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Automatic Control System Of Groundwater Table For Subsurface Irrigation

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Abstract.

Drainage for agriculture is essential in Finnish circumstances. Since 1995 controlled drainage has been part of the national agricultural environmental program. The development project aims to promote farmers to operate and manage the outlets of subsurface drainage systems and the pumps of subsurface irrigation. The task of the present project was to develop an automatic system to control the water table including the possibility to recycle the drainage water. The project aims also to promote efficient water use, help water conservation, to maximise work efficiency of water table management, to give better image for farmers as users of modern technology and help them to use economical production methods. The solution was supposed to serve especially subsurface drainage on sandy potato fields.

The project was mainly financed by EMOTOR program of EU and made in practice by Finnish Field Drainage Centre under supervision of the University of Oulu. The region has a special status as the High Grade Seed Potato growers of EU. The pilot system has been built in autumn 2000 and will be tested in practice during the growing season of 2001.

Keywords.

Subsurface irrigation, subsurface drainage, automatic subsurface irrigation, agriculture, nutrient load, crop yield

Introduction

Drainage for agriculture is essential in Finnish circumstances. The total area of the agricultural fields is 2,5 million hectares and 50 % of it has subsurface drainage systems. Since 1995 controlled drainage has been part of the national agricultural environmental program. That is why approximately 20 000 hectares has controlled drainage and over 15 000 hectares are under preparation.

At the moment controlled drainage covers approximately 5% of the fields that are suitable for controlled drainage. Controlled drainage suits fields that are either sandy loam or silt loam and gradient is less than 1%. Subsurface irrigation, where extra water is being led to the field, is just starting to become more common in Finland.

The farmers have been interested in finding out a technical solution to help the work and to make more accurate water table control of controlled subsurface drainage networks.

Because of Finland's location, the growing season is short (May – September) and it has to be exploited as well as possible. This is why it is important to keep the soil humidity in a level which the plants growing phase requires. Winter circumstances have also to be kept in mind when talking about automated subsurface irrigation. The yearly rainfall in Finland is 600 – 750 mm.

Subsurface irrigation affects the crop yield and nutrient leaching from the field.

In Finland subsurface irrigation has been explored in one testfield. The area consisted of about 8 hectares of flat fine sand field and the results are available from years 1994-1996. The crop was potato and oat. Subsurface irrigation suits well in potato growing because potato doesn't have strong roots and it is also sensitive to humidity changes. In addition to this, with right humidity it is possible to prevent some potato diseases.

Subsurface irrigation in the Tyrnävä testfield raised the ground water table approximately 45-80 cm with single and dual-level pipes compared to the non irrigated area. The effect of irrigation is clearly visible in the results. (figure 1) With oat the crop was 40-70% higher and in potato 80-110% higher compared to the comparison area. Irrigation reduced nitrogen concentration in potato tubers which is an advantage when speaking of potato quality (Paasonen et al., 2000).

The effects of subsurface irrigation in water protection are still somewhat unclear but subsurface irrigation affects the soils water balance and nutrient circulation. The effect of water table management in nutrient leaching is heavily dependent on the quality of the field, drainage, weather and controlling actions.

Subsurface irrigation can increase the runoff in growing season and early autumn. The storage capacity of the field and runoff water reservoirs should be as large as possible because with these it is possible to reduce the runoff waters. It is possible to move the moment of the nutrient load by damming and reduce or prevent the runoff waters totally in summertime. The water storage capacity affects the gradient of the field and drainage pipes, and the controlling structure. With the water protection aspect, it is important to strive for water table control of larger areas in which case also damming arterial drains comes into question.

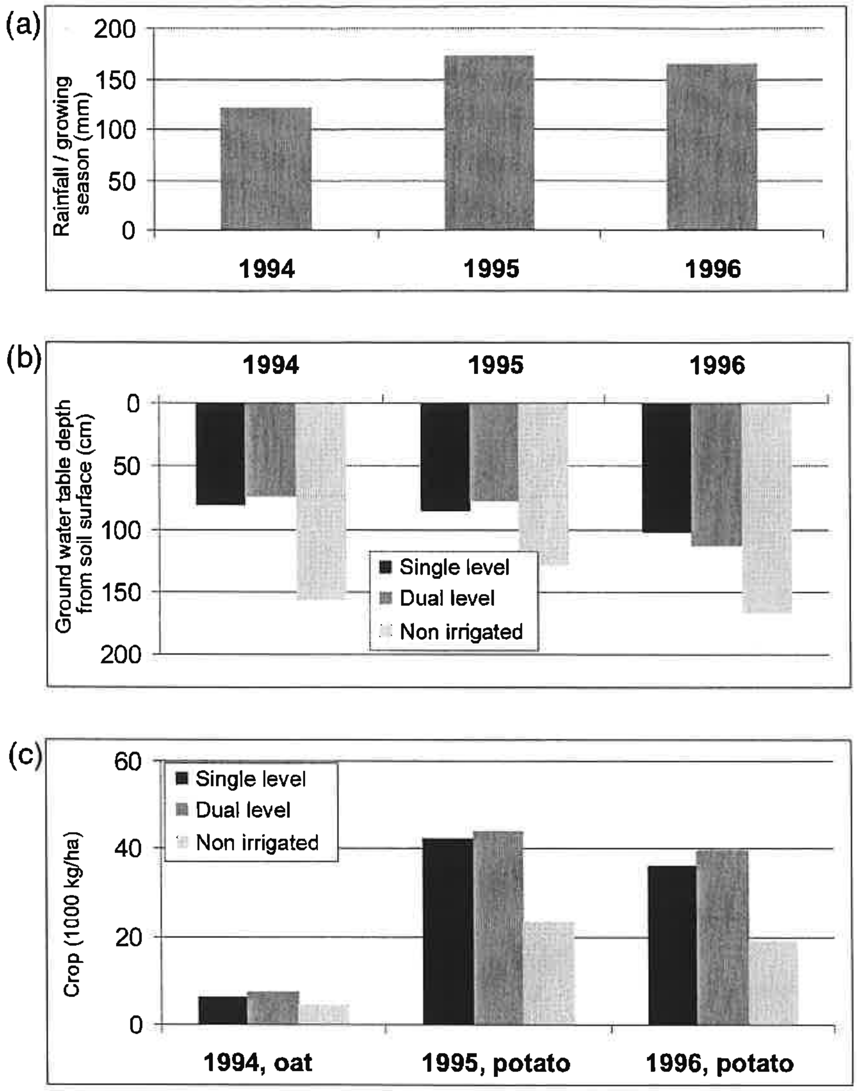

Figure 1. (a) Rainfall in the growing season, (b) the average ground water table depth during the growing season and (c) grain-/tuber yield (fresh weight) in the sub-areas of the Tyrnävä site.

The nitrogen concentrations in ground water measured in the Tyrnävä testfield were smaller in the subsurface irrigated area than in the non irrigated area. (figure 2) Due to model calculations subsurface irrigation reduced nitrogen load 0.4-2kg ha^{-1} (3-13%) but in rainy years it actually increased the nutrient flow in certain controlling alternatives (Paasonen-Kivekäs et al., 2000).

The amount of phosphorus leached from the fields to the water system through subsurface drainage is estimated to be approximately 0.3-0.6 kg ha^{-1} in Finland. Part of this is soluble phosphate phosphorus which is hazardous. The amount of phosphate phosphorous in subsurface drainage water is usually rather small, but can momentarily raise high, especially if rainfall and runoff take place soon after phosphorous fertilising. By securing that the runoff water stays in the soil for at least 24 hours so that the momentary high phosphorous concentration has enough time to restrain into the soil, the leaching of liquid phosphorous in the runoff waters can be reduced. (Peltovuori 2000).

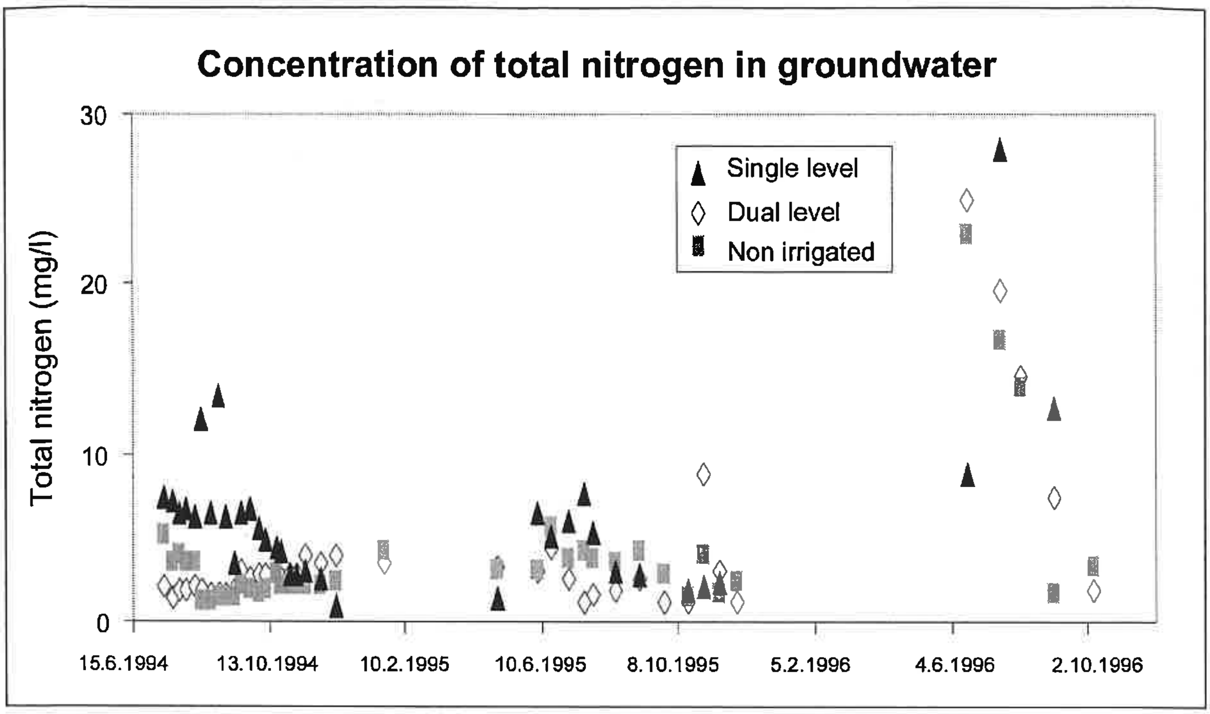

Figure 2. Concentration of total nitrogen in the groundwater in the sub-areas of the Tyrnävä testfield.

When surface runoff increases, the leaching of particle phosphorous also increases. To avoid this, the ground water level has to be lowered before rainfall.

It is 25-30% more expensive to build a subsurface irrigation system than normal subsurface drainage. The benefits are greater crop, better crop quality, decreasing of nutrient leaching and the moment of nutrient load being transferred.

The expences of automated subsurface irrigation consists of the expenses of the measuring station and control well. The measuring station consists of solar panels and batteries, a data logger, a stand and a radiomodem. With one measuring station it is possible to take care of measuring of one field (max. 4 control wells). The investments for one station were about 3000 USD in the pilot area. If one measuring station takes care of about 12 hectares, the cost for a station is about 250 USD per hectare.

A control well consists of a linear actuator, water level sensor and cables. The expenses for these are about 750 USD. When control well can handle three hectares, the cost of a control well is about 250 USD per hectare.

The costs of automating will therefore be about 500 USD per hectare.

Because of the known profits of subsurface irrigation, in this research we wanted to solve how to carry out an automated system to adjust the ground water table in Finnish circumstances. The system has been designed and carried out but other than that, there is no further experience.

The system gives an extra efficiency to control drainage to mitigate the nutrient leaching in intensive potato production. The development project aims also to promote efficient water use, help water conservation, to maximise work efficiency of water table management, to give better image for farmers as users of modern technology and help them to use economical production methods.

By automating the subsurface irrigation system the quantity of work required for observing and adjusting the ground water level is being reduced. The automating makes possible constant and accurate data acquisiting. Also the weather forecasts can be efficiently exploited.

With automated subsurface irrigation the adjustment is better controlled and by some studies, the crop has increased by 5% (Fouss and Rogers 1998).

Automating

Description of the system

The automated subsurface irrigation consists of subsurface drainage system, automated control wells, water reservoir, pump, the measuring equipment for ground water table and other possible variables, data logger, data transferring and other computer equipment and controlling software. Data can be transferred either with cables or wireless (figure 3).

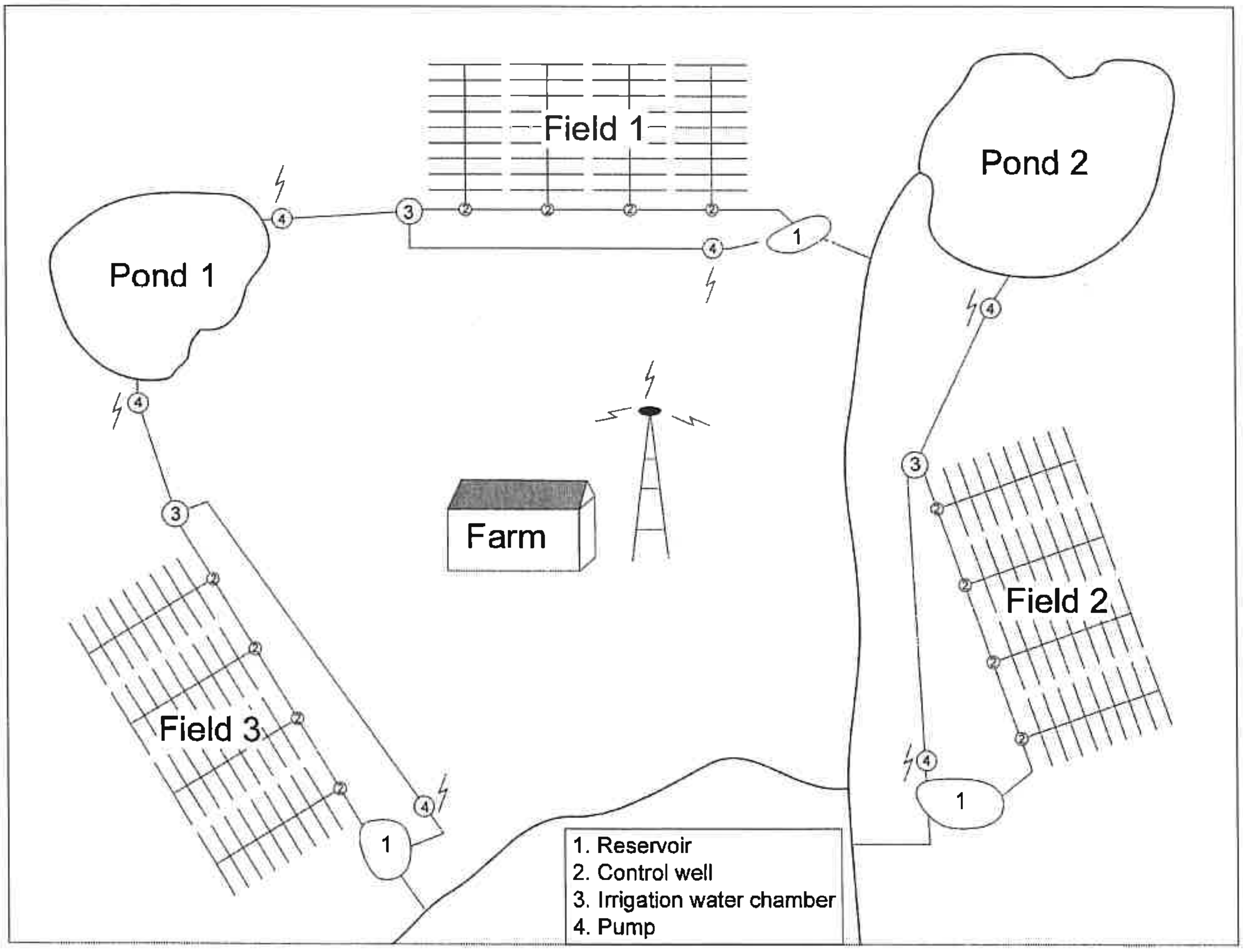

Figure 3. Layout of an automatic subsurface irrigation system.

When planning the system, there is several parameters to pay attention to: frost, ground frost, humidity and thunderstorms. The price of the equipment and availability of electricity also influence when planning the system. In a field with no subsurface drainage, the sizes of the drainage and collector pipes have to be selected as well as the founding levels for the control wells, depth of the pipes and the need of frost protection. The well should be one suitable for automating. In a field where subsurface drainage exists, the system should be built around it and the equipment should be compatible with the existing structure.

Automating can also be carried out in several phases so the expenses stay quite small in the beginning.

The first phase should be automating the pumping of the extra water, so that the pumping of extra water can be switched on and off by a switch connected into the damming system in the control well. The switch should be connected with the well situated the lowest. From the well to the pump there is a connection by a cable and controlling the pump happens with a switch so there is no need for electricity to control the pump. The pumping starts when the switch doesn't touch the water surface. The pump itself works with electricity.

In the next phase the wells are automated by connecting a control structure on top of the well. The controlling of the control wells is done with a pre-programmed data logger that guides the damming heights of the wells by the programmed commands. The controlling structure and data logger are connected with electric current. In this phase the ground water level is measured manually. The system can be extended by installing water level sensors to the control wells and separate controlling pipes in the field for measuring the ground water level. The pumping of extra water is connected to be controlled by the data logger that defines the need for pumping by comparing the water levels.

The system can be extended further by making it fully computer-controlled. In that phase the measured data from the field is being automatically saved by a computer which controls the wells automatically by an irrigation program. The pumping of extra water is done either with the computer or with the data logger.

The task of the present project was to develop an automatic system to control the water table including the possibility to recycle the drainage water. The solution was supposed to serve especially for subsurface drainage of sandy potato fields. The designed system includes:

- the manholes of subsurface drainage system with motor to move the control device either with energy of normal electricity or removable and solar recharged battery
- the programs to collect and process the water table data for use of automation of control device in manholes, the information can be moved either with cables or wireless.
- the automation includes both fixed control and computer based alternative.
- the programs to control the pump to deliver extra water either from recycling pond or other reservoir.
- the programs to inform the farmer of the functioning of the system and data collected.

The pilot system has been built in autumn 2000 and will be tested in practice during the growing season of 2001.

In the testfield the groundwater level is controlled by solar powered data-logger having wireless connection with the central computer at farm which in turn controls these data-loggers.

Observation

In automated subsurface irrigation the ground water table is measured and it is also possible to measure soil humidity, temperature and rainfall.

The measuring points are located in the field between the drains and in the control wells. Mechanical measuring using the float has turned out to be expensive and insecure. Ultrasound measuring system that measures the distance of the ground water table is vulnerable in installing phase and the sensors get easily broken in sub-zero temperature. Best experiences in measuring the water table are from using water level sensors. These sensors don't endure freezing though, so they have to be removed from the wells before winter.

The measuring of the soil humidity is easiest to do with commercial humidity measuring sensors and connect them with the data logger.

The testfield data-logger can control up to four controlwells and furthermore it can be equipped with eight extra groundwater level sensors in the field as well as other measurement sensors i.e. rainfall, solar radiation, relative humidity, air and soil temperature, soil moisture etc. (figure 4).

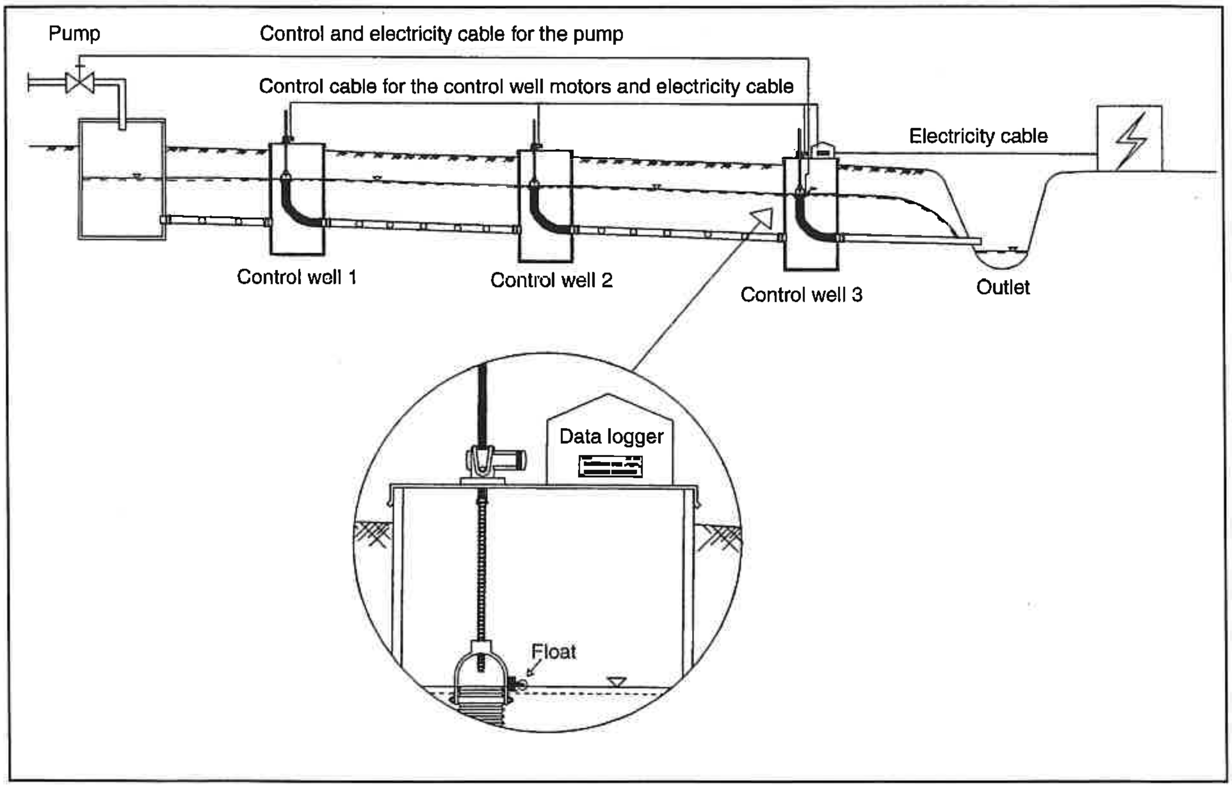

Figure 4. The principle of controlling the control wells.

Data acquisition and transfer

The data logger is being used for collecting the data from the measuring points and activities of the pumps and controlling structure. From the data logger the data is being transferred with either radiomodem or cables to a computer. If the wells are situated near the central computer, the data logger can be replaced with data collector cards and data transferring is being handled by cables. The information from the field is being saved into a computer that is on at all times.

Wireless data transfer is an expensive alternative compared to cables. Cables can be installed either under or on top of soil surface. Cable running on top of soil has to be collected out of the way during cultivation and other operations in the field.

In the testfield measurement interval is 15 minutes and after each occurence the data-logger sends the measurement data to the central computer by a radiomodem. Central computer calculates immediately the difference between the programmed target level and recent measured level and returns the control value back to the data-logger during the current radio connection.

Programming the system

In the testfield the control well is supplied with water level sensor and linear actuator to change the level of the outlet tube corresponding to the actual control value. In the case of low water level the data-logger turns the auxiliary water pump on. Linear actuator is powered by the logger and so the pump is the only equipment in need of grid power.

The central computer at farm can control up to eight fields (loggers). Scheduled target water levels for the growth period are given by the control software setup option at accuracy of one day. Besides the main function - water level control - the central computer records the measured and control data for further analysis and for on-line monitoring on PC-screen (figure 5). The user can switch to manual water level control from automatic control for example based on weather forecasts or at an unexpected event.

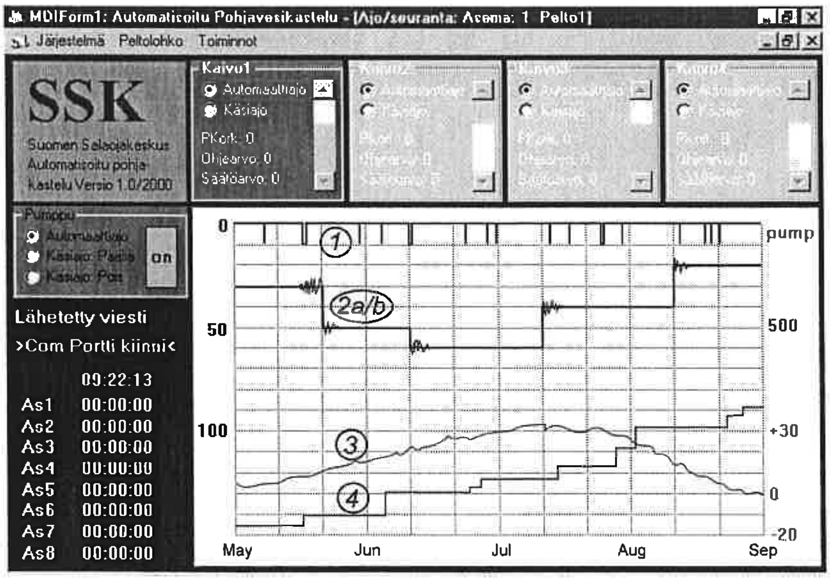

Figure 5. The control and monitoring software of the subsurface irrigation system.

1) pump on/off
2a) control value (target water level) ——
2b) measured water level ^^^^^^
3) air temperature
4) cumulative rainfall

Conclusion

The first pilot system of automatic control system of ground water table for subsurface irrigation was built in Finnish circumstances in autumn 2000. The automation includes both fixed control and computer based alternative. The groundwater level is controlled by solar powered data-loggers having wireless connection with central computer at farm which controls these data-loggers. The system was tested in practise and the costs were calculated. During the planning process special attention was paid for the circumstances like ground frost, humidity and thunderstorms.

Because agriculture is one of the major source of non-point leaching of nitrogen and phosphorus, subsurface irrigation is considered as a tool to mitigate the leaching. The subject is discussed according to the earlier experiences of control drainage in Finland.

The system itself was tested but the period of practical experiences is still very short. The expenses of the pilot system were 500 USD per hectare in average. The future tasks of the project are to collect the experiences of the farmer, how to use of the system, how it affects to the yield and to calculate the economical benefits of the system. Special attention should be also paid to the water conservation aspects in northern circumstances.

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