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Validation of the AMBAV soil-water balance model to simulate soil water content in a grass field

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Abstract: The validation of soil water balance models and the evaluation of the quality of the model predictions at field-scale require time-series of in situ measured model outputs. Therefore, the objectives of this study were comparison of the simulated soil water content (SWC) by AMBAV (Agrarmeteorologisches Modell zur Berechnung der Aktuellen Verdunstung) model as a cheap and reliable method with the corresponding results by soil samples (observed data) and validation of AMBAV soil water balance model in a grass field in Braunschweig, Germany. AMBAV model uses synoptic data sets and Penman-Monteith formula. This experimental dataset included a period of 7 months. Three statistical tests, such as R^2 (coefficient of determination), MARE (mean absolute relative error) and PE (prediction efficiency) were performed. Differences between observed and simulated active root zone SWC were not significant ($pr > t = 0.097$). Low MARE values and high values of PE and R^2 indicated that the soil water balance simulation model can be used safely to simulate the soil-water content in the active root zone of the grass. The AMBAV model was able to find the optimum date for grass-specific irrigation as an agro-meteorological.

Keywords: AMBAV model, Model validation, Soil moisture content, Soil water balance

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Introduction

Obtaining soil moisture information through field practices, like soil sampling and using soil moisture sensor on daily basis is cumbersome, time consuming and expensive (Jacques et al. 2001). Therefore, it is important to define an approach to monitor and characterize soil water over a wide range of temporal and spatial scales for efficient water management (Islam and Engman 1996). A simulation model approach is an appropriate alternative to predict SWC in the depth of crop's root zone. Soil water balance models for the simulation of runoff generation, infiltration, soil water storage, evapotranspiration, capillary rise and percolation are used within irrigation support management to transfer the results of the field trials to the farmers (Jones and Kinity 1986; Singh et al. 1999; Clemmens et al. 1999; Dechmi 2003). One of the soil moisture simulation model is AMBAV (Agrarmeteorologisches Modell zur Berechnung der Aktuellen Verdunstung = agro-meteorological model for calculating the actual evapotranspiration) model (Löpmeier, 1994 and Braden, 1995) which has developed by German weather service (www.agrowetter.de) that separately calculates soil moisture, potential and actual evapo-transpiration, effective precipitation (which is more than 2 mm), interception and the soil water balance in the crop-soil-system under different crop covers. Friesland and Lopmeier (2007) concluded that AMBAV model shows realistic soil moisture results in a sugar beet, winter wheat and winter ray fields compared with the Müncheberg data set of measurements from 1993 to 1998, even though the soil texture, biometric and phenological data are only roughly adjusted. Simulation models must be substantiated that within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model with due attention to number of simplified assumptions (Schlesinger et al. 1979) and ensured that the computer program of the computerized model and its implementation are correct. Therefore, there is a need to confirm the models with the real field measurements and they must be evaluated and validated under different condition (different soil, crop and weather condition) before practical using at the field scale. Wehenkel (2005) validated soil water balance model using a 6-year period with time-series of automatically recorded, daily volumetric soil water contents measured with the time-domain reflectometry with intelligent microelements (TRIME) method and daily pressure heads measured with tensiometers. Results showed that a combined use of both measurement techniques, which takes into account their respective advantages and disadvantages, gives a more complete overview on the simulation quality of the soil water balance model than the single use of one of those techniques. Sheikh et al (2009) introduces a simple two-layer soil water balance model developed to Bridge Event and Continuous Hydrological (BEACH) modelling. BEACH uses daily meteorological records, soil physical properties, basic crop characteristics and topographical data. The basic processes incorporated in the BEACH were precipitation, infiltration, transpiration, evaporation, lateral flow, vertical flow and plant growth. Their results showed that BEACH has the capability to estimate soil moisture content with acceptable accuracy and it is a useful teaching tool for learning about distributed water balance modelling and land use scenario analysis. In the past decades, many such validation studies in the field have been carried out (e.g. Diekkr¨uger et al. 1995; Svendsen et al. 1995; Vanclooster et al. 1995; Bonilla et al. 1999; Kendy et al. 2003; Wegehenkel 2004; Panigrahi and Panda 2003). In these studies, methods such as the gravimetric method, neutron probes and time-domain-reflectometry (TDR) for the measurement of soil water contents (SWC) were often applied.

However, newly method such as TDR and neutron probe are able to measure soil water content, but the soil sampling method is the most accurate method to determine actual soil water content and all other soil moisture sensor most be compared and validated with sampling method. Therefore, the objectives of this study were comparison of the simulated SWC by AMBAV model as a cheap and reliable method with the corresponding results by soil samples (observed data) and validation of AMBAV soil water balance model in a grass field.

Materials and Methods

Study site

Data were collected on a flat field of grass (It is called country 2011, a mixture of 35% *Festuca pratensis*, 35% *Lolium perenne*, 15% Phleum pratense, 10% *Poa pratensis* and 5% *Festuca ruba*) at the Institute of Agricultural Technology and Biosystems Engineering, Federal Research Institute for Rural Areas, Forestry and Fisheries, Braunschweig, Germany (www.vti.bund.de/en/institutes/ab). It was located between latitudes 52°1752, 80”N- 52°1802,41”N, and longitudes 10°2708,39”E-10°27370,27”E, respectively. The physical and chemical characteristics of the soil at the experimental site are summarised in Table 1.

Table 1. Description of the soil parameters at the experimental site (Salac, 2005)

Soil parameters	Top soil (0-30 cm)	Sub soil (30-60 cm)
pH	5.5	4.8
Organic matter [%]	1.4	0.7
Clay [%]	6.3	5.4
Silt [%]	46.7	47.2
Sand [%]	47	47.5

AMBAV model

AMBAV model uses the Penman-Monteith formula and synoptic data from a German weather service located 1.4 km to the south of the study site. The model that being use by local meteorological advisory services was designed to produce recommendations for irrigation amounts and scheduling for different soil types based on hourly weather data from the meteorological station network (Löpmeier, 1994; Braden 1995). Soil water dynamics are simulated using a mechanistic model based on the Richards equation that represents the movement of water in unsaturated soils (Richard, 1931). Soil water characteristics and hydraulic conductivity functions have been described by pedotransfer functions (Vereecken et al. 1989, 1990). The coefficients have been recalculated in order to get field capacities (FC) and permanent wilting points (PWP) in accordance with the German soil evaluation (Ad-hoc-Arbeitsgruppe Boden 1996). The model has ability to consider different soil textures. The AMBAV model cannot be used for uneven fields and it is valid for a flat field only like our study field. The model uses different parameters including physical processes like infiltration from rainfall or irrigation, redistribution in the soil-root zone, plant water uptake in the form of actual evapotranspiration, and percolation out of the soil reservoir.

Additionally, the model considers the dynamics of the crop's root growth model that affect plant water uptake and hence the soil water in the unsaturated zone. In the AMBAV model, the phenological and morphological development of the plants are considered in the form of:

- the partitioning of the radiation absorbed by the plants and the soil surface,
- the aerodynamic transport from the soil surface and the plants and
- resistance against plant transpiration (bulk stomatal resistance).

For these purposes, plant height, leaf area index and bulk stomatal resistance are generating inside the AMBAV model for each crop depending on a certain phenological phase. In this model, the calculations of the water budgets of the different soil layers and the hydrological properties of the corresponding soil are parameterized on the basis of Bodenkundliche Kartieranleitung KA4 (Boden 1994). Input files are separated into starting file, parameter files and meteorological files that should be filled with adequate data sets. In this study, the grass phenology data and soil data as input data were:

Starting of vegetation period = 02.03.2007 Starting of dormant period = 30.11.2007
Irrigation starting = 65 % of total available water content (TAWC)
Field capacity = 24 (vol %) Permanent wilting point = 4 (vol %)
Maximum root depth of grass = 60 cm
SWC at the beginning (02.03.2007) at depths of 0 to 40 cm = 85.7 % of TAWC
SWC at the beginning (02.03.2007) at depths of 40 to 70 cm = 82.7 % of TAWC
The simulated SWC in the root zone of grass can be calculated as follows:

SWC in the root zone [vol%]=([available water in root zone [mm] +(PWP=24mm)]/ 600) $\times$100 (1)

In addition, the AMBAV model has the ability of considering the effect of different irrigation method (sprinkler irrigation, drip irrigation and surface irrigation) to simulate the SWC because they have different deep percolation and efficiency. Therefore, due to using centre pivot irrigation system to irrigate grass field in this study, the data of sprinkler irrigation method was used in the model.

Validation of the AMBAV model

Validation of the AMBAV climatic water balance model to simulate soil moisture content was evaluated by comparing simulated values with observed data (soil sampling). This experimental dataset includes a period of 7 months. Auger boring was used to take soil samples in 30-cm increments to 60 cm (maximum root depth of grass) in three replications. Air dried samples were crushed and sieved through a 2 mm sieve, and then the SWC was measured using gravimetric method. In addition, the available data on bulk density at FAL (ρ_b = 1.42 gr/cm^3) was used to calculate the volumetric SWC. Proc t-test statistical analyses were carried out on the data using Statistical Analysis System program (SAS Institute, 1996) through analyses of variance. In order to validate the model, comparisons were made between the simulated and observed values and three statistical tests were performed. These tests are coefficient of determination (R^2), MARE (mean absolute relative error) and prediction efficiency (PE) index. The MARE index is computed as:

$$\mathrm{MARE} = \left\{ \sum_{i=1}^{N} \frac{(\mathrm{SWC}_{i,observed} - \mathrm{SWC}_{i,simulated})}{\mathrm{SWC}_{i,observed}} \right\} / N \quad (2)$$

Where $\mathrm{SWCi}_{,observed}$ and $\mathrm{SWCi}_{,simulated}$ are the observed and simulated SWC in the active root zone of the crop on ith time, i the index of the time that is taken as 1time in the study, and N is the total number of times for which observations are taken. The PE index is computed as:

$$\mathrm{PE}=1- \left\{ \sum_{i=1}^{N} \frac{(\mathrm{SWC}_{i,observed} - \mathrm{SWC}_{i,simulated})^2}{(\mathrm{SWC}_{i,observed} - \underline{\mathrm{SWC}_{observed}})^2} \right\} \quad (3)$$

Where $\mathrm{SWC}_{observed}$ is the arithmetic mean of the individual observations of SWC in the active root zone of the crop.

The mean difference, Md (Eq. 4), suggested by Addiscott and Whitmore (1987) and the relative root mean square error, RRMSE (Eq. 5), proposed by Loague and Green (1991) were used to assess the degree of coincidence between simulated and observed values. The Md as an index shows tendency of the model to overestimate or underestimate the soil sample values. It is a measure of the average difference between simulated and observed values. An Md value equal to zero denotes no difference between simulated SWC and soil sample values even though simulated and soil sample values can differ for individual measurements dates. RRMSE, as an index of the total error, and similar to the coefficient, provides a percentage for the total difference between simulated and observed values based on soil sample measured mean basis. A smaller RRMSE indicates better performance. The Md and RRMSE statistical parameters were defined as:

$$\mathrm{Md}= \frac{\sum_{i=1}^{n} (E_i - M_i)}{n} \quad (4)$$

$$\text{RRMSE}=\left[\frac{1}{n}\sum_{i=1}^{n}(E_i - M_i)^2\right]^{0.5} \times \left(\frac{100}{\overline{M}}\right) \quad (5)$$

where Ei is the simulated value, Mi is the corresponding observed value, n is the number of measurements and $\overline{M}$ is the mean of the soil sample measurements.

Results

A comparison between the observed and simulated SWC in the upper 60 cm (root zone) of grass crops from February to August (main vegetation period of grass) revealed a close results and reasonable agreement as the model satisfactorily simulated the SWC (Figure 1).

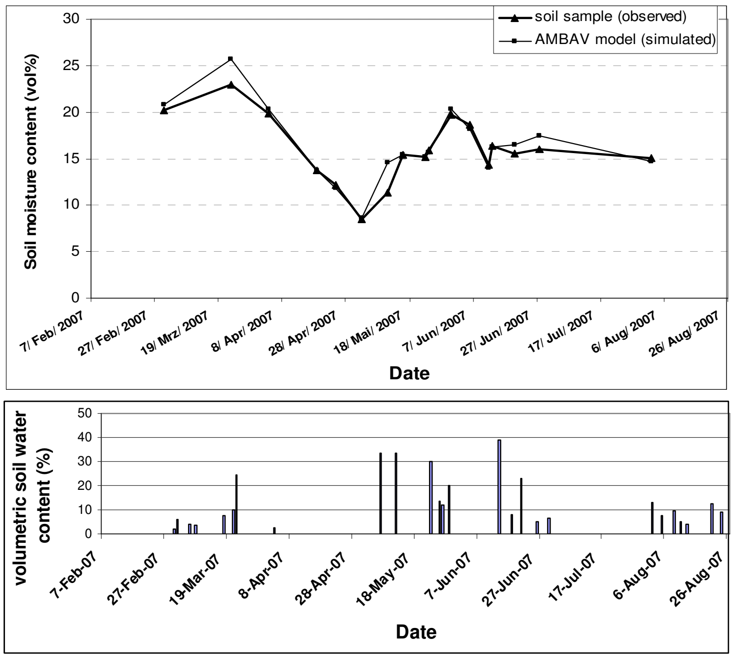

Figure 1: Observed and simulated SWC in the upper 60 cm of grass (up) and Precipitation + Irrigation (down)

Periods without or with small watering (precipitation plus irrigation) correspond well with decreasing soil moisture, whereas considerable amounts of precipitation plus irrigation cause sharp rises in the soil water curve as in the beginning of May and middle of June. At the end of April, the lowest soil moisture content was reached. Simulated values during the measuring period obtained by using the AMBAV model are shown in Table 2 in millimetres of water available in the root zone of the grass. Irrigation recommendation in Table 2 is calculated based on 35 % depletion in available water in the active root zone of the grass (Management allowable depletion = 35 %). SWC in the root zone of the grass (Table 2) was calculated based on Eq. (1). Calculation of the water balance component in Table 2 shows that irrigation plus precipitation and saved water in the soil at the beginning of the period is equal to deep percolation plus evapotranspiration.

Based on Proc t-test statistical analyses (SAS 9.1), differences between observed and simulated values were not significant at the 5 % level (pr > t = 0.097). To develop the model`s predictive performance, the R^2 value of the observed and the simulated values were estimated. In Figure 2, simulated values are compared to those found by soil samples by plotting on 1:1 line to assess the accuracy of AMBAV model. The linear relationship was determined as y = 1.0538x-0.3664 (R^2=0.92). Line slope (1.0538) is close to 1 and intercept (0.3664) is close to zero. This result shows a good alignment along the 1:1 line and demonstrates that simulated values by AMBAV model were close to those found in the soil samples. The R^2 value was 0.92 (Figure 2). Since the R^2 value was close to one, it confirms the presence of a good agreement between observed and simulated values. These results are in agreement with Friesland and Lopmeier (2007).

In some cases, differences between the observed and simulated values were significant (5% level). In addition to the graphical presentation, statistical tests were carried out to investigate the model's predictive performance. The MARE value was found to be 0.11(estimated using the methods outlined in Eq. 2). Furthermore, the PE index (estimated using the methods outlined in Eq. 3) was founds to be 0.999 (99.9%).

Table 2: Water balance from 02.03.2007 to 05.08.2007 during measuring period by AMBAV model

Water balance from 02.03.2007 to 05.08.2007					
Saved water in the soil (mm)	Deep percolation (mm)	Evaporation (mm)	Irrigation (mm)	Precipitation (mm)	Water balance (mm)
47.1	9.8	418.0	38	342.6	0.0

Irrigation data for Grass and sprinkler irrigation								
Date	Recommended irrigation (mm)	Available water				Evaporation (mm)	Irrigation (mm)	Precipitation n (mm)
		0-30cm in % F.C.	30-60 cm in %FC	Root zone (mm)	Deep percolation (mm)			
02.03.	0	85.7	82.7	101.1	0.0	0.7	0	2.2
03.03.	0	95.2	82.7	106.7	0.0	0.1	0	5.8
04.03.	0	93.7	82.3	105.6	0.0	1.1	0	0.0
05.03.	0	96.5	82.0	107.1	0.0	0.9	0	2.4
……	………………	…………..	………	……….	………..	…………….		
01.08.	30 + 25	55.0	37.0	55.2	0.0	3.9	0	0.0
02.08.	30 + 15	69.8	36.9	64.0	0.0	1.3	0	10.1
03.08.	30 + 20	64.2	36.3	60.3	0.0	3.7	0	0.0
04.08.	30 + 25	58.5	35.7	56.5	0.0	3.8	0	0.0
05.08.	30 + 30	52.5	35.0	52.5	0.0	4.0	0	0.0

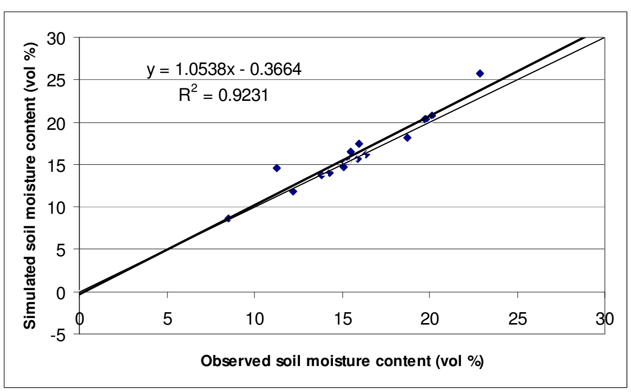

Figure 2: Relationship between observed and simulated soil water content

Discussion

The lowest and highest soil moisture content were simultaneously reached. It is well to discern that simulated and observed curves reveal their peaks and minimum widely in parallel. The SWC of the 0–60 cm depth from the model and observed values showed a full recharge of soil water up to field capacity in March.

However, a significant finding observed in the present study is the same trend of variation of SWC throughout the measuring period for both observed and simulated cases. The soil was watered many times due to irrigation and rainfall. During the periods when there was neither rainfall nor any supplemental irrigation, observed and simulated SWC in the root zone of the grass was depleted gradually. This is due to the loss of water by the grass in the form of evapotranspiration. However, if during the grass-growing season there was any rainfall or irrigation, then water content in the root zone of the grass increased.

The reason for significant differences between the observed and simulated might be due to a) spatial variation in SWC and b) ABMAV model assumes that all the soil water in excess of soil storage capacity percolates out of the active root zone of the grass instantaneously, which is not true under actual field conditions.

Low MARE value and high values of PE and R^2 indicate that the AMBAV model can be used safely to simulate the soil-water content in the active root zone of the grass. The Md and RRMSE results support the AMBAV model, also. +0.49 volumetric percent of Md value was calculated for SWC. This result demonstrates that simulated values by AMBAV model were close to those found in soil samples. Also, the RRMSE value of 7.37 shows a low data scattering by AMBAV model.

The development of fast and less costly method of the AMBAV model instead of timely, difficult and expensive soil sampling and soil moisture sensor is a great interest and one of the most promising new methods and techniques. The result of this study is in agreement with Friesland and Lopmeier (2007) and confirmed their results. According to the results of this study, it can be concluded that the AMBAV model performance was satisfactory in simulating the root zone SWC of the grass under field conditions. The AMBAV model was able to find the optimum date for grass-specific irrigation as an agro-meteorological. It is necessary to validate this model for different crops, soil types and weather condition.

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