

Full Length Research Paper

Development of a low-cost tensiometer driven irrigation control unit and evaluation of its suitability for irrigation of lychee trees in the uplands of Northern Thailand in a participatory approach

Satid Pinmanee¹, Wolfram Spreer^{1,2*}, Klaus Spohrer², Somchai Ongprasert^{1,3} and Joachim Müller^{1,2}

¹The Uplands Program, Faculty of Agriculture, Chiang Mai University, Chiang Mai, Thailand.

²Institute of Agricultural Engineering, University of Hohenheim, Stuttgart, Germany.

³Department of Soil Resources and Environment, Mae Jo University, Chiang Mai, Thailand.

Accepted 27 October, 2010

In upland areas of Northern Thailand, lychee (*Litchi chinensis*, Sonn.) is one of the predominant fruit crops. Fruit development takes place during the dry season (January until June). Therefore, high lychee yields can only be obtained under irrigation. As water is an increasingly scarce resource in the hillsides, strategies for more efficient water use are fundamental for a sustainable increase in agricultural production. An Automatic Tensio Control (ATC) unit was developed to use soil matric potential to open and close the inlet valve of a micro-irrigation lateral. In order to test the functioning of the ATC in the field, four different irrigation regimes have been tested in cooperation with local farmers on 10 year old lychee trees on a commercial orchard in Mae Sa Mai, close to Chiang Mai, Thailand. Testing the ATC on station and under field conditions, it has proven its reliability in maintaining a favorable moisture regime in the soil. The irrigated lychee trees responded to ATC irrigation with a higher yield and higher fruit weight compared to the other treatments. ATC works without electric components, so that it can be operated in areas without electricity. Furthermore, it is assembled from cheap and simple materials. Thus, it can be easily copied and adapted to different agro-ecological and socio-economic environments.

Key words: *Litchi chinensis*, automatic irrigation, appropriate technology, soil moisture.

INTRODUCTION

This study was carried out in the Mae Sa Valley, in the upland area North of Chiang Mai. Lychee (*Litchi chinensis* Sonn.), the predominant fruit crop of the area is mainly cultivated by farmers belonging to the Hmong ethnic minority. Fruit development takes place during the hot dry season (January until June). Therefore high lychee yields can only be obtained under irrigation. As water is an increasingly scarce resource in the hillsides, strategies for more efficient water use are fundamental

for a sustainable increase in agricultural production. In the present, irrigation scheduling is often based on experience and observation of the soil moisture in the upper horizon. Furthermore, fields are scattered on steep slopes and are not accessed on a regular base. Thus, irrigation intervals are often sub-optimal to guarantee good supply of the plants without excessive water consumption. Irrigation control devices are still not commonly used in upland agriculture, especially in remote places without public power supply.

Nowadays, the use of soil-moisture sensors is the state or the art of optimizing irrigation scheduling and reduces water losses (Pathan et al., 2007). Automatic irrigation is widely used all over the world in intensive agricultural

*Corresponding author. E-mail: spreerwo@uni-hohenheim.de.
Tel: +66 53944647. Fax: +66 53893099.

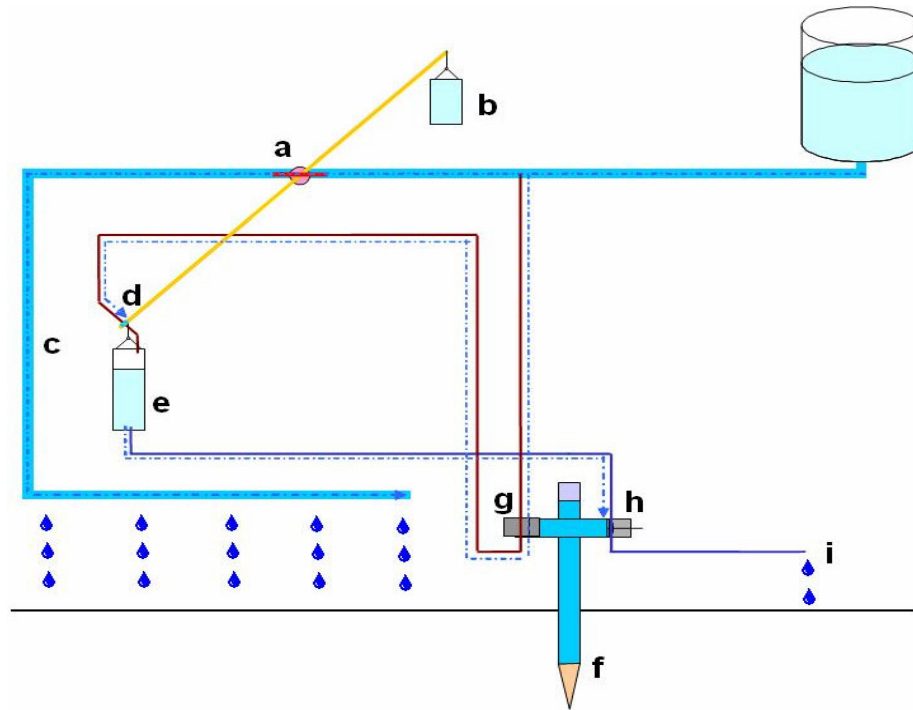


Figure 1. Schematic of the ATC functioning: (a) Operation valve, (b) counterweight, (c) main line and drip line, (d) overflow protection valve, (e) control cylinder, (f) tensiosensor, (g) inlet valve, (h) outlet valve and (i) outflow.

production. Automatic irrigation control units are based on measuring soil, climatic and plant parameters. In many cases models are employed to calculate the actual amount of irrigation water needed (Agulia, 2003). Tensiometers are frequently used as sensors that directly operate irrigation control units, because the plant water requirement can be directly attributed to the soil matric potential (Al-Amoud and Mohammed, 1995; Smajstrla and Locascio, 1996). Especially in drought stress sensitive annual plants like tomato tensiometer driven units guarantee an adequate supply of irrigation water (Munoz-Carpena et al., 2005). However, due to expensive sensors or data processing units, mostly powered by electricity, they are restricted to areas with access to the public electricity grid, or need a separate power supply which makes them more expensive and more vulnerable to malfunctions under field conditions (Chesmore, 2001),

Mechanical devices to control irrigation based on soil matric potential have been developed (Peterson et al., 1993; Meron et al., 2001). The pressure range determines the requirements to sturdiness and processing of materials. Fittings and pre-fabricated pieces are expensive or not readily available in developing countries. Possible wearing parts are difficult to purchase as spare parts.

The aim of this study was to develop a full-automatic tensiometer-based irrigation control unit, which is

completely built from local materials and can be operated without electrical power supply. The device was tested to monitor its functioning under controlled conditions and on a farmer's orchard in the upland areas close to Chiang Mai, Thailand. After discussion with the farmers the device was compared to common place irrigation strategies, practised in the region. Yield and fruit quality analysis after one irrigation season were evaluated.

'Participation' was understood as the involvement of all individuals and groups who are directly and indirectly affected by our research activities (Neef et al., 2006). The research process was designed in a transparent way with the aim to increase the sustainability of research activities and improve their results. Farmers were consulted and invited to work out the problem statement together with the scientists. The testing of the device in the practise was done in close cooperation with the farmers and results were discussed. Thus, during the whole process of development, testing and evaluation a high degree of participation was achieved.

MATERIALS AND METHODS

The functioning of the Automatic Tensio Control (ATC) is displayed in Figure 1. The central functioning part of the ATC is the tensiosensor, which is introduced into the rootzone. This unit is connected to a lever which opens and closes the operation valve, mounted on the main line. A counterweight on one end of the lever

keeps the operation valve closed. If the soil dries out and the soil matric potential in the rootzone surpasses 450 mbar, the inlet valve of the tensio sensor opens and water from the main line flows into the control cylinder. When the control cylinder is full with water, its weight presses the lever down. The operation valve opens and at the same time the overflow protection valve is closed, to prevent water from flowing into the control cylinder. In this position with the main valve open, water runs into the irrigation system. When the soil matric potential drops below 300 mbar, the outlet valve of the tension-sensor opens and water flows from the bottle into the outflow. When the control cylinder is empty, the counterweight closes the operation valve.

For on-station testing one unit of the ATC was installed in a concrete container of 1 m³ volume, where one lychee tree was planted in substrate taken from a nearby orchard. The ATC was connected to a 16 mm PE pipe on which four drippers (Netafim JR8) were mounted in a complete circle 20 cm around the tree trunk. The set up was sheltered from rain by use of a transparent plastic roof. A pressure sensor was connected to the tension-unit of the ATC in order to monitor the soil matric potential. The main valve was connected to a 30 V power source by an electric contact, which closed a circuit, when the valve was open. Both soil-water-tension and time of opening of the valve were recorded by a datalogger in a 10 min interval.

For the field testing, four different irrigation regimes have been tested with 10 year old lychee trees on a smallholder farmer's orchard in Mae Sa Mai, close to Chiang Mai, Thailand, at 18.55°N, 98.53°E and an altitude of ca. 800 m a.s.l.. The heavy, loamy soil (Acricisol) and the steep slope of the experimental field well represent the prevailing agro-ecological conditions in the zone for which the automatic tensio control (ATC) was developed. Irrigation started after flowering of the trees in February and was continued until harvest in June. From March on several rainfall events made irrigation temporarily obsolete. All trees on the experimental plot were supplied by four pressure compensated drippers (Netafim JR8) mounted on 16 mm PE pipe. Four lines of seven trees were watered by one 100 L barrel each, located 10 m above the trees, filled from a water basin nearby through a gravity pipeline with a flow meter and a float switch at the barrel inlet. With a ball valve at the outlet of each barrel, all lines could be irrigated independently.

Local lychee farmers in the area predominantly belong to the Hmong ethnic minority. They mainly rely on their experience in scheduling irrigation and often underlie severe water shortage during the dry season. To ensure that the results would be meaningful to them, the treatments were designed considering the wishes expressed by the owner of the orchard. Thus, the following treatments have been applied

Tensiometer control

A tensiometer was installed at a depth of 30 cm within the rootzone of the first tree in the row. The farmer was advised to irrigate at a soil matric potential above 400 mbar and stop at below 200 mbar. Therefore, a manometer was mounted as reading unit and the respective values were identified by different coloured stickers. This setup was chosen as a locally available soil moisture monitoring device as it is produced in Thailand.

Visual control

Irrigation was scheduled by the owner of the orchard following his traditional criteria, such as weather observation, manual and visual appraisal of top soil moisture and leaf water status. Irrigation was restricted by overall water availability, as prevailed for the rest of the orchard. Due to the farmer's limited time, some irrigation

was carried out by the author of this study in agreement with him.

ATC

One unit was installed at the first tree in the row, with the sensor cup at 30 cm in the rootzone. The operation valve was connected to the inlet of the lateral line to automatically irrigate within the above described range in soil matric potential.

Excess irrigation

Based on the owner's observation that a lychee tree close to his basin produced better yield at higher quality than other trees in his orchard, he requested to include an excessively irrigated treatment into the experiment. In this treatment the valve to the drip line was always kept opened, so that the barrel only served as small buffer and pressure stabilizer. However, water was always flowing, when available on the orchard.

Each monitoring tree was divided into eight equal sectors for monitoring yield and fruit quality. One sector was harvested per treatment and complete yield was determined by a mechanical scale. The water use efficiency (WUE) was calculated as the quotient of yield (kg) and total water consumption (m³). Due to the rainfall WUE could not be attributed to irrigation water only, as proposed by FAO (Doorenbos and Kassam, 1979). In each sector 15 fruits were randomly collected to determine fruit weight (electronic scale), size (vernier caliper) and water content (gravimetric method). Total soluble solids (TSS) content in the fruit flesh was measured using a portable digital refractometer (Atago® PR-32, Saitama, Japan).

RESULTS AND DISCUSSION

Figure 2 shows the functioning of the ATC under controlled conditions. Whenever the valve opened a 30 V current was measured. Depending on the evapotranspiration the irrigation intervals changed over the monitoring period. Whenever the soil matric potential amounted to more than 450 mbar, the ATC activated the main valve and irrigation took place. The graph shows the precise reaction of the control valve to the soil matric potential, keeping it within the predetermined conditions.

Also under field conditions the ATC worked without disturbances. The functioning of the unit was checked each time when the other treatments had to be irrigated, but no change in the setting had to be undertaken. Farmers positively responded to this observation. However, they considered further trials necessary, before they would depend on an automatic control device.

The amount of irrigation that was applied by the ATC was higher than in the two manually irrigated treatments. However, with 41.56 kg/ tree the calculated yield surpassed those treatments to the extent that WUE did not decrease. Interestingly, the overall supply to the tree considering rainfalls did not vary much between visual control and ATC with 2.79 and 3.39 m³/tree, respectively.

It can thus be assumed, that the higher yield response to ATC was based on the temporal distribution of water availability.

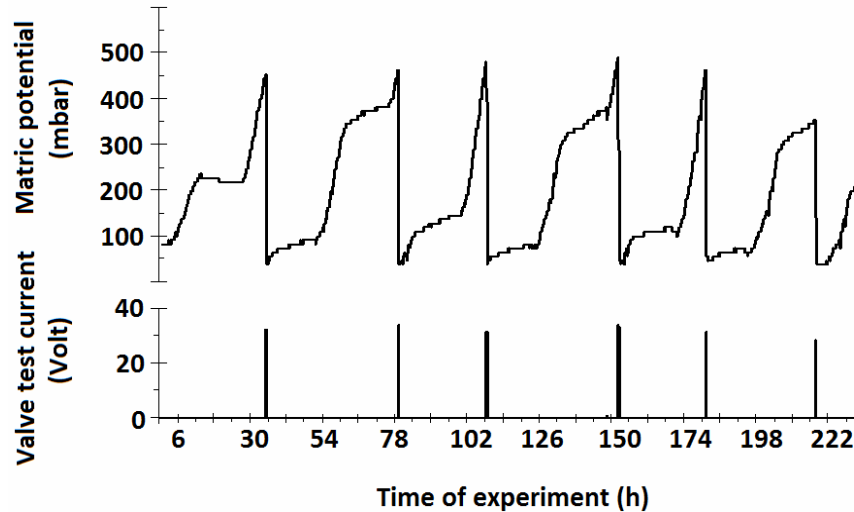


Figure 2. Monitoring of the ATC over one week. The soil matrix potential is given in mbar. At the opening of the main valve an electric circuit delivered a test voltage of ca. 30 V.

Table 1. Water consumption, yield and water use efficiency of ATC as compared to farmer practise, tensiometer controlled irrigation and overirrigation in lychee trees. Same letters indicate no statistical difference at $P < 0.05$.

Treatment	Water availability ($\text{m}^3 \text{ tree}^{-1}$)			Yield/tree (kg)	WUE
	Irrigation	Rain	Total		
Tensiometer	0.31	2.57	2.88	29.19 <i>bc</i>	10.18 <i>a</i>
Visual control	0.22	2.57	2.79	36.72 <i>ab</i>	12.94 <i>a</i>
ATC	0.82	2.57	3.39	41.56 <i>a</i>	12.27 <i>a</i>
Excess irrigation	2.19	2.57	4.76	25.66 <i>c</i>	5.34 <i>b</i>
LSD _{0.05}				0.54	3.37
SE				0.89	0.60

Table 2. Fruit quality parameters of lychees from ATC irrigated trees as compared to farmer practise, tensiometer controlled irrigation and overirrigation. Same letters indicate no statistical difference at $P < 0.05$.

Treatment	Avg. fruit weight (g)	Edible parts (% of fruit)	TSS in edible parts ($^{\circ}\text{Brix}$)	Fruit water content (%)
Tensiometer	16.45 <i>b</i>	62.49 <i>b</i>	15.62 <i>b</i>	80.28 <i>b</i>
Visual control	16.35 <i>b</i>	62.82 <i>b</i>	16.60 <i>a</i>	83.36 <i>a</i>
ATC	17.80 <i>a</i>	64.23 <i>a</i>	15.25 <i>b</i>	82.76 <i>a</i>
Excess irrigation	16.84 <i>ab</i>	62.45 <i>b</i>	13.86 <i>c</i>	82.43 <i>ab</i>
LSD _{0.05}	0.98	1.61	0.75	2.21
SE	0.18	0.29	0.13	0.40

The excess irrigation treatment showed significantly lower yields lead, leading to an extremely low WUE (Table 1). The average fruit size and the share of edible parts were highest under ATC irrigation. However, these

fruits had a rather low Brix value. With respect to those quality parameters, the conventionally irrigated (visual control) fruits had the most favorable properties: high water content with a high concentration of TSS (Table 2).

A possibly positive impact of light to moderate Drought stress on fruit quality has to be further investigated for lychee

CONCLUSION

Testing the ATC on station and under field conditions, it has proven its reliability in maintaining a favourable moisture regime in the soil. The irrigated lychee trees responded to ATC irrigation with a high yield. Even though the small sample size and the restricted possibilities for yield measurement under field conditions could put a question mark on the statistical relevance of the findings, the results illustrate the clear advantages of the ATC:

Automatic functioning: Without additional maintenance in the field, the only labour requirement is that for installation of the device. In further studies the actual labour saving effect has to be quantified and expressed as opportunity costs. Furthermore, it needs to be considered that when farmers have to survey irrigation, they tend to extend irrigation times in order to decrease the changeover times. This is an additional source of sub-optimal allocation of water.

Optimal irrigation water allocation: As compared to the traditional irrigation which is based on rather superficial observation of soil, plant and climate parameters in combination with the farmer's experience, the ATC relies purely on maintaining a constant soil matric potential in soil. It is therefore more precise and reacts more immediate to changes in the soil moisture. Even when soil moisture is controlled by measuring devices, e.g. tensiometers, fluctuations are generated due to the observation interval.

Among the mentioned positive effects, the full automatic functioning of the device was considered most important by the farmers. The lower labor requirement enables them to dedicate more time to other farm activities. However, even after one season of operation, farmers expressed concern about the reliability of the device and further tests have been requested for. The higher yield compared to the visual control, as traditionally practiced by the farmer, was not considered substantial.

As a conclusion, the ATC an automatic device has proved its functionality for fruit tree irrigation. It works without electric components, so that it can be operated in areas without electricity. Furthermore, it is assembled from cheap and simple materials. Thus, it can be easily copied and adapted to different conditions. Further tests need to be carried out in order to evaluate its long-term reliability and its adaptability to different agro-ecological, as well a socio-economic environments.

ACKNOWLEDGEMENT

This work was financed by Deutsche Forschungsgemeinschaft (DFG) in the frame of the collaborative research program "Sustainable rural development in mountainous regions of Southeast Asia" (SFB 564).

REFERENCES

- Agulia (2003). Development of an automatic irrigation control system for outdoor vegetable growing. Verlag Ulrich E. Grauer, Beuren, Germany. 3-86186-434-7 (in Germany).
- Al-Amoud Al, Mohammed FS (1995). Automatic irrigation scheduling by remote controlled tensiometers under arid climatic conditions. *Int. Agric. Eng. J.*, 4 (3), 131-145.
- Chesmore ED (2001). Advances in electronic technology for sensing and monitoring in agriculture and horticulture. *Acta Hortic.*, 562: 141-147.
- Doorenbos J, Kassam AH (1979). Yield response to water. Food and Agricultural Organization of the United Nations, Rome, Italy.
- Meron M, Hallel R, Bravdo R, Wallach R (2001). Tensiometer actuated automatic micro irrigation of apples. *Acta Hortic.*, 562: 63-69.
- Munoz-Carpena R, Dukes MD, Li YC, Klassen W (2005). Field comparison of tensiometer and granular matrix sensor automatic drip irrigation on tomato. *Hort Technol.*, 15: 584-590.
- Neef A, Heidhues F, Stahr K, Sruamsiri P (2006). Participatory and Integrated Research in Mountainous Regions of Thailand and Vietnam: Approaches and Lessons Learned. *J. Mountain Sci.*, 3(4): 305-324.
- Pathan SM, Barton L, Colmer TD (2007). Evaluation of a soil moisture sensor to reduce water and nutrient leaching in turfgrass (*Cynodon dactylon* cv. Wintergreen). *Aust. J. Exp. Agric.*, 47: 215-222.
- Peterson DL, Glenn DM, Wolford SD (1993). Tensiometer-irrigation control valve. *Appl. Eng. Agric.*, 9(3): 293-297.
- Smajstrla AG, Locascio SJ (1996). Tensiometer-controlled, drip-irrigation scheduling of tomato. *Appl. Eng. Agric.*, 12(3): 315-319.