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Software for the management of weather stations and for agrometeorological calculations

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Abstract

Surface weather stations in agricultural areas are commonly managed non-professionally, usually in areas with more than one station. Climate is defined as the average meteorological conditions of a region, and knowledge of climate is essential for agricultural development. We have developed a program for the management of meteorological data from different automatic weather stations capable of estimating evapotranspiration, water-balance components, and crop yields. The software System for Water Balance (SYSWAB) was developed using Java as the programming language and MySQL as the database management system. The user can choose among 6 evapotranspiration models in the system, the water balance calculations followed the Thornthwaite and Mather (1955) model. The software calculates the potential and actual yield following the Doorenbos and Kassam (1979) method (FAO). SYSWAB was tested by estimating the evapotranspiration and actual yield for a coffee crop. The evapotranspiration ranged from 70 to 113 mm in the months with high temperatures and from 40 to 70 mm in months with lower temperatures. SYSWAB accurately estimated the yield. The observed and simulated yields did not differ significantly at $p<0.01$. The FAO model used was thus accurate, and the program algorithm was sound. The program can be downloaded free of charge at: http://comp.muz.ifsuldeminas.edu.br/downloads/ver/syswab-system-for-water-balance.

Keywords: Climate; Estimate yield; Monitoring; Water balance.
Abbreviations: SYSWAB_system for water balance; DEF_water deficiency; PET_potential evapotranspiration; AET_actual evapotranspiration; SWS_water storage in the soil; CWB_climatological water balance; CRWB_crop water balance; PY_potential yield; AY_actual yield; WC_available water capacity.

Introduction

The climate is defined as the average weather of a region (Rolim et al., 2007) and it´s knowledge is essential for agricultural development (Sá Junior et al., 2012). Climatic variability has a large impact on agricultural production (Aparecido et al., 2014), so monitoring the climate is very important, because it allows for better yield forecasts and planning of agricultural activities and assists in decision making.

Several agrometeorological monitoring systems have been developed around the world, such as those of the Monitoring Reporting Verification project (JRC-DG Climate) in Europe, the Climate Change Program Office (CCPO - USDA) in the United States of America, the World Agro-meteorological Information Service (WAMIS) in Africa, and the International Society for Agricultural Meteorology (INSAM) in China. Database organization and associated calculations, however, are often not automatic (Gommes, 2004; Stigter, 2007).

Crops are dependent on many meteorological parameters (Poudel and Koji, 2013). The climatic conditions are thus characterized as highly relevant variables in agricultural production (Aparecido et al., 2015), having direct and indirect influences on different crops (Brixner et al., 2014), such as the availability of energy for photosynthesis (Oliveira et al., 2012) and the accumulation of biomass (Angelocci et al., 2008).Meteorological elements can be monitored by conventional (CWS) or automatic (AWS) weather stations. These stations, especially AWSs, provide much data that, if not adequately organized, do not generate useful information. The most critical meteorological elements for crop development are rainfall, air temperature, and solar radiation (Hoogenboom, 2000). The monitoring of these is relevant because water deficiency affects growth (Santos and Carlesso, 1998) and crop development (Peixoto et al., 2006; Albuquerque et al., 2013), thermal availability influences the phenological development of plants, and solar radiation provides the energy for the partitioning of carbohydrates and individual plant components (Oliveira et al., 2012). Organized information can be used in crop models. The crop models can be embedded in software, which in turn can be incorporated into information systems to assist the interpretation of diverse processes, such as climatic conditions (Aaslyng et al., 2005) associated with crop growth and development (Challa, 1989). Crop models estimate yield by correlating the physical and physiological processes of crops with various meteorological elements (Baier, 1979). The model proposed by Doorenbos and Kassam (1979) is most commonly used to estimate the loss of crop yield due to water deficiency.

Few weather stations are managed by public computational systems (Vanuytrecht et al., 2014). The objective of this study was thus to develop a program for the management of meteorological data capable of estimating evapotranspiration, water-balance components, and crop yields.

Results and Discussion

Software development

Published scientific software commonly performs only specific functions, such as those developed by Campbell Scientific that only manage data. Evett and Lascano (1993) developed ENWATBAL.BAS for calculating water balance, and Rolim et al. (1998) developed a program that estimated potential and actual crop yields following the Doorenbos and Kassam (1979) models. The SYSWAB system combines the management of weather stations with agrometeorological calculations such as those for water balance, degree days, crop potential, and actual yield. The program is available free of charge at:
http://comp.muz.ifsuldeminas.edu.br/downloads/ver/syswab-system-for-water-balance

Example of climatic characterization by a weather station registered in the SYSWAB system

The high air temperatures in the Muzambinho region of southeastern Brazil lead to high potential evapotranspiration (PET), mainly in the summer. PET ranges from 70 to 113 mm in summer and from 40 to 70 mm in winter (Fig. 1). These values are similar to those reported by the National Institute of Meteorology (INMET, 2014), with a confidence interval of 99%. Climatological water balance (CWB) is a measure of the availability of soil water. The highest daily water surplus, ca. 13 mm, occurs in this region from September to April. Water deficiency (DEF) averaging 1 mm daily occurs between April and September (Figs. 2 and 3). The lowest soil-water storage (SWS) occurs between May and September, ranging from 60 to 65 mm (Fig. 4).

Yield estimation

The production of coffee (*Coffea arabica* L.) in Mococa in the state of São Paulo varied widely annually from 2001 to 2012. The highest and lowest yields were 23 and 6 sacs ha^{-1} in 2002 and 2003, respectively. The yields for 2007, 2008, and 2009 were 9, 17, and 11 sacs ha^{-1}, respectively (Fig. 5A). The estimated yield calculated by SYSWAB did not differ significantly (p<0.01) from the actual yield (AY), with low mean absolute percentage error (MAPE) and systematic error (Es) and with an adjusted coefficient of determination (R^2adj) near 1.0, indicating that the estimate was accurate with a low bias. The estimate of coffee yield in Mococa had an R^2adj of 0.73, a MAPE of 18.78%, and an Es of 4.2 g (Fig. 5B). The MAPE of 18.78% for AY accounts for ± 2.8 sacs ha^{-1}, a low value for a cultivation error, supposing a regional average yield of 15 sacs ha^{-1}.

Materials and Methods

System programming

SYSWAB was developed using Java as the programming language and MySQL as the database management system. Graphics were generated by the JFreeChart library, and reports were generated by the iReport tool. These tools are free and do not require a license to use (Fig. 6). The user of SYSWAB is able to register several AWSs, providing the geographical coordinates, altitudes, and the models of the stations. After registration, text (Fig. 7) files containing the meteorological data at each AWS can be added and stored in the database. The meteorological data can be updated daily and accessed at any time. The main functions of SYSWAB are to estimate PET, calculate CWB and crop water balance (CRWB), manage irrigation drip systems, and estimate potential yield (PY) and AY.

Calculations of water balance

The SWS in CWB and CRWB was calculated following Thornthwaite and Mather (1954):

$$SWS = WCe^{\frac{(-)\sum(P-PET)}{WC}} \quad (1)$$

Where, WC is the available water capacity; SWS is the soil-water storage, and (-)∑(P-PET) is the sum of negative values of (rainfall – PET).

Yield modeling

PY was estimated following the agroecological zone model proposed by Doorenbos and Kassam (1979):

$$PY = PPB \times Ccol \times Cres \times Clai \times NDAYS \quad (2)$$

where PPB is the gross potential yield of dry matter (kg ha^{-1}), Ccol is the coefficient of the harvest index, Cres is the respiration coefficient, Clai is the coefficient of the leaf area index, and NDAYS is the length of the crop phenological phase (days). AY was also estimated by the model proposed by Doorenbos and Kassam (1979), using the sensitivity of the crop to water stress (Ky) due to water restrictions:

$$AY = PY \times \left[1 - Ky \times \left(1 - {AETc}/{PETc}\right)\right] \quad (3)$$

Where, AETc is the actual crop evapotranspiration (mm period^{-1}), and PETc is the (potential) crop evapotranspiration (mm period^{-1}); The program management used in SYSWAB contains three components (Fig. 8). AWS assesses the meteorological conditions and subsequently generates text files to add to the database. SYSWAB develops all the functions previously described, but the database stores the data and coefficients. SYSWAB estimates PET by various methods proposed by Budyco (1989), Camargo (1971), Hargreaves-Samani (1985), Penman-Monteith (Allen et al., 1994), and Thornthwaite (1948) and using . Class A pan data, all at desirable scales of daily, weekly, 10-day period, monthly and annually. The user can also add PETs manually.CWB and CRWB are calculated by the methodology proposed by Thornthwaite and Mather (1955). The user can also select the weather station and the desired period and input the WC and the prior storage (prior SWS), if necessary, to calculate CWB. To calculate CRWB, the user has the option to select a particular crop, providing the basal temperature (°C), total degree days (°C day), and the duration of each stage of cultivation (days) in addition to the above information. The WCs may be developed on the same timescales previously described. PY (theoretical maximum of cultivation) and AY (water restricted) were estimated using the FAO agroecological zone model described by Doorenbos and Kassam (1979). After choosing the crop, the user must add the final crop moisture (harvest index), the thermal requirements of the crop cycle, the basal temperature, and the leaf area index for each phenological phase.

Table 1. Crop coefficient (Kc), sensibility to drought coefficient (Ky) and leaf area index (LAI).

Phenological phase	Kc	Ky	LAI
Flowering (FLR)	1.2	3.0	3.0
Frutification 1 (FRU1)	1.1	2.0	4.0
Frutification 2 (FRU2)	1.0	1.0	5.0
Maturation 1 (MAT1)	0.9	0.5	5.0
Maturation 2 (MAT2)	0.8	0.3	5.3

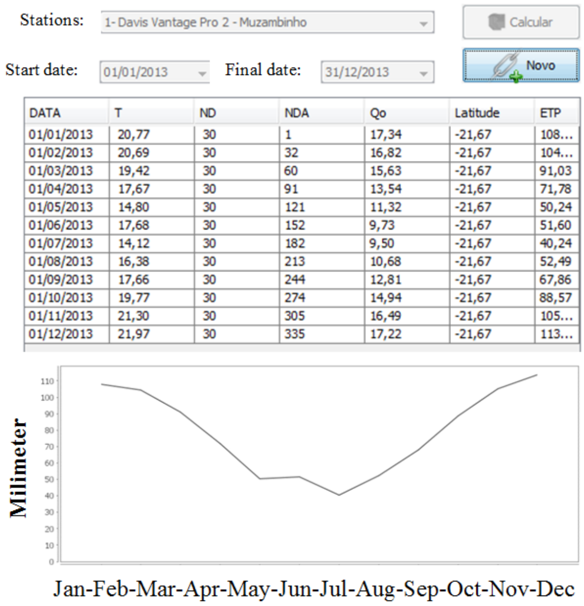

Fig 1. Estimation of monthly evapotranspiration potential in 2013 to Muzambinho, Brazil, using method of evapotranspiration following Camargo (1971) model programmed in the SYSWAB software.

Table 2. Cycle duration (days) and the sum of degrees-days (∑GD) for different phonological phases in the Arabic coffee tree.

Cultivating	Phases				
	FLR	FRU1	FRU2	MAT1	MAT2
∑GD	360	963	842	360	360
Cycle	30	80	70	30	30

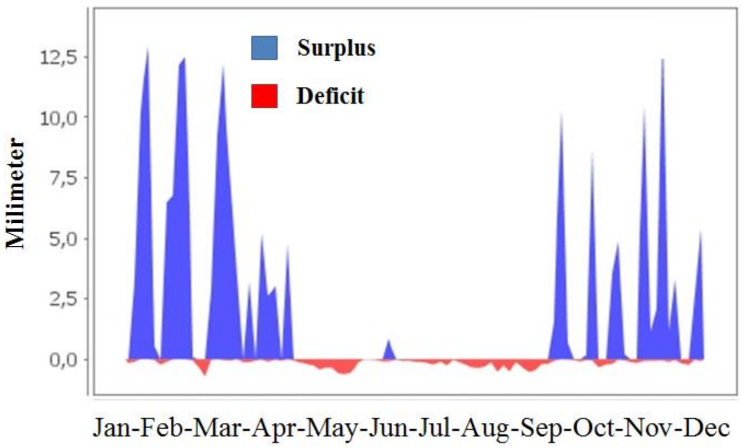

Fig 2. Estimation of daily water balance extract in 2013 to Muzambinho region, Brazil, using method of water balance following Thornthwaite and Mather (1955) model programmed in the SYSWAB software. In blue and red are surplus and deficit water, respectively.

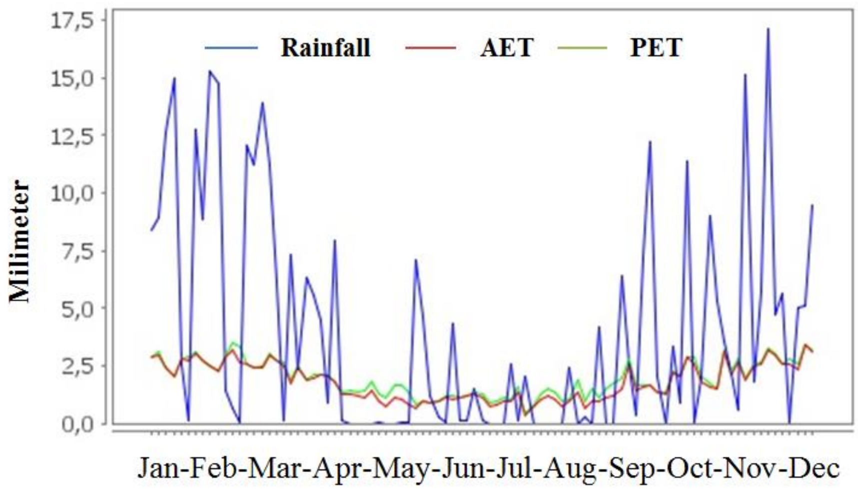

Fig 3. Estimation of daily water balance complete in 2013 to Muzambinho region, Brazil, using method of water balance following Thornthwaite and Mather (1955) model programmed in the SYSWAB software (PET is potential evapotranspiration and AET is actual evapotranspiration).

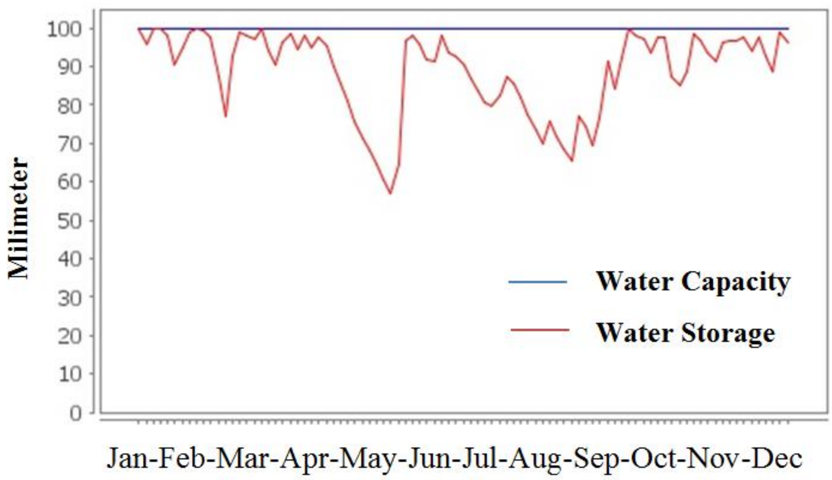

Fig 4. Estimation of soil water storage (SWS) and available water capacity (WC) in 2013 to Muzambinho region, Brazil, using method of water balance following Thornthwaite and Mather (1955) model programmed in the SYSWAB softwar

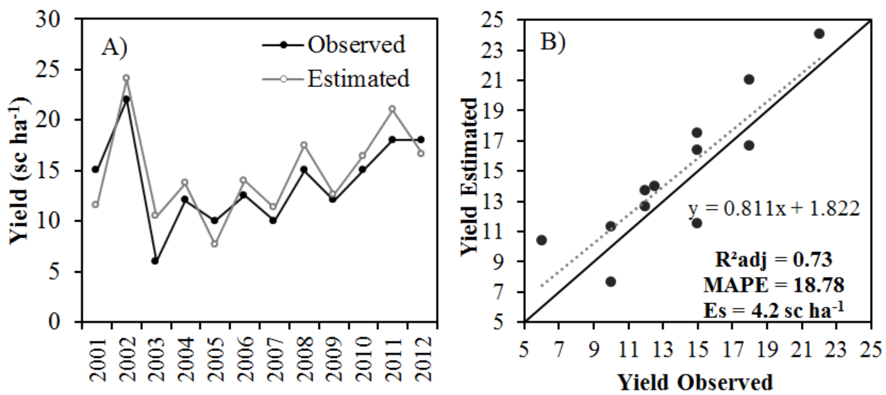

Fig 5. Values observed and estimated yield of coffee crop in the period from 2001 to 2012 (A) and performance evaluation of yield estimate by SYSWAB (B) in Mococa region, Brazil.

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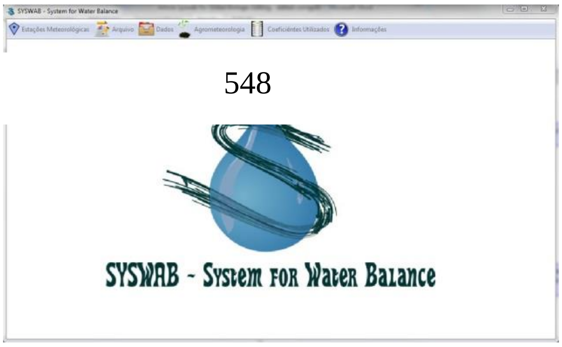

Fig 6. SYSWAB's software menu. The program can be downloaded free of charge at: http://comp.muz.ifsuldeminas.edu.br/index.php?op=downloads-sw&id=0

Date	Time	Temp Out	Hi Temp	Low Temp	Out Hum	Dew Pt.	Wind Speed	Wind Dir	Wind Run
01/01/13		0:30	20.3	20.4	20.2	79	16.5	1.6	NE
01/01/13		1:00	19.9	20.2	19.4	88	17.9	1.6	NE
01/01/13		1:30	19.4	19.7	19.3	80	15.9	0.0	NE
01/01/13		2:00	19.4	19.9	18.8	91	17.9	0.0	NE
01/01/13		2:30	18.7	18.8	18.5	92	17.4	1.6	NE
01/01/13		3:00	18.2	18.4	18.1	92	16.8	1.6	N
01/01/13		3:30	18.0	18.1	17.9	92	16.7	1.6	NNW
01/01/13		4:00	18.3	18.8	18.1	88	16.3	0.0	NNW
01/01/13		4:30	18.9	19.1	18.7	88	16.9	0.0	SSW
01/01/13		5:00	18.6	18.7	18.5	89	16.8	0.0	SSW
01/01/13		5:30	18.9	19.0	18.7	88	16.9	0.0	SW
01/01/13		6:00	19.1	19.2	18.9	88	17.0	0.0	SW
01/01/13		6:30	18.9	18.9	18.8	88	16.9	0.0	SW
01/01/13		7:00	18.8	18.9	18.6	89	17.0	1.6	SW
01/01/13		7:30	18.7	19.1	18.6	89	16.9	0.0	W
01/01/13		8:00	19.3	19.8	19.1	88	17.3	0.0	W
01/01/13		8:30	20.0	20.2	19.8	89	18.1	0.0	WSW
01/01/13		9:00	21.5	22.9	20.3	79	17.7	1.6	SW
01/01/13		9:30	23.0	23.8	22.7	76	18.5	3.2	SW
01/01/13		10:00	24.7	25.1	23.8	77	20.4	3.2	SSW
01/01/13		10:30	24.9	25.3	24.6	75	20.2	3.2	SSW
01/01/13		11:00	26.0	26.4	25.1	74	21.0	3.2	SSW
01/01/13		11:30	26.8	27.1	26.4	69	20.7	4.8	SW
01/01/13		12:00	27.4	27.9	27.1	68	21.0	4.8	SSW
01/01/13		12:30	27.3	27.7	26.8	69	21.1	4.8	S
01/01/13		13:00	28.0	28.2	27.3	68	21.5	4.8	S
01/01/13		13:30	28.0	28.7	27.3	63	20.3	3.2	SE
01/01/13		14:00	28.5	28.9	28.0	68	22.0	4.8	E
01/01/13		14:30	28.8	29.5	28.2	63	21.1	3.2	E
01/01/13		15:00	29.4	29.7	29.2	62	21.3	3.2	E

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Fig 7. Fragment of the file with extension text "txt" with data from the AWS.

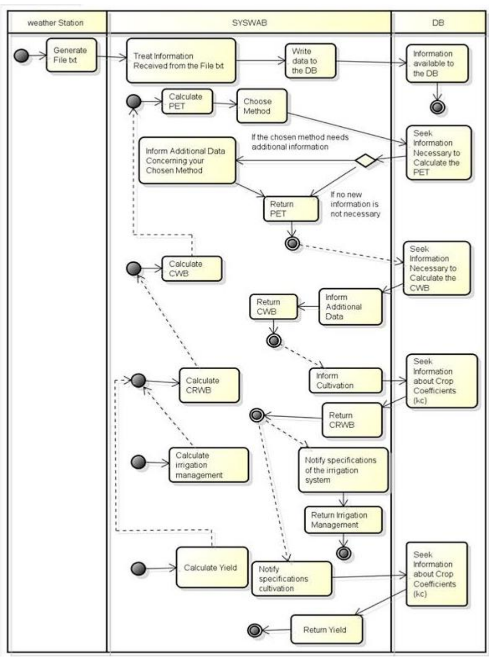

Fig 8. Activity diagram of the SYSWAB operation. Legend: full circle: beginning of the activity; circle with white edge: end of the activity; diamond: conditional; solid arrow: normal flow direction within an activity; dashed arrow: switching activity; rectangle: activity.

To test SYSWAB, PET was estimated by the method of Thornthwaite (1948), and CWB was estimated for the Muzambinho region (21º22′33″S, 46º31′32″W; 1050 m a.s.l.). The calculations were performed on a daily scale for 2013 using a WC of 100 mm. SYSWAB also estimated AY for a coffee crop at Mococa (21°18′33″S, 46°52′32″W; 850 m a.s.l.), an important region for coffee production in Brazil. The simulated yield data were compared with observed data for 2001-2012 obtained from local farmers for the "Catuaí" cultivar planted with 3.0 × 1.0 m spacing.

The calibration coefficients for the AY estimates were calculated iteratively using linear programming with the generalized reduced gradient model (Lasdon and Waren, 1982) to minimize the difference between the estimated and observed data. The basal temperature used was 10.2 °C (Pezzopane et al.,
2008), the crop coefficient (Kc) was that proposed by Sato et al. (2007), the coefficient of drought sensitivity (Ky) was that proposed by Arruda and Grande (2003), the leaf area index (LAI) was that proposed by Barbosa et al. (2012), and the harvest index was 56%.

The estimate of the yield was evaluated for accuracy by the MAPE (%), for precision by R^2adj (Cornell and Berger, 1987), and tendency by Es (same units as for the data):

$$MAPE = \frac{\sum_{i=1}^{N}\left(\left|\frac{Yest_i - Yobs_i}{Yobs_i}\right| * 100\right)}{N} \quad (4)$$

$$R^2\ adjusted = \left[1 - \frac{(1-R^2)\times(N-1)}{N-k-1}\right] \quad (5)$$

$$Es = \sqrt{\frac{\sum_{i=1}^{N}(Yobs_i - Yest_{-C})^2}{N}} \quad (6)$$

where $Yest_i$ is the estimated variable, $Yobs_i$ is the observed variable, $Yest_{-C}$ is the variable estimated by regression between the observed ($Yobs_i$) and estimated ($Yest_i$) variables, N is the number datapoints, and k is the number of independent variables in the regression.

Conclusions

SYSWAB is a program for the management of weather stations and for agrometeorological calculations that reliably converts raw data into practical information. The system successfully calculated water balance following the Thornthwaite and Mather (1955) model and yield estimates for different crops following the FAO models. For example, the estimates of coffee yield for Mococa were accurate, with an R^2adj of 0.73.

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