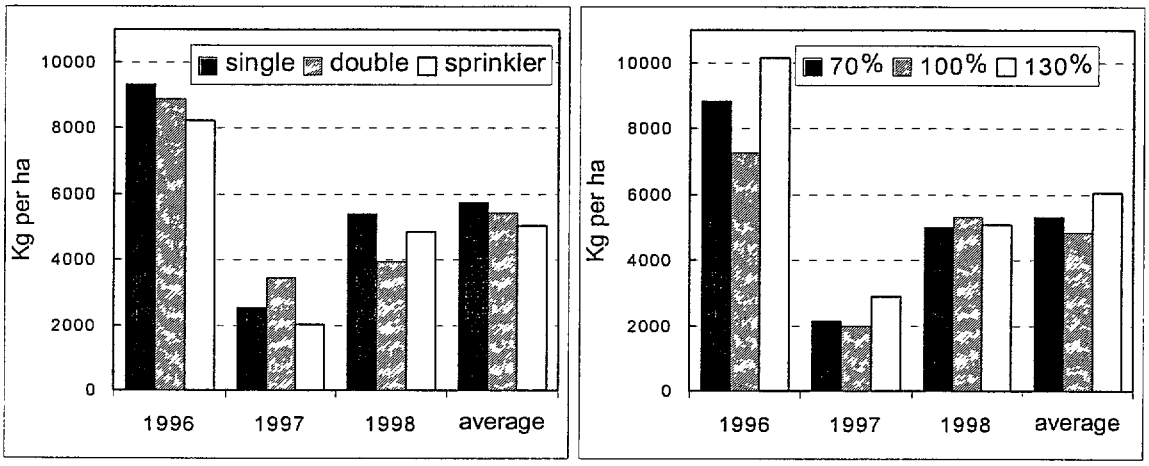


Figure 10. Estimated yields in Apple irrigation, Cholpon ATA 1996-98.

Yields were not harvested in the conventional way, because of local difficulties keeping the fruit on the trees until full ripeness, so the data in Fig.10 are somewhat tentative..

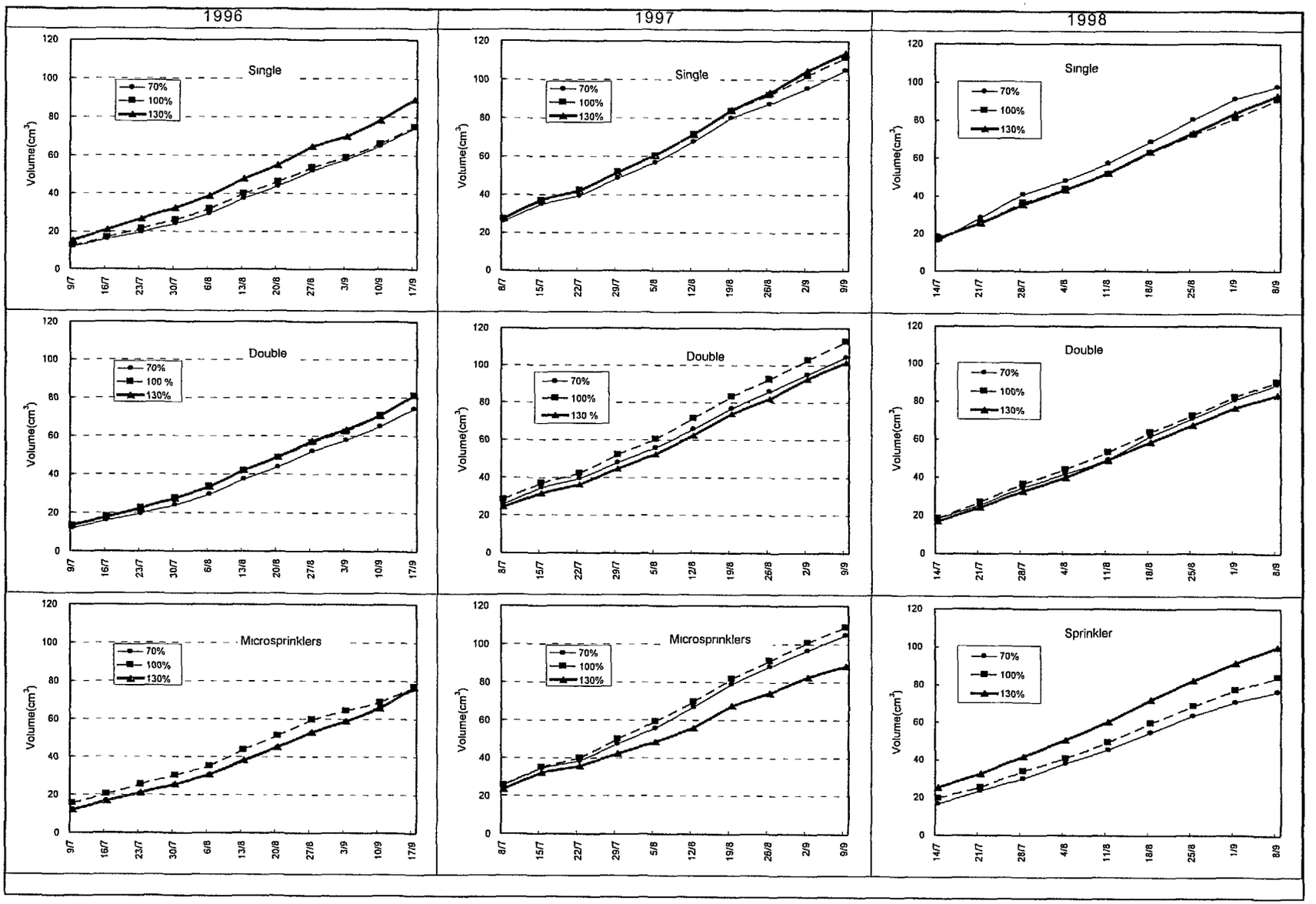


Figure 9. Fruit volumes monitoring in Apple irrigation, Cholpon Ata 1996-98

Yield magnitude is acceptable by local standards. Factorial ANOVA showed no interactions, nor significant differences, so only main effect means are presented. Micro-sprinklers yielded a little less than drip, no advantage was found to double over single laterals. There was no influence of irrigation amounts on harvested yields. The logical conclusion is that even 70% of the scheduled amount was sufficient

B4.Summary and conclusions:

Apple irrigation by three irrigation methods was tested in a three-year field experiment at Cholpon Ata, Khyrghizstan, on the sandy soil of the Yssyk-Kul Lake shores, in order to introduce light interception factored PET based irrigation scheduling methods.

Results indicate that under supplemental irrigation in 3-4 mm/day ET demand conditions, there is no particular advantage to single or double laterals drip irrigation over micro sprinklers.

Irrigation scheduled to 40% of PET, corresponding to 25% ground shade cover was sufficient to achieve the maximum yield and fruit size in all but two cases out of nine.

C. Impact, Relevance and Technology transfer:

a. Collaboration

1. Initial impact of the collaboration is the mutual familiarization with scientific abilities of both sides and proper definition of objectives and goals to achieve though the project.

2. Introduction of state of the art irrigation scheduling methods to Khyrghiz agronomy.

3. Verification of the meteorological ET estimation model under high altitude - intermittent rainy conditions, and substantiation of the concept under diverse climatic conditions, not only under Mediterranean type climates.

b. Project impact and technology transfer

One of the possible impacts is the rising interest in microirrigation in the Yssyk-Kul region. This will be important in the near future, after the agrarian reform and privatization, when agriculture cropping will change from commodities to fruit production to export markets. One of the activities within the project was to hold open days in the experimental station to increase visibility.

The project familiarized local farmers and regional authorities with drip and micro sprinkler irrigation, and advanced irrigation control devices.

c. Strengthening of Khyrghiz institutions

- Leading scientist from the KSRII spent two months of training in MIGAL.
- The KSRII team was exposed to hands-on operation of advanced environmental and irrigation research equipment and learned to use it in real life situations at home.
- To aspirants of the KSRII are working for advanced degrees in the projects.

  Arynova,N.A. Principles and methods of the crops water need determination using an automatic weather station (in imitation of the orchard drip irrigation)

  Jooshev, P.M. Using drip irrigation technology for the apple orchard in Kyrghyzstan.

- The KSRII was enriched with enriched with advanced equipment which is strengthening local research capabilities.

D. Project activities and outputs

An Initial meeting was held at the KSRII in March 1995.

A full day Seminar was held in MIGAL during the 2-month training period of the KSRII PI's.

Three annual meetings in 1996, 1997 and 1998 were held in Bishkek and on location in Cholpon Ata, with participation of all the PI's, the aspirants and management support staff.

A field day for the Yssik-Kul region professional, extension and management personnel, with participation of the press and UNDP officials was held at Cholpon Ata in 1996 to inaugurate the experimental site and equipment. Press releases and reports were documented in the annual report.

The following reports were presented (in Russian):

Kulov,K.M., N.A. Arynova, and P.M. Jooshev. 1997. Operative planning of irrigation scheduling using automatic weather station and Penman equation. In *Transactions of the National Seminar of Desert Prevention in Kyrghyzstan,* 145 pp, Bishkek

Jooshev, P.M. 1997. Evaluation of irrigation schedule efficiency using neutron probe. In *Transactions of the National Seminar of Desert Prevention in Kyrghyzstan,* 145 pp, Bishkek

Atakanov, A.J. and N.A.Arynova. 1997. Some results of drip irrigation in arid zone of Kyrghyzstan. In *Transactions of the National Seminar of Desert Prevention in Kyrghyzstan,* 145 pp, Bishkek

E. Project productivity.

The project accomplished most of its goals:

1. The applicability of PET based irrigation scheduling in high altitude terrestrial climate with sporadic summer rainfall was demonstrated, and initial parameters and methods of crop coefficient determination were established.

2. State of the art meteorological data acquisition and processing equipment was installed and operated. Hardware, software and the underlying scientific background were assimilated.

3. State of the art irrigation equipment was installed at the site and was successfully operated all three years. Irrigation scheduling and equipment maintenance was performed competently. Lack of nearby technical support and infrastructure impeded the operation of the IRRINET electronic irrigation controller.

Less success was reached in pure scientific aspects of the project, at results publication in scientific journals. This is primarily attributed to the extreme plant material variability of the orchard.

F. Future work.

Implicit goal of the project was the introduction of modern and water use efficient irrigation methods to broad fruit grower audiences in the Yssyk Kul Lake region. We found that the local establishment at that time was totally uninterested, basically because lack of profitable marketing outlets for the apple production. The expected changes of the agraric reform also hindered incentives. It looks like the current privatization of agriculture will pour new interest in efficient and high yielding irrigation methods.

When this time comes, using the knowledge acquired in the project, the KSRII can take a front position in implementation.