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Use of atmometers to estimate reference evapotranspiration in Arkansas

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Evapotranspiration (ET) data from atmometers were compared against evapotranspiration estimated by the FAO-56 Penman-Monteith equation, recommended method, in order to evaluate the accuracy of atmometers. Measurements by 3 atmometers with grass cover and 3 atmometers with alfalfa cover were compared, for one growing season, to Penman Monteith based grass and alfalfa equation–($ET0_{\_PM}$ and $ETr_{\_PM,,}$ respectively). Comparison between cumulative Evapotranspiration measured by atmometers and $ET0_{\_PM}$ or $ETr_{\_PM}$ showed that Atmometers, for both grass and alfalfa, underestimate evapotranspiration by 12.5-21 and 15% respectively. The three Atmometers with alfalfa cover give the same cumulative value (636 mm) compared to the atmometers with grass cover which exhibit different results (atmometers 1 and 3 (467 mm) and atmometers 2 gives 419 mm). Correlation between ET from atmometers and $ETr_{\_PM}$ or $ET0_{\_PM}$ estimates were generally good. Evaporation from atmometers with alfalfa cover showed the highest correlation to $ETr_{\_PM}$ (R^2 varying from 0.68 to 0.72) whereas evaporation from atmometers with grass cover present the lowest correlation (R^2ranges from 0.49 to 0.68). The results indicated that with the proper regression equation and a good calibration, atmometers could be used to estimate ET for crop water requirement where evapotranspiration estimates are not available from weather stations.

Key words: Atmometer, evaporation, evapotranspiration, irrigation, Penman-Monteith equation.

INTRODUCTION

In Arkansas, groundwater withdrawal for irrigation doubled from 1980 to 2000 (Winthrop Rockefeller Foundation, 2008). The same report highlighted that 73% of Arkansas water withdraw were used for irrigation and 80% of the water used for irrigation was groundwater. As a result, irrigation is the main activity contributing to the

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increasing of water withdrawal (Valipour 2015a, b). Therefore, particular attention has to be taken in order to better manage irrigation and estimate accurately the crop water requirement.

Reliable estimation of crop water requirements is very important and vital where water resources are limited and crops are constantly under the influence of low rainfall and high temperature (Tabari et al., 2013). Therefore, accurate quantification of crop water requirements is needed for optimizing water productivity, efficient use of water resources and improving management practices to reduce surface and groundwater deterioration (Irmak et al., 2006; Al Wahaibi, 2011; Valipour 2014a, b; 2015c).

The evapotranspiration (ET) is generally used for estimation of crop water requirement. Thus, as mentioned by Jia et al. (2013), knowledge of ET is very important for water management and water resource planning. Different methods are developed for estimating ET. Most of them use equations to determine the value of ET at daily, weekly, monthly, or seasonal basis. These equations use weather variables as inputs such as solar radiation, air temperature, wind speed, and relative humidity (Irmak et al., 2005, Valipour 2014c, d).

Among these methods, The Penman-Monteith model is the most accurate and widely used. The Food Agriculture Organization (FAO, 2015) and American Society of Civil Engineers (ASCE) have recommended it for use in irrigation management. However, it demands a lot of weather variables (Irmak et al., 2003) which could not be available everywhere.

The rice research center of University of Arkansas is using Atmometers in some of its fields, to determine ET for irrigation management and scheduling. The same technology has been installed in some farmer fields in order to know when and how much to irrigate. The results from Atmometers are judged accurate and very close to ETP Penman Montheith from some studies conducted in different regions: Hess (1996) and Knox et al. (2011) in England, Irmak et al. (2005) in Nebraska (USA), and Magluilo et al. (2003) in Mediterranean area.

The aim of this study is to compare the Evapotranspiration Penman- Monteith with the evaporation from atmometers (ET_gage) and to evaluate the seasonal variability between same atmometers of commercial types.

MATERIALS AND METHODS

The study was conducted at the Rice Research and Extension Center at Stuttgart in Arkansas (34°28'7.31"N, 91°24'56.14"W) at 62.2 m above mean sea level. Data of four months (May, June, July, and August 2013) of one meteorological station and 6 Atmometers (ET_gages of two types of covers: grass and alfalfa) were used.

Atmometers (Figure 1) are water-filled devices, in which the actual evaporation of water is measured over time. A graduated glass sight on the water supply tank allows the user to easily measure the evaporation that occurred over a given period. Distilled water was used to fill the cylindrical reservoir of each atmometer made of white PVC, which reflects the radiant energy and is less subject to temperature raising of the water. The individual readings taken from each atmometer (ET_{gage}) at the daily basis was determined by the difference between water levels on consecutive days. If readings are not taken for the week end, we have assumed reading Sunday = Saturday = (reading Monday - reading Friday)/2.

For each type of cover (grass and alfalfa), data from the three atmometers were compared in order to check their consistency. Evapotranspiration from Penman Monteith (ETO_PM) was calculated using the Equation (1).

$$ET_0 \text{ or } ET_r = \frac{0.408\,(R_n - G) + \gamma(C_n/(T+273))u_2(es - ea)}{\Delta + \gamma(1 + C_d u_2)} \quad (1)$$

Where ET0 (Penman Monteith grass reference evapotranspiration) or ETr (Penman Monteith alfalfa reference Evapotranspiration) is in mm/day; Rn = net radiation at the crop surface (MJm_2 day_1); G = soil heat flux density (MJm_2 day_1); T = air temperature at 2 m high (°C); u2 = wind speed at 2 m high (m s_1); es = saturation vapor pressure (kPa); ea = actual vapor pressure (kPa); es-ea = saturation vapor-pressure deficit (kPa). Cn is numerator constant for reference type and calculation time step, and Cd is denominator constant for reference type and calculation time step For grass reference and daily step, Cn = 900, Cd = 0.34 and alfalfa reference, Cn = 1600, Cd = 0.38.

The Computer program Cropwat 8 was used to calculate ETo_PM (Allen et al., 1998) at the daily basis. Cropwat 8 is developed by FAO for the calculation of crop water and irrigation requirements based on soil, climate and crop data. Also, the program can be used to develop irrigation schedules for different management conditions and to calculate the water supply for different crop patterns (FAO, 2015). The inputs of the application are maximum and minimum air temperature, humidity relative, average wind speed, and percentage of daytime. The comparisons between Penman Monteith grass or alfalfa reference evapotranspiration ($ET0_{\_PM}$ or $ETr_{\_PM}$) and evapotranspiration from atmometers with grass or alfalfa cover ($ET0_{\_At}$ or $ETr_{\_At}$) were tested by fitting linear regressions.

$ET0_{\_PM}$ or $ETr_{\_PM}$ was considered as the dependent variables. The Student's test (t test) was applied to evaluate the significance of the intercept and the slope of the regression. All tests were performed at alpha = 1%. Also a 95% Prediction interval was determined and the regression was bounded by a lower and upper limit values. To evaluate the degree of agreement between evapotranspiration from the atmometers and ETP Penman, coefficients of determination (R^2) were calculated.

RESULTS AND DISCUSSION

Average monthly climatic information

Table 1 gives the average monthly climatic information from May to August 2013. It shows that the average temperature is the same for June, July and August. The month of May with 21°C presents the lowest value. The relative humidity is greater than 80% for May, July, and August and achieves its lowest value at June with a value of 76%. August presents the lowest average wind speed (1.22 m/s), solar radiation (19.9 MJ/m^2/day), and average hour sun (Hour).

To Penman Monteith and Atmometers (Grass)

A comparison between cumulative values of $ET_{\_At}$ and

Figure 1. Atmometer.

ET0_PM during the four months (June to August 2013) is shown in Figure 2. Cumulative ET0_PM is always greater than the cumulative values of ET_At. The ETO_PM exhibits a cumulative value of 526.2 mm. Atmometers 1 and 3 are very consistent and present slightly the same values, 462.7 and 462.5 mm respectively. In contrary, the atmometer 2 shows the lowest values (419.1 mm). These results highlight that atmometers underestimate the value of evapotranspiration during the growing season in Arkansas by 12.5% for atmometers 1 and 3 and 21% for atmometers 2. This result confirms the finding of Gavilán and Castillo (2009) in Spain and Alam and Trooien (2001) under semiarid conditions. Irmak et al. (2005) pointed out that rainfall may play a significant role in this underestimation because the wetness of the canvas cover and the membrane as well as the accumulation of rainwater would cause a reduction in the vapor pressure gradient between the plate surface and the surrounding air on rainy days. These results are different from those of Knox et al. (2011) and Alam and Elliott (2003) which showed that atmometers overestimate the value of evapotranspiration. Another study by Magliulo et al. (2003) in South Italy found that a slight underestimation of pan ET0 by atmometer. The difference can be explained by the climatic differences in these zones (Valipour, 2015d) or by a reading error (Dukes et al., 2004) because different persons were involved in the data collection and this fact can cause inconstancy in data reporting. The different values from atmometers 1 and 3 on one hand, and 2 on the other hand reveal that it may be by manufactory variability. Gavilan and Castillo (2009) revealed that may be a difference value from atmometer of same cover due sometimes to manufactory variability. It will be interesting to use these three same atmometers for long terms to see how they will perform.

Depending on the geographical area, the model, formula; or method used to calculate evapotranspiration, results are different compared to FAO Penman Monteith method (Snyder et al., 2005). Valipour (2015d) showed that Temperature based formula and temperature and relative humidity based formula overestimated Penman Monteith Evapotranspiration in some provinces in Iran.

Farmers use to irrigate, at average, every three to five days; therefore the mean of the five-day sum values of evaporation were computed using the atmometers and the Penman Montheith. Also, Magliulo et al. (2003) pointed out that for practical purposes, a weekly schedule in ET0 monitoring via atmometers is to be advised to

Table 1. Average monthly climatic information.

Variable	Month			
	May	June	July	August
Average temperature (°C)	21	26.5	26.4	26.4
Daily relative humidity (%)	80	76	81	85
Average wind speed (m/s)	2.89	1.97	1.46	1.22
Average daily income solar radiation ($MJ/m^2/day$)	21.5	22.8	22	19.9
Average hour sun (Hour)	7.9	8.5	8.2	7.3

Table 2. Comparison between 5 days-sum ETo_PM and ETO_At.

Variable	Atmometer ($ET0_{\_Atm}$)			Penman- Montheith ($ET0_{-PM}$)
	Atmometer 1	Atmometer 2	Atmometer 3	
Mean (mm)	15.56	14.19	15.60	18.56
Standard deviation (mm)	4.09	3.47	4.07	2.42
Standard error	0.87	0.74	0.87	0.42
Coefficient of variation (%)	26	24	26	13
T test	-2.96	-4.85	-2.94	
P value	0.006	<0.001	0.006	

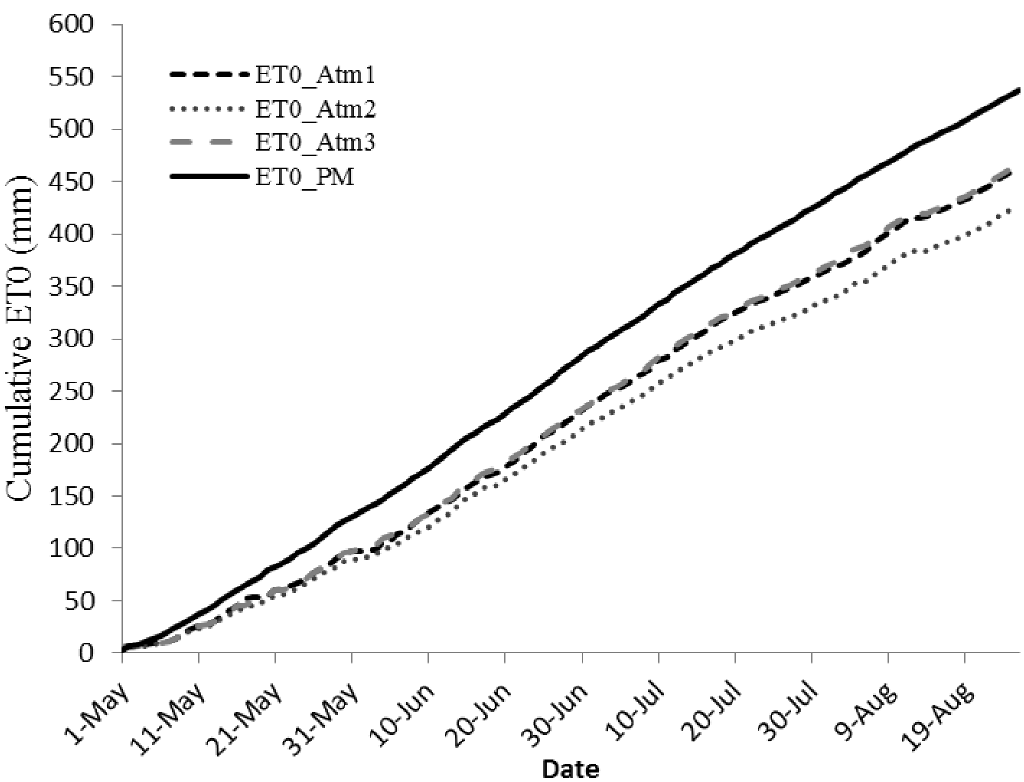

Figure 1. Cumulative potential evapotranspiration.

achieve best results, especially when manual instruments with visual reading are used. Here, we considered the week as the five days. The values calculated are shown in Table 2. In addition, Table 2 provides the standard deviation, the standard error, the coefficient of variation, and the value of t test. It can be seen that the mean

Table 3. Regression of atmometers reference grass and evapotranspiration Penman Monteith.

Atmometer	Regression slope	Regression intercept	R^2
Atmometer 1	0.41	12.1	0.49
Atmometer 2	0.57	10.4	0.68
Atmometer 3	0.49	10.9	0.67

ranges from 14.19 mm to 15.60 mm for the atmometers and 18.56 mm for the ETo_PM. The three atmometers yield higher standard deviation and error compared to the ETo_PM method. The t test shows that there is a significance difference between mean value from the atmometers and the Penman Montheith method (Pvalue <0.007). The ratio between average five days sum ET0_PM and ET0_At is 1.19, 1.31, and 1.13 for atmometers 1, 2 and 3 respectively.

The five-days sum evaporation values computed using the different methods (Penman Montheith and Atmometers) were analyzed by using a simple linear regression equation (Y = Ax +B) where Y represents ETo_PM and X values from the atmometers. A and B arerespectively the slope and the intercept of the regression. The results are shown in Table 3. There is good correlation ($R^2 > 0.65$) between atmometers 1, 3 and the ETO_PM but the correlation between ETO_PM and atmometer 2 shows a low R^2 value (0.49). This result confirms those shown above.

None of the regressions had a slope of 1 or an intercept of 0 (Table 3). All three slopes are less than 0.6 and statically different from 1 and the intercept is statistically different from 0 (Student's t-test at the 0.01 level). These results show that values from atmometers need to be calibrated before using them in irrigation scheduling. Most of the study comparing atmometers and the ETo_{PM} showed that a calibration is needed Figure 3 presents the regression with a 95 % interval confidence. It shows that all the point fall in the confident interval showing an acceptable agreement between ET PM and ETO_At.

ETr Penman Montheith and Atmometers (Alfalfa)

Cumulative ETr_PM is greater than those of the three atmometers for all periods (Figure 4). The result reveals that the atmometers underestimate ETr. On the other hand the cumulative ETr of the three atmometers are nearly the same for the four Months (May to August 2013). This shows that the values from the three atmometers reference alfalfa are very consistent whereas the atmometers reference grass showed manufacture variability.

Table 4 gives the different statistics for the evapotranspiration from Atmometers alfalfa and Penman Monteith. The mean evapotranspiration reference is smaller for atmometers compared to Penman Monteith with high standard deviation. If we consider the atmometers; they have the same mean 21 m, 21.9 mm and 21.7 mm respectively and the same standard deviation and standard error.

The ratio between average five days sum ETr_PM and ET0_At is 1.19, 1.31, and 1.13 for atmometers 1, 2 and 3 respectively. The mean value of the ETr_PM five day average is significantly different from the mean of the 3 atmometers (Pvalue < 0.005). Like in grass atmometers, a five days sum Evapotranspiration has been calculated and regression on ET_PM against ETr_At is performed; the results show coefficient of determination more than 65% for all 3 regressions.

Figure 5 presents the different regressions on evapotranspiration from atmometers against Alfalfa reference evapotranspiration. Overall, all points fall in the area between the lower and upper band of a confidence interval of 95% except for one point which is not representative of the all data points. These results show that the atmometers based alfalfa give best estimation of the evapotranspiration compared to grass atmometers.

The atmometer 1 presents a lower $R^2 = 0.68$ compared to the atmometers 2 and 3 which show a R^2 of 0.71 and 0.72 respectively (Table 5). Overall, the three regressions present good correlation between ETr_At and ETr_{PM} ($R^2 > 0.65$). The standard error estimates of the three regressions are relatively high with the highest value for atmometer1 (6.43 mm) which has also the lower R^2 (0.68).

Conclusion

This study evaluated the performance of 6 atmometers (3 with grass cover and 3 with alfalfa cover) to estimate reference evapotranspiration against the grass and alfalfa Penman Monteith Equation (ETO_{PM} and ETr_{PM}, respectively) in Arkansas. Atmometers underestimated reference evapotranspiration during the growing season between 12.5 to 21%. Results obtained from comparison between 5-day ETgage measured by atmometers and estimated $ET0\_{PM}$ or ETR_{PM} using the FAO-56 Penman-Monteith equation showed a relative good correlation resulting in R^2 values varying between 0.48 and 0.72. Atmometer with alfalfa cover had better performance compared to grass cover. Manufacturing variability evaluation between atmometers of same cover showed that Atmometers with grass cover present some

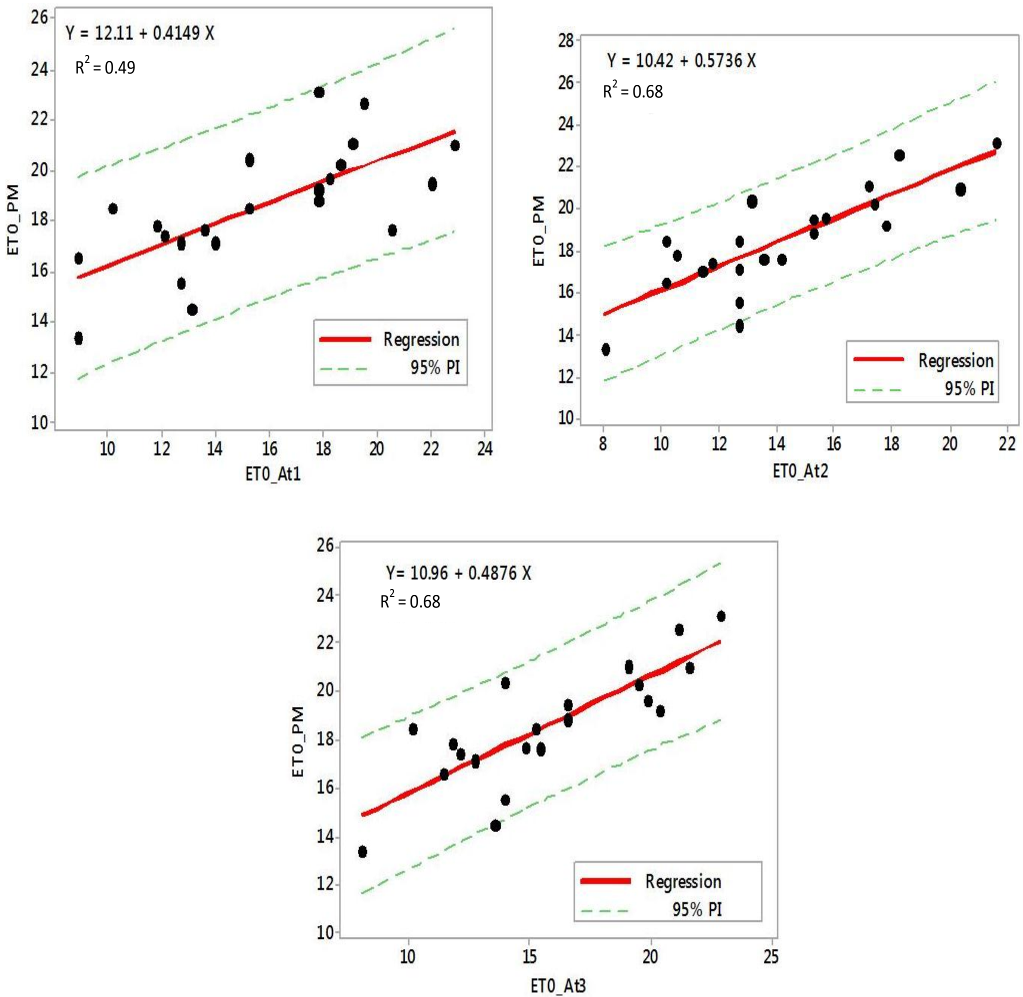

Figure 3. Correlation of Penman evapotranspiration to evapotranspiration measured by atmometers grass reference. The dashed lines show a 95% prediction interval.

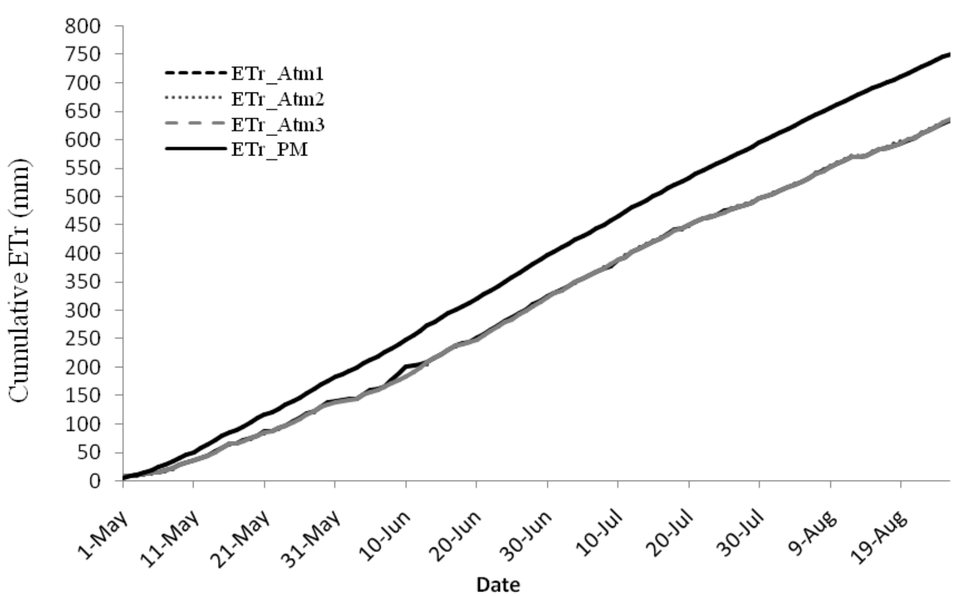

Figure 4. Cumulative potential evapotranspiration.

Table 4. Comparison between 5 days-sum ETr_PM and ETr_At.

Variable	Atmometer ($ETr_{\_Atm}$)			Penman- Montheith ($ETr\text{-}_{PM}$)
	Atmometer 1	Atmometer 2	Atmometer3	
Mean (mm)	21	21.9	21.7	25.9
Standard deviation (mm)	5.5	5.3	5.5	3.39
Standard error	1.14	1.10	1.14	0.70
Coefficient of variation (%)	26	24	25	13
T	-3.67	-3.08	-3.10	
P value	0.001	0.004	0.004	

Table 5. Regression of atmometers reference alfalfa and evapotranspiration Penman Monteith.

Atmometer	Regression slope	Regression intercept	R^2	Standard error estimate (mm)
Atmometer 1	0.31	14.9	0.68	6.43
Atmometer2	0.54	14.2	0.71	4.96
Atmometer 3	0.52	14.71	0.72	5.2

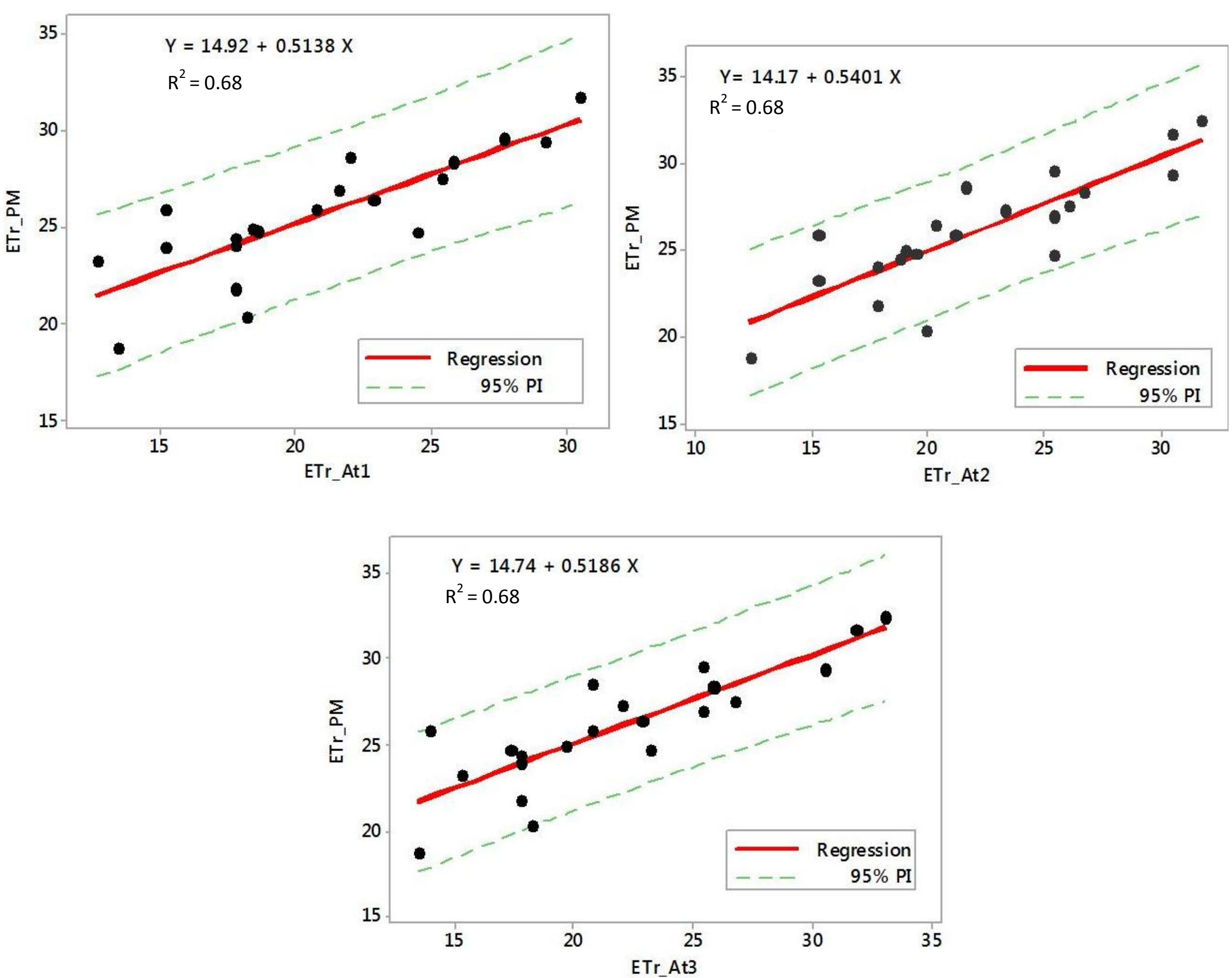

Figure 5. Correlation of Penman evapotranspiration to evapotranspiration measured by atmometers alfalafa reference Stuttgar, Arkansas. The dashed lines show a 95% prediction interval.

disparities. For grass cover, Atmometers 1 and 3 overestimated water losses as compared to atmometer 2. With a proper regression equation and a good calibration, atmometers could be used to estimate ET for crop water requirement where evapotranspiration estimates are not available from a weather station.

Conflict of Interests

The authors have not declared any conflict of interests.

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