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Evaluation of Crop Coefficient, Cumulative and Dynamic Evapo-Transpiration of Winter Wheat under Deficit Irrigation Treatments in Weighing Lysimeter in Beijing, China

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Abstract

The availability of water plays an important role in plant growth, yield and quality of crops In 2012-2013 experiment, Irrigation treatments were (1): Irrigation before sowing (60 Liter), (2): Irrigation before sowing (30 Liter) + before freezing (30 Liter); (3): before sowing (30 Liter) + before freezing (30 Liter) + in the beginning of erecting stage (60 Liter) + at flowering stage (60 Liter); (4): before sowing (30 Liter) + before freezing (30 Liter) + at booting stage (60 Liter) + at flowering stage (60 Liter). The weighing lysimeter system is located in National Precision Agriculture Demonstration Station in Xiaotangshang Town of Beijing. The maximum evapotranspiration value in March, April and May was obtained for lysimeter 10 (I2) (558.70 kg), lysimeter 11 (I3) (467.25 kg), and lysimeter 10 (I2) (488.68 kg), respectively. Knowledge about changes of soil water changes during successive growing seasons from planting to final ripening is a necessary tool for an effective planning of irrigation programs, in order to improve both quality and quantity of crop. From October to June, evapo-transpiration trends increased steadily, especially in last four months, in which the lysimeter fields were covered by winter wheat completely. In 2013-2014 experiment, Irrigation treatments were (1) no irrigantion, (2) irrigation only at jointing stage (60L), (3) irrigation at jointing (60L) and flowering stage (60L), (4) at jointing stage (April 8th, 60L), 100% flowering stage (April 30th, 60L), and grain filling period (May 10th, 60L) before irrigation, crop coefficient (KC) was low and exactly after irrigation, it increased and then it decreased gradually day by day. R^2 between evapotranspiration which is on the basis of hourly weather data and daily weather data with measured ET in big lysimter was 0.962 and 0.953, respectively. Evapotranspiration and crop coefficient almost exactly match according to R^2 of the regression. In conclusion, evapotranspiration and KC give a closer idea of the *value of research on relationship between evapotranspiration and crop coefficient.*

Keywords

Evapotranspiration, crop coefficient, Winter wheat, Deficit irrigation, weighing lysimeter

1. Introduction

Water is a key driver of agricultural production in the world and provides more than a quarter of the total world cereal output (Shekari et al., 2015; Mursalova et al., 2015). In the past four decades, annual cereal production increased 3.8-fold from 100 million tones in 1961 to 410 million tones in 2004 (FAO, 2005). In China, irrigated land accounts for 40% of the total arable land, and it produces 75% of China's total food grain (Jin & Young, 2001). Irrigation is a necessary input to a high crop yield; on average, the yield of wheat in irrigated land was over 70% higher than that in rainfed land in North China Plain, the breadbasket of China (Liu et al., 2007a). Growing population requires more irrigation to further increase food production. However, the increasing water scarcity and the competition from other sectors have put agricultural water use under great pressure (Yang & Zehnder, 2001; Liu et al., 2007b; Guler, 2010). Irrigation water is becoming an increasingly scarce resource in many areas, as a consequence an appropriate choice of irrigation scheduling is necessary to maximize yield and profit (Zhou et al., 2007, 2011). It is known that shoratge of water restricts crop productivity and the purpose of irrigation is to minimise crop water stress and to achieve maximum yield (Ghane et al., 2009; Wang et al., 2009; Ghassemi-Golezani et al., 2015). However maximising yield should not be the sole objective and other constraints (e.g., water availability, irrigation cost, etc.) should be considered, especially in the arid regions. The response of crop yield to irrigation has been studied extensively. Through proper irrigation management, it should be possible to provide only the water matches the crop evapotranspiration (Quanqi et al., 2008). An important issue in sustainable agriculture is to optimise productivity with respect to resourse inputs such as water (Huang et al., 2002; Kovacevic et al., 2013). Accounting for 40% of China's total arable land, irrigated land produces 75% of China's total food grain (Jin & Young, 2001). Moreover, the reduction in cereal production due to severe drought resulted in 20 million tons of food imports in 1995, acounting for 10% of the total world cereal exports (FAO, 2005). Given the limitation in water resources and the continous increase in food demand, it is necessary to improve crop production per unit of water use (Xia et al., 2005). One of the most useful and meaningful procedures an instructor can emphasize to researchers in a beginning of soil physics course is the determination of the rate and direction of soil water movement which is possible by lysimeter (Wherley et al., 2009). Much attention has been paid to the research on the application of the weighing lysimeter. Su et al. (2005) studied the crop water demands for sprinkler-irrigated winter wheat and sweet corn using a weighing lysimeter and calculated the crop coefficients. Niu et al. (2011) employed a large-scale weighing lysimeter to study cucumber transpiration processes in solar greenhouse and established three empirical models for estimating of cucumber transpiration rate. Liu et al. (2002) studied the daily evapotranspiration of irrigated winter wheat and maize using a large-scale weighing lysimeter to improve field water utilization efficiency. Because weighing lysimeters provide scientific the basic information for research related to the evapotranspiration, high quality of the collected data from lysimeter is of great significance. Since ET is the primary process affecting irrigation requirements of plants, precise estimation of ET is very important in agriculture production (Kirnak & Short, 2001). Kang et al. (2003) and Casa et al. (2000) estimated crop coefficient and evapotranspiration of winter wheat, maize and linseed, respectively. Their results helped to the precise planning and efficient management of irrigation in the experimental regions. Unlu et al. (2010) considered lysimeters as the standard tools for evapotranspiration (ET) measurements. In order to understand and determine the optimal management possibilities, the water balance must be considered more than growing season which can be done by lysimeter station (Zupanc et al., 2005). The aim of this research is evaluating cumulative evapo-transpiration, dynamic evapo-transpiration and crop coefficient of winter wheat under deficit irrigation treatments in weighing lysimeter in Beijing, China.

2. Method

The weighing lysimeter system is located in National Precision Agriculture Demonstration Station in Xiaotangshang Town of Being (40^o 10/N, 116^o 27/E). The system was consisted of 24 lysimeters with 1.0 m*0.75 m*2.3 m (L*W*H). The machine structure of the lysimeter was counter-balanced and the schematic diagram of the lysimeter is shown in Figure 1. The background soil characteristics of the experimental plot, determined at the beginning of the experiment, were as follows: sand 516 g kg^{-1}, total N 102 g kg^{-1}, available phosphorus (P) 23.4 mg kg^{-1}, exchangeable potassium (K) 98.7 mg kg^{-1}, organic matter 13.4 g kg^{-1}, pH 7.3 and bulk density 1.43 g cm^{-3}. The average of air temperature (^{o}C), and relative humidity average is shown in Figure 2.

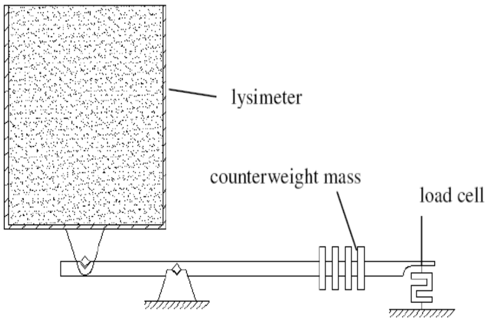


Figure 1. The Schematic Diagram of the Weighing Lysimeter

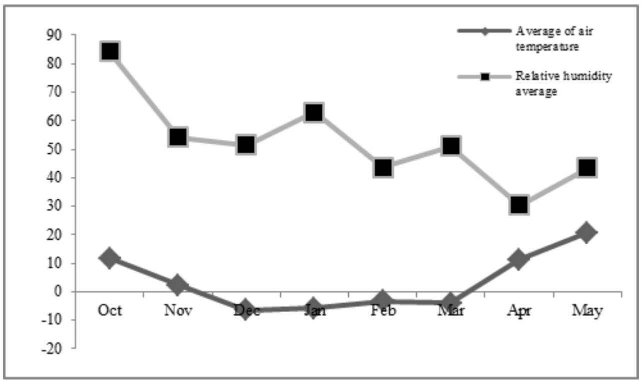


Figure 2. The Average of Air Temperature and Relative Humidity Average

The load cells used in the system are NS1-3M2-100Kg with a sensitivity of 1.9951,V/V for the lysimeters and the NS6-2-50Kg of 1.9969mV/V for percolation. Graphs show the average of air temperature, and relative humidity average, respectively. The experimental station field in Xiaotanshan has sandy clay loam texture.

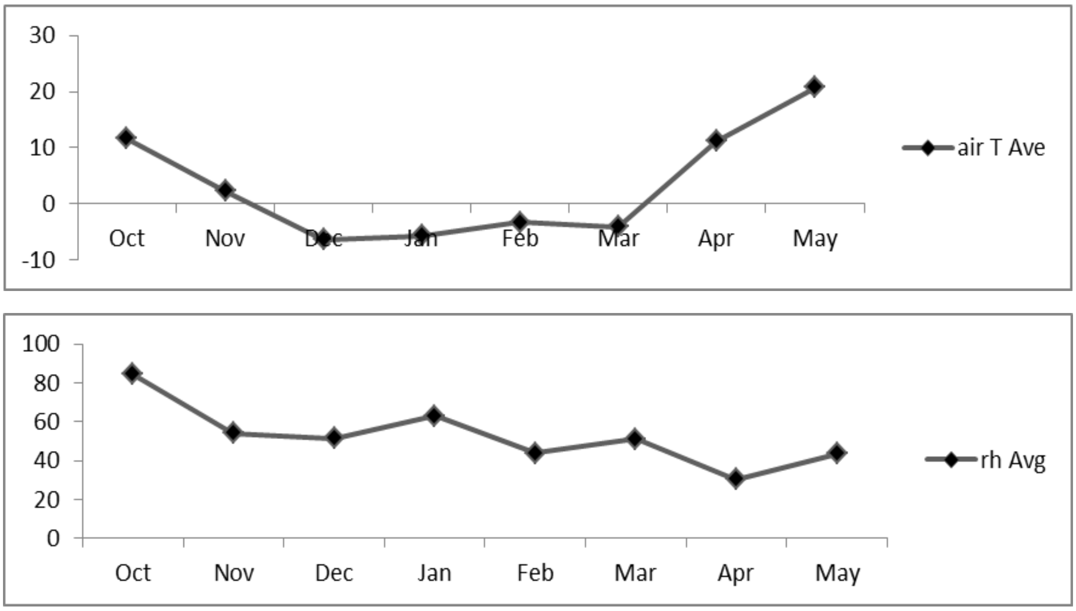


Figure 3. The Average of Air Temperature (^{o}C), and Relative Humidity Average

Table 1. Mechanical Analysis, Ph, Total Nitrogen, Available Phosphorus, Exchangeable Cations and Cation Exchange Capacity of Xiaotanshan

Depth	%	%	%	pH	Total	Av.Phosphorus	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	H^{+}	Al^{3+}	CE	ECEC
(cm)	sand	silt	clay		N%	(mg kg^{-1})	($cmoLkg^{-1}$)	($cmoLkg^{-1}$)	($cmoLkg^{-1}$)	($cmoLkg^{-1}$)			(cmolkg)	($cmolkg^{-1}$)
0-30	56.2	22	21.8	7.3	0.14	47.15	16.4	4.63	0.13	0.12	0.36	1.49	22.8	23.1
30-60	30.2	30	39.8	7.1	0.06	1.4	32.3	6.72	0.19	0.59	0.16	1.49	41.31	41.5

60-90	18.2	36	45.8	7.2	0.06	0.15	70.24	7.96	0.24	0.55	0.21	0.88	79.9	80.1
90-150	62.2	32	15.8	7	0.03	2.2	83.3	5.28	0.03	0.36	0.16	0.67	89.7	89.9

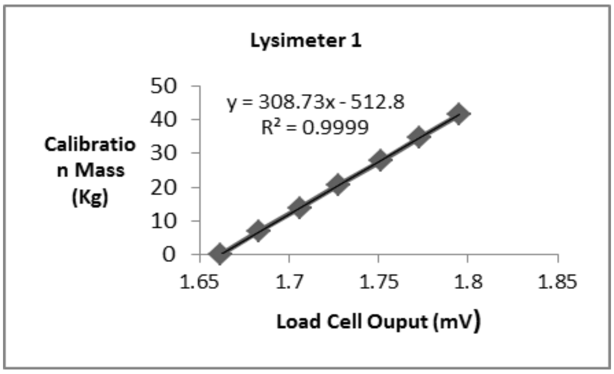
In 2012-2013 experiment, Irrigation treatments were (1) (Lysimeters 1, 5, 9, 13, 17 and 21): Irrigation before sowing (60 Liter), (2) (Lysimeters 2, 6, 10, 14, 18, and 22): Irrigation before sowing (30 Liter) + before freezing (30 Liter); (3) (Lysimeters 3, 7, 11, 15, 19, and 23): Irrigation before sowing (30 Liter) + before freezing (30 Liter) + Irrigation in the beginning of erecting stage (60 Liter) + Irrigation at flowering stage (60 Liter); (4) (Lysimeters 4, 8, 12, 16, and 24): Irrigation before sowing (30 Liter) + Irrigation before freezing (30 Liter) + Irrigation at the booting stage (60 Liter) + Irrigation at flowering stage (60 Liter). Pre-irrigation was done on 6th Oct. the laid out of experiment was randomized complete block design, repeated six times. The plantation was done on 10th Oct in 2012. 500 seeds per each lysimeter were used in each lysimeter. For small lysimeter, to supply N, P and K, 337 g urea per each lysimeter, 337 g diamonium phosphate per each lysimeter, and 202 g K_2O per each lysimeter was used, respectively. 26.68 g zink sulfate and 2.25 kg chicken manure was also used per each lysimeter. The distance between rows was 15 cm, and the distance between seeds was one cm. Hand weeding was done for weeds management. Lunxuan 987 was used in this experiment. All practices such as control of weeds, pests, and disease were done regularly during period. In 2013-2014 experiment, Irrigation treatments were (1) no irrigation, (2) irrigation only at jointing stage, (3) irrigation at jointing and flowering stage, (4) irrigation at jointing stage (April 8th), 100% flowering stage (April 30th), and grain filling period (May 10th). Pre-sowing irrigation was done on 5th Oct and irrigation before freezing was done on 23th November 2013. Winter wheat lysimeters were harvested at 6th June. Pre-irrigation was done on 6th Oct. the laid out of experiment was randomized complete block design, repeated six times. The plantation was done on 10th Oct in 2013. Big lysimeter had 20 lines and 300 seeds were planted for each line (6000 seeds). Each of 24 small lysimeters had 5 lines and 100 seeds per line were planted. 28.12 g/lysimeter Urea, 28.12 g/lysimeter diammonium phosphate, 17 g/lysimeter potassium sulfate, 17 g/lysimeter magnesium sulfate, 2.25 g/lysimeter zink sulfate and 2.25 kg per lysimeter chicken sludge was used for fertilization of small lysimeter. For big lysimeter, 337.3 g urea, 337 g diamonium phosphate, 27 g zink sulfate, 202 g K and 27 kg chicken manure was applied. The row distance of line in big lysimeter was 15 cm. The laid out of experiment was randomized complete block design, repeated six times. Statistical analyses for ANOVA were carried out by using MSTAT-C, whereas the means were compared through Duncan’s Multiple Range Test at ($p = 0.05$) and Excel program to illustrate and compare data on figures. (Jointing stage = 31, Booting stage = 41).

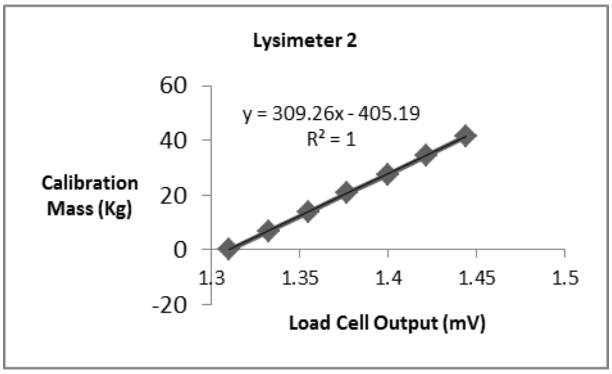
3. Results and Discussion

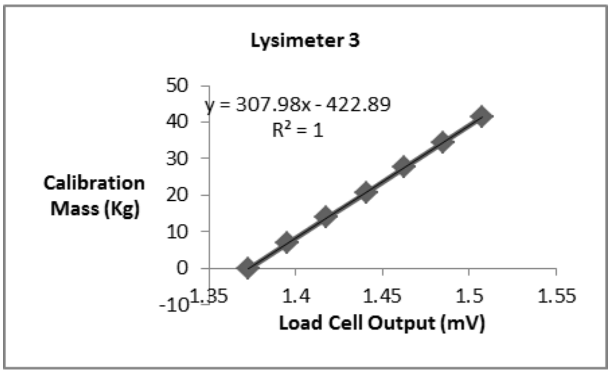
3.1 Load Cell Calibrated Results

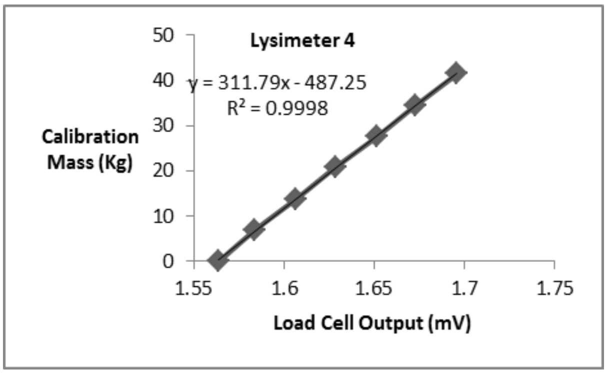
The 24 lysimeters were calibrated respectively. The calibration result of each lysimeter was shown here. There were strong linear relationship between the load cell output (mV) and the calibration mass (Kg).

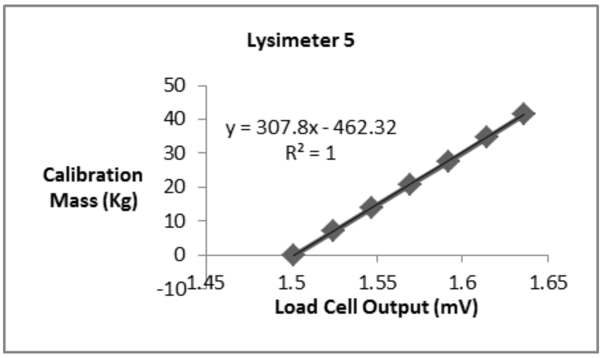
The determination coefficients of the No. 1, No 2, No 3, No 4, No 5, and No 6 lysimeters were 0.999, 1, 1, 0.999, 1, and 0.999, respectively. The calibration equations were established and the calibration coefficients were used for the conversion from the load cell output to the change of mass of the lysimeters.











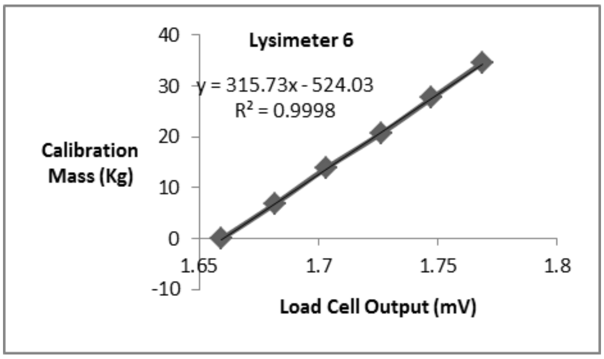
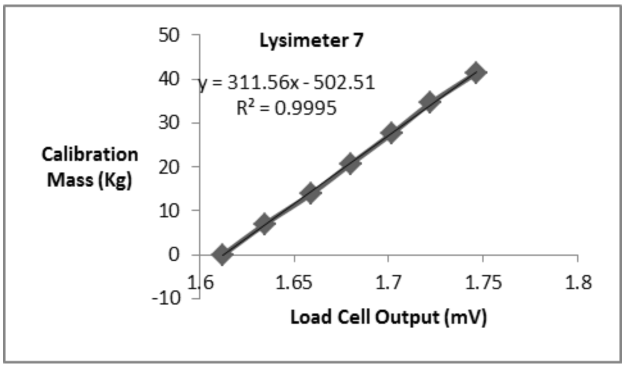
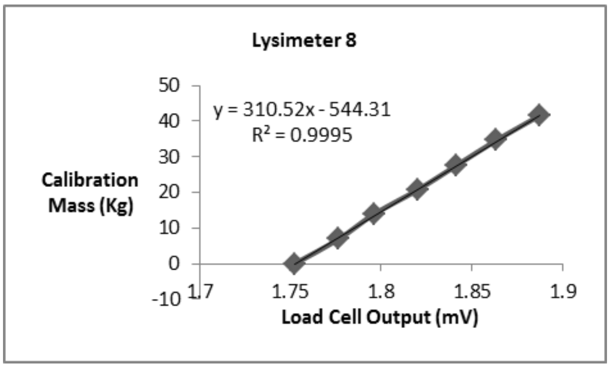
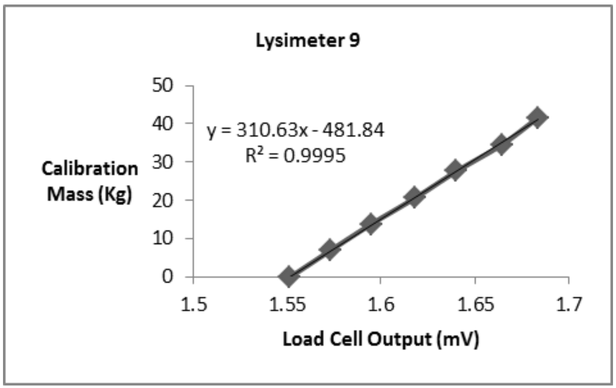


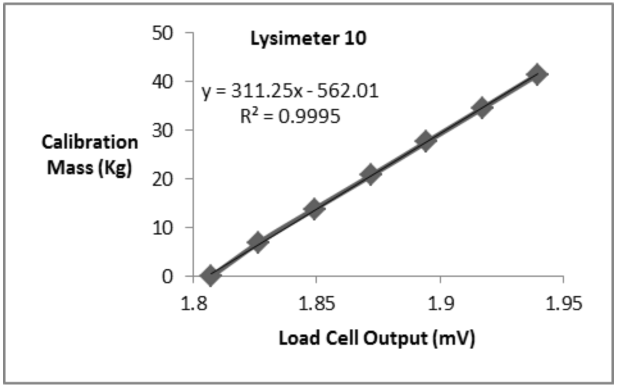
Figure 4. Determination Coefficient in Lysimeter 1, 2, 3, 4, 5 and 6

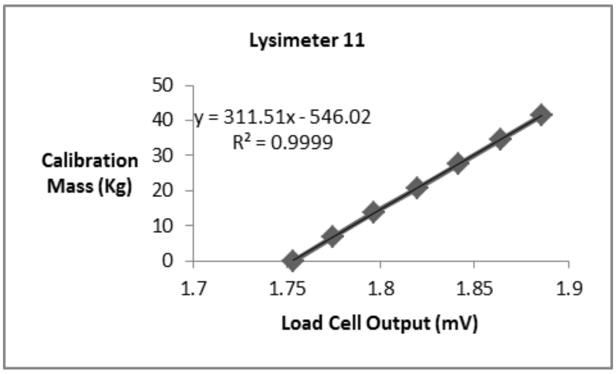
There were strong linear relationship between the load cell output (mV) and the calibration mass (Kg) for Lysimeter No. 7, 8, 9, 10, 11 and 12. The determination coefficients of the No. 7, No 8, No 9, No 10, No 11, and No 12 lysimeters were 0.999, 0.999, 0.999, 0.999, 0.999, and 0.999, respectively.




Lysimeter 8
y = 310.52x - 544.31
R² = 0.9995
Calibration Mass (Kg)
50
40
30
20
10
0
-10
1.7
1.75
1.8
1.85
1.9
Load Cell Output (mV)


Lysimeter 9
y = 310.63x - 481.84
R² = 0.9995
Calibration Mass (Kg)
50
40
30
20
10
0
1.5
1.55
1.6
1.65
1.7
Load Cell Output (mV)


Lysimeter 10
y = 311.25x - 562.01
R² = 0.9995
Calibration Mass (Kg)
50
40
30
20
10
0
1.8
1.85
1.9
1.95
Load Cell Output (mV)


Lysimeter 11
y = 311.51x - 546.02
R² = 0.9999
Calibration Mass (Kg)
50
40
30
20
10
0
1.7
1.75
1.8
1.85
1.9
Load Cell Output (mV)

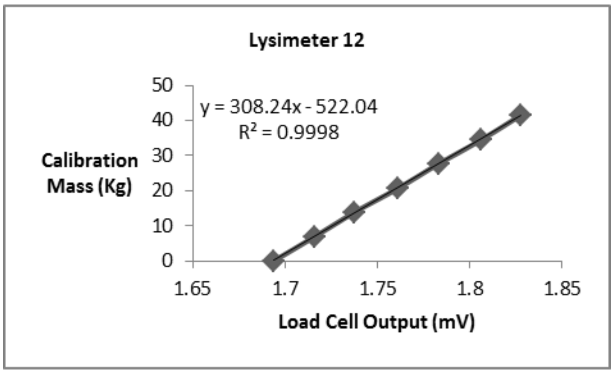
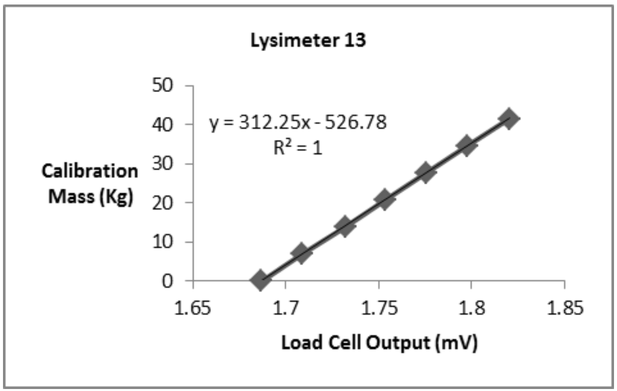
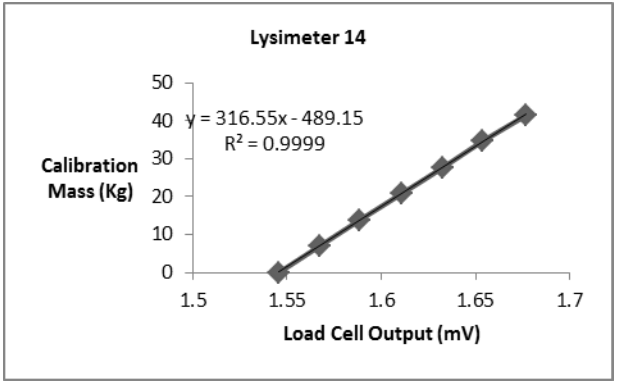


Figure 5. Determination Coefficient in Lysimeter 7, 8, 9, 10, 11 and 12

To determine the relationship between calibration mass and load cell output, R^2 was measured. In this study the determination coefficients for lysimeter No 13, 14, 15, 16, 17 and 18 were 1, 0.999, 0.999, 0.999, 0.999, and 0.998, which showed that the load cell output (mV) and the calibration mass (Kg) was highly related.





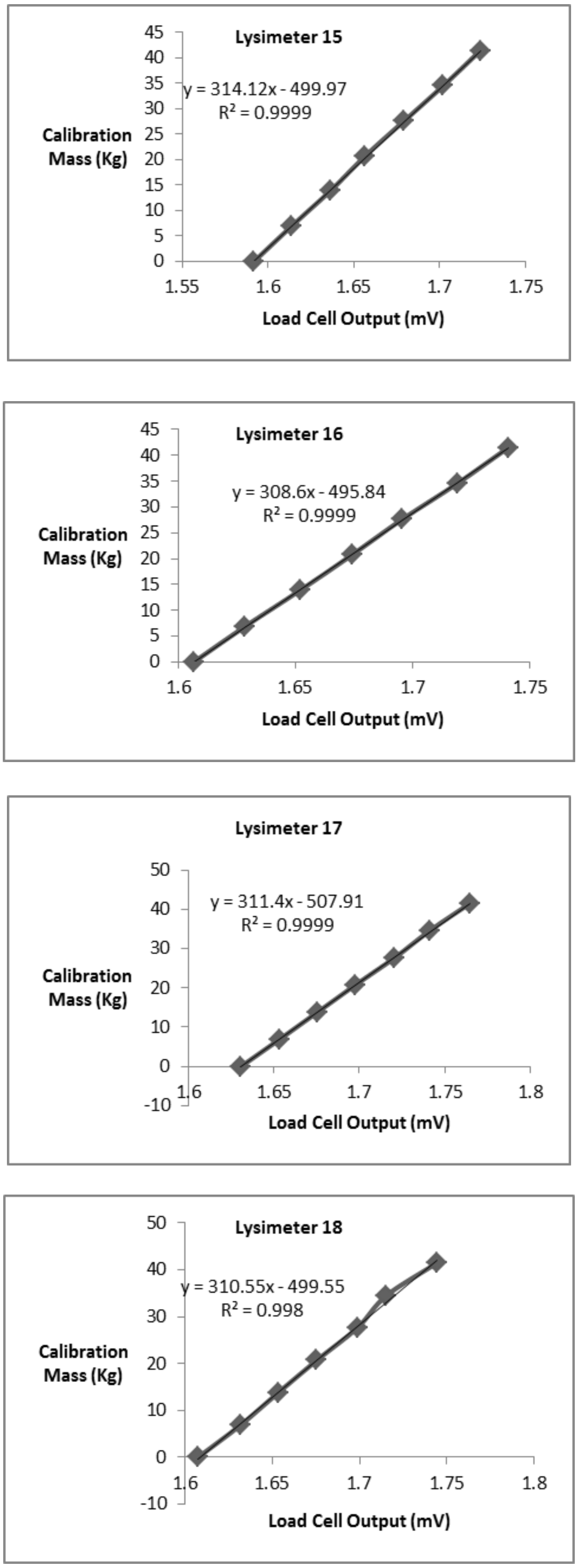
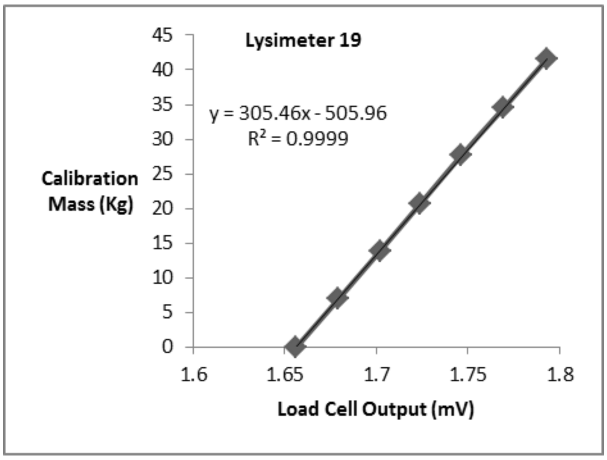
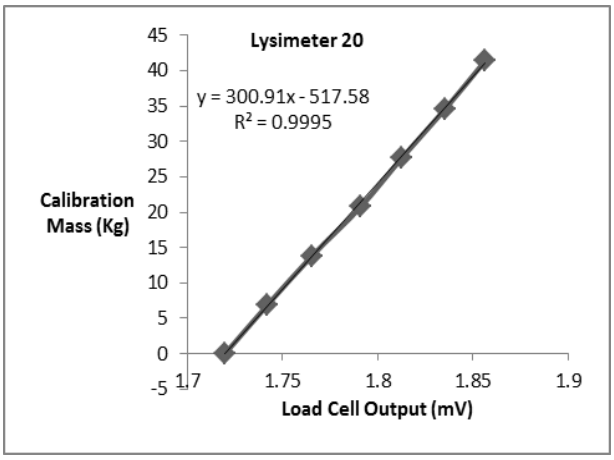
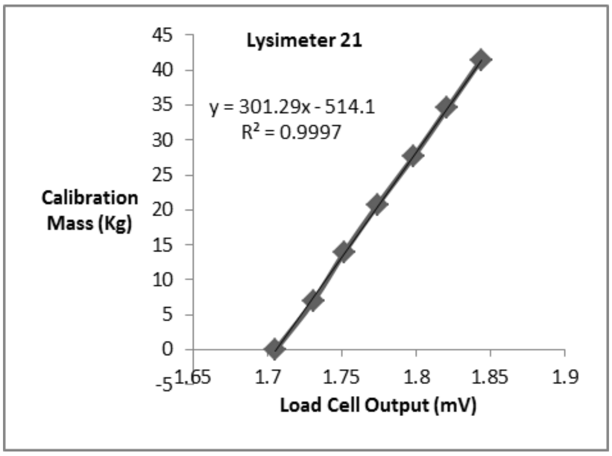


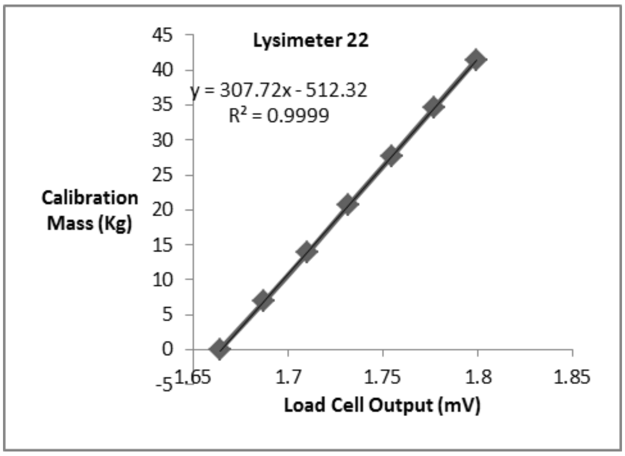
Figure 6. Determination Coefficient in Lysimeter 13, 14, 15, 16, 17 and 18

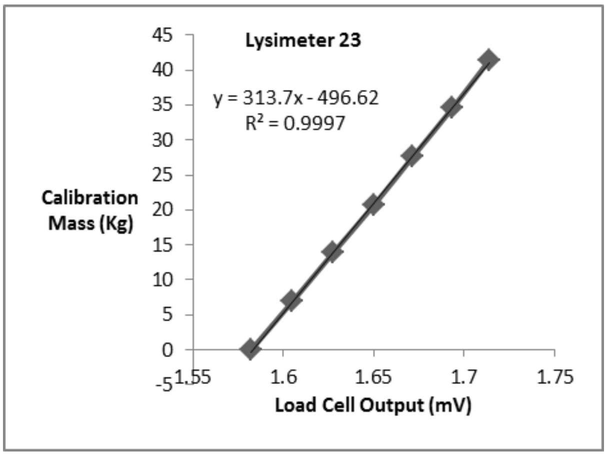
Load cell output (mV) was linearly correlated to calibration mass (Kg) for lysimeters No. 18, 19. 20, 21, 22, 23, and 24 as shown in figures below. R^2 were obtained 0.998, 0.999, 0.999, 0.999, 0.999, 0.999, and 0.999 for lysimeters No 18, 19, 20, 21, 23, and 24, respectively. As shown in the figures (graphs), load cell output (mV) and calibration mass (Kg) almost exactly match according to R^2 of the regression. In conclusion, calibration mass data calculated from lysimeters give a closer idea of the value of research on relationship between load cell output and calibration mass.











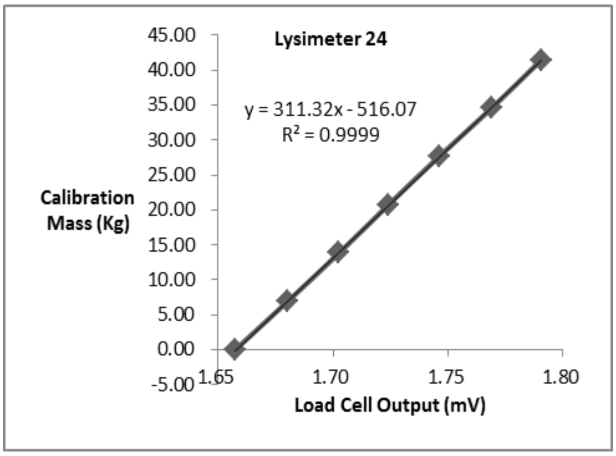


Figure 7. Determination Coefficient in Lysimeter 19, 20, 21, 22, 23 and 24

3.2 Accumulative Evapo-Transpiration

3.2.1 Trends and Dynamic of Evapo-Transpiration in 2012-2013

Accumulative evapo-transpiration trends for small lysismters in different months were shown in graphs below. In all figures, from October to June, evapo-transpiration trends increased steadily, especially in last four months, in which the lysimeter fields were covered by winter wheat completely. The highest mean evapo-transpiration in March was obtained for lysimeter 10 (I2) (558.7015 kg), followed by lysimeter 11 (I3), 8 (I4) and 6 (I2), respectively. The minimum one was achieved in lysimeter 2 (I2), which was 401.6342 kg. Field studies using lysimeters represent an accurate tool in the determination of water balance components in the soil, representing the real field conditions. In Apirl, lysimeter 11 (I3) had obtained the highest mean of evapo-transpiration, which was 467.2533 kg, followed by lysimeter 10 (I2), 8 (I4) and 12 (I4). The lowest one was observed in lysimeter 2 (I2) (301.6719 kg). The higher mean evapo-transpiration in May, was achieved for lysimeter 10 (I2) (488.6864 kg), followed by lysimeter 6 (I2), 11 (I3), and 8 (I4). The minimum one was obtained for lysimeter 2 (I2) which was 336.5792 kg. A significant increase in wheat yield may be achieved through improved irrigation management and soil water content. It is essential to minimize losses of water to ensure more water for crop production by improving irrigation schedules. Benli et al. (2006) also reported that crop water requirements vary during the growing months, mainly due to variation in crop canopy and climatic conditions, and are governed by crop evapotranspiration (ET_c).

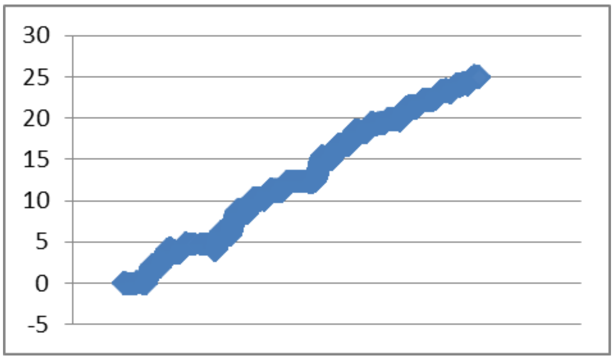


Figure 8. Evapo-Transpiration Trend in October of 2012

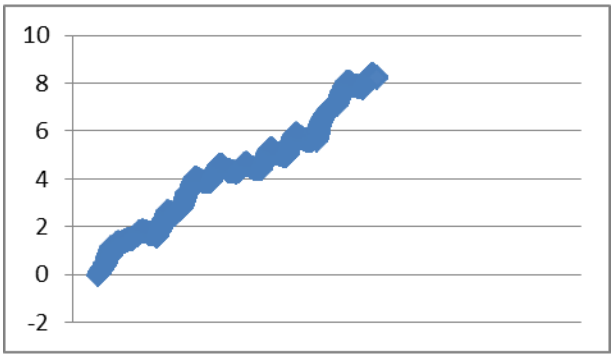


Figure 9. Evapo-Transpiration Trend in Novermber 2012

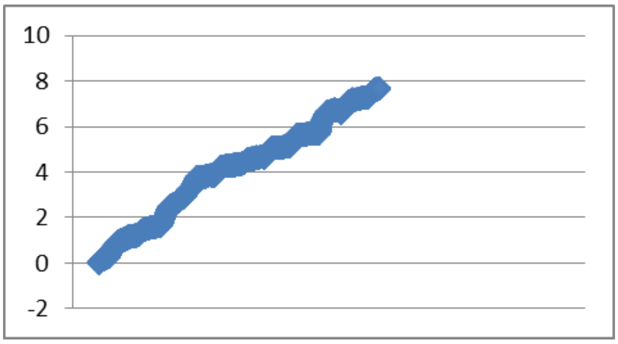


Figure 10. Evapo-Transpiration Trend in December 2012

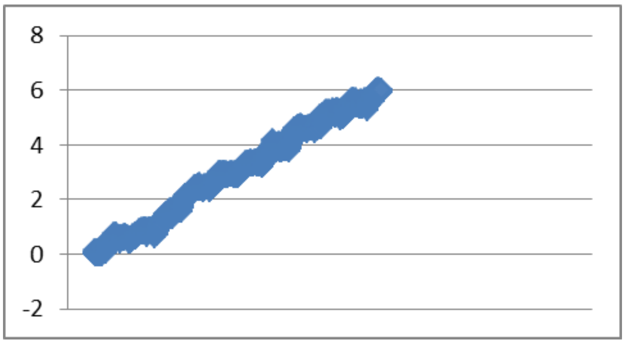


Figure 11. Evapo-Transpiration Trend in January 2013

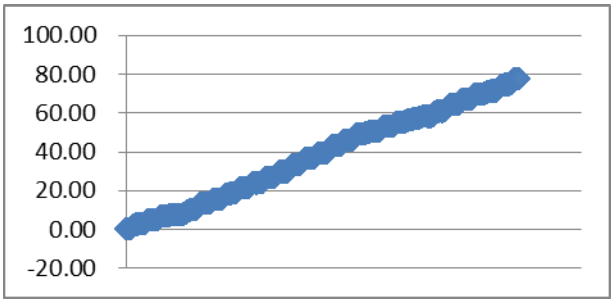


Figure 12. Evapo-Transpiration Trend in February 2013

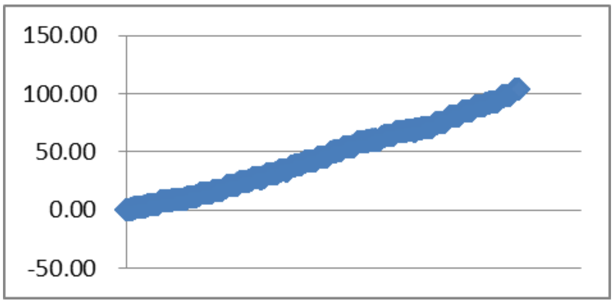


Figure 13. Evapo-Transpiration Trend in March 2013

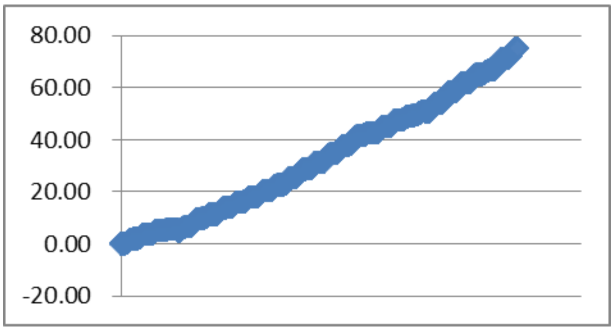


Figure 14. Evapo-Transpiration Trend in April 2013

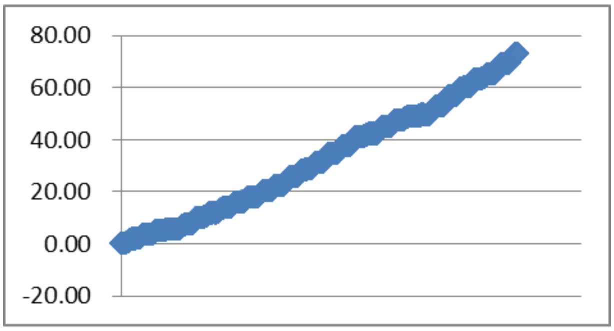


Figure 15. Evapo-Transpiration Trend in May 2013

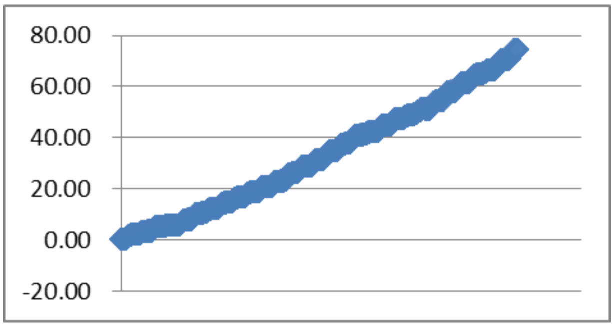


Figure 16. Evapo-Transpiration Trend in June 2013

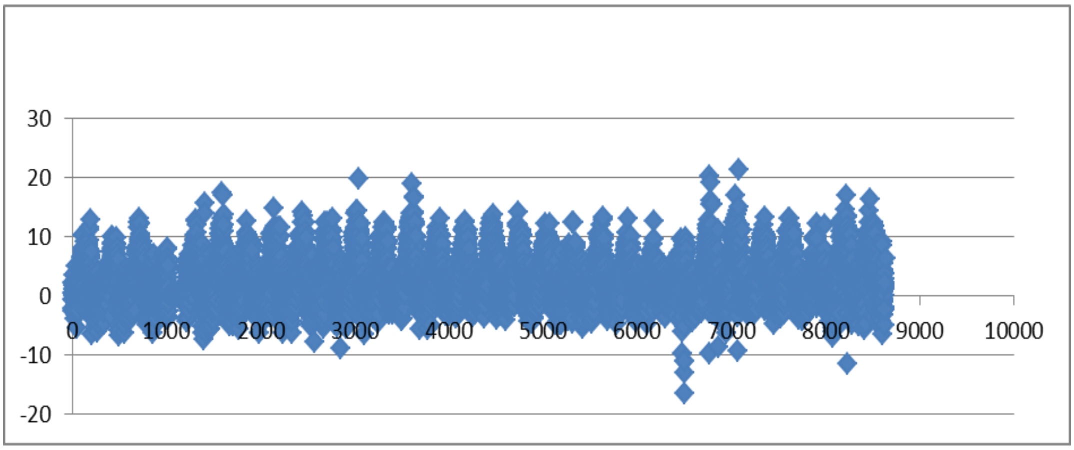


Figure 17. Dynamic of Evapo-Transpiration in March 2013

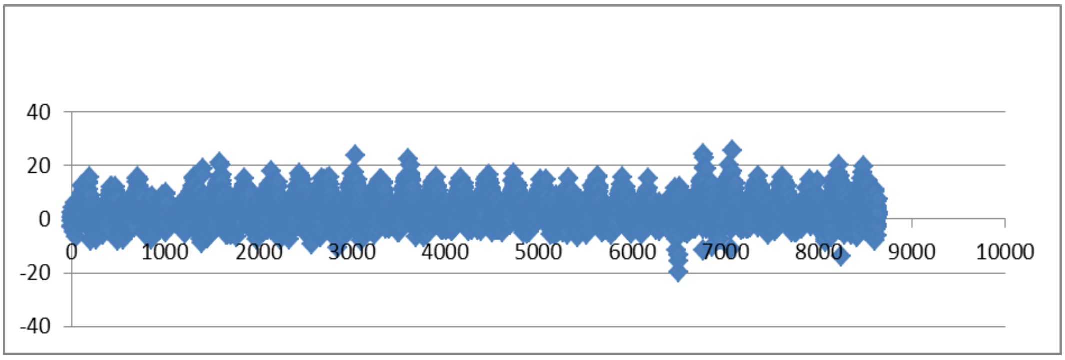


Figure 18. Dynamic of Evapo-Transpiration in April 2013

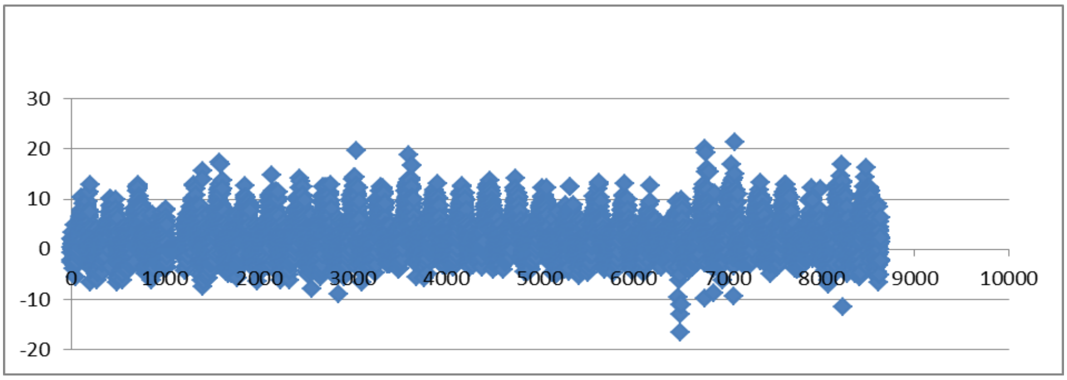


Figure 19. Dynamic of Evapo-Transpiration in May 2013

3.2.2 Results of 2013-2014

Accumulative evapo-transpiration trends for small lysismters in different months were shown in graphs below. In all figures, from October to June, evapo-transpiration trends increased steadily, especially in last four months, in which the lysimeter fields were covered by winter wheat completely. The results of this research is in agreement with the findings of Doorenbos and Pruitt (1977) and Salama et al. (2015), reported the influence of plant type, growth characteristics and the environmental conditions on crop evapotranspiration and increase in water consumptive use with the progress in plant growth.

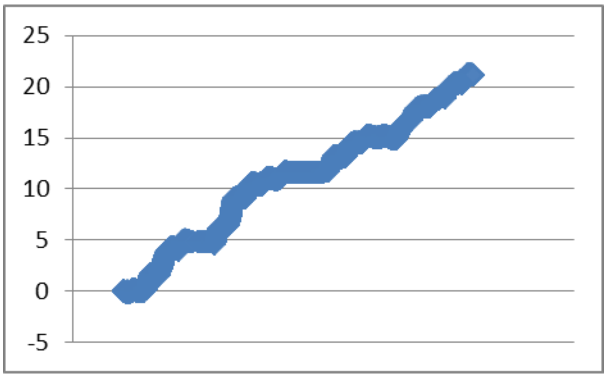


Figure 20. Evapo-Transpiration Trend in October 2013

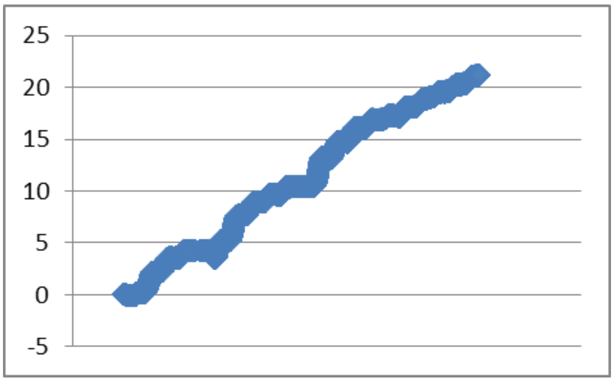


Figure 21. Evapo-Transpiration Trend in November 2013

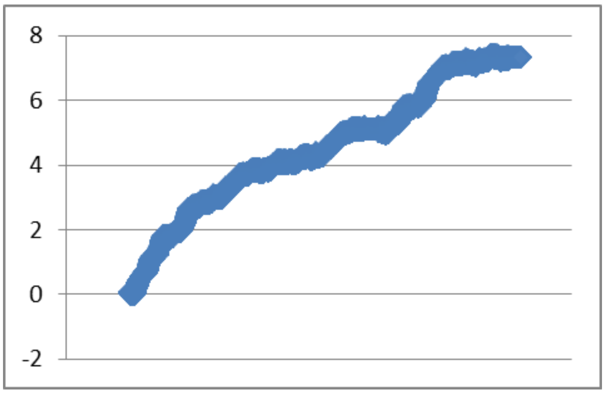


Figure 22. Evapo-Transpiration Trend in December 2013

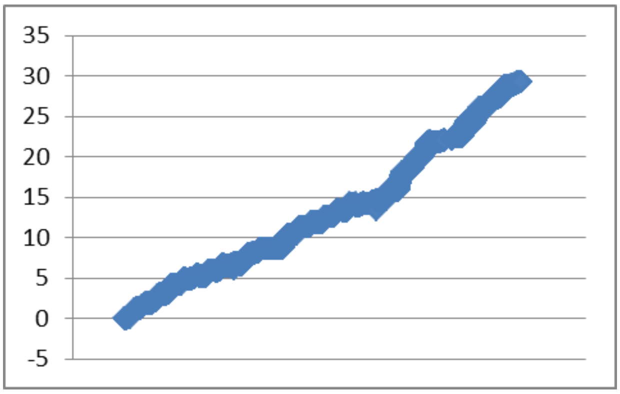


Figure 23. Evapo-Transpiration Trend in January 2014

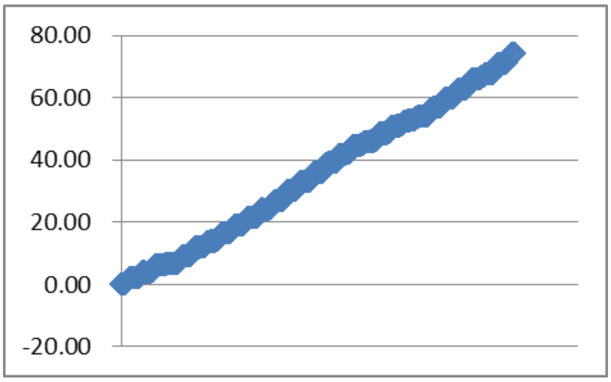


Figure 24. Evapo-Transpiration Trend in Feburary 2014

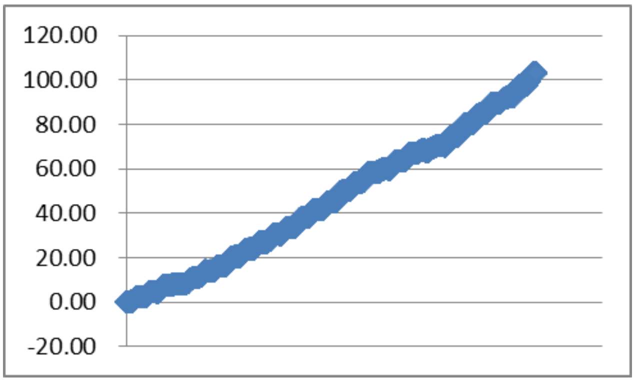


Figure 25. Evapo-Transpiration Trend in March 2014

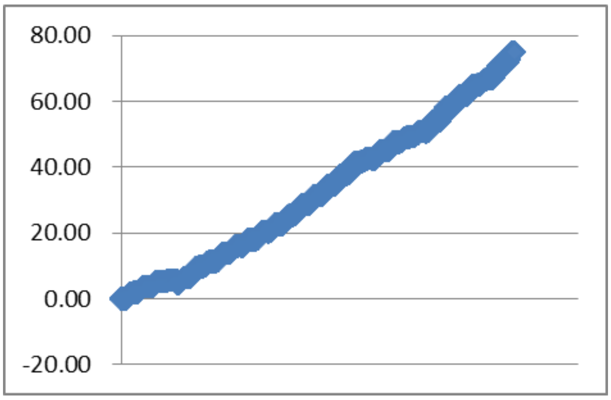


Figure 26. Evapo-Transpiration Trend in April 2014

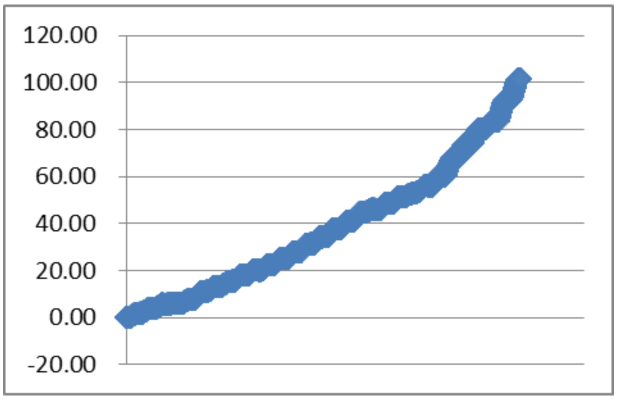


Figure 27. Evapo-Transpiration Trend in May 2014

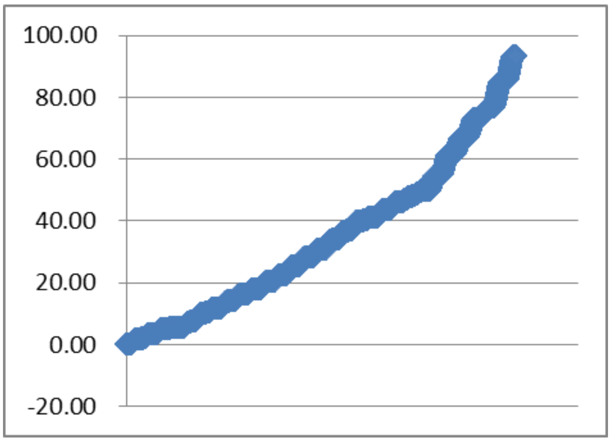


Figure 28. Evapo-Transpiration Trend in June 2014

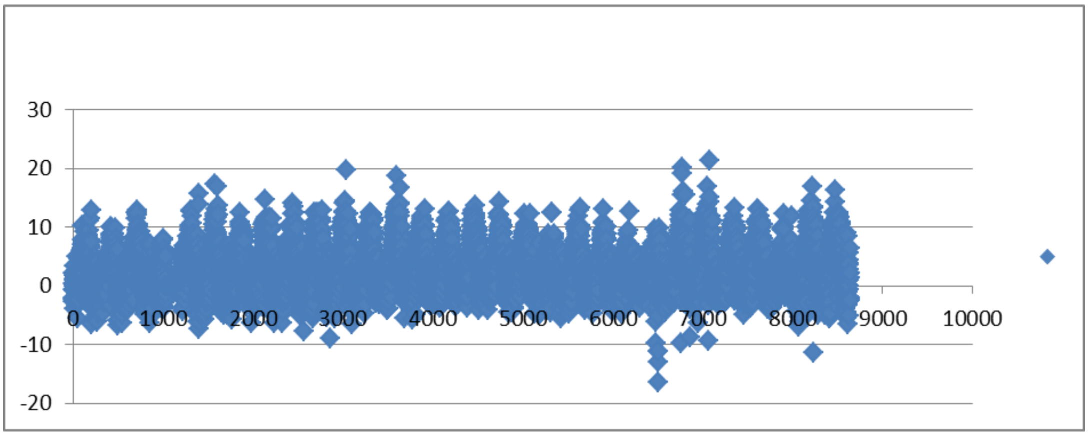


Figure 29. Dynamic of Evapo-Transpiration in April 2014

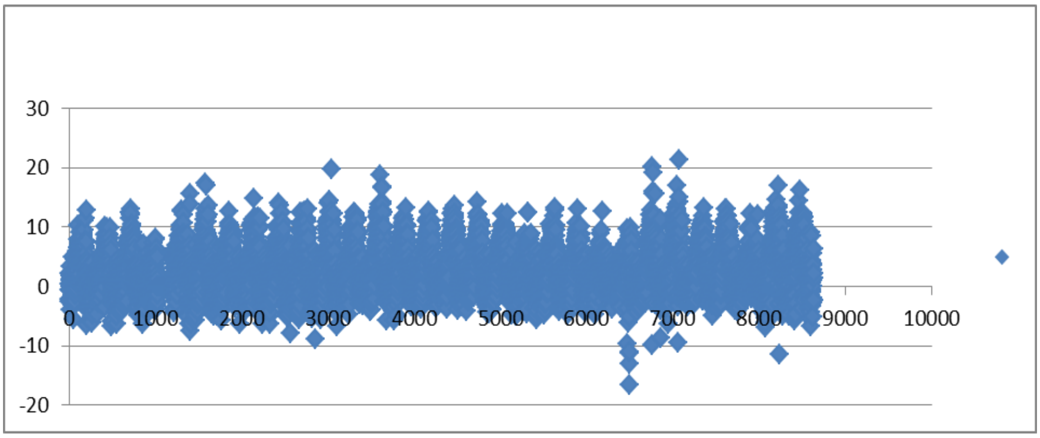


Figure 30. Dynamic of Evapo-Transpiration in May 2014

In tables below, reference evapotranspiration in March and main data which obtain from lysimeter is shown. As can be seen in these tables, both these two tables are very similar to each other which means that all data are accurate.

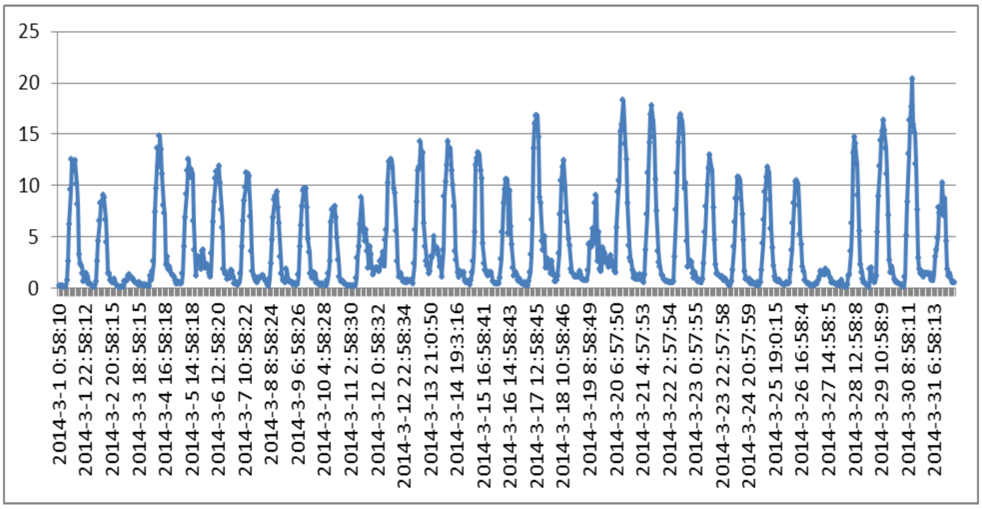


Figure 31. Reference Evapotranspiration in March (2014) in Big Lysimeter

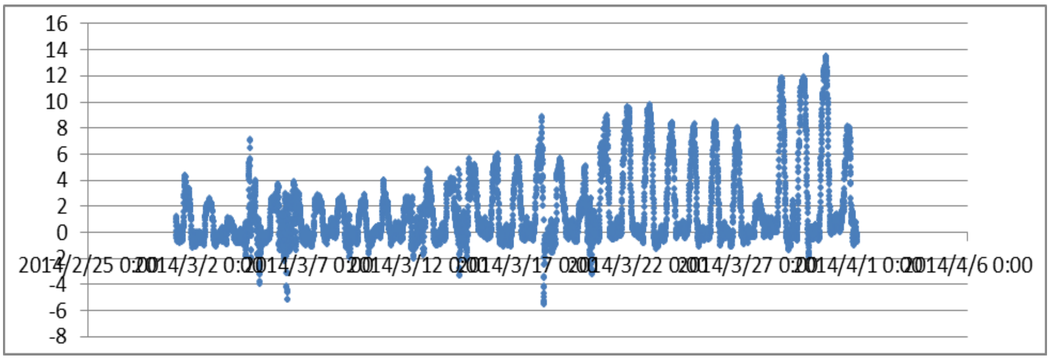


Figure 32. Data of Evapotranspiration Which Directly Grain from Lysimeter

The table below shows crop coefficient trend from February to June of 2014 for big lysimeter. As the table shows, both irrigation and rainfall increased KC and after that it decreased gradually. Even on this table, those days we irrigation is clear. For example, on 9th April, the irrigation was done, which was jointing irrigation, and before that KC was stable. Before irrigation KC was low and exactly after irrigation, it increased and then it decreased gradually day by day. For instance, after 22th May, the decrease was shown in the table.

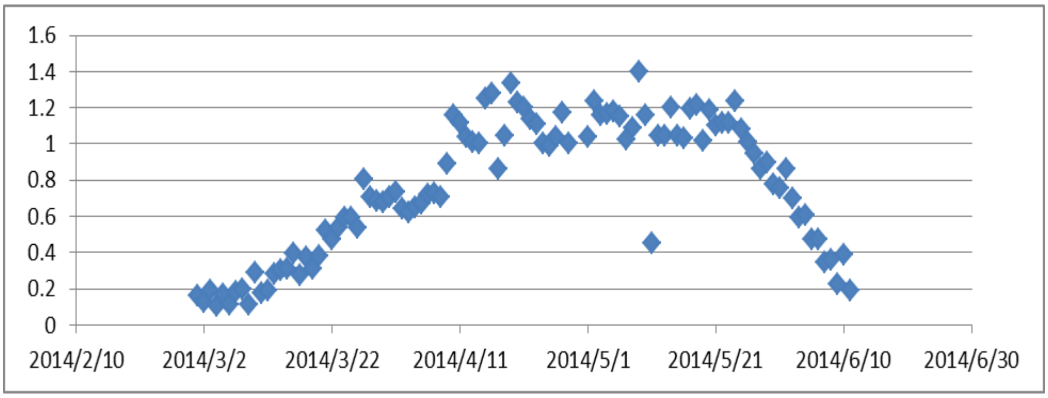


Figure 33. Crop Coefficient (KC) from February to June of 2014 in Big Lysimeter

R^2 was measured between evapotranspiration and crop coefficient (KC) in this experiment to determine the relationship between evapotranspiration and KC. R^2 between evapotranspiration which is on the basis of hourly data and big lysimter, lysimeter 13 and 18 was 0.962, 0.953, and 0.963, respectively. As shown in the figures, evapotranspiration and crop coefficient almost exactly match according to R^2 of the regression. In conclusion, evapotranspiration and KC give a closer idea of the value of research on relationship between evapotranspiration and crop coefficient.

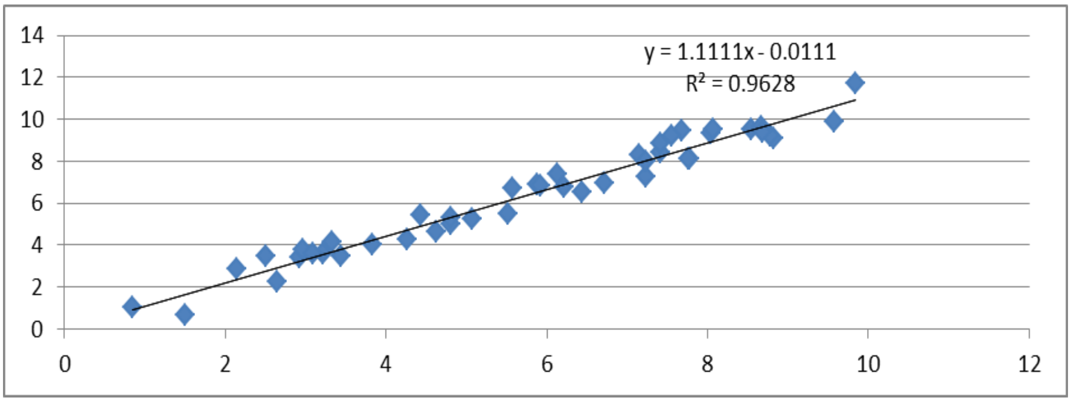


Figure 34. Determination of Coefficient between Evapo-Transpiration and Crop Coefficient (KC) on the Basis of Hourly Data in Big Lysimeter

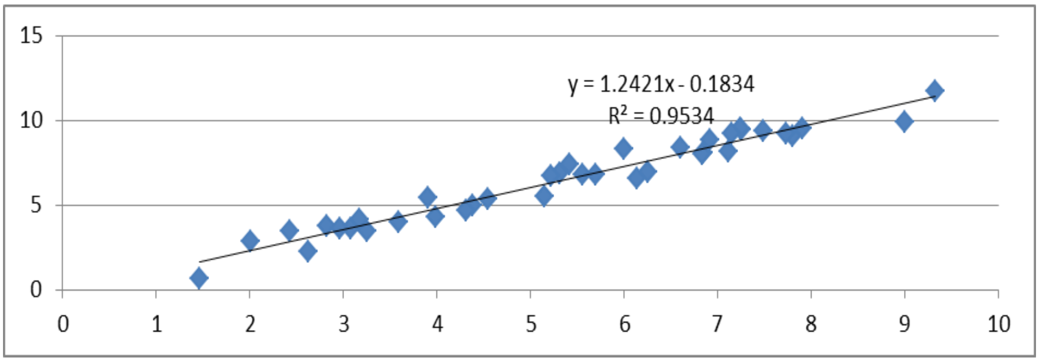


Figure 35. Determination of Coefficient between Evapo-Transpiration and Crop Coefficient (KC) on the Basis of Hourly Data In Lysimeter 13

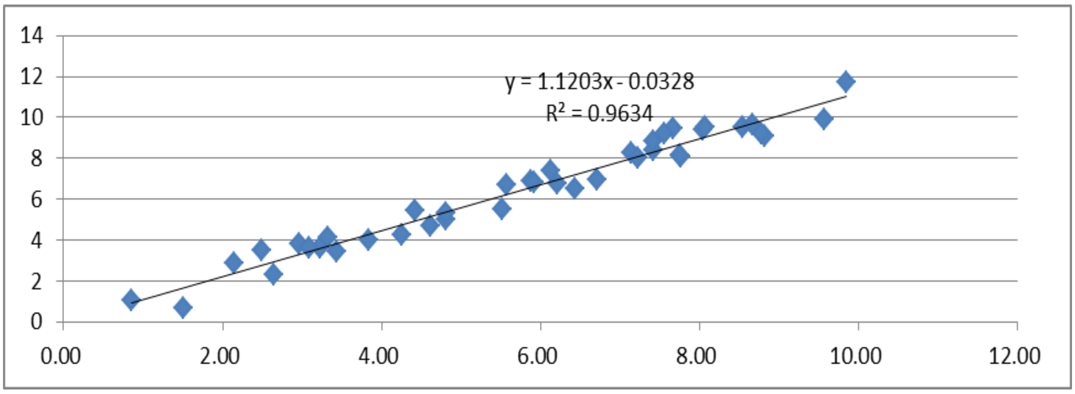


Figure 36. Determination of Coefficient between Evapo-Transpiration and Crop Coefficient (KC) on the Basis of Hourly Data in Lysimeter 18

4. Conclusion

Crop evapo-transpiration (ET_c) determination is important to guide irrigation scheduling and to manage water resources. Salama et al. (2015) also noted that estimating evapotranspiration is an important part of agricultural water management in local and regional water balance studies. Lysimeters are the most reliable research tool for direct measurement of ET_c (Trajkovic, 2010). Lysimeters are the most reliable method to measure ET from a vegetated area, as long as they are properly installed, operated and managed (Martin et al., 2001). ET_c is important in irrigation planning and scheduling and is an integral part of field management, especially in arid and semi-arid regions. In both two experiments, from October to June, evapo-tranpiration trend increased steadily, especially in last four months, in which the lysimeters field was covered by winter wheat completely. In 2012-2013, the highest evapo-transpiration value in March, April and May was obtained for lysimeter 10 (I2) (558.70 kg), lysimeter 11(I3) (467.25 kg), and lysimeter 10 (I2) (488.68 kg), respectively. Abdou and Flury (2004) concluded that lysimeters studies are considered to be an intermediate approach between field studies and small-scale laboratory experiments. Lysimeters, after being exposed to the same environmental conditions, are more likely to mimic natural field soils that columns in the laboratory. Good practice of irrigation scheduling consists in applying water to the root zone in the right and frequency to reduce the low yield and low quality that results from water stress (Xia et al., 2005; Han et al., 2008; Kulkarni, 2011). In 2013-2014, both irrigation and rainfall increased KC and after that it decreased gradually. Before irrigation KC was low and exactly after irrigation, it increased and then it decreased gradually day by day. R^2 between evapo-transpiration which is on the basis of hourly weather data and daily weather data with measured ET in big lysimeter was 0.962 and 0.953, respectively. In conclusion, evapo-transpiration and KC give a closer idea of the value of research on relationship between evapo-transpiration and crop coefficient. The responses of crops or stages of plant growth, make a different water stress effects. However, crops are particularly sensitive to water stress during the reproductive growth stages and this can significantly impact yields. Estimating of crop evapotranspiration needs more calculations on soil-plant-atmosphere, and improving irrigation management practices significantly increase wheat yield and plays an important role in water management in North China Plain. Crop evapotranspiration values varied with the variation of the wheat growth stage, soil and climatic conditions. This trial was conducted only in one place and on one cultivar; the future experiment should be conducted for different cultivars in different research stations in North China Plain.

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