Precise Irrigation Scheduling Using Soil Moisture Sensors

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The efficient use of irrigation water requires several kinds of information. One element of an efficient irrigation scheduling is monitoring the soil to assure that the crop irrigation goals are being met. Various soil moisture measuring devices have been tested for irrigation scheduling in silt loam and sandy loam. Aquaflex, Gro-Point, Moisture-Point, neutron probe, tensiometer, Watermark soil moisture sensor and Gopher probes were compared. Several sensors were tested as read automatically by a datalogger and read manually with a hand-held meter. Practical suggestions are provided to use soil moisture sensors to the benefit of crop production and water conservation.

Introduction

Precise irrigation scheduling is necessary to optimize marketable yield of high value crops while conserving water and protecting water quality. Irrigation scheduling is greatly facilitated by any soil moisture sensor which can provide timely and responsive information on soil water or soil water potential status. For a particular sensor to be useful for a particular crop and soil, it needs to respond rapidly and reliably to the range of variation of water status in that soil which is important for marketable yield. Several sensors were tested for their responsiveness and usefulness for irrigation scheduling in soils typical of the Treasure Valley of the Snake River Plain of Oregon and Idaho.

Materials and Methods

Experiment 1. Six soil moisture sensors were compared by their performance in response to wetting and drying in a micro sprinkler irrigated hybrid poplar plantation at the Malheur Experiment Station in Ontario, Oregon.

The trees had been planted in April 1997 on Nyssa-Malheur silt loam soil on a 14-ft by 14-ft spacing. The tree rows are oriented to the northwest. The trees are irrigated using a micro sprinkler system (R-5, Nelson Irrigation, Walla Walla, WA) with the risers placed between trees along the tree row at 14-ft spacing. The sprinklers delivered water at the rate of 0.14 inches/hour at 25 psi and a radius of 14 ft. The area used for the sensor performance trial was managed to receive two inches of water whenever the soil water potential at 8-inch depth reached -50 kPa.

Two Aquaflex sensors (Streat Instruments, Christchurch, New Zealand) were installed on September 14, 2000. Each sensor was installed at 8-inch depth along the tree row and between two trees. The two Aquaflex sensors were connected to an Aquaflex datalogger. On July 23, 2001, six types of soil moisture sensors were added to the study. One sensor of each type was installed in four groups adjacent to the existing Aquaflex sensors. The position of each sensor was randomized between groups. The sensors in each group were installed in a line parallel to and approximately 8 inches from the Aquaflex sensors. The sensors were installed at 8-inch depth. Each Aquaflex sensor had a group of sensors on each side. The sensors added to the study were tensiometer (Moisture Indicator, Irrometer Co., Riverside, CA), Watermark soil moisture sensor model 200SS (Irrometer Co. Inc., Riverside, CA), Neutron Probe model 503 DR hydroprobe (Boart Longyear, Martinez, CA), Moisture Point (Environmental Sensors Inc., Escondido, CA), Gro Point (Environmental Sensors Inc., Escondido, CA), and Gopher (Cooroy, Queensland, Australia). The four Gro Point sensors were connected to two Gro Point 3 channel data loggers. The Watermark sensors were connected to an AM400 Soil Moisture Data Logger (M.K. Hansen Co., East Wenatchee, WA). All other sensors were read manually at 9:00 a.m. from Monday through Friday. The tensiometers and Watermark sensors measure soil water potential. The other sensors use various techniques to measure volumetric soil water content.

The tensiometer and Watermark sensors required that a hole in the soil be made with a standard 7/8-inch diameter soil auger for installation. The tensiometers required regular resetting due to the column of water breaking suction around -60 to -70 kPa. The Gro Point sensor was relatively compact and was easy to bury. The neutron probe and the gopher required the installation of PVC access tubes for each monitored location. The Moisture Point used a 3-ft probe permanently installed at each location to be monitored. The Moisture Point probe required a hole made with a probe provided by the company for installation. The neutron probe, Gopher, and Moisture Point allowed measurement of soil moisture at different depths at each location. The Aquaflex was 10 ft long and was installed horizontally, requiring a 10-ft trench dug to the depth of installation.

Both the neutron probe and Gopher required site specific calibration. One undisturbed core soil sample was taken in each instrument location during sensor installation. The soil samples were immediately placed in tin cans and weighed, then oven dried at 100°C for 48 hours and weighed again. Volumetric soil moisture content was calculated for the soil samples using the gravimetric method. After the sensors were installed, 2 inches of water was applied. On July 25, another set of soil samples was taken and volumetric soil moisture content was determined as before. The sensors were read at the same time as the soil samples were taken. The neutron probe was read as counts during 32 seconds. The volumetric soil water content determined from the soil samples was regressed against the neutron probe and gopher readings. The coefficient of determination (r^2) for the regression equation for the neutron probe was 0.93 at $P = 0.01$. The regression equation was used to transform the neutron probe readings to volumetric water content. A calibration for the Gopher sensor was not possible due to a lack of correlation between the gopher readings and the volumetric soil water content determined from the soil samples. The average soil moisture data from the neutron probe and from the tensiometers was compared using regression against the average soil moisture data for each of the other sensors.

Experiment 2. Six soil moisture sensors were compared by performance in their response to wetting and drying in a drip-irrigated potato field at the Malheur Experiment Station in Ontario, Oregon. The sensors were Aquaflex, Gro Point, Moisture Point, Neutron Probe, tensiometer, and Watermark. The Watermark sensor was tested as read automatically by a datalogger and read manually with a hand-held meter, model 30 KTCD-NL (Irrometer Co., Riverside, CA), as previously calibrated (Shock et al., 1998).

Potato seed of cultivar ‘Mazama’ was planted on April 26, 2002 in rows spaced 36 inches apart. The potato seed pieces were spaced 9 inches apart in the row. The soil was an Owyhee silt loam with a pH of 8.1 and 2 percent organic matter. Drip tape (T-tape, T-systems International, San Diego, CA) was laid at 4-inch depth between two potato rows. The drip tape had emitters spaced 12 inches apart and a flow rate of 0.22 gal/min/100 ft. The crop was irrigated daily to replace the previous day’s evapotranspiration. Potato evapotranspiration (Et_c) was calculated with a modified Penman equation (Wright 1982) using data collected at the Malheur Experiment Station by an AgriMet weather station. From July 15 to July 25 and again from July 30 to August 7, the crop was not irrigated to evaluate sensor performance under variable soil moisture, during both wetting and drying conditions.

In mid-June the sensor study was installed along one of the potato rows. Six types of sensors were installed between the drip tape and the potato row. The sensors were installed 8 inches from the drip tape and 10 inches from the potato row. The sensors were centered at 9-inch depth. The experimental design was a randomized complete block design with four replicates. These instruments were installed, managed, and calibrated as in experiment 1 above.

Experiment 3. The response of Watermark soil moisture sensors to irrigation events and the termination of irrigation was read automatically using an AM400 Hansen datalogger and an Irrometer Watermark Monitor (Irrometer Co.).

Automated reading of Watermark soil moisture sensors was done in a furrow-irrigated Greenleaf silt loam planted to onions. The sensors were installed with their centers 8 inches deep directly below the onion plants. The sensors were installed in the lower part of the field where the furrow irrigations were less effective at wetting the soil. Six Watermark soil moisture sensors and a temperature probe were connected to an AM400 Hansen datalogger which read the sensors three times a day. Data was recovered from the AM400 using a palm computer as previously described (Shock et al. 2001).

Seven Watermark soil moisture sensors and a temperature probe were connected to the Irrometer Watermark Monitor. A computer and the WaterGraph program (Irrometer Co., Inc.) was used to set the sensor data collection frequency at 15 minutes. Data was recovered from the Irrometer Watermark Monitor using a laptop and the WaterGraph program.

All experiments. All trials reported here benefited from simultaneous crop evapotranspiration irrigation management information (Wright, 1982) available from a US Bureau of Reclamation AgriMet station on site.

Results and Discussion

Experiment 1. The tensiometer, Watermark, neutron probe, Gro Point, and Aquaflex responded to the wetting and drying cycles of the soil (Figure 1). The neutron probe and Aquaflex sensors seemed to be less responsive to the soil drying between irrigations than the Gro Point sensor. Lower responsiveness of the neutron probe is not surprising since neutrons radiate deep into the soil were drying does not proceed as quickly. Then slower neutrons can bounce back to the neutron probe sensor. All sensors showed correlations ($r^2 > 0.7$) to the neutron probe and correlations ($r^2 > 0.5$) to the tensiometer except the Moisture Point sensor (Figures 2 and 3). The Moisture Point estimates of soil water were substantially lower than the neutron probe data (Figures 2 and 3).

Experiment 2. The tensiometer, Watermark sensor, and neutron probe responded to the wetting and drying cycles of the soil (Fig. 4). The Gro Point responded, but the amplitude of the response was less than that of the neutron probe. The Moisture Point was the least responsive to the wetting and drying cycles of the soil compared to the other sensors, probably due to the soil pulling away from the sides of the probe. For undetermined reasons, the Aquaflex datalogger only collected 3 days of data; this did not allow for a graphic display.

The watermark sensor measured with the AM400 datalogger and the 30 KTCD-NL meter showed close correlations to the tensiometer (Fig. 5). The AM400 and the 30 KTCD-NL readings of different Watermark Sensors were fairly closely correlated to each other; both instruments used similar equations to convert Watermark sensor electrical resistance to SWP (Shock et al. 2001).

All sensors showed correlations ($r^2 > 0.6$) to the neutron probe except the Moisture Point sensor (Fig. 6). The Aquaflex and Gro Point estimates of soil water were often lower than the neutron probe (Fig. 4). The Moisture Point estimates of soil water were substantially lower than the neutron probe, Aquaflex, and Gro Point.

Experiment 3. The automated collection of Watermark sensor data by an AM400 Hansen datalogger and an Irrometer Watermark Monitor (Irrometer Co.) provided similar interpretation of wetting and drying cycles (Fig. 7). Watermark sensors responded to irrigation within one hour. Small differences in calibration equations can be noted (Fig. 7 D) and slight differences in the interpretation of soil water potential near saturation are evident (Fig. 7 C).

The AM400 was convenient for following and scheduling irrigation events in the field due to its graphic display. Irrometer Watermark Monitor was convenient for setting the data logger reading frequency, easy retrieval, and automatic interpretation of the data. The operation, advantages, and limitations of Watermark soil moisture sensors are described elsewhere (Shock 2003).

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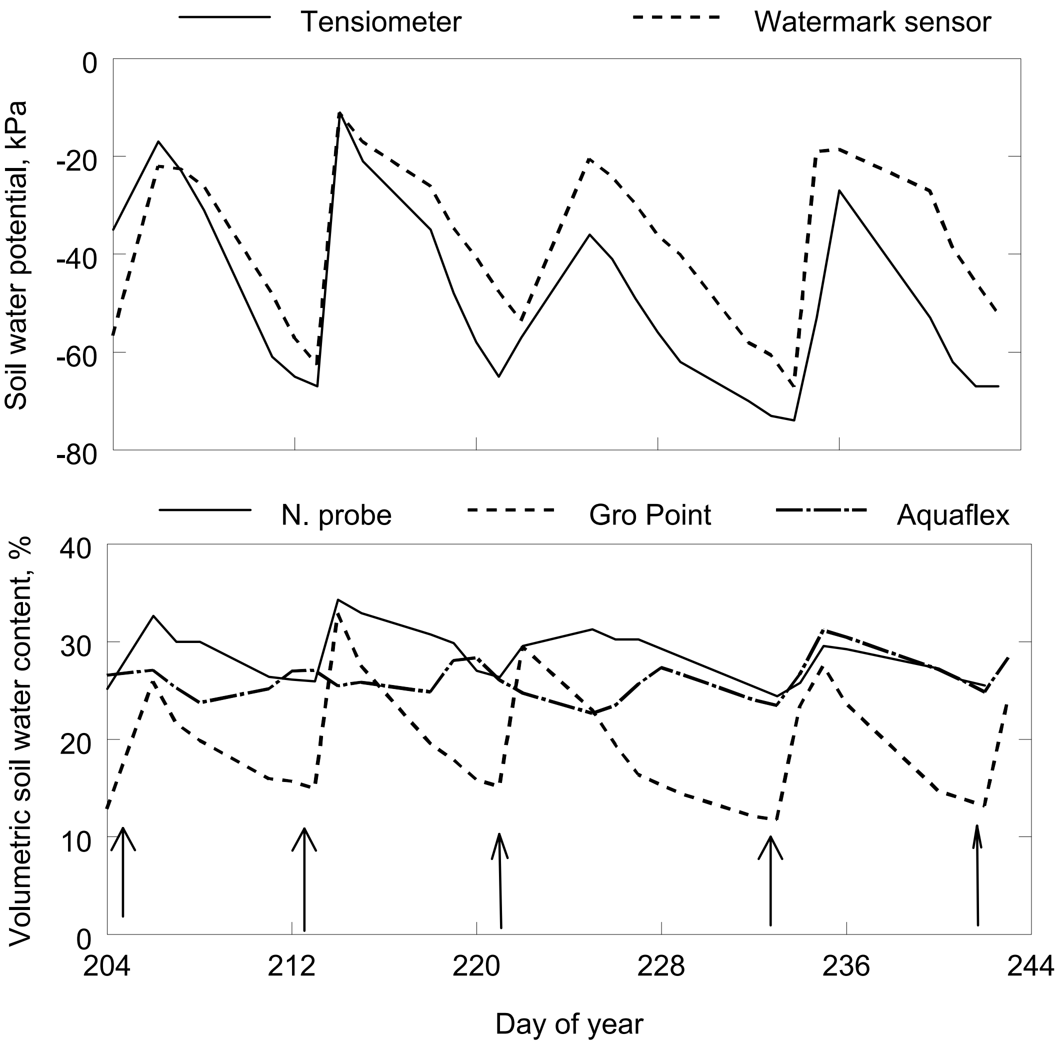


Figure 1. Soil moisture data over time for five types of soil moisture sensors in Experiment 1. Arrows denote irrigations with approximately 2 inches of water applied. The Moisture Point sensor was not available during this time due to repairs being made. Malheur Experiment Station, Oregon State University, Ontario, OR.

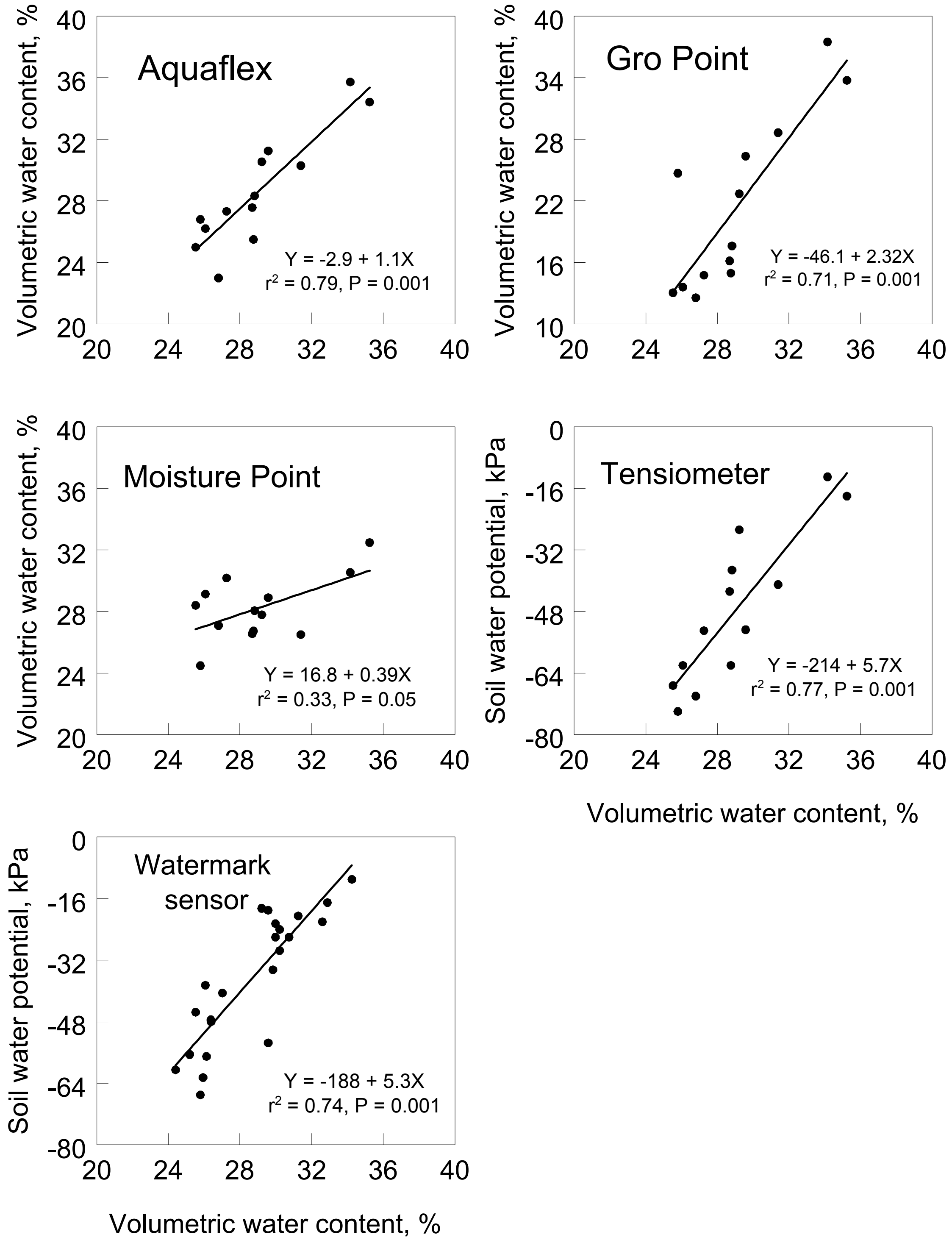


Figure 2. Volumetric soil water content measured in Experiment 1 by a neutron probe (X axis) regressed against soil moisture data (Y axis) measured by 5 types of soil moisture sensors. Data points for the Aquaflex sensor are the average of two sensors. Data points for the other sensors are the average of four sensors. Malheur Experiment Station, Oregon State University, Ontario, OR.

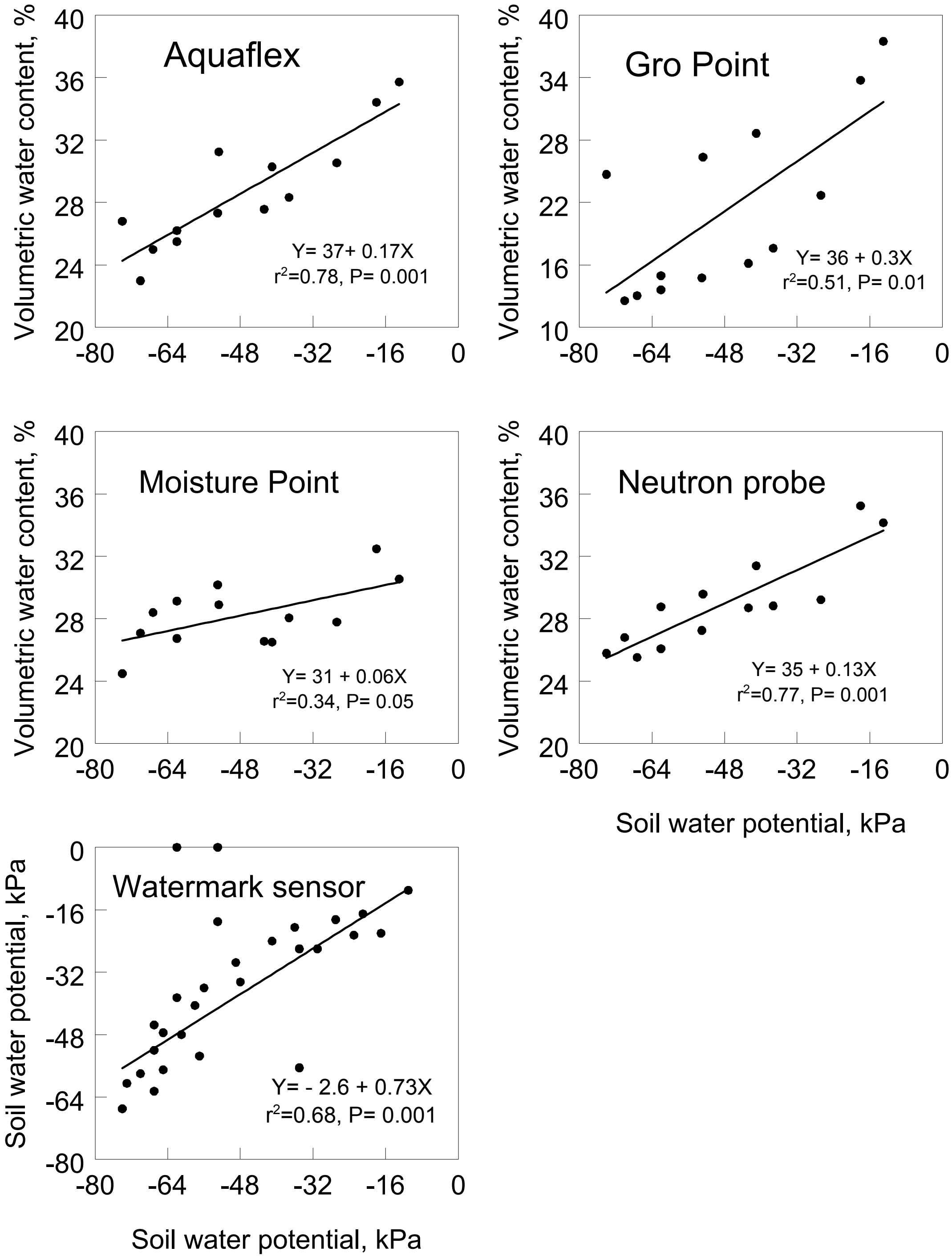


Figure 3. Soil water potential measured in Experiment 1 by tensiometers (X axis) regressed against soil moisture data (Y axis) measured by 5 types of soil moisture sensors. Data points for the Aquaflex sensor are the average of two sensors. Data points for the other sensors are the average of four sensors. Malheur Experiment Station, Oregon State University, Ontario, OR.

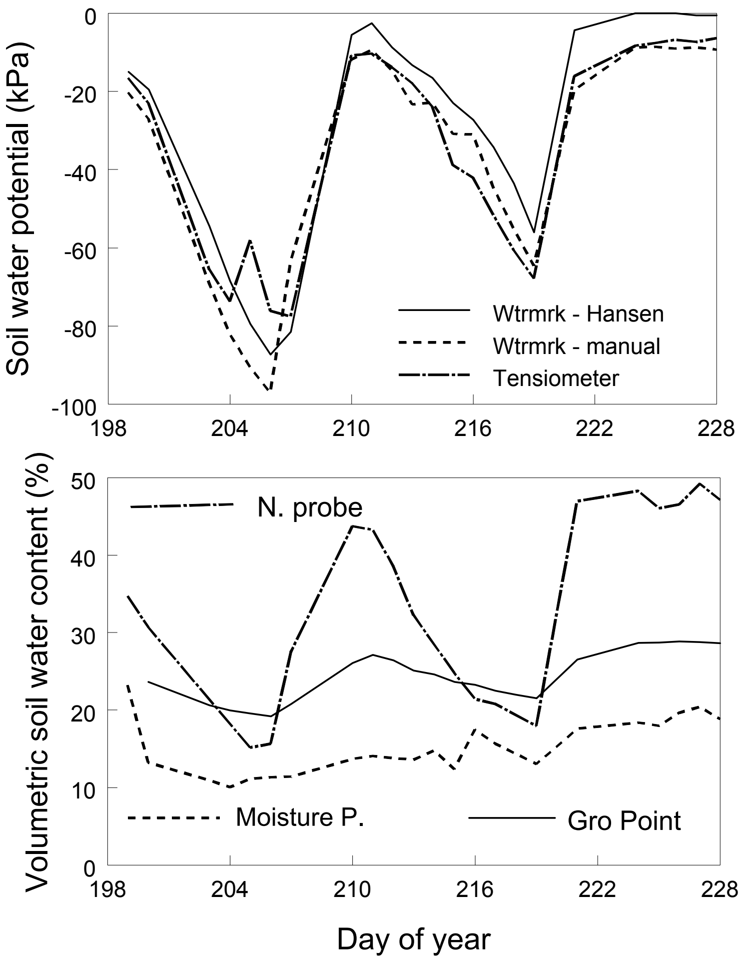


Figure 4. Soil moisture over time for five types of soil moisture sensors in Experiment 2. Malheur Experiment Station, Oregon State University, Ontario, OR, 2002.

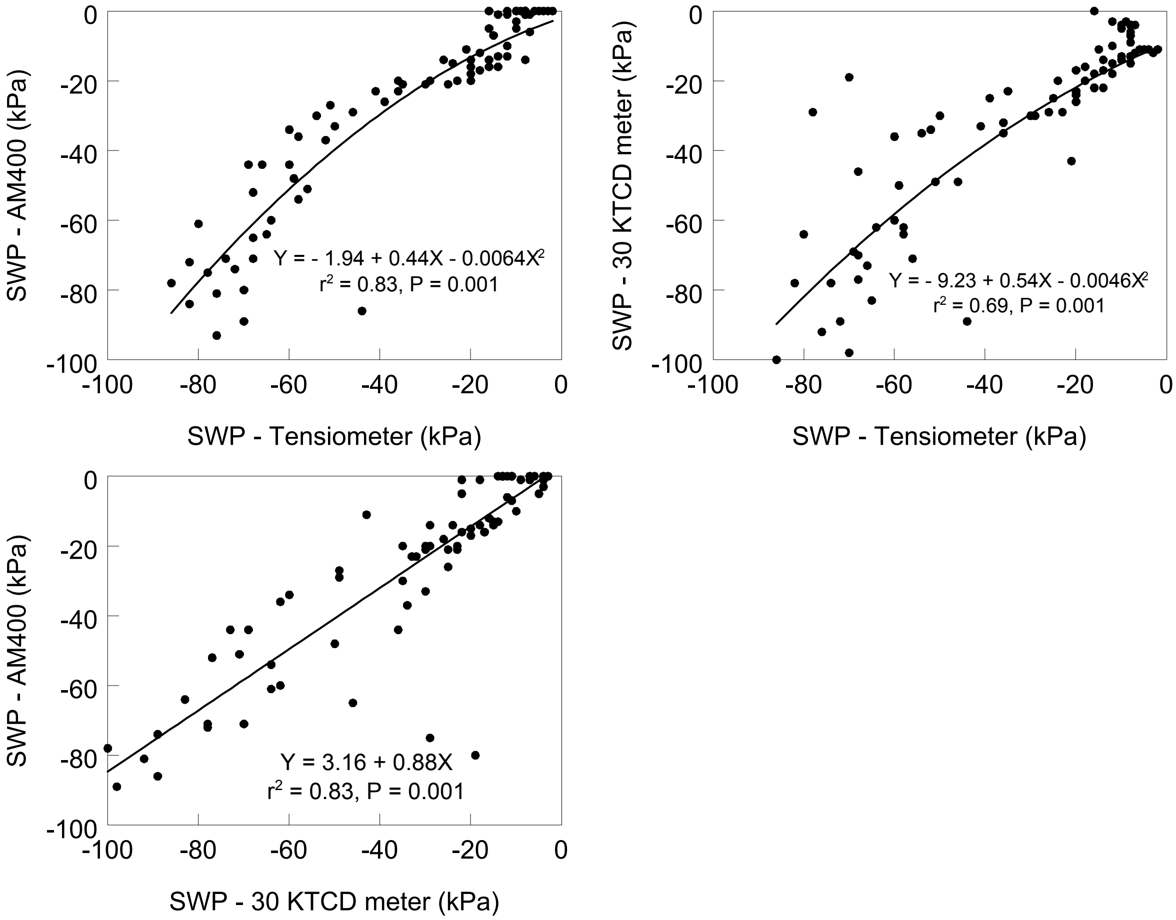


Figure 5. Regressions of soil water potential (SWP) measured in Experiment 2 by three instruments. Malheur Experiment Station, Oregon State University, Ontario, OR, 2002.

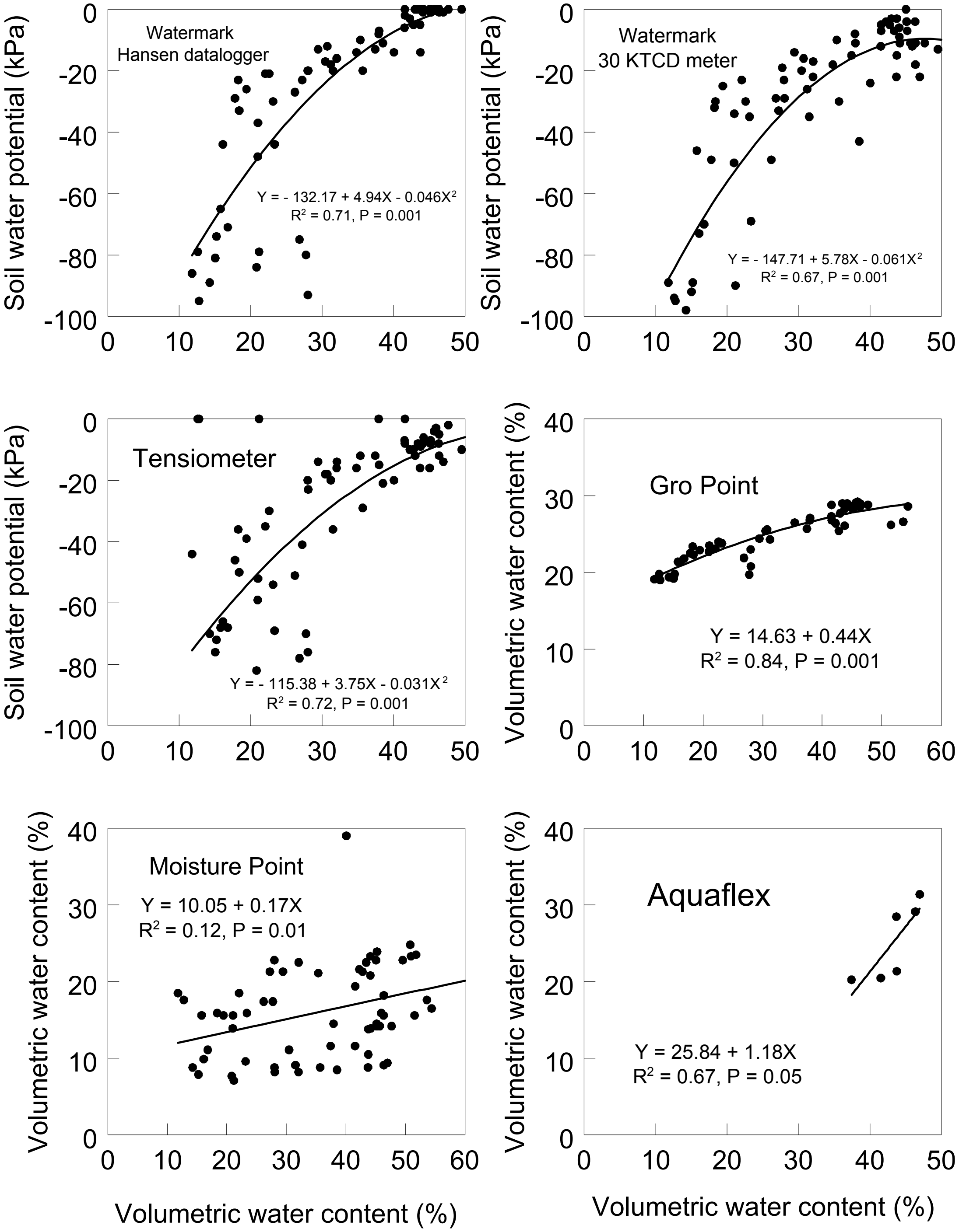
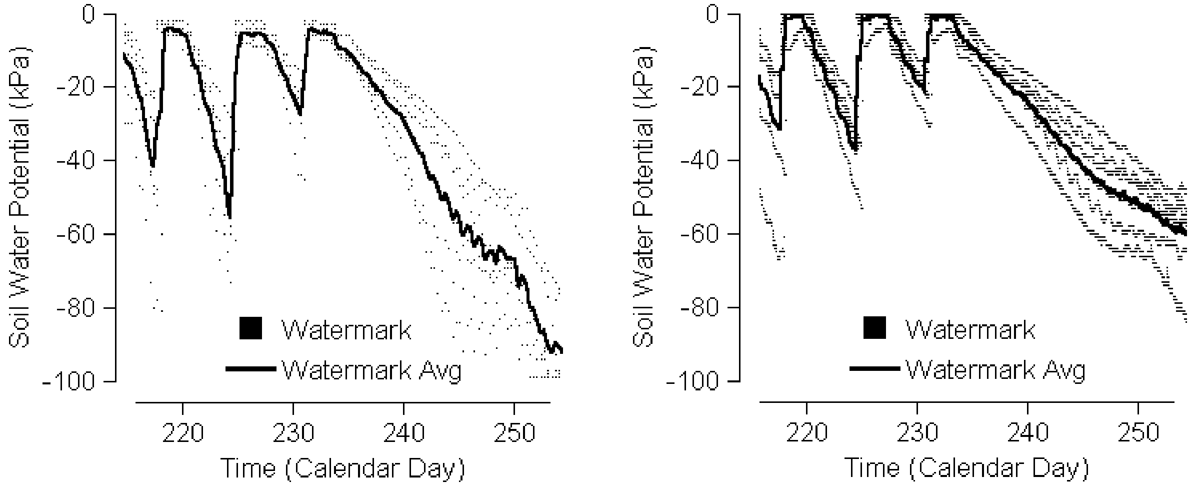
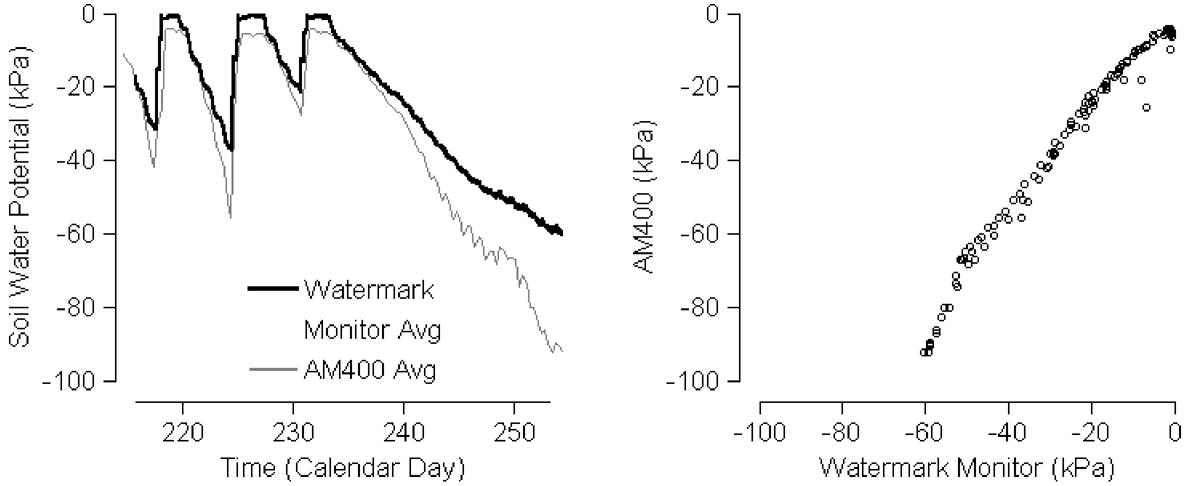


Figure 6. Volumetric soil water content measured in Experiment 2 by a neutron probe (X axis) regressed against soil moisture data (Y axis) measured by 6 types of soil moisture sensor. Malheur Experiment Station, Oregon State University, Ontario, OR, 2002.



A. Time vs AM400

B. Time vs Watermark Monitor



C. Comparison over time

D. Watermark Monitor vs AM400

Figure 7. Response of Watermark soil moisture sensors to irrigation events and the termination of irrigation as measured by an AM400 Hansen datalogger (A) and an Irrometer Watermark Monitor (B). The average readings of the an AM400 Hansen datalogger and an Irrometer Watermark Monitor are compared over time (C) and over the measured range of soil water potential (D).