# Soil Moisture Sensor Irrigation Controllers Response to Different Temperatures and Salinities

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**Abstract.** *Soil moisture sensor systems (SMSs) have demonstrated that can reduce irrigation application in Florida. However, SMSs have not been tested under Florida soils, irrigated with reclaimed water, which contains salts that can affect the measured soil water content (SWC). The objective of this research was to test different commercially available SMSs under controlled conditions, and analyze their responses under different levels of water salinity and temperature. Three brands/models were selected for this experiment: Acclima/SCX, Baseline/WaterTec S100, and Dynamax/IL200-MC. Containers filled with a sandy soil were manufactured so that they could be saturated from the bottom to minimize entrapped air and fitted with sintered metal filters to allow vacuum application for water removal in a timely manner. The containers were installed in a controlled-temperature chamber and were saturated and dried down across three temperatures (10, 25, and 35ºC) and three electrical conductivities (0.0, 0.7, and 5.0 dS/m). Each container was placed on a platform-scale to determine soil-water loses, by weight variation over time. The scale readings were compared to the SMS readings, and calibration curves were developed through regression analysis. Preliminary outcomes show that most replications resulted in linear regressions with $R^2$ values higher than 0.94, indicating that all the units tested had a high precision for measuring the SWC, but calibration is necessary to achieve accurate readings. Increasing the temperature from 25ºC to 35ºC and/or the salinity from 0.0 to 0.7 dS/m neither affect the accuracy nor the precision of the different SMS systems, when SWC values below 15% were considered.*

**Keywords.** Reclaimed water, salinity, soil moisture sensor, soil temperature, soil water content.

## Introduction

New commercially available soil moisture sensor systems (SMSs) consist of a probe inserted in the root zone and a controller that is connected to the time clock, or timer, of an automatic irrigation system. In the controller, the user can set a soil water content threshold and, therefore, the SMS will allow or bypass a scheduled irrigation cycle, depending on the soil water content at the programmed start time.

Most of these SMSs respond to electromagnetic properties of the soil, more specifically, to the dielectric permittivity. Of all the constituents of the soil, water is the only one with a high dielectric permittivity. Therefore, changes in the water content have the most significant effect on the total permittivity of the soil. These SMSs operate by sending a signal to the soil environment. This signal is distorted by the amount of dielectric permittivity, which is then translated into a specific soil water content, usually displayed in the SMS controller as volumetric soil water content (SWC). If the SWC is above the threshold set in the controller (too wet) the SMS will bypass that scheduled irrigation cycle, and vice versa.

SMSs have demonstrated that they can save irrigation water in Florida (Cardenas-Lailhacar et al., 2008 and 2010; Haley and Dukes, 2011; McCready et al., 2009). However, SMSs have not been tested under Florida soils irrigated with reclaimed water. This source of irrigation usually contains more salts than potable water, which can affect the dielectric permittivity and, hence, the readings of SMSs when measuring SWC. Likewise, temperature affects the electric properties of the soil, which can alter the accuracy of the SMS readings (Evett et al., 2006). Moreover, Cardenas-Lailhacar and Dukes (2010) tested the precision of different SMSs under field conditions, and found statistical differences between some brands, and sometimes even within replicates of a SMS brand.

The objective of this research was to test different commercially available SMSs under controlled-temperature conditions, and analyze their responses and readings under different levels of water salinity and temperature. This paper presents preliminary results.

## Materials and Methods

This study was conducted in a controlled-temperature chamber at the University of Florida in Gainesville. Inside the chamber, platform scales with a resolution of 0.02 kg were set (Champ SQ base with CW-11 Indicator [Ohaus Corp., NJ]). Three SMS brands/controllers/probes were selected for this experiment: Acclima/SCX/Digital TDT (Acclima Inc., ID), Baseline/WaterTec S100/biSensor (Baseline Inc., ID), and Dynamax/IL200-MC/SM200 (Dynamax Inc., TX). The controllers of all these systems display the SWC of the sampled soil.

Plastic containers with overall dimensions of 55 x 38 x 25 cm high were packed with 28 l of air-dried soil extracted from the top 15 cm of an Arredondo fine sand (loamy, siliceous, semiactive, hyperthermic Grossarenic Paleudult) (Thomas et al., 1985; USDA 2007). The containers were built such that they could be saturated with water from the bottom (to minimize entrapped air that could affect the SMS readings) and, afterwards, to allow the free drainage of excess water. In addition, sintered metal filters were placed at the bottom of the containers to allow vacuum application for water removal in a timely manner. Each container was placed over a platform scale to determine soil water lose, by weight variation over time. The scale readings were corrected through the gravimetric method (Gardner, 1986) from soil samples cores of 52.5 mm diameter and 103.4 mm high at the end of each test. Soil bulk densities ranged from 1.35 to 1.49 g/cm3. The scale readings were transformed to SWC by mass balance, and then compared with the SMS readings. Calibration curves were then developed through regression analysis.

The containers were saturated and dried down across three temperatures: 10, 25, and 35ºC. The water applied had three levels of salinity: 0.0, 0.7, and 5.0 dS/m. Each SMS brand/controller/probe had three replicates. After developing the regression analysis for each, a contrast analysis was performed between the treatments within a brand, to evaluate if there were statistical differences when increasing the temperature and/or the salinity. These analyses were performed using the statistical analysis software (SAS, 2008) and the Statistica software (StatSoft, 2008).

## Results and Discussion

Results presented here do not include all the possible combination treatments between temperature and salinity that will be conducted. This manuscript includes the combinations of 0.0 dS/m at 25ºC, 0.0 dS/m at 35ºC, and 0.7 dS/m at 35ºC.

Figures 1, 2, and 3 show examples of the SWC measured by the scales versus the Acclima, Baseline, and Dynamax sensors readings, respectively, for the combination of 0.0 dS/m at 35ºC. For each treatment, a linear regression was calculated, and the resulting equations and $R^2$ values are given. Table 1 summarizes the results of the regression analyses for the treatments presented here.

Linear $R^2$ values greater than 0.92 were obtained in every treatment, except for Dynamax at 0.0 dS/m and 35ºC, which resulted in $R^2$=0.81.

These values indicate that the different brands showed a high precision to estimate the SWC at the salinities and temperatures tested. Moreover, linear $R^2$ values greater than 0.94 were verified for every single replication (data not shown), which indicate that all the individual replications tested had a high precision for measuring the SWC. This can be visualized in Figures 1 to 3, where the curves of each individual replicate can be easily followed. Moreover, Figure 3 shows that two of the replicates from Dynamax had very similar readings, but the other replicate (even though it had an $R^2$ value of 0.94) had a different slope, which finally drove the combined coefficient of determination of the treatment to a lower value (0.81) compared to the $R^2$ values of the individual replicates.

Even when the different brands resulted in high precision readings, none of the slopes and intercepts (Table 1) matched exactly the 1:1 line (slope=1 and intercept=0), so calibration of these systems is necessary if accurate readings are required out of the box without external calibration.

Table 2 shows the contrast analyses that were performed between treatments within a brand to see if different temperature and/or salinity would produce different SMS readings. Results show that increasing the temperature from 25ºC to 35ºC and/or the salinity from 0.0 to 0.7 dS/m did not affect the accuracy nor the precision of Acclima and Baseline systems. In the case of Dynamax tested at 35ºC, however, increasing the salinity from 0.0 to 0.7 dS/m had a significant effect on the slope of the regression. These preliminary results suggest that Dynamax systems are more sensitive to changes in the salinity of the soil environment, and site-specific calibrations should be performed to achieve an adequate control of irrigation.

Because of the experimental design, the soil in the plastic boxes could retain water above the normal field capacities found in the sandy soils of Florida, which are usually below 15%. Therefore, a more detailed analysis was performed on the results below 15% of SWC, determined by the scale readings. Figures 4, 5, and 6 show, as examples, the individual replicates and the combined results of all replicates for brands Acclima, Baseline, and Dynamax, respectively; at 0.0 dS/m and 35ºC. A linear regression, and the resulting equation and $R^2$ value are presented below the 1:1 line. Even when the linear $R^2$ values for the individual replicates, in this example, were above 0.94, it is clear that the individual replicates had sigmoidal shape curves. Thus, a polynomial regression was also fitted to increase the coefficient of determination and to obtain a better calibration curve fit. The $R^2$ values of these examples are presented above the 1:1 line of Figures 4 to 6. It can be seen that all replicates resulted in $R^2$ values 0.995 or above, reaching very precise SWC readings. However, when the replicates are combined, the $R^2$ values tend to decrease, showing that differences exist between the units when reading the same SWC. Table 3 shows the results by treatment considering linear and a $5^{th}$ order polynomial regression curves. In general, the Acclima and Baseline treatments resulted in higher linear $R^2$ values than Dynamax. If a fifth order polynomial regression is fitted, higher R2 values were obtained for all the treatments. If necessary, performing individual calibrations on these sensors could result in very precise and accurate readings, which is of more relevance in the Dynamax sensors. Table 4 shows the contrast analyses between treatments within a brand, for SWC values below 15%, to see if different temperature and/or salinity would produce different SMS readings. In these cases, none of the treatments resulted in significant differences (P-values>0.05). Therefore, for SWC below 15%, increasing the temperature from 25ºC to 35ºC and/or the salinity from 0.0 to 0.7 dS/m did not affect the accuracy nor the precision of the different SMS systems.

## Conclusions

These results corroborate that the laboratory design is adequate for verifying the precision and accuracy of the SMSs tested over a range of salinity values, water contents, and temperatures.

Linear $R^2$ values of 0.94 or above were verified for every single replication, indicating that all the units tested had a high precision for measuring the SWC. However, neither the slopes values were equal to one, nor the intercepts equal to cero, so calibration of these systems is necessary to achieve an adequate control of irrigation, or if accurate readings are required.

Increasing the temperature from 25ºC to 35ºC and/or the salinity from 0.0 to 0.7 dS/m did not affect the accuracy nor the precision of the different SMS systems when SWC values below 15% were considered. For higher SWC values, the Dynamax systems tended to be more sensitive to changes in the salinity of the soil environment.

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Table 1. Regression analysis by treatment .

| Brand | Treatment | | Regression Analysis | | |
|---|---|---|---|---|---|
| | dS/m | ºC | $R^2$ | Slope | Intercept |
| Acclima | 0.0 | 25 | 0.980 | 0.863 | 4.02 |
| | 0.0 | 35 | 0.981 | 0.982 | 2.41 |
| | 0.7 | 35 | 0.986 | 0.940 | 3.66 |
| Baseline | 0.0 | 25 | 0.982 | 0.910 | -2.68 |
| | 0.0 | 35 | 0.977 | 1.004 | -2.40 |
| | 0.7 | 35 | 0.931 | 0.930 | 0.12 |
| Dynamax | 0.0 | 25 | N/A | N/A | N/A |
| | 0.0 | 35 | 0.811 | 1.210 | 2.76 |
| | 0.7 | 35 | 0.921 | 1.083 | 5.00 |

N/A = not applicable

Table 2. Contrast analysis between treatments within a brand.

| Brand | Analysis | Treatment Contrasts | | | | | P-value |
|---|---|---|---|---|---|---|---|
| | | dS/m | ºC | | dS/m | ºC | |
| Acclima | Regression | 0.0 | 25 | vs.[z] | 0.0 | 35 | 0.1765 |
| | Regression | 0.0 | 35 | vs. | 0.7 | 35 | 0.1990 |
| | Regression | 0.0 | 25 | vs. | 0.7 | 35 | 0.5292 |
| Baseline | Regression | 0.0 | 25 | vs. | 0.0 | 35 | 0.8794 |
| | Regression | 0.0 | 35 | vs. | 0.7 | 35 | 0.3253 |
| | Regression | 0.0 | 25 | vs. | 0.7 | 35 | 0.2557 |
| Dynamax | Regression | | | | | | 0.0004 |
| | Intercept | 0.0 | 35 | vs. | 0.7 | 35 | 0.1195 |
| | Slope | | | | | | <0.0001 |

[z]vs. = versus

Table 3. Linear and fifth order polynomial regression analysis by treatment, for soil water contents below 15%.

| Brand | Treatment | | Linear | | | 5th order Polynomial |
|---|---|---|---|---|---|---|
| | dS/m | ºC | $R^2$ | Slope | Intercept | $R^2$ |
| Acclima | 0.0 | 25 | 0.891 | 1.192 | 1.15 | 0.934 |
| | 0.0 | 35 | 0.928 | 1.140 | 1.39 | 0.945 |
| | 0.7 | 35 | 0.919 | 1.065 | 2.50 | 0.984 |
| Baseline | 0.0 | 25 | 0.967 | 1.142 | -5.22 | 0.988 |
| | 0.0 | 35 | 0.953 | 1.383 | -5.48 | 0.976 |
| | 0.7 | 35 | 0.885 | 0.955 | -1.90 | 0.948 |
| Dynamax | 0.0 | 25 | 0.937 | 0.918 | 1.71 | 0.943 |
| | 0.0 | 35 | 0.777 | 1.677 | -0.30 | 0.813 |
| | 0.7 | 35 | 0.751 | 1.450 | 2.19 | 0.795 |

Table 4. Contrast analysis between treatments within a brand, for soil water contents below 15%.

| Brand | Analysis | Treatment Contrasts | | | | | P-value |
|---|---|---|---|---|---|---|---|
| | | dS/m | ºC | | dS/m | ºC | |
| Acclima | Regression | 0.0 | 25 | vs. | 0.0 | 35 | 0.8719 |
| | Regression | 0.0 | 35 | vs. | 0.7 | 35 | 0.0520 |
| | Regression | 0.0 | 25 | vs. | 0.7 | 35 | 0.2778 |
| Baseline | Regression | 0.0 | 25 | vs. | 0.0 | 35 | 0.5778 |
| | Regression | 0.0 | 35 | vs. | 0.7 | 35 | 0.2435 |
| | Regression | 0.0 | 25 | vs. | 0.7 | 35 | 0.3671 |
| Dynamax | Regression | 0.0 | 35 | vs. | 0.7 | 35 | 0.9125 |

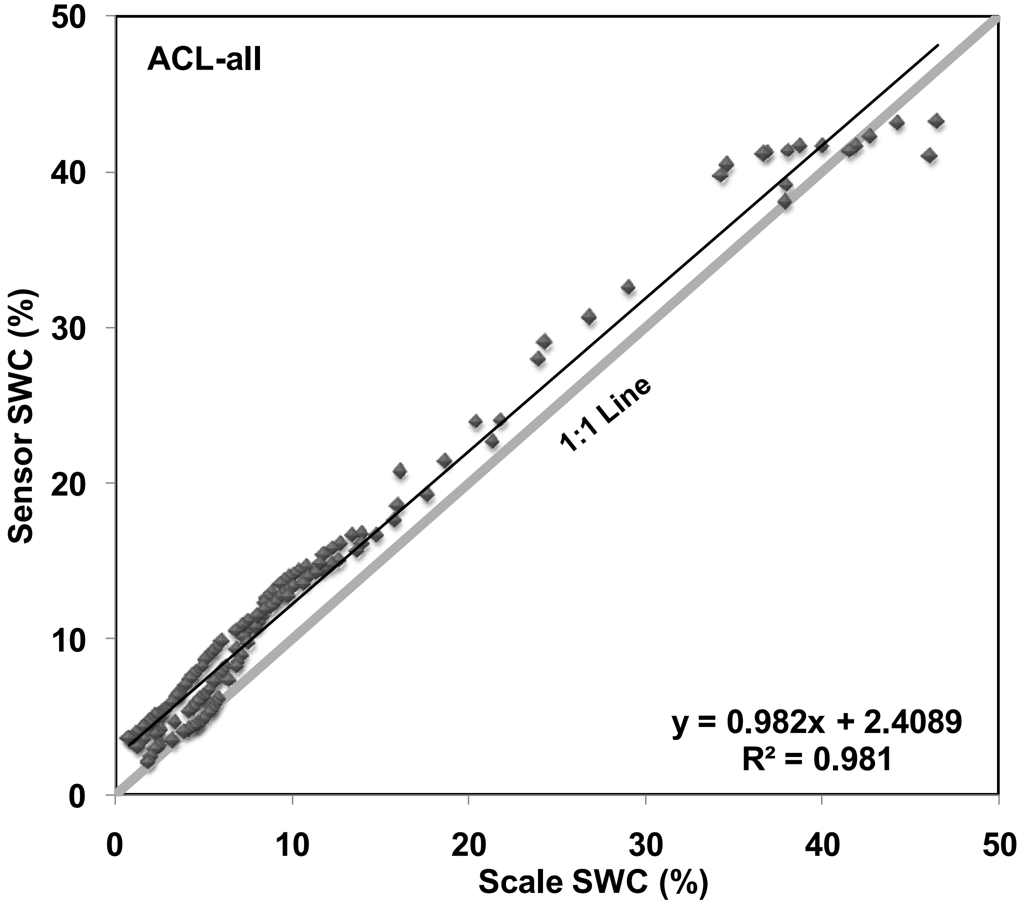


Figure 1. Acclima sensors readings versus soil water content measured by the scales at 0.0 dS/m and 35ºC. A linear regression fit is represented as a solid line, and the resulting equation and $R^2$ value are given.

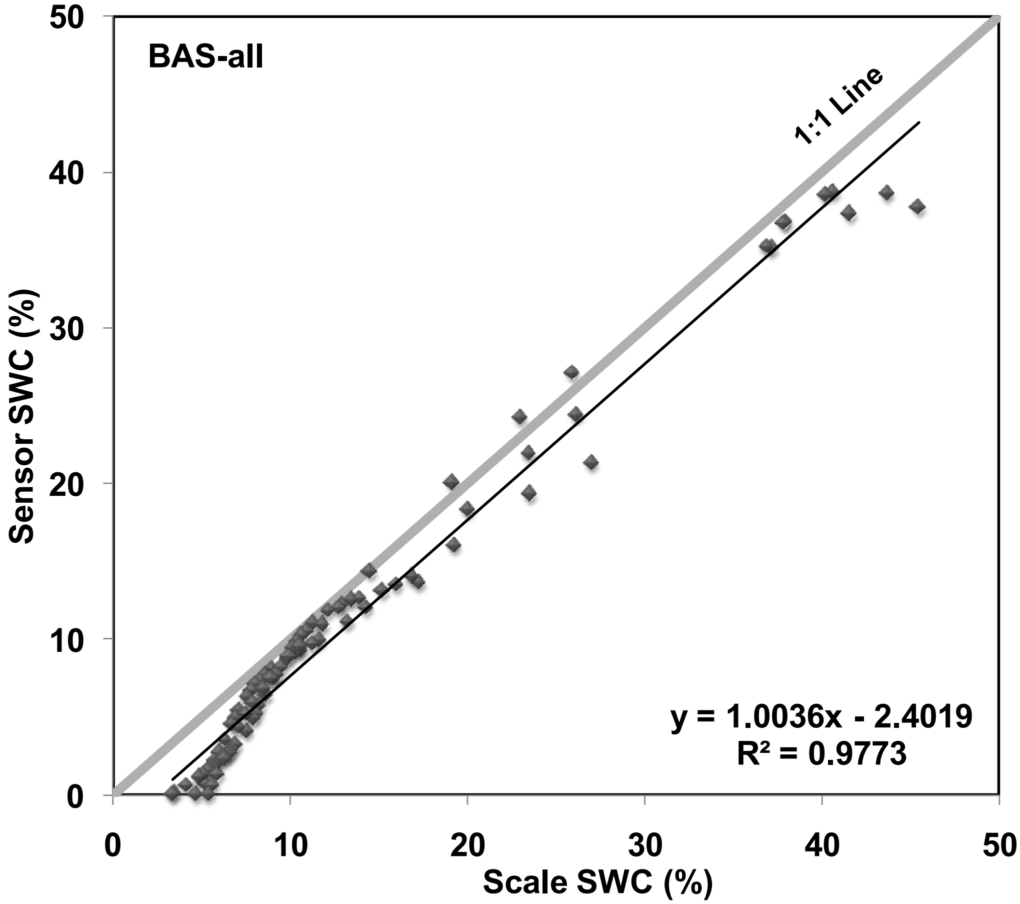


Figure 2. Baseline sensors readings versus soil water content measured by the scales at 0.0 dS/m and 35ºC. A linear regression fit is represented as a solid line, and the resulting equation and $R^2$ value are given.

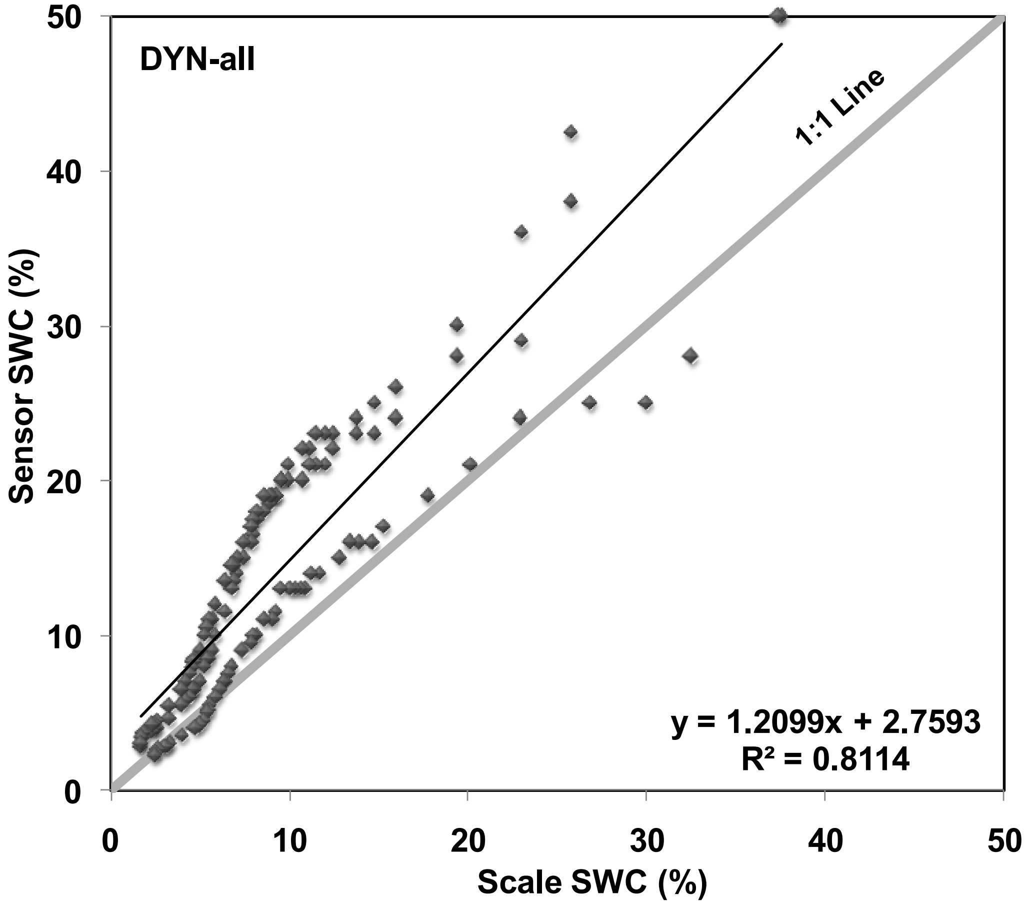


Figure 3. Dynamax sensors readings versus soil water content measured by the scales at 0.0 dS/m and 35ºC. A linear regression fit is represented as a solid line, and the resulting equation and $R^2$ value are given.

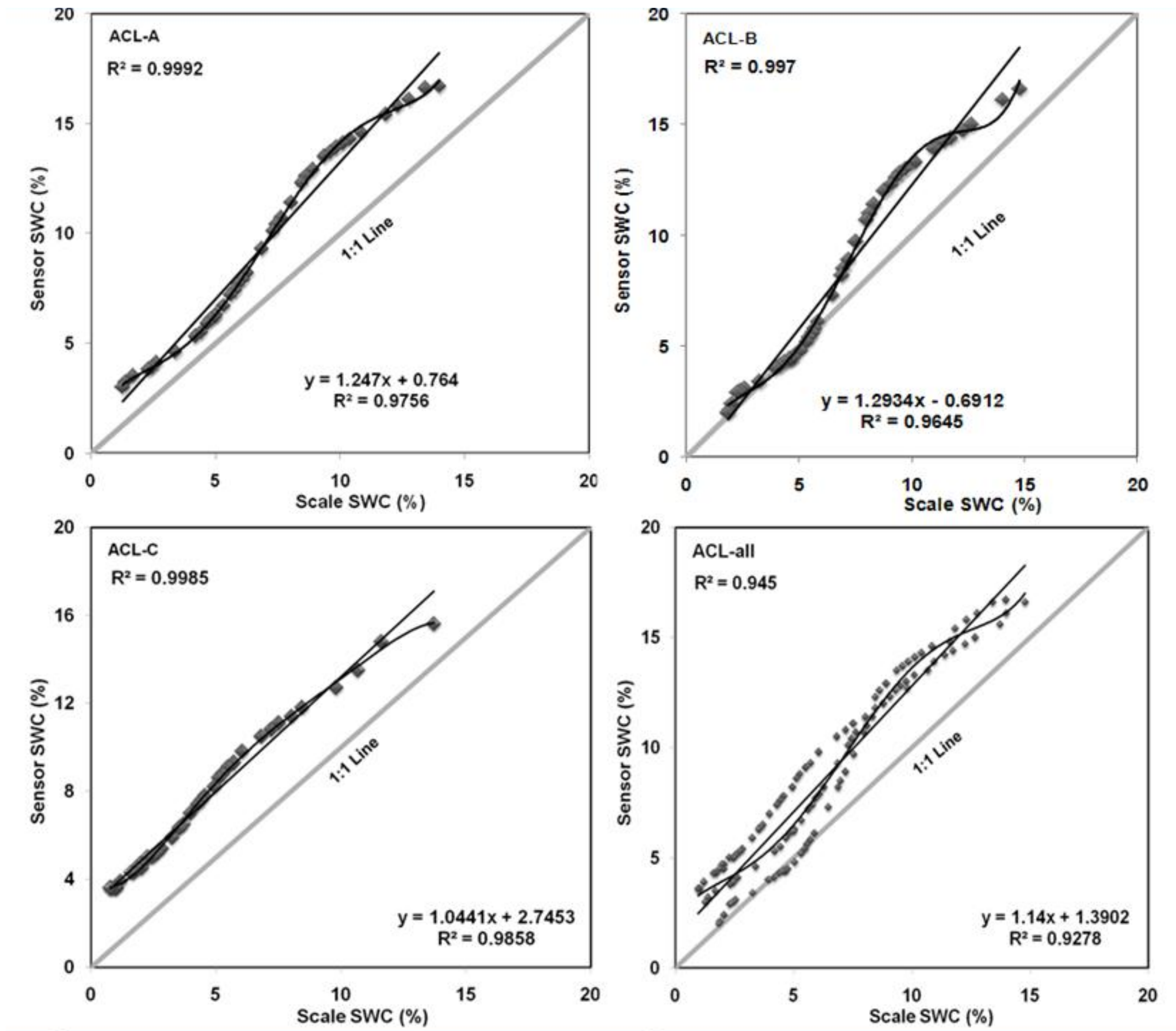


Figure 4. Soil water content below 15% as measured by the scales versus the individual replicates of the Acclima sensors (ACL-A, ACL-B, and ACL-C), and the combination of them (ACL-all), readings at 0.0 dS/m and 35ºC. A linear regression and the resulting equation and $R^2$ value are presented below the 1:1 line. A polynomial regression was also fitted to increase the $R^2$ value, which is presented above the 1:1 line.

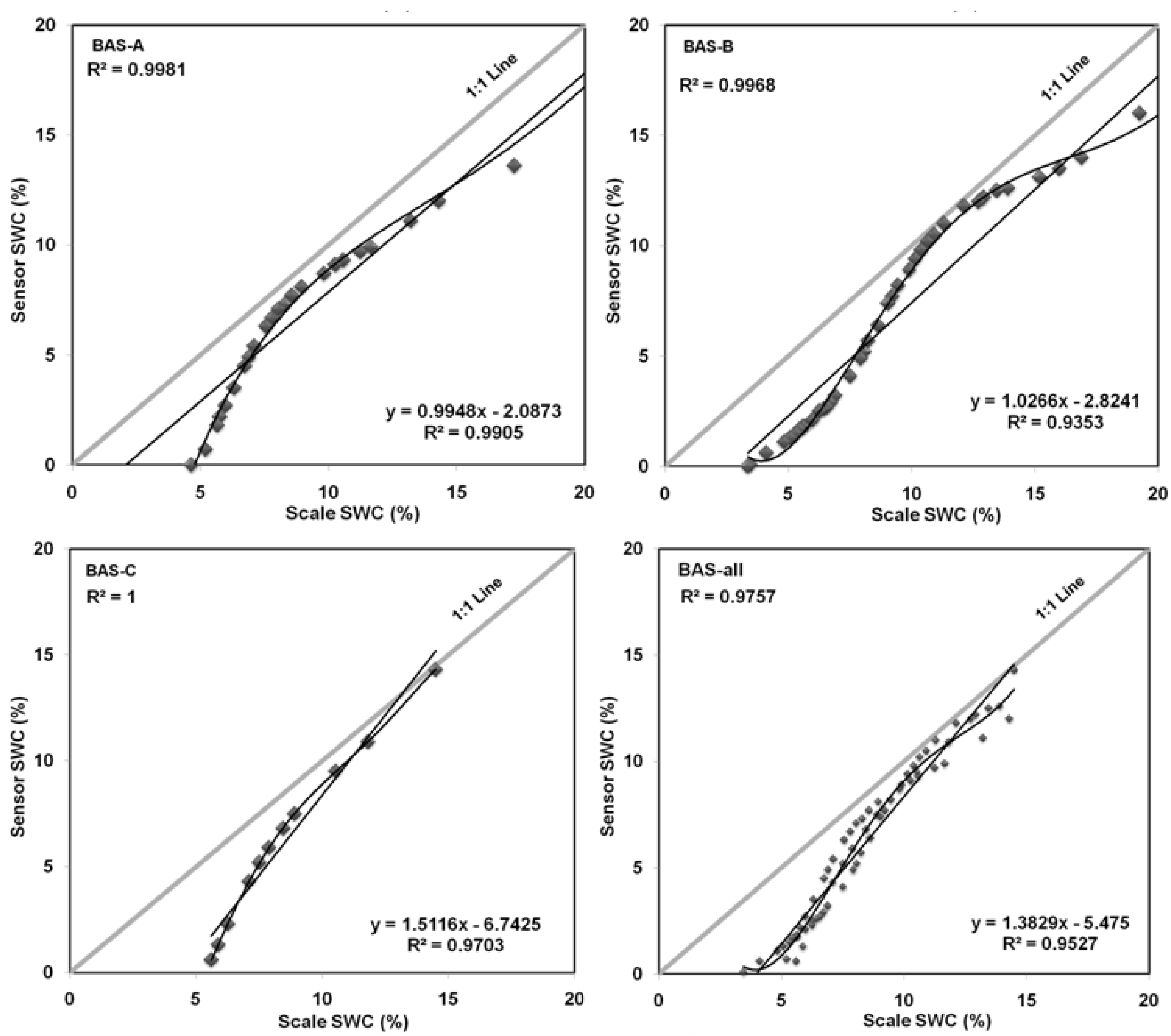


Figure 5. Soil water content below 15% as measured by the scales versus the individual replicates of the Baseline sensors (BAS-A, BAS -B, and BAS -C), and the combination of them (BAS - all), readings at 0.0 dS/m and 35ºC. A linear regression and the resulting equation and $R^2$ value are presented below the 1:1 line. A polynomial regression was also fitted to increase the $R^2$ value, which is presented above the 1:1 line.

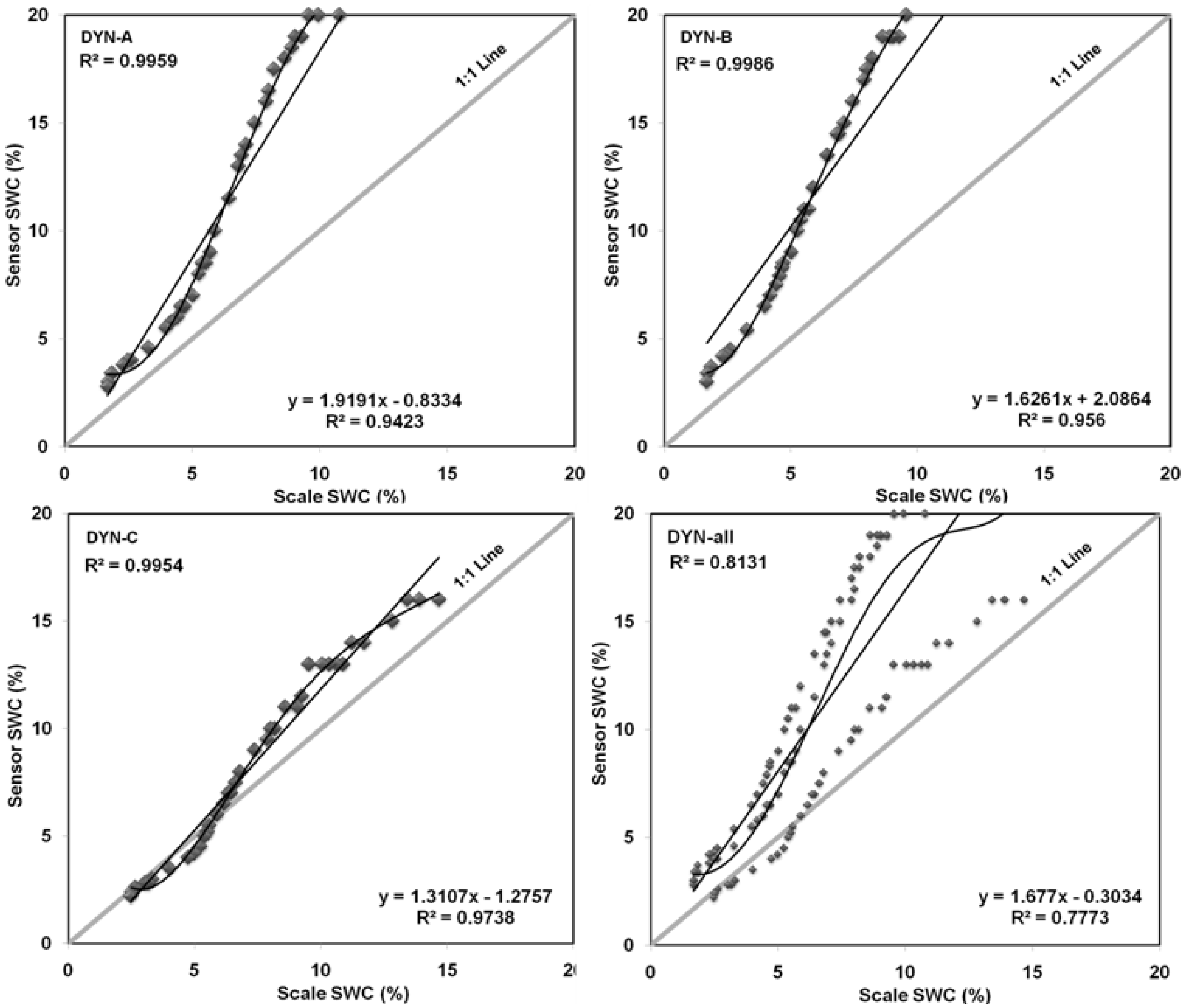


Figure 6. Soil water content below 15% as measured by the scales versus the individual replicates of the Dynamax sensors (DYN-A, DYN -B, and DYN -C), and the combination of them (DYN -all), readings at 0.0 dS/m and 35ºC. A linear regression and the resulting equation and $R^2$ value are presented below the 1:1 line. A polynomial regression was also fitted to increase the $R^2$ value, which is presented above the 1:1 line.