Study on Simple Transpiration Model and Fitted Measurement Time for Dominant Plant at Mudstone Area in Taiwan

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Abstract: The dominant process in water relation of the whole plant is the absorption of large quantities of water from the soil, its translocation through the plant and eventual loss to the surrounding atmosphere as water vapor.The measurement of transpiration for the potted plant could be taken as the required water index for the fitted plants, find the main mechanism of transpiration and quantifing these changes of microclimate at local region.

The transpiration model also could incorporate the microclimate model to quantify the humidity ratio of the inner air. The purpose of this study is to utilize solar radiation（*Rs*, W/ m^2）and saturated vapor pressure deficit （*VPD*, mbar） to get a transpiration （*Tr*, g/(m^2 • hr)） physical regression model. In order to get the best model and fitted time, physics theorem, mathematics theorem, and statistics tools combine to infer a transpiration model. The weight measurement technique was adopted and a measuring device was established. According to micrometeorology, solar radiation and vapor pressure difference are function of transpiration. Transpiration was studied as a function of solar radiation and vapor pressure deficit by proposed physical formula and regression analysis. The experiment results indicated that the transpiration was significant for different plant and time periods.

The results by statistics analysis show that there is a significant difference between morning and afternoon in the Taiwan mudstone area for Thorny bamboo (*Bambusa stenostachya*) (morning: $Tr = –346.45+0.48Rs+10.91VPD$; afternoon: $Tr = –313.48+1.27Rs+ 4.53VPD$); there is no significant difference between morning and afternoon for Honduras mahogany (*Swietenla macrophylla*) ($Tr = 164.64–0.095Rs+2.91VPD$). For Thorny bamboo, the fitted measurement time of transpiration by weight difference method is 20 minutes and 35 minutes for Honduras mahogany. The quantitative effect of solar and vapor pressure deficit on transpiration for two fitted plant at mudstone area are discussed and have some further research.

Keywords: mudstone area, transpiration, weight difference method, regression model

1 Introduction

The importance of transpiration on water conservation has been proved by many experienced scholars for many years, also, the transpiration varies from different categories of plants, especially, and the difference is being more obvious at Taiwan mudstone area. Meanwhile, the transpiration model, physiological response and physical effect also varies from area to area. The main procedures of carrying water through the plant is by means of extracting and absorbing lots of water directly from soil, and then, by way of internal transmission, and finally transpired as water vapor in air. Actually, only less than 5 % of water absorbed is being utilized for its growth and for biochemical response (Hopkins, 1995), the dissipation of water caused while the water translocation through the whole plant defined as transpiration effect. Although only less water vapor was dissipated through some small stomata in the bark or its branches, however, more than 90 % of water was transpired through stomata of leaves.

The measurement of transpiration includes direct (flowerpot observation, sap flow method, lysimeter,) and indirect (water budget, energy balance, …) methods, since the indirect method of which with some complicated of meteorological factors involved, therefore, it will become more difficult for prediction and verification of the transpiration, hence, the control technology and strategy for plant physiology will become impractical.

The transpiration effect means the transaction of heat and quantitative, its internal heat transaction was done via transpiration, and displayed in a form of potential heat.The micro-climate model with transpiration measurement and test (Chen,1998) which were incorporated with quantitative effects of transpiration in environmental control strategy can help set up the control index for plant physiology as a basis or target for economic crops as when to irrigate or plant, etc. The transpiration has connections with leaf temperature, the transpiration interfered by harsh environments will make the leaf temperature unstable and abnormal. Hence, the researches on the leaf temperature and transpiration can help provide a warning signal and to predict the crops growth in a stress condition. To inhibit the shallow layer landslide of plant, except the physical effect of root, the other important mechanism is the transpiration effect.

According to Morr-Culumn Law for shallow layer landslide, the plant transpiration reduces the water pore pressure in soil, which in turn, to enhance the shear strength of soil. So, the transpiration physiological response and physical effect of root have played an important role in the stability of slope lands. The transpiration effect has become one of the important mechanisms for hydrological circulation, which also has a important relationship with soil mositure distribution, watershed management and plant growth, etc.. If regional evapotranspiration mechanism can be understood and set in advance, then, the management for water resources will be benefited. Besides, the growth and production and even the survival of plant in stress all have connection to the evapotranspiration. Actually, the plants would possibly be died by over-transpirated, or grow abnormal due to no suitable mechanism applied while in stress. The research on evapotranspiration at mudstone area in south-east of Taiwan are mostly based on heat budget method, or with some meteorological data applied to Penman's method to predict the evapotranspiration (Hsu and Sung,1987). And, on the research of single plant, Lin and Liu (1997) had proceeded some experiments on 10 kinds of broad leaf trees, and had set up the relationship among effective solar radiation, leaf temperature and water vapor pressure, etc. Since some of important factors including repetition and linear relation of factors were not included in their experiments, therefore, the further validity and prediction for the subject will be unknown.

Generally speaking, most of researchers normally focus on one-way of analysis and to decide the coefficient (R^2) as the best mode, but normally ignore the basic presumption for pre-work analysis, this is the common mistake that some researchers had, and the mistake is sometime risky and misleading for further analysis (Myers, 1986; Chen, 1998), hence, the overall of consideration for tested data including coefficient of determination (R^2), standard error (S), prediction sum of square ($PRESS$) and Press should be taken into account in advance.

For large plant researches, most of prediction and estimation are based on energy balance method or air power method, and seldom consider the influences of the physiological response, physical effect, difference of categories on plant transpiration, etc.. One of method for measuring transpiration is to put the test plant with flowerpot on electronic scale to continuously record the difference of weight, and calculate the variation of weight vs timing. Normally to say, this method is appropriate for measuring little crops including cucumber, tomato (Joliet and Bailey ,1992), rose and chrysanthemum (Fynn *ea al*., 1993). Kramer (1983) thought the measurement of weight difference would be more convincible and practical in outdoor conditions, however, the influence of fitted measurement time and volume of container should be taken into account. In addition, Baille (1992) also compared the difference between weight measurement and energy balance method, and found the weight measurement is more accurate than the other one, but the weight measurement can not record all of the evapotranspiration as energy balance method can do in greenhouse.

Therefore, Coulon *ea al*. (1996) proceeded an experiment to measure the transpiration and micro-climatic data to execute irrigation control by computor, the set-up of fitted measurement time with transpiration mode can be applied for irrigation work for plants and plant physiological response as well as for the study of climate change with which influences the water consumption, the variation of different categories of plants, etc..

With reference to above mentioned researches and experiments, our study adopted weight measurement to calculate the evapotranspiration of test plant in a fitted flowerpot located on electronic scale as to get more accurate data. As known, the transpiration is mainly depending on solar radiation and saturated water vapor pressure (Zhang *et al*., 2001 ; Fynn *et al*., 1993), therefore, this section is to discuss and estimate the transpiration used on meteorological model, and the difference of mechanism and fitted measurement time applied to the transpiration of different categories of plants, which only few researches ever mentioned.

Since the transpiration of plants at mudstone area is very significant, to enable to increase the growth rate, plant survival and stress tolerance, the study on the evapotranspiration as well as its mechanism and response time become essential. Our study is mainly to set up some simple measuring instruments for the measurement purpose of evapotranspiration, to test and record the transpiration for some test plants in flowerpot at mudstone area as well as the study of its physiological response (fitted measurement time), and further to precisely estimate the transpiration at mudstone area. This research is to use statistics tools to discuss the fitted response time on transpiration on plants of which based on different mechanisms.

2 Material and methods

2.1 Experiment location

One of the experiments is located in Hon-chuan-tou watershed near to Wu-sen-tou reservoir, in Liu-chia of Tai-nan county. This experiment location which is near to Wu-sen-tou water conservation area has an indepentent area around 40 hectares is belonging to Chia-nan Water Management Research & Development Foundation, and the other one is located at the 3rd floor of Department of Soil and Water Conservation in National Chung–Hsing University.

2.2 Dimension of flower pot

The cylindrical form of experimented flowerpot is with a 30 cm (Height) * 24 (Diameter) of volume. This experiment is to plant a 30 cm of seedling with collected soil sample from mudstone area as a media, and after 3 months of planting in Autumn, then, to start recording 5 times of transpiration rates during that all day.

2.3 Testing methods

To put one set each of flowerpot on each of two electronic scale. And with use of aluminum foil, pare cotton and tape beneath to flowerpot as an isolation from possible evaporation from soil. As shown in Fig. 1, the E20 solar radiation was located near to plant canopy, and the HL20 data acquisition system was set at 60 seconds of scan rate, with 5 minutes, 10 minutes, 15 minutes, 60 minutes of recording intervals in average to record the weight differences from different timing to represent the transpiration.

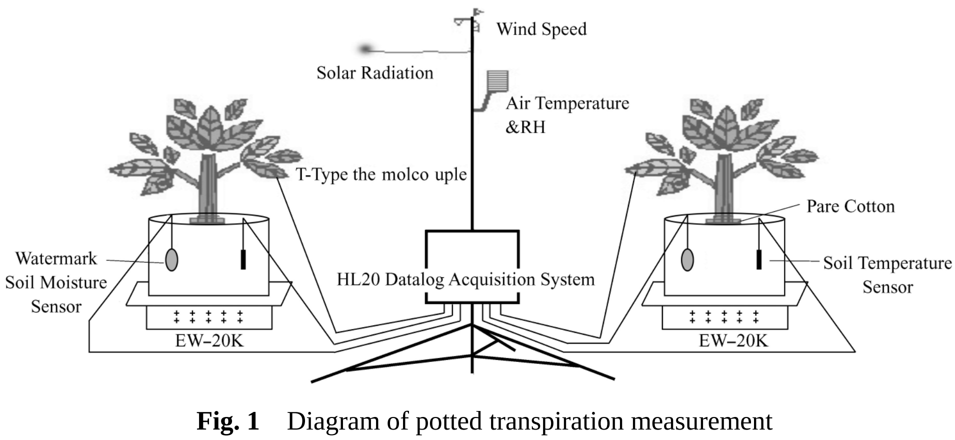

Fig. 1 Diagram of potted transpiration measurement

2.4 Data analysis

In this experiment, the HL20 data acquisition system measured and recorded meteorological parameters including solar radiation, air temperature and relative humidity, leaf temperatures, soil temperature, soil potential and weight difference of test plant, etc.. The data process for evapotranspiration was based on measured meteorological parameters and mentioned weight differences on 5 minutes, 10 minutes, 15 minutes, 60 minutes recording intervals. According to Goff-Gratch formula for temperature and from measured air temperature and humidity data, then, we can estimate the saturated vapor pressure and vapor pressure respectively. As to the values of transpiration (*Tr*), solar radiation (*Rs*) and saturated vapor pressure difference (*VPD*), we adopted linear model for regression analysis, and further to evaluate the validity, reasonableness, prediction and fitted measurement time, etc..

3 Evaluation of simple transpiration model

To compare each of collected data to evapotranspiration model, and use statistic tools for further understanding of its validity and prediction , etc.. In order to compare the validity and prediction ability of different models by coefficient of determination (R^2), standard error (S), prediction sum of square and (*PRESS*). Enabling to realize if any obvious difference existed on Thorny bamboo and Honduras mahogany in the morning or afternoon, we adopted “ F ” of statistical technique to check the difference.

With 5 minutes, 10 minutes, 15 minutes, 60 minutes recording intervals, we used to record the transpiration difference, average solar radiation and average saturated vapor pressure to get the regression models. And, the obtained maximum and minimum of regression models, of which their measuring intervals are the fitted measurement time for transpiration model of fitted plants.

4 Results and discussion

4.1 Variation of daily transpiration

The change of micro climate and one-day testing results of transpiration for Thorny bamboo and Honduras mahogany in typical Autumn had been record by HL20. The solar radiation increased from AM 6:00 in the morning, and fast decreased in the afternoon from AM 12:00 to PM 2:00, and the air temperature and relative humidity were demonstrated as in a reverse relationship. The weight of Thorny bamboo was fast reduced from 15,800 g to 15,640g within 12 testing hours, and the weight of Honduras mahogany was reduced from 15,810g to 15,759g. We had recorded the change of weights and the micro meteorology climate data by HL20 data acquisition system.

Since there is no sunlight during the night time, therefore, the weight change will be not apparent. After 5 days of testing for transpiration measurement, we got the daily transpiration for Thorny bamboo was (160.2±10.2)g, and 110.3g in the afternoon, which occupied 68.9±8% of the testing day. The transpiration for Honduras mahogany was (51.0±5)g , and 24.2g in the morning, which occupied 47.5±7% of the testing day. In addition, the soil water potentials for both of test plants were varied within the ranges of 0.3 bar to 0.5 bar. By statistic t-test, the soil water potential was no significant difference for transpiration of Throuy bamboo and Honduras mahogany.After testing finish, we got the leaf Area Index(LAI) by LI-3,000A instrument of LI-COR company. The LAI was 1.86 for Thorny bamboo, and Honduras mahogany was 1.21.

4.2 Simple transpiration model

We double check and verify the measured data by model of $ET=A*Rs+B*VPD+C$, and by this model to check the F value (p=0.05), and found that the results had indicated that the harsh micro-climate condition at mudstone area of south-east Taiwan including the solar radiation, saturated vapor pressure had reacted on this model, also, the result shown that it has no connection to where the test site located.

According to some relevant reports previous mentioned (Fynn *et al*., 1993; Chen, 1998; Zhang *et al*., 2001) as well as our experiment of using statistical regression analysis, we knew that the influence to evapotranspiration mechanism is determined by the factors of solar radiation (*Rs*) and saturated vapor pressure deficit (*VPD*), etc.. As to the soil potential in root zone, wind speed at plant canopy and soil temperature, we found the influence was little, and this result was in accordance to the viewpoint of Hopkins (1995).

(1) The discussion of fitted measurement time on transpiration effect

For the sake of transpiration effect of plants, and different category of plant with different transpiration rate, therefore, the differences based on different timing of recording intervals will affect the validity and prediction of transpiration model. Our research is to record weight differences based on 5 minutes, 10 minutes, 15 minutes, 20 minutes, 60 minutes of recording intervals to represent transpiration rates for tested plants, and to find out its best model respectively by R^2 , *S* and *PRESS*. And its difference with recording intervals meant the transpiration rates were indicated as following:

① The fitted measurement time for thorny bamboo

5 min : $Tr = -1.369 - 0.005Rs + 0.134VPD$ $R^2=0.39$ $S=1.79$ $PRESS=168.38$ (1)

10 min : $Tr = -3.63 - 0.012Rs + 0.314VPD$ $R^2=0.55$ $S=1.95$ $PRESS=124.89$ (2)

15 min : $Tr = -7.49 - 0.27Rs + 0.663VPD$ $R^2=0.68$ $S=2.84$ $PRESS=96.38$ (3)

20 min : $Tr = -10.95 - 0.036Rs + 0.941VPD$ $R^2=0.86$ $S=1.94$ $PRESS=68.32$ (4)

25 min : $Tr = -16.23 - 0.058Rs + 1.411VPD$ $R^2=0.79$ $S=2.53$ $PRESS=84.89$ (5)

30 min : $Tr = -9.78 - 0.038Rs + 0.831VPD$ $R^2=0.71$ $S=2.82$ $PRESS=93.72$ (6)

② The Fitted Meaurement Time for Honduran Mahogany

5 min : $Tr = 0.086 - 0.004Rs - 0.016VPD$ $R^2=0.22$ $S=1.85$ $PRESS=183.42$ (7)

10 min : $Tr = 1.28 - 0.00023Rs - 0.021VPD$ $R^2=0.31$ $S=1.99$ $PRESS=161.23$ (8)

15 min : $Tr = 2.558 - 0.0013Rs - 0.037VPD$ $R^2=0.48$ $S=2.34$ $PRESS=142.36$ (9)

20 min : $Tr = 3.87 - 0.0026Rs - 0.078VPD$ $R^2=0.56$ $S=2.31$ $PRESS=129.18$ (10)

25 min : $Tr = 3.98 - 0.0042Rs - 0.082VPD$ $R^2=0.62$ $S=2.29$ $PRESS=109.26$ (11)

30 min : $Tr = 4.117 - 0.003Rs - 0.11VPD$ $R^2=0.71$ $S=3.12$ $PRESS=97.37$ (12)

35 min : $Tr = 5.23 - 0.003Rs - 0.097VPD$ $R^2=0.81$ $S=1.86$ $PRESS=85.89$ (13)

40 min : $Tr = 5.16 - 0.0042Rs - 0.008VPD$ $R^2=0.78$ $S=2.34$ $PRESS=98.76$ (14)

According to statistical regression analysis and experience got, we know the variations of wind speed and solar radiation as well as the plant physiological response will make R^2 become lower and PRESS higher within a short period of time. Also, after comparison, we knew the formulas (4) and (13) would be the best models for validity and prediction.

Hence, by weight difference of transpiration rate measured, the fitted measurement time of transpiration is 20 minutes for thorny bamboo, and the Honduras mahogany is 35 minutes.

(2) The transpiration model for thorny bamboo

The HL20 data acquisition system recorded and stored the data of transpiration rate of thorny Bamboo and the solar radiation, and we found the sunshine duration had affected the transpiration rate. As recorded, the transpiration rate was increased when solar radiation increased from AM6:00 to AM12:00 in the morning, and it was decreased when solar radiation decreased from AM12:00 to PM 7:00 in the afternoon. And, we got the transpiration rate in the morning period was (49.9g, 31.3 %) lower than that (110.3g, 68.9 %) in the afternoon period. To be combined with solar radiation (*Rs*), saturated vapor pressure deficit (*VPD*), transpiration (*Tr*) and analyzed by regression trend chart, we knew the relationship for *Tr*, *Rs* and *VPD* were linear, and the simple transpiration model indicated as below:

① In the morning: $Tr = -346.45 + 0.48Rs + 10.91VPD$ $R^2=0.83$ $S=1.91$ $PRESS=88.381$ (15)

② In the afternoon: $Tr = -313.48 + 1.27Rs + 4.53VPD$ $R^2=0.86$ $S=1.82$ $PRESS=74.89$ (16)

To evaluate the influences of solar radiation and saturated vapor pressure on transpiration, we demonstrated them by 3D chart (Fig. 2), and from the above 2 models, we knew the model for morning period would be the best model for validity and prediction of transpiration. Also, we knew the reason which made the coefficient R^2 lower was that the transpiration rate in a short period of time would not be able to completely react on the effect of transpiration. And, this point is same to Aston’s report in 1984. Hence, to measure the transpiration rate by weight difference method, the fitted measurement time would be the most significant factor which affects the accuracy of transpiration rate.

(3) The transpiration model for honduras mahogany

As mentioned previously, the relationship of solar radiation and saturated vapor pressure to transpiration was linear, and we found no significant influence when the comparison (*F*, *p*=0.05) of morning *Tr* and afternoon *Tr* made based on model *ET*=*A***Rs*+*B***VPD*+*C*. So, we got the following results:

$$Tr= 164.64–0.095Rs+2.91VPD \qquad R^2=0.81 \quad S=1.86 \qquad PRESS=85.89 \tag{17}$$

As indicated in Fig. 3 for honduras mahogany, we found the transpiration rate in the afternoon period (26.8g, 52.5 %) was higher than that in the morning period (24.2g, 47.5 %), and it was 1.11 times of transpiration rate than that in the morning.

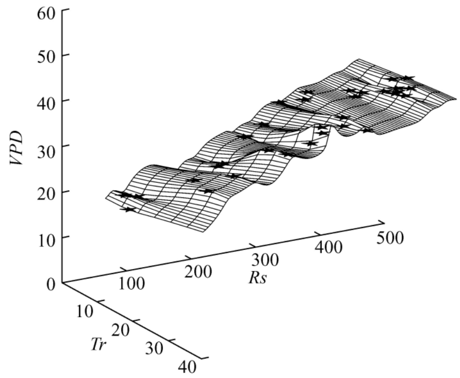

Fig. 2 Three –dimensional plot of transpiration as a function of *Rs* and *VPD* for Thorny bamboo

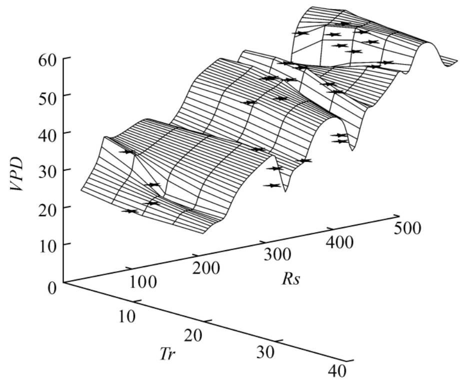

Fig. 3 Three-dimensional plot of transpiration as a function of *Rs* and *VPD* for Honduras mahogany

5 Conclusions and suggestion

Due to the poor condition of soil and micro-climate condition, the mudstone area in the South-west of Taiwan has always had a bad name“ cancer “ to represent its poor environmental condition. This area always lacks water, and the accumulated heat makes the temperature difference even higher between day and nighttime, therefore, a suitable mechanism has become more significant. This chapter is to seek for a simple transpiration model by means of previous efforts of experienced scholars as mentioned plus modern statistical regression analysis to predict and verify it. Furthermore, we obtained its relationship incorporated into micro-climate condition for some conclusions and suggestion as below:

(1) From the measured data by simple transpiration model applied to partial regression leverage plots, we found the transpiration (*Tr*), solar radiation (*Rs*) and saturated vapor pressure difference (*VPD*) were linear, and the results was that transpiration models of Thorny bamboo applied for morning (*Tr*= –346.45+0.48*Rs*+10.91*VPD*) and afternoon (*Tr*=–313.48+1.27*Rs* +4.53*VPD*) periods were different, and we found it has no significant difference for Honduras mahogany (*Tr*=164.64–0.095*Rs*+2.91*VPD*). Hence, with leaf area index (*LAI*) considered, we adopted this model with unit transformation to infer each of the transpiration estimations for Horny bamboo and Honduras mahogany in the mudstone area.

(2) As transpiration is measured by weight difference, the fitted measurement time is 20 minutes for Thorny bamboo, and 35 minutes for Honduras mahogany. And from one day of transpiration rate measured, we knew the transpiration rate of Thorny bamboo in the afternoon occupied a ratio of 68.9% of total transpiration, and that of Honduras mahogany in the morning occupied a ratio of 47.5% of total transpiration. To sum up, the daily transpiration of Thorny bamboo ((160.2±10.2)g) was much more than that of Honduras mahogany ((51.0±5)g).

(3) According to the previous mentioned reports and regression analysis, we knew that the mechanism to influence transpiration also includes solar radiation (*Rs*), and saturated vapor pressure deficit (*VPD*), etc.. As to the water potential in root zone, soil temperature and upper layer of wind speed, the influences were little.

(4) This research mainly focuses on measurement of transpiration and model verification, etc.. Although the influence of leaf area index (*LAI*) was being considered for this research, however, the influence mechanism as well as some factors including leaf area, leaf angle would still be required for further discussion. For future of further discussion, researchers can add those factors included in their researches to enable precise estimation of the transpiration for fitted plants.

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