Modeling soil water content and drainage in a subsurface drained prairie field using GPFARM-Range model

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ABSTRACT

A fraction of subsurface drained corn-soybean field has been converted to grassland in the Midwestern US prairies under the Conservation Reserve Program. This conversion has significantly improved environmental quality but may have altered the local hydrological cycle. Soil water, drainage, and evapotranspiration are very important factors in hydrological processes. Simulating these factors is essential to addressing hydrological processes appropriately. The Great Plains Framework for Agricultural Resource Management in Rangelands (GPFARM-Range) model is one of the recently developed rangeland management tools. The objectives of this paper are (1) to investigate the performance of GPFRAM-Range model in simulating soil moisture in prairie subsurface drained fields; and (2) to investigate the performance of GPFARM-Range model when using water flux to mimic drainage discharge rate. The data on soil water content, drainage, and crop biomass were collected at a subsurface drained prairie near Gilmore City, Iowa. This research compared simulated soil water content for four soil layers and total soil water storage with observed data. This research indicated that GPFARM-Range model was sufficient to simulate either soil moisture or subsurface drainage flow. When model simulated the soil moisture well (with percent bias (PBIAS) 5.1% and 1%, Nash-Sutcliffe model efficiency (NSE) 0.67 and 0.56 for calibration years and validation years, respectively), it can only simulate the subsurface drainage with PBIAS of -18.32% and NSE of 0.26, while keeping the subsurface drainage well (with four-year simulated water flux of 37.1 cm compared with observed four-year water flux of 37.0 cm), it can only simulate the soil moisture with NSE of 0.65 and 0.47 for calibration years and validation years, respectively. In scenario 1, which GPFARM-Range model simulated better on drainage than soil moisture, the evapotranspiration for perennial grasses were mostly higher (42.8 cm for 2006, 47.8 cm for

2007, 45.8 cm for 2008 and 44.8 for 2009) than corn in odd years and soybean in even years (41.7 cm for 2006, 49.9 cm for 2007, 40.2 cm for 2008 and 43.6 cm for 2009) except for 2007. For the other sites that planted soybean in odd years and corn in even years, the evapotranspiration for perennial grasses were higher in 2007 (47.1 cm compared with 47.8 cm) and 2009 (41.8 cm compared with 44.8 cm). The corn and soybean sites were planted from the same field at the same time. For the scenario 2, which GPFARM-Range model simulated better on soil moisture than subsurface drainage rate, the evapotranspiration for pasture land were relatively higher than scenario 1, which were 45.4 cm for 2006, 53.5 cm for 2007, 52.6 cm for 2008 and 50.6 cm for 2009. This study also demonstrated that it was not sufficient to mimic subsurface drainage using water flux from the last soil layer, which might due to the time lag.

RÉSUMÉ

Une fraction du drainage souterrain des champs de maïs-soja a été transformée en pâturage dans les prairies américaines sous le “Conservation Reserve Program”. Cette transformation a considérablement amélioré la qualité environnementale, mais c’est possible qu’il ait modifié le cycle hydrologique local. Teneur en eau du sol et l’évapotranspiration sont des facteurs très importants dans les processus hydrologiques. La simulation de ces deux facteurs est essentielle pour déterminé les processus hydrologiques de façon appropriée. Le modèle GPFARM-Range (Great Plains Framework for Agricultural Resource Management) est l’un des outils récemment développés en vue de la gestion des pâturages. Les objectifs de cet article sont : (1) Évaluer la performance du model GPFARM-Range pour simuler l'humidité du sol dans les prairies avec le drainage souterrain, et (2) Étudier la performance du model GPFARM-Range en utilisant flux de l’eau pour imiter le débit du drainage. Cette recherche a comparé la simulation de la teneur en eau du sol pour les quatre premières couches de sol ainsi que le stockage total de l'eau du sol avec les données observées. Cette recherche a fait preuve que le modèle GPFARM-Range n’est pas suffisant pour simultanément simuler l'humidité du sol et l’écoulement du drainage souterrain au site à proximité de Gilmore City, Iowa. Quand le modèle a bien simulé l’humidité du sol (avec le pourcentage de biais (PBIAS) de 5,1%; le rendement de Nash-Sutcliffe (NSE) 1% et l’année du calibrage et de la validation respectivement de 0,67 et 0,56), il était capable de simuler le drainage souterrain seulement avec le PBIAS de -18,32% et le NSE de 0,26, alors que pour le cas de la bonne simulation du drainage souterrain (avec le flux de l’eau simulé de quatre ans de 37,1 cm en comparaison avec ceux d’observé de 37,0 cm), il était possible de simuler l’humidité du sol avec le NSE de 0,65

et 0,47 pour respectivement les années de calibrage et de validation. Dans le premier scenario où le modèle a mieux simulé le drainage que l'humidité du sol, l'évapotranspiration pour les pâturages vivaces était majoritairement plus (42,8 cm en 2006; 47,8 cm en 2008 et 44,8 en 2009) que celle de maïs aux années impaires et de soja aux années paires (41,7 cm en 2006; 49,9 cm en 2007; 40,2 cm en 2008 et 43,6 en 2009) à l'exception de 2007. Pour les autres sites qui avaient cultivé le soja aux années impaires et le maïs aux années paires, l'évapotranspiration pour les pâturages vivaces était plus en 2007 (47,1 cm en comparaison avec 47,8 cm) et en 2009 (41,8 cm en comparaison avec 44,8 cm). Les sites du maïs et du soja ont été cultivés du même champ et en même temps. En cas du deuxième scenario où le modèle a mieux simulé l'humidité du sol que le taux du drainage souterrain, l'évapotranspiration pour les pâturages était relativement plus que le premier scenario (45,4 cm en 2006; 53,5 en 2007; 52,6 cm en 2008 et 50,6 cm en 2009). Cette étude a également fait preuve que ce n'était pas suffisant de seulement imiter le drainage souterrain en utilisant le flux de l'eau de la dernière couche du sol, ce qui pourrait être à cause du décalage.

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CHAPTER 1: INTRODUCTION

Since the late 1800s, in order to sustain intensive agricultural practices, many artificial drainage networks have been implemented in the prairie in the Midwestern United States and Canada (Danielson 1988; Rashford et al., 2011). The Farm Service Agency authorized the Conservation Reserve Program (CRP) to establish a long-term, resource-conserving plant cover on eligible land by signing the contracts with agricultural producers (McKenzie 1997). Farmers who were selected in this project consented to remove agricultural production from environmentally sensitive area and plant species that can improve environmental health and quality. In rewards, farmers can get the yearly rental payment. The long-term goal of the program was to re-establish valuable land cover to improve water quality, prevent soil erosion, and establish wildlife habitat (U.S. Department of Agriculture 2000). Under the Conservation Reserve Program, some subsurface drained corn-soybean field has been converted to grassland. This conversion has significantly altered the local hydrological cycle and improved environmental quality (U.S. Department of Agriculture 1997).

Changes in landscape management will influence the ecosystems, particularly with regard to the hydrologic cycle (Stephens et al; de Fraiture et al., 2008). Soil water content under pasture with prairie grasses was found to be significantly lower than corn-soybean rotation fields (Qi et al., 2011c). Perennial systems, due to more evapotranspiration loss, had less soil water content compared with cropping systems (McIsaac et al., 2010). Soil water content and evapotranspiration are very important factors in hydrological processes which also include infiltration, runoff (Bardossy and Lehmann 1998; Herbst et al., 2006), erosion (Moore et al., 1988; Wang et al., 2001), and flooding (Kitanidis and Bras 1980). Evapotranspiration is essential to simulate crop growth in agricultural systems (Fang et al., 2014). Compared with corn-soybean, perennial pasture species with deeper rooting systems and longer growing season, are expected to deplete more soil water, which differs hydrological cycle in comparison to corn-soybean field. Additionally, agricultural system can led to more drainage and lower soil water compared with natural system (Mitchell et al., 2012; Smettem 1998; Williams and Gascoigne 2003). Daigh et al. (2014) indicated that prairies contributed less cumulative drainage flow with greater evapotranspiration rate and lower soil water storage, consequently, resulting in lower peak flow intensities, longer time lag of both peak flow and drainage initiation. Overall, prairie systems can mitigate flood frequency in subsurface-drained landscapes.

Converting cropping system to prairie system can improve water quality through drainage system. Non-point source (NPS) nutrients through groundwater discharge and tile drainage has always been a major concern within cropping systems in Iowa (Buck et al., 2000; Dodds and Welch 2000; Hallberg 1987). NO_3-N loss was found particularly high during late winter and spring when stormflow increased (Alberts et al., 1978; Jaynes et al., 1999; Owens et al., 1991; Pionke et al., 1999). Excessive nutrients in soil water might influence soil erosion and degradation, as well as human and aquatic health (Buck et al., 2000). Qi et al. (2011b) reported that NO_3-N loss was significantly lower for prairie system than cropping system.

The evapotranspiration from perennial grasses is usually larger than corn and soybean. Checking soil moisture availability is necessary because soil moisture might limit prairie growth during summer time, when evaporation for prairie usually exceeds precipitation (Begg 1959; Smith and Stephens 1976). Besides, the seasonal and yearly variation of prairie growth should be considered, which is directly relevant to the framers' profits (Smith and Stephens

1976). The soil moisture under perennial grasses was found lower than under corn-soybean rotation (Qi et al., 2011b). The research site (Gilmore city, Iowa) was setup in 2004 for pasture fields, therefore no long-term experimental data available. Using model to simulate hydrological process becomes an option for evaluating the long-term impact of prairie.

Although there are many management tools to assess the environmental and hydrological scenarios for subsurface drained cropland, tools that can manage soil moisture, nutrient loss, and forage growth for perennial grassland are still in urgent call. Agricultural system models are useful tools to evaluate various agronomic management practices after careful calibration. The Great Plains Framework for Agricultural Resource Management in Rangelands Model (GPFARM-range) model has been successfully used to simulate water availability and crop production using long-term weather data. Bryant and Snow (2008) demonstrated that the GPFARM-Range model had strengths to simulate forage growth in grassland after comparing nine different rangeland agro-ecosystem models. In eastern Colorado, different datasets have been tested for crop growth, water balance, and nutrient cycling modules. The results indicated that forage module in the GPFARM-Range model did not sufficiently response to environmental stress (Andales et al., 2003; Andales et al., 2005). After several improvements such as separated transpiration and root growth for different functional groups and developed a phenology module, it was demonstrated that forage was successfully predicted in high plain grassland in Cheyenne, Wyoming (Andales et al., 2006).

Ascough et al. (2010) indicated that the GPFARM-Range model had high accuracy in simulating soil water content comparing to other agricultural system models, and it was even comparable with the RZWQM (Root Zone Water Quality Model). The GPFARM-Range model has been used to simulate cash crop and animal growth, but has not been tested against soil water content and drainage in a prairie field. The objectives of this paper are (1) to investigate the performance of GPFRAM-Range model in simulating soil moisture in prairie subsurface drained field; and (2) to investigate the performance of GPFARM-Range model when using water flux to mimic drainage discharge rate.

CHAPTER 2: LITERATURE RIVEW

2. Overview of Models

Several models are compared to the GPFARM-Range model with regard to some key functions such as their accuracy of simulating below-ground water, evapotranspiration, and whether they have complete hydraulic components and ability to simulate different functional groups for pasture.

2.1 APSIM

The Agricultural Production Systems Simulator (APSIM) is an advanced simulator in agricultural system. It can simulate both crop and pasture systems with different soils, water and nutrient modules interact with each other (Holzworth et al., 2014; Probert et al., 1998). APSIM has more complex process to simulate water movement and evaporation. In water module which is called SOILWAT, two methods are used to calculating water movement underneath soil. One is based on Richard's equation (Probert et al. 1998) and the other is based on the first-order mechanism (Verberg et al., 1996b; Verburg et al., 1996a). Two methods are interchangeable while it might cause water uptake error when water or nutrients are limited (Snow et al., 2014). Several research suggest that using different evaporation parameters for summer and winter would get better simulations (Verburg et al., 2003a; Verburg et al., 2003b). Due to the complexity and potential error, APSIM might not be the suitable model to simulate soil moisture in pasture land.

2.2 DairyMod

DairyMod model has the ability to simulate biophysical pasture growth in dairy or livestock systems. However, it has relative simple water and nutrient simulation process (Baldwin et al., 1987). Moreover, rather than being a key output component need further calibration, potential evaporation is an input under the model's setup, so the DairyMod is not suitable for this research.

2.3 FASSET

The Farm Assessment Tool (FASSET) can simulate both crops and pastures in agricultural systems. The sub-model, which simulates hydrology in the agricultural system, is a one-dimensional vertical model. This model is capable of simulating snow effect, evaporation from both crops and soil surface, transpiration, infiltration, water uptake through crop roots and percolation underneath soil surface (Berntsen et al., 2003). While it does not take into consideration of surface runoff and drainage components.

2.4 GRAZPLAN

GRAZPLAN can simulate pasture production, water balance and ruminant dynamics in agricultural system. The GrassGro module is capable of simulating soil moisture and pasture growth. However, the water lateral flow and crack flow are omitted in this module and there is also lack of drainage component (Moore et al., 1997). Moreover, some research found that there were some discrepancies when simulating pasture and animal production during severe drought areas. This might related to the model limitations of specifying soil physical characteristics (Donnelly et al., 2002).

2.5 HPM

The HPM (Hurley Pasture Model) focuses on nutrient flow and water dynamics in grassland (Bryant and Snow 2008). The model is capable of simulating canopy evapotranspiration, soil water content, water flux, and drainage, while it assumes the soil evaporation and surface runoff as zero (Thornley 2001).

2.6 GPFARM-Range model

The Great Plains Framework for Agricultural Resource Management in Rangelands (GPFARM-Range) model is a recently developed rangeland management tool. Driven by climate data, this model is capable of predicting plant growth, animal weight gain/loss, and carbon-nitrogen cycle for grazed rangelands using parameters of plant, soil, and animal. GPFARM-Range model aims to assist agricultural consultants and other users to plan strategies for rangeland or agricultural system based on economic, production and environmental impact (Ascough et al., 2010). All the inputs including climate, soil, plant, weed, chemical and economic parameters are accessed through Microsoft databases. Simulation of soil water dynamics, crop growth, animal production, and nutrient dynamics are through an object-oriented modeling framework (Ascough et al., 2010). This model can simulate up to 10 distinct horizons in soil profile. There are five functional groups in plant parameters, including warm season grasses, cool season grasses, legumes, shrubs, and forbs. Water balance and potential evapotranspiration (PET) module, both adapted from the Root Zone Water Quality Model (RZWQM) uses the Shuttleworth-Wallace double layer form of the original Penman-Montieth ET model (Farahani and Ahuja 1996; Hanson et al., 1998). The water balance and chemical transport module (WBCT) calculates daily soil water budget and chemical balance for a layered soil profile. Precipitation, evapotranspiration, runoff, snow melt, infiltration, soil water redistribution are included in the hydraulic process. Precipitation and irrigation water enters into soil profile mostly through macro-pores, and excess water after infiltration is considered as runoff. The GPFARM-Range model is capable of using actual precipitation intensities from breakpoint rainfall data, which has been proved to be an active method in soil water content simulation (J. C. Ascough et al., 2007). Infiltration into soil profile is calculated by modified Green-Ampt equation, using 1 hour time interval during daily rainstorm. Darcy's law is used to calculate the soil water redistribution within soil profile at 1 hour to daily intervals. The limitation of the GPFARM-Range model is that there is no drainage component in this model and water table is not accounted into hydraulic properties. However, drainage is estimated by water flux out of the bottom of soil layer. Potential transpiration, bare soil evaporation, and residue-covered soil evaporation are calculated in the PET module. Soil evaporation calculated the soil water content from first 5 cm of top soil layers towards the surface and limited by Darcy flux (Ascough et al., 2010). Actual transpiration is calculated by the sum of the root water uptake from each soil layer, available water, and potential transpiration.

Overall, GPFARM-Range model outperforms other models in its simulation accuracy and completeness which makes it appealing as a target model to simulate the two key components in this project: soil water content and water flux.

CHAPTER 3: METHODS

3.1 Site Description

The field experiment was conducted at the Agricultural Drainage Water Quality-Research and Demonstration Site (ADWQ-RES, former Agricultural Drainage Well Site) near Gilmore City in Pocahontas County, Iowa. Predominant soil are Nicollet (fine-loamy, mixed, superactive, mesic Aquic Hapludoll), Webster (fine-loamy, mixed, superactive, Calcareous, mesic typic endoaquolles), Canisteo (fine-loamy, mixed, superactive, calcareous, mesic typic Endsaquolls), and Okoboji (fine, smectitic, mesic Cumulic Vertic Endoaquolls) (Lawlor et al., 2008). Total area of research site is 4.5 ha which 3.8 ha is experimental plot and remaining is buffer and border. The size of each plot is 0.05 ha (15*38 m). The subsurface drain tiles were installed at the depth of 1.06 m. The plots (figure 1) were established after subsurface drain line established in 1989. Drainage water from each center line was collected in an aluminum culvert with automatic pumping, flow volume monitoring, and water sampling systems (Lawlor et al., 2008). “Duration” red (Trifolium retense) and “Pinnacle” ladino (Trifolium repens) clovers with “Extend” orchardgrass (Dactylis glomerata) were planted in four plots (10-1, 14-2, 17-2, and 19-1) on April 18, 2005. Data covers the period of four years, from 2006 to 2009.

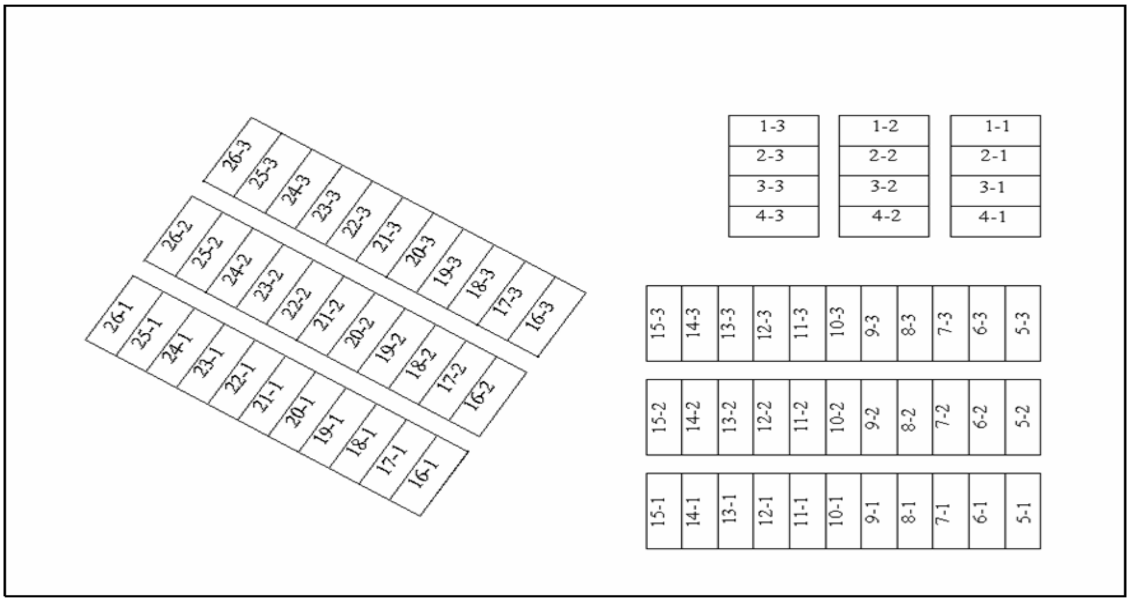

Figure 1. Experimental site map with corresponding plot numbers (adapted from Lawlor et al., 2008)

3.2 Data Collection

Weather data including precipitation, air temperature, solar radiation, relative humidity and wind speed were recorded by an automatic meteorological station at the site at a 5-min interval (Qi et al., 2011b). All missing data and winter snow depth were obtained from the National Climate Data Center (NCDC) stations at Humboldt and Pocahontas. The weather data, including hourly precipitation, daily maximum and minimum air temperatures, solar radiation, wind speed and relative humidity, were examined for outliers before imported into the model. Bulk density, particle size distribution, and saturated hydraulic conductivity, were determined from undisturbed soil cores. The soil water content was measured using a Theta probe (for top 5 cm soil) and PR2 profile probe (for soil from 5-100 cm depths) starting in spring 2006. Although there were four plots (10-1, 14-2, 17-2, 19-1) planting perennial grasses, there were only three plots (14-2, 17-1, 19-1) had observed data. In each soil water measurement plot, it was measured at two locations: north and south center between two tile drains. The PR2 probe was site-specifically calibrated in two continuous years of 2006-2007 (Qi and Helmers, 2010), while the parameters of the theta probe were adopted from Kaleita et al. (2005).

Soil water storage (SWS) was calculated in the depth of 0-60 cm during 2006 to 2009. The permittivity of the top soil (0-5 cm) was measured by a Theta probe for five times and the permittivity of the other soil layers were measured by a PR2 profile probe. Saturated hydraulic conductivity was measured with three runs for each soil core using the falling head method. Residual water content was estimated by extrapolating each of the soil water characteristics curves to a point where the gradient approached zero (Qi et al., 2011a). The subsurface drainage flow was measured by flowmeters and the reading was recorded weekly or biweekly manually.

3.3 Model Initialization

All the precipitation duration was set to 4 hours when precipitation occurred. Measured bulk density, particle size distribution, volumetric water content, and saturated hydraulic conductivity were used as input parameters in the GPFARM-range model. Total permeable soil depth was set at 390 cm according to a previous drainage simulation in corn-soybean fields by Singh et al. (2006). Soil cores were used to measure soil properties from depth of 0 to 120 cm, while soil properties were assumed to be the same as the depth of 90 to 120 cm (Qi et al., 2011a). In order to coordinate soil moisture with observed data, soil layers were manually reset to 7 layers, which were 0-6 cm, 6-15 cm, 15-30 cm, 30-60 cm, 60-90 cm, 90-200 cm, 200-390 cm.

There is no drainage component in the GPFARM-range model. In order to simulate drainage discharge rate for this research, an assumption using water flux from last soil layer to mimic drainage discharge rate was made, which was a strategy used by Tonitto et al. (2007a and 2007b) when simulating drainage using the DNDC model. Excess water can penetrate through last soil layer and accumulate in the impermeable layer which is similar to the process that excess water drained out through drainage pipe.

Crop parameters were manually adjusted to fit the measured biomass and yield components. Because phenology was not recorded in this study, parameters that affect the growing season length were estimated from the literature. Detailed crop parameters are listed in table 1. The Biomass to leaf area conversion factor is used to convert phytomass (m^2/g) to leaf area index (LAI). Hanson et al. (1988) suggested using 0.015 m^2/g for grasses and 0.03 m^2/g for forbs and shrubs. BiomLA values of 28.0 m^2/kg for cool season grasses and 35.0 m^2/kg for legumes were based on the literatures from Shipley (1995) and Garnier et al. (2001). The maximum relative growth rate, 0.18 per day for cool season grasses and 0.17 per day for legumes, were chosen from a range suggested by Groeneveld (1998). The proportion of cool season grasses and legumes were set 0.35 and 0.65, respectively. Initial live root biomass set at 5295 kg/ha for cool season grasses and 500 kg/ha for legumes was based on suggested range from Reeder et al. (2001). The proportion of live root biomass translocated to shoot at green-up or emergence shows how much root biomass can be translocated from the roots to the shoots. Although this parameter is not very sensitive and there are not many literatures reported the root-to-shoot translocation proportion within a given day, the value of 0.5% is adequate for the general prairie species (Wright et al., 1987). Other parameters were unchanged from the default values.

Table 1. Plant parameters for GPFARM-range model

Parameters	Cool season grasses	legumes	units
BiomLA	28.0	35.0	m^2/kg
elongateGDD	735	812	^oC-days
RootTrans	0.005	0.005	kg/kg
emergGDD	200	105	^oC-days
lastGDDSen	2380	2382	^oC-days
matureGDD	2200	1335	^oC-days
maxGR	0.18	0.17	proportion/day
propPop	0.35	0.65	kg/kg
rootDepth	50	152	cm
RSRatio	26.9	8	kg/kg
senGDD	1800	1858	^oC-days
tempBase	0	3	^oC
tempMax	36	35	^oC
tempOpt	20	20	^oC

BiomLA, biomass to leaf area conversion factor; elongateGDD, Growing Degree Days (GDDs) to end of vegetative phase and start of elongation phase; RootTrans, proportion of live root biomass translocated to shoot at green-up or emergence; emergGDD, GDDs required for emergence or green up; lastGDDSen, last GDDs of senescence after which all aboveground live biomass dies; matureGDD, GDDs to maturity; maxGR, maximum relative growth rate; proPop, proportion of from each functional group; rootBiomass, initial live root biomass; rootDepth, rooting depth; RSRatio, root to shoot ratio; senGDD, growing degree days until senescence begins; tempBase, base temperature for growth; tempMax, maximum temperature for growth; tempOpt, optimum temperature for growth.

3.4 Model calibration and evaluation

The calibration was conducted following the protocol provided by Ma et al. (2011 and 2012). The protocol suggested two options for a model calibration strategy: select one treatment in one or multiple years or use multiple treatments in 1 year. In this study, we chose to use the data from 2006 to 2007 as calibration and data from 2008 to 2009 as validation for soil moisture. During 2006 to 2009, the three plots (14-2, 17-2, and 19-1) were under the same treatment of pasture plantation. The annual precipitation from 2006 to 2008 were 62.6 cm, 105.0 cm, 92.6 cm, and 68.4 cm, respectively. In general, temperature in 2006 was warmer than the long-term average. However, the temperature in 2008 was slightly lower than long-term average. Thus, the calibration years adequately represented the range of weather at the site over the twenty years.

A number of statistics were used to quantify the goodness-of-fit of simulated data with observed information (Fang et.al. 2014). In this study, we used percent of bias (PBIAS), Nash-Sutcliffe model efficiency (NSE), root mean squared error (RMSE), index of agreement (IoA), and coefficient of determination (R^2). Equations for these statistical approaches are listed below.

$$NSE=1.0-\frac{\sum_{i=1}^{n}(P_i-O_i)^2}{\sum_{i=1}^{n}(O_i-O_{avg})^2}$$

$$PBIAS=\left(\frac{P_i-O_i}{O_i}\right)*100\%$$

$$RMSE=\sqrt{\frac{1}{N}\sum_{i=1}^{n}(P_i-O_i)^2}$$

$$R^2=\left\{\frac{\sum_{i=1}^{n}(O_i-O_{avg})(P_i-P_{avg})}{\left[\sum_{i=1}^{n}(O_i-O_{avg})^2\right]^{0.5}\left[\sum_{i=1}^{n}(P_i-P_{avg})^2\right]^{0.5}}\right\}^2$$

$$IoA=1-\frac{\sum_{i=1}^{n}(P_i-O_i)^2}{\sum_{i=1}^{n}(|P_i-\overline{O}|+|O_i-\overline{O}|)^2}$$

Where P_i is the ith simulated value, O_i is the ith observed value, O_{avg} and P_{avg} are the average of observed and simulated values, respectively, and n is the number of the data pairs. In this study, model performance was defined "acceptable" when PBIAS was within ±15% (Ahuja 2000; Hanson et al., 1999; Tsuji et al., 1998), NSE was >0.5 (Moriasi et al., 2007), R^2 was larger than 0.6, RMSE/O_{avg} less than 0.3.

Before calibration, soil moisture was overall overestimated. In the first soil layer, soil moisture was close to the observed soil moisture in early growing season and overestimated in late growing season in calibration years (2006-2007), while soil moisture was slightly underestimated in early growing season and overestimated in late growing season in validation years (2008-2009). In the second and the third soil layer, soil moisture was underestimated in early growing season and overestimated in late growing season for both calibration and validation years. In the fourth soil layer, soil moisture was overall overestimated in the whole growing season for 2006 and underestimated in early growing season; while it matched quiet well in late growing season for 2007. For validation years, it is underestimated in early growing season and overestimated in late growing season.

To calibrate the hydrology component, three parameters were adjusted to reduce error between the measured and simulated soil moisture (table 2). In this study, it was indicated that default pore size distribution and bubbling pressure led to an overestimation of soil moisture for almost all layers. The pore size distribution (λ) was found to be an extremely sensitive parameter based on research by Dhollander (1979), Assouline (2005) and Liu and Dickinson (2003). Using original pore size distribution resulted in an overestimation in soil moisture almost in every layers, increasing pore size distribution can help water penetrate to the next soil layer. The bubbling pressure (air entry pressure) is also a sensitive parameter, which refers to the pressure head of the soil water when air of zero gage-pressure enters soil with a continuous water phase. Bubbling pressure (also known as air-entry pressure, h_b) is negative while model internal already alters it to positive. Although there are many literatures such as Rogowski (1971) and Bouwer (1966) suggested the range of bubbling pressure, we calibrated it against measured soil moisture. In this study, the saturated hydraulic conductivity (Ksat) was found to be not as sensitive to soil moisture as pore size distribution and bubbling pressure. Increasing Ksat in the last layer from 0.1 cm/h to 2 cm/h allowed more water to penetrate through the last soil layer to get better subsurface drainage simulation. After calibration, simulated results indicated that total water flux from 2006 to 2009 was 114.16 cm, while observed drainage discharge rate was 148.18 cm. In order to further increase water flux from the last layer meanwhile keeping soil water content unaffected, it is necessary to decrease evapotranspiration. Mean stomatal resistance is a sensitive parameter for changing evapotranspiration. This parameter indicates how much water vapor respires through the stomata of a leaf, which reflects the transpiration. Decreasing transpiration can increase the amount of water seeping through soil profile. Increasing stomatal resistance from 50 s/m to 250 s/m can increase water flux from the last soil layer.

Table 2. Soil bulk density (BD) and texture and calibrated hydraulic properties of bubbling pressure (hb), pore size distribution index (λ), saturated hydraulic conductivity (Ksat), water content (WC),saturated water content(wcSat) and residential water content (wcRes) for sandy loam soil near Gilmore city, Iowa.

	Depth	BD	Clay	Sand	WC	kSat	wcSat	wcRes	h_b	λ
Layer	cm	g/cm^3	%	%	m^3/m^3	cm/h	m^3/m^3	m^3/m^3	cm	
1	0-6	1.37	0.32	0.32	0.359	4.84	0.482	0.071	4.60	0.240
2	6-15	1.38	0.32	0.32	0.372	3.30	0.476	0.072	5.20	0.158
3	15-30	1.39	0.14	0.33	0.391	5.05	0.473	0.079	4.40	0.143
4	30-60	1.39	0.27	0.43	0.388	4.09	0.474	0.068	4.80	0.148
5	60-90	1.45	0.22	0.44	0.454	2.64	0.450	0.034	3.40	0.230
6	90-200	1.46	0.22	0.44	0.450	2.64	0.450	0.033	4.00	0.200
7	200-390	1.50	0.22	0.44	0.450	2.00	0.450	0.033	4.00	0.200

To calibrate plant growth component, several parameters were adjusted to reduce errors between simulated and observed soil water content (table 3). Increasing BiomLA can increase plant transpiration rate and therefore enhance water infiltration into the soil (Wight 1983). In this study, we found that decreasing BiomLA can improve the soil moisture statistics especially for layer 2 (6-15 cm) and layer 3 (15-30 cm). The elongateGDDs is calculated between vegetative phase and elongation phase. In this study, it was suggested that changing parameter elongateGDD had no influence on both soil moisture statistics and pasture biomass. RootTrans shows how much root biomass allowed to be translocated from the roots to the shoots. Increasing this parameter decreases the plant production. Although this parameter is not very sensitive and there are not many literatures reported the root-to-shoot translocation proportion within a given day, the values of 0.5% are adequate for the general prairie species (Wight 1983). In this study, changing this parameter has no impacts on soil moisture statistics.

EmergGDD indicates the date when pasture emergence stage happens. Increasing this parameter postpones the first day for cumulating growing degree days. Original emergGDD was 200 ^{o}C-days for cool season grasses and 105 ^{o}C-days for legumes. Those parameters were adjusted to 450 ^{o}C-days for cool season grasses and 350 ^{o}C-days for legumes for better soil water content simulation. Original dates that cool season grasses and legumes started to grow were April 7 in 2006, April 2 and March 29 in 2007, April 22 and April 19 in 2008, and April 11 and April 2 in 2009. While after calibration the simulated first growth dates were April 26 and May 3 in 2006, May 2 and May 4 in 2007, May 15 and May 19 in 2008, and May 6 and May 8 in 2009.

LastGDDSen indicates that last growing degree days of senescence after which all aboveground live biomass dies. Increasing this parameter slows down the senescence process. Original lastGDDSen was 2380 ^{o}C-days for cool season grasses and 2382 ^{o}C-days for legumes.

This parameter was adjusted to 5000 ^{o}C-days for both plants. This parameter can slow down the senescence rate after peak standing crop. Original data kept the biomass very high (around 1000 kg/ha) in last growing month which didn't match real situation. After changing lastGDDSen to 5000 ^{o}C-days, biomass for both perennial grasses kept around 100 kg/ ha. MatureGDD indicates how many growing degree days required for pasture maturity. MatureGDD postpones the peak standing date and slow down the senescence process. In this study, it is suggested that changing matureGDD has no obvious impacts for both soil moisture statistics and pasture biomass.

The maximum relative growth rate (maxGR) is related to various leaf area ratio, net assimilation rate, specific leaf area, leaf mass ration, respiration and photosynthesis. The maxGR can vary when a low number of tillers are growing (Groeneveld 1998). In this study, the maxGR had slight influence on soil moisture statistics, yet is not big enough to change it. Roots are essential for water and nutrient uptake by plants (Zheng and Wang 2007). Maximum possible soil water transpiration can be determined by root depth, and this factor is the connection between soil environment to the atmosphere through water and energy exchanges (Feddes et al., 2001). In this case, deeper root depth makes calibrated soil moisture closer to the observed soil moisture during early season; while it makes even more overestimated during late season for both cool season grasses and legumes, which makes soil moisture statistics worse.

Increasing root to shoot ratio decreases the peak standing crop. The root to shoot ratio will be lower when light is limited compared with the situation where water is limited (Kozlowsk.Tt 1971; Struik 1970). Generally, grasses have much higher root to shoot than shrubs, and shrubs have slightly higher root to shoot ratio than forbs (Wight 1983). Detailed root to shoot ratio for different grass species are listed in Wight's book. In this study, changing root to shoot ratio for cool season grasses and legumes does not have a consistent impact on soil moisture statistics (in some cases, it improves the statistics, while others make them worse), which can't be unified. SenGDD indicates accumulated growing degree days between emergence and achieving peak standing crop. Increasing this parameter extends pasture growth period. The SenGDD (3600 ^{o}C-days for cool season grasses and 2900 ^{o}C-days for legumes) was calculated by using BELL function which adopted from Wright et al. (1987). Original last dates when cool season grasses and legumes had biomass were Aug 03 and Aug 26 for 2006, Aug 03 and Aug 24 for 2007, Aug 19 and Sept 19 for 2008, and Aug 15 and Sept 13 for 2009. According to observations, the last dates that cool season grasses and legumes accumulated biomass should end around late October or early November. After calibration, the last dates that cool season grasses and legumes accumulated biomass were Nov 16 for 2006, 2008, and 2009, Nov 15 for 2007.

Table 3. Calibrated plant parameters using in GPFARM-range model.

Parameters	Cool season grasses	legumes	unit
BiomLA	35	20	m^2/kg
elongateGDD	735	812	^oC-days
RootTrans	0.005	0.005	kg/kg
emergGDD	450	350	^oC-days
lastGDDSen	5000	5000	^oC-days
matureGDD	2200	1335	^oC-days
maxGR	0.18	0.17	proportion/day
propPop	0.35	0.65	kg/kg
rootDepth	50	152	cm
RSRatio	26.9	8	kg/kg
senGDD	3600	2900	^oC-days
tempBase	0	3	^oC
tempMax	36	35	^oC
tempOpt	20	20	^oC

BiomLA ,biomass to leaf area conversion factor; elongateGDD, Growing Degree Days (GDDs) to end of vegetative phase and start of elongation phase; RootTrans, proportion of live root biomass translocated to shoot at green-up or emergence; emergGDD, GDDs required for emergence or green up; lastGDDSen, last GDDs of senescence after which all aboveground live biomass dies; matureGDD, GDDs to maturity; maxGR, maximum relative growth rate; proPop, proportion of from each functional group; rootBiomass, initial live root biomass; rootDepth, rooting depth; RSRatio, root to shoot ratio; senGDD, growing degree days until senescence begins; tempBase, base temperature for growth; tempMax, maximum temperature for growth; tempOpt, optimum temperature for growth.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Calibration and Evaluation

The water balance from 2006 to 2009 simulated by the GPFARM-Range model is shown in table 4. For each year (2006-2009), the differences were all within ± 0.5 cm: almost equal to zero. The inputs for the water system are initial soil water storage at the beginning of the day and total water supply at soil surface; while outputs are soil water storage in the soil profile at the end of the day, deep seepage, evaporation, transpiration, and runoff. The initial soil water storage at the beginning of the day was calculated by volumetric soil water content multiplied by soil depth. When temperature was lower than 0^o C, precipitation became snowfall, and total water supply is set to zero. When temperature was higher than 0^o C, total water supply equaled to the sum of snow melt, irrigation, and rainfall (if applicable). In this study, there was no irrigation water applied to the field. From the comparison between total water supply and precipitation, it was indicated that part of the water were from the melting of snow accumulated from last year (e.g. Precipitation on 2006 was 62.636 cm, but total water supply was 66.248 cm). The default convection factor for precipitation to snow was 0.5 in the GPFARM-range model. Gilmore City locates in the northwest of Iowa where the wind speed could be lower than grassland in Colorado and Wyoming. According to long-term weather data in Gilmore city, the average wind speed from 1989 to 2009 was 3.8 m/s. Based on characteristics of its geography and wind speed, rainfall to snow convection factor was revised to 1. The annual precipitation from 2006 to 2008 were 62.6 cm, 105.0 cm, 92.6 cm and 68.4 cm, respectively. In general, temperature in 2006 was higher than the long-term average, however, temperature of 2008 was slightly lower than long-term average. Initial soil water storage ranged from 106.9 cm (2008) to 110.0 cm (2009). The volume of soil water at the end of day ranged from 106.9

cm (2007) to 110.4 cm (2009). In general, there were no significant differences in the soil water storage at the beginning/end of those four years. The evaporation ranged from 18.2 cm (2007) to 19.5 cm (2008). The transpiration ranged from 24.1 cm (2006) to 29.2 cm (2007). The evapotranspiration in 2006 and 2009 was lower compared with that in 2007 and 2008. The only runoff occurred on Aug 21, 2007, following a continuous 5 cm precipitation from Aug 18, 2007 to Aug 20, 2007 and a subsequent 9 cm on that day. The high saturated hydraulic conductivity also contributes to the fast infiltration process. Therefore, we were expecting a low frequency runoff event. Deep seepage varied from 22.5 cm (2006) to 56.6 cm (2007). The deep seepage followed the same pattern with precipitation, indicating the ability of the model to simulate seepage losses in response to precipitation variations.

Table 4. Water balance from 2006 to 2009 on cool season grasses and legumes at Gilmore city, Iowa, using GPFARM-Range (all values in cm).

Year	Precip	SW_i	WS_i	SP	AE	AT	SW_o	SR	ΔS
2006	62.6	108.8	66.2	22.5	18.8	24.1	109.6	0	0.2
2007	105.0	109.6	102.3	56.6	18.6	29.2	106.9	0.4	0.0
2008	92.6	106.9	91.0	42.2	19.5	26.3	110.0	0	0.0
2009	68.4	110.0	72.3	26.9	18.2	26.6	110.4	0	0.0

Precip, precipitation; WS, total water supply at surface; SP, deep seepage; SW_i, initial volume of water in the soil profile; SW_o, volume of water in the soil profile at the end of day; AE, actual evaporation; AT, actual transpiration; SR, runoff; Δ S, change in soil water storage.

The simulated evapotranspiration of corn-soybean rotation obtained by the Root Zone Water Quality Model (RZWQM) (Qi et al., 2011a) and of pasture by the GPFRAM-Range are illustrated in figure 2. CTRL1 and CTRL2 represent corn-soybean rotation with corn in odd and even years, respectively. The same research site and period offered the possibility of comparing the evapotranspiration of these two different land uses. In figure 2, evapotranspiration for perennial grasses were mostly higher (42.8 cm for 2006, 47.8 cm for 2007, 45.8 cm for 2008 and 44.8 for 2009) than corn in the odd years and soybean in the even years (41.7 cm for 2006, 49.9 cm for 2007, 40.2 cm for 2008 and 43.6 cm for 2009) except for 2007. For the other site that planted soybean in odd years and corn in even years, the evapotranspiration of perennial grasses were higher in 2007 (47.1 cm compared with 47.8 cm) and 2009 (41.8 cm compared with 44.8 cm). This might be because that perennial grasses have higher leaf area compared with corn and soybean, which provides greater area for photosynthesis and transpiration (Dohleman and Long 2009). Moreover, perennial grasses have longer growing season compared with corn and soybean (Dohleman and Long 2009; Heaton et al., 2004). The reason that in certain years that evapotranspiration for grassland were lower than corn and soybean fields was that we manually decreasing evapotranspiration for better water flux simulation.

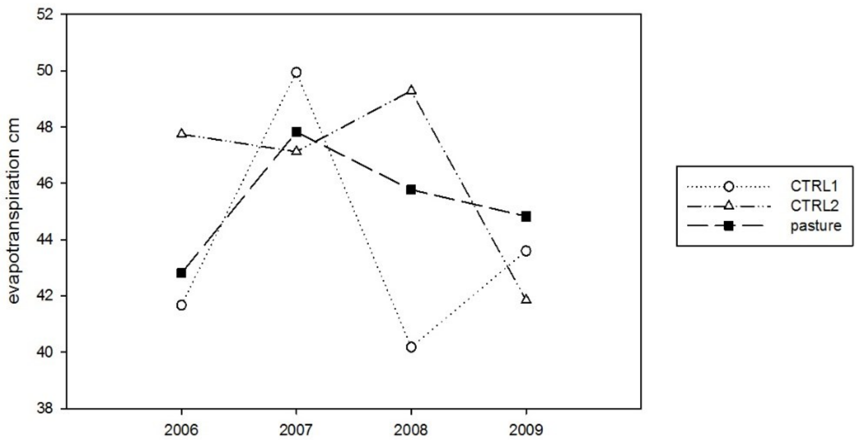

Figure 2. Evapotranspiration comparison between corn in odd years and soybean in even years without cover crop (CTRL1), soybean in odd years and corn in even years without cover crop (CTRL2) and pasture.

Simulated soil water content and total soil water storage for the calibration years are, in general, acceptable. The simulated and observed soil water content and soil water storage in the growing period (April to November) for the calibration and validation years are shown in Figure 3 and 4, respectively. The statistics for soil moisture simulation under calibration and validation periods are listed in Table 5. In the first soil layer, soil moisture simulated reasonably well in calibration and validation years, with PBIAS of 5.67% and 3.57% in calibration years and validation years, respectively. In the second soil layer, soil moisture was slightly underestimated in early growing season and overestimated in late growing season for both calibration and validation years. The PBIAS for soil water content in second layer were 2.44% for calibration years and 1.43% for validation years. The NSE was 0.31 in calibration years and 0.35 in validation years, which due to significant overestimation during June to October. In the third layer, the soil water content was overestimated in both late growing season for 2006 and in late growing season for validation years. The PBIAS for the third layer was -0.50% and 0.95%, with an NSE of 0.63 and 0.36 for calibration years and validation years, respectively. In the fourth soil layer, soil moisture was overall overestimated in the whole growing season in 2006 and marginally underestimated in early growing season, while it matched well in late growing season for 2007; slightly underestimated in early growing season and overestimated in late growing season in 2008 while it has significant overestimation through May to November in 2009. The PBIAS of the soil water simulation in the fourth soil layer was 4.18% for the calibration years and -0.21% for the validation years, with NSE of 0.53 and 0.38 for calibration years and validation years, respectively. Although some individual soil layer have low NSE values, the simulated PBIAS of the soil water storage were 4.88% and 0.93% for calibration and validation years, and NSE were 0.65 and 0.47, respectively.

Table 5. Statistics for comparison of simulated and observed soil water content and total soil water storage for the calibration and validation years under pasture using GPFARM-Range model.

	Soil water content								Total soil water storage (0-60 cm)	
Statistics	Layer 1 (0-6 cm)		Layer 2 (6-15 cm)		Layer 3 (15-30 cm)		Layer 4 (30-60 cm)			
	Cal	Val	Cal	Val	Cal	Val	Cal	Val	Cal	Val
PBIAS	5.67%	3.57%	2.44%	1.43%	0.50%	0.95%	4.18%	-0.21%	4.88%	0.93%
NSE	0.48	0.63	0.31	0.35	0.63	0.36	0.53	0.38	0.65	0.47
IoA	0.87	0.77	0.87	0.63	0.83	0.63	0.78	0.71	0.87	0.80
R^2	0.78	0.60	0.81	0.65	0.86	0.68	0.85	0.67	0.89	0.73
RMSE	0.04	0.05	0.04	0.04	0.03	0.03	0.04	0.03	1.65	1.52
RMSE/AVG	0.21	0.21	0.13	0.15	0.10	0.09	0.11	0.08	0.09	0.08

Cal, calibration; Val, validation; PBIAS, percent bias; NSE, Nash-Sutcliffe efficiency; IoA, Index of agreement; R^2, coefficient of determination ; RMSE, root mean squared error.

From the soil moisture simulation curve, it is indicated that the simulation results of water content in the surface layer (0-6 cm) was serrated and showed no observable trend compared with other layers. Moreover, there are some other interacting factors such as surface energy dynamics which might influence the simulation of the first soil layer water content (Qi et al., 2013). Compared with simulation results between calibration years and validation years, it was indicated that all the statistics from validation years are worse than that of calibration years.

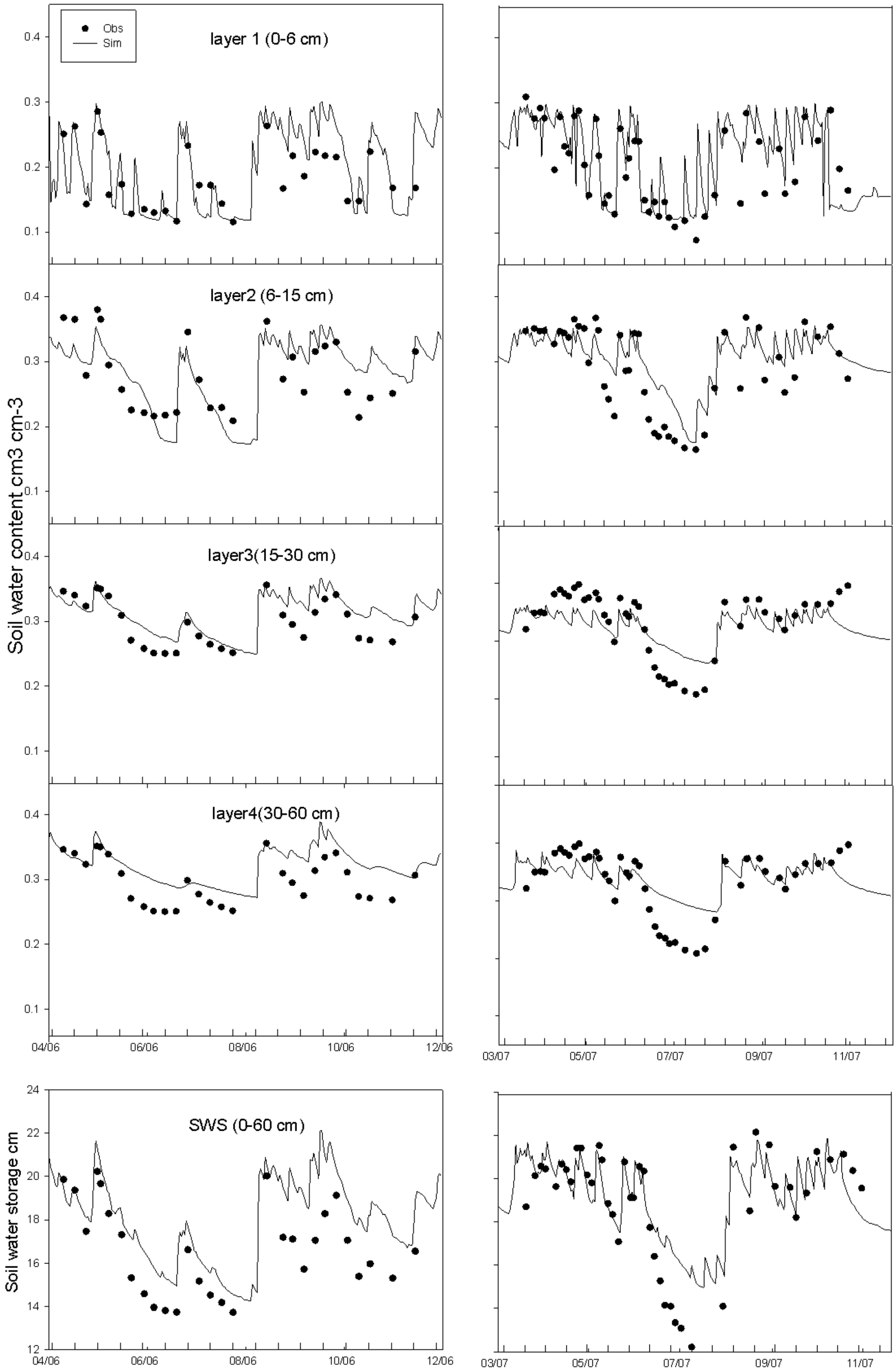

Figure 3. Observed (Obs) and simulated (Sim) soil water content and soil water storage for the calibration years (2006-2007) under pasture using GPFARM-Range model.

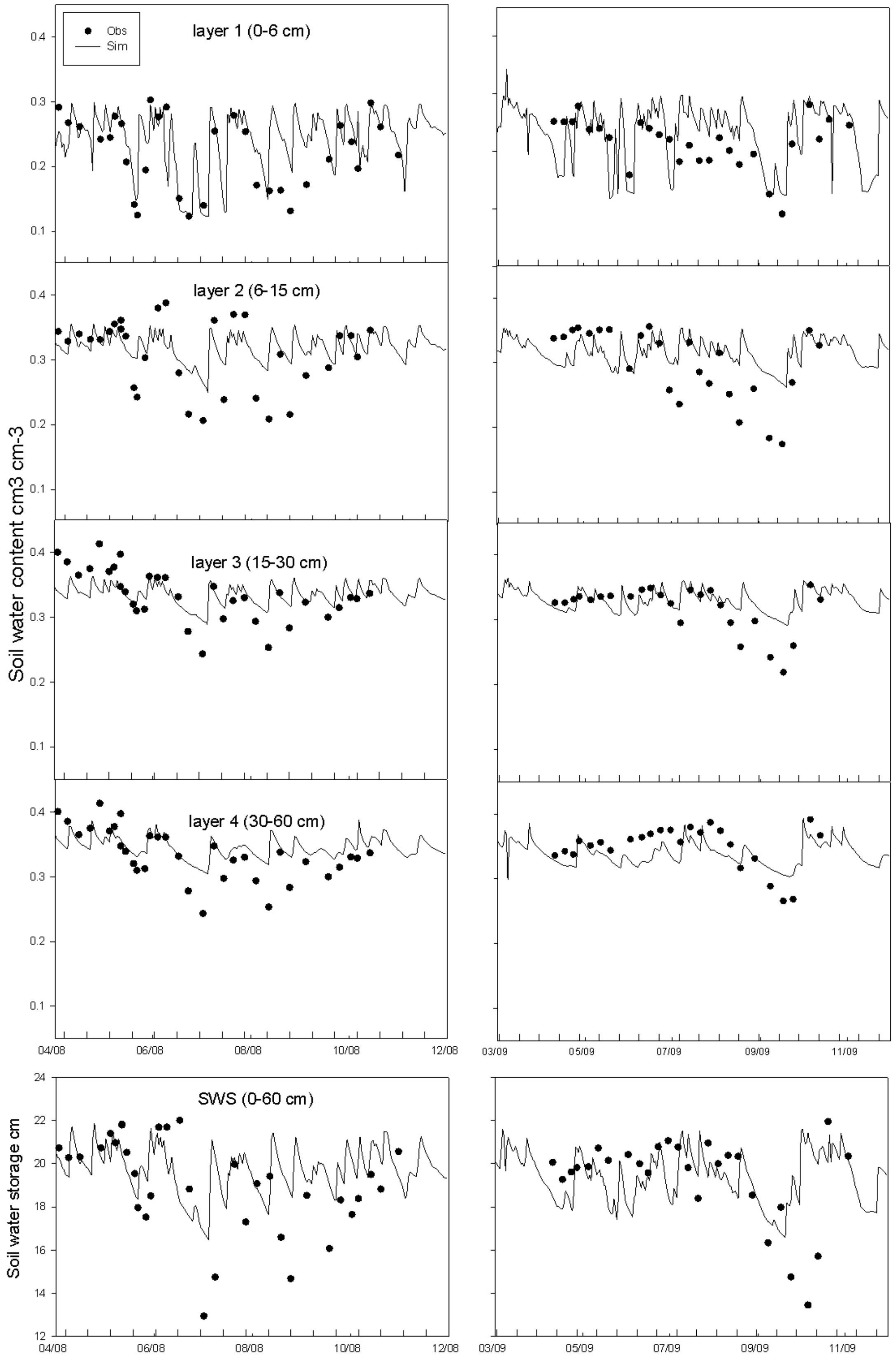

Figure 4.Observed (Obs) and simulated (Sim) soil water content and soil water storage for the evaluation years (2008-2009) under pasture using GPFARM-Range model

Table 6 shows the simulated peak standing biomass and observed peak standing biomass under pastures in the simulation years using the GPFARM-Range model. It was indicated that simulated biomass had not significant difference, ranged from 2390 kg/ha to 2528 kg/ha. However, observed biomass varied in different years. The highest peak standing biomass was 5794 kg/ha in 2006, while the lowest was 857 kg/ha in 2008. Detailed pasture biomass in the simulation years are shown in figure 5. It was demonstrated that in 2006 and 2007, most simulated biomass were higher than 2000 kg/ha, while they were lower than 2000 kg/ha in 2008 and 2009. We didn't calibrate pasture biomass for the simulation years but we can still see that the simulated biomass in 2006 and 2008 has significant difference with observed pasture biomass. The fitness on forage growth simulation could be a reason to illustrate the differences on soil moisture simulation during calibration and evaluation years.

Table 6. Observed (Obs) and simulated (Sim) soil water content and soil water storage for the evaluation years under pasture using GPFARM-Range model.

Peak standing biomass kg/ha	2006	2007	2008	2009
Simulated	2390	2394	2497	2528
Observed	5794	3364	857	1969

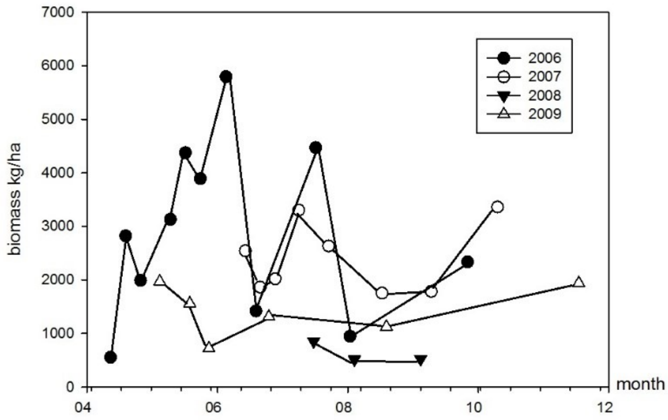

Figure 5. Observed pasture biomass in simulation years

The calibrated water fluxes are listed in table 7. It was indicated that in 2006,the water flux from last soil layer was high, reaching 22.49 cm, while the observed drainage, which was merely 10.82 cm. One possible reason for this high water flux vlaue is that might be due to the accumulated snow melting from last year. Similary, the low water flux from last layer in 2009 could be explained by model's mechanisms which accounts for the snow or rainfall accumulated on the surface to the next year. From table 9, it was indicated that water flux from last layer in 2006 and 2007 were much higher than the observed drainage, while water flux from last layer in 2008 and 2009 were much lower. It was very hard to adjust water flux with the existence of different rends. However, the average observed drainage from 2006 to 2009 was 37.04 cm, while the average of simulated water flux from last soil layer was 37.07 cm which was very close to the observed value. The PBIAS of the water flux was -0.07%, which was in the acceptable range, and the value of NSE was 0.40. Monthly comparison between simulated water flux from last soil layer and observed drainage is listed in table 9. Blanked observed drainage means there was no observed data during that month. From table 8, it was indicated that usually the first or first two observed drainage had relatively high values. This could be caused by the rising temperature and snow melting in April. However, the simulated water flux showed the different pattern. There was no significant difference in simulated water flux among different months except heavy rainfall happened in certain month, and soil profile can still have water go through last soil layer even in the winter time. The simulated water flux had time lag problem compared with the observed drainage. This was because drainage line was installed in the depth of 1.06 m, while the last soil layer was 3.9 m. Moreover, the saturated hydraulic conductivities in the last few soil layers were much lower the layers near soil surface; it slowed down the process of water penetrating through soil profile.

Table 7. Water flux calibration and evaluation under pasture using GPFARM-range model (all values in cm).

Year	Sim water flux	Obs drainage
2006	22.49	10.82
2007	56.62	43.67
2008	42.24	53.41
2009	26.94	40.28
4-year average	37.07	37.04
PBIAS	0.07%	
NSE	0.40	
IoA	0.79	
R^2	0.66	
RMSE	12.32	
RMSE/AVG	0.33	

Table 8. Monthly comparison between simulated water fluxes from last layer with observed drainage, using GPFARM-range model near Gilmore City, (all values in cm).

Year	Month	Sim	Obs	Year	Month	Sim	Obs
2006	Jan	1.3		2008	Jan	2.3	
	Feb	1.1			Feb	1.5	
	Mar	1.3			Mar	1.3	
	Apr	2.3	8.1		Apr	1.1	12.7
	May	3.3	2.3		May	2.0	11.7
	Jun	2.8			Jun	15.0	22.1
	Jul	2.1	0.3		Jul	6.7	1.3
	Aug	1.6			Aug	3.2	
	Sep	1.2			Sep	2.1	
	Oct	1.2			Oct	1.8	2.6
	Nov	1.2			Nov	1.6	3.1
	Dec	1.1			Dec	1.6	
2007	Jan	1.1		2009	Jan	1.5	
	Feb	1.0			Feb	1.2	
	Mar	1.1	0.9		Mar	1.3	
	Apr	2.1	11.1		Apr	2.0	7.3
	May	5.7	3.0		May	2.3	4.6
	Jun	4.4	0.4		Jun	2.0	3.9
	Jul	2.9			Jul	1.8	6.5
	Aug	7.1	17.5		Aug	1.9	1.2
	Sep	12.2	0.8		Sep	1.8	
	Oct	5.2	9.8		Oct	1.7	9.7
	Nov	5.5			Nov	2.6	5.3
	Dec	3.5			Dec	3.0	1.7

Because we can not get satisfied statistics on both soil moisture and drainage at the same time, we examined another scenario, with the expectation to get a better simulation results on soil moisture. Based on the previous research, the statistics on soil moisture showed worse simulation on second, third and fourth soil layers especially in validation years. Specifically, from April to June, the GPFARM-Range model was usually underestimated the soil moisture; and from July to November, the GPFRAM-Range model was usually overestimated the soil moisture. Moreover, based on the analysis of forage growth, the peak standing crop for 2006 for cool season grasses and legumes were on July 14, which were 842.39 kg/ha and 1502.18 kg/ha; the peak standing crop for 2007 were 891.1 kg/ha on July 1 for cool season grasses and 1502.19 kg/ha on July 4 for legumes; the peak standing crop for 2008 were 943.44 kg/ha on July 15 for cool season grasses and 1553.18 kg/ha on July 29 for legumes; the peak standing crop for 2009 were 948.7 kg/ha on July 18 for cool season grasses and 1572.51 kg/ha on July 22 for legumes. All the peak standing crop happened in July; it is also a threshold time point that soil moisture shows different trend before and after. In order to improve soil moisture simulation performance, we did several parameter changes: increasing evapotranspiration to reduce the water content in the soil, slowing down the forage growth process, and extending the senescence stage. The stomatal resistance was set to 50 s/m (250 s/m in scenario 1). Soil parameters are listed in table 9 and crop parameters are listed in table 10.

Table 9. Soil hydraulic parameters in scenario 2

	Depth	Ksat	h_b	λ
Layer	cm	cm/h	cm	
1	0-6	4.84	4.60	0.240
2	6-15	1.50	5.20	0.158
3	15-30	2.00	4.40	0.143
4	30-60	3.00	4.30	0.148
5	60-90	3.00	3.40	0.360
6	90-200	2.00	4.00	0.360
7	200-390	0.10	4.00	0.330

Ksat, saturated hydraulic conductivity; h_b, bubbling pressure; λ, pore size distribution.

Table 10.Crop parameters in scenario 2.

Parameters	Cool season grasses	Legumes	Units
emergGDD	500	450	^oC-days
maxGR	0.13	0.13	proportion/day
senGDD	3000	2300	^oC-days
senRate	0.001	0.001	proportion/day

emerGDD, GDDs required for emergence or green up; maxGR, maximum relative growth rate; senGDD, growing degree days until senescence begins; senRate, senescence rate.

Changing emergence GDD from 450 ^oC-days and 350 ^oC-days for cool season grasses and legumes to 500 ^oC-days and 450 ^oC-days postponed the dates that forage started to have biomass. Original dates that cool season grasses and legumes started to grow were on late April to early May. After calibration, the simulated first growth dates were on middle to late of May. The peak standing crop still happened around middle or late July, while biomass value was slightly different. On 2006, the peak standing crop were 780.33 kg/ha and 1366.56 kg/ha for cool season grasses and legume, respectively; on 2007, the peak standing crop were 712.08 kg/ha for cool season grasses and 1335.48 kg/ha for legumes; on 2008, the peak standing crop were 952.59 kg/ha for cool season grasses and 1567.2 kg/ha for legumes; on 2009, the peak standing crop were 974.12 kg/ha for cool season grasses and 1565.08 kg/ha for legumes. Changing max growth rate from 0.18 and 0.17 to 0.13 and 0.13 for cool season grasses and legumes can postpone the peak standing crop date, from middle or late July to late August or to early September. It also improved the statistics on soil moisture especially in validation years. Moreover, decreasing the senescence GDD and senescence rate improved the soil moisture simulation on validation years especially in second, third and fourth layers.

The simulated evapotranspiration comparison between corn-soybean rotation and pasture on scenario 2 is illustrated in figure 6. The evapotranspiration for scenario 2 for pasture land

(45.4 cm for 2006, 53.5 cm for 2007, 52.6 cm for 2008 and 50.6 cm for 2009) were higher than scenario 1. The statistics for soil moisture simulation are illustrated in table 12. Simulated soil water content and total soil water storage for the calibration years and validation years were, in general, acceptable. The simulated and observed soil water content and soil water storage in the growing period (April to November) for the calibration and validation years are shown in figure 7 and 8, respectively. In the first soil layer, soil moisture simulated reasonably well in calibration years, with PBIAS of 6.11% and NSE of 0.52, while in validation years, the PBIAS was 3.41%, and NSE was 0.23 which not larger than 0.5. The PBIAS for soil water content in second layer was 1.14% for calibration years and 1.75% for validation years. The NSE was 0.70 for calibration years and 0.51 in validation years. The PBIAS for the third layer was 0.95% and 1.69%, with NSE of 0.68 and 0.50 for calibration years and validation years, respectively. The PBIAS of the soil water simulation in the fourth soil layer was 4.97% for the calibration years and -0.08% for the validation years, with NSE of 0.51 and 0.39 for calibration years and validation years, respectively. Although NSE on layer 1 and layer 4 for validation years were lower than 0.5, soil water storage had PBIAS for 5.09% and 0.97% for calibration and validation years, with NSE of 0.67 and 0.56 for calibration and validation years, respectively.

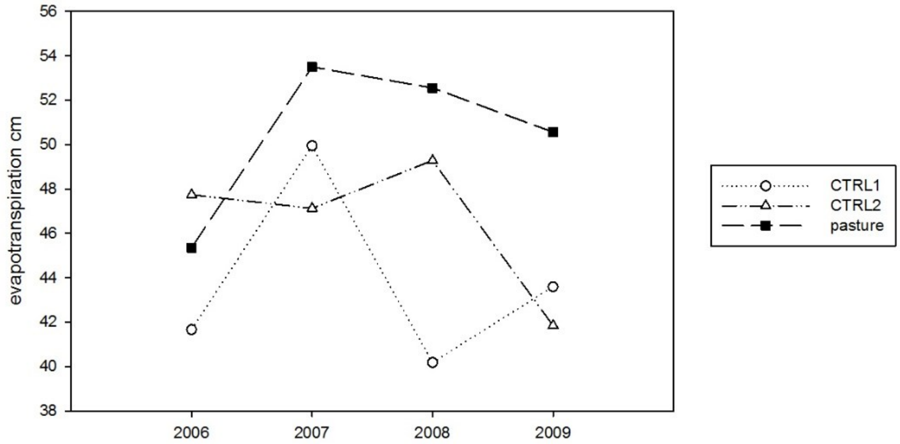

Figure 6. Evapotranspiration comparison between corn in odd years and soybean in even years without cover crop (CTRL1), soybean in odd years and corn in even years without cover crop (CTRL2) and pasture in scenario 2.

Table 11. Statistics for comparison of simulated and observed soil water content and total soil water storage for the calibration and validation years under pasture using GPFARM-Range model.

	Soil water content								Total soil water storage (0-60 cm)	
Statistics	Layer 1 (0-6 cm)		Layer 2 (6-15 cm)		Layer 3 (15-30 cm)		Layer 4 (30-60 cm)			
	Cal	Val	Cal	Val	Cal	Val	Cal	Val	Cal	Val
PBIAS	6.11%	3.41%	1.13%	1.75%	0.95%	1.69%	4.97%	-0.08%	5.09%	0.97%
NSE	0.52	0.23	0.70	0.51	0.68	0.50	0.51	0.39	0.67	0.56
IoA	0.89	0.82	0.93	0.80	0.88	0.75	0.78	0.73	0.90	0.85
R^2	0.83	0.68	0.86	0.76	0.84	0.76	0.83	0.65	0.89	0.77
RMSE	0.04	0.04	0.03	0.04	0.03	0.03	0.04	0.03	1.59	1.39
RMSE/AVG	0.20	0.20	0.12	0.12	0.09	0.08	0.11	0.08	0.09	0.07

Cal, calibration; Val, validation; PBIAS, percent bias; NSE, Nash-Sutcliffe efficiency; IoA, Index of agreement; R^2, coefficient of determination ; RMSE, root mean squared error.

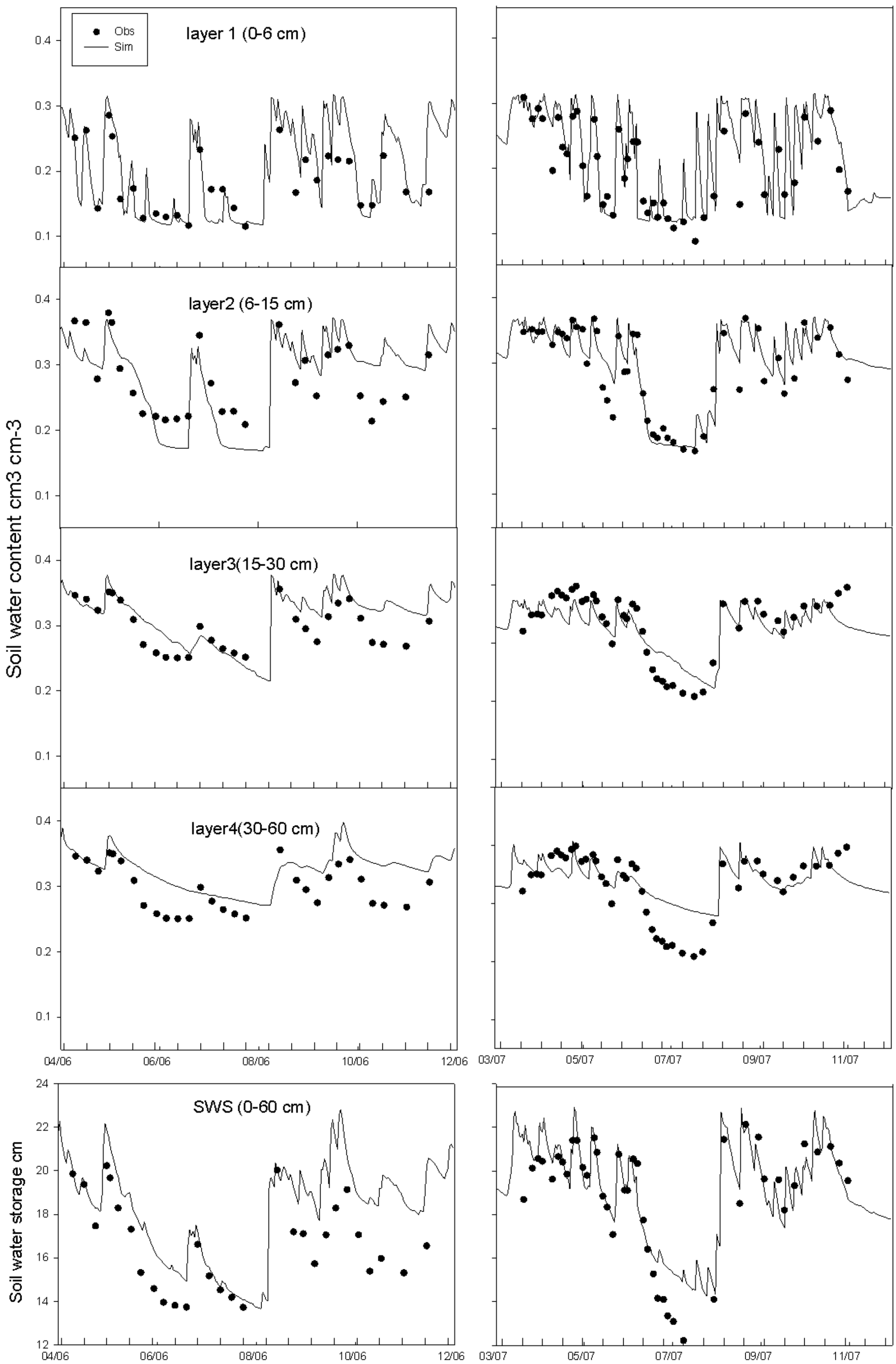

Figure 7. Observed (Obs) and simulated (Sim) soil water content and soil water storage for the calibration years (2006-2007) under pasture using GPFARM-Range model in scenario 2.

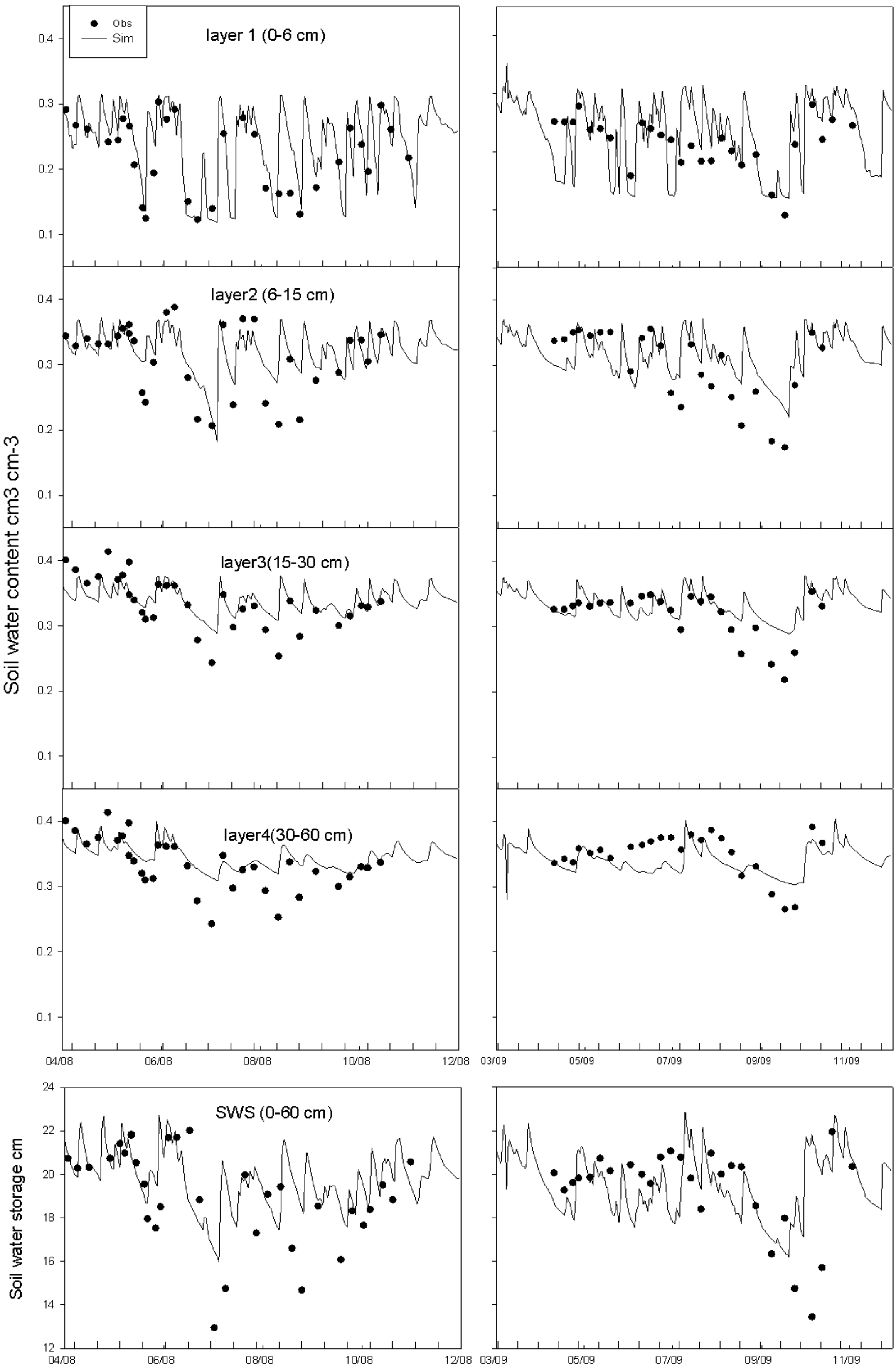

Figure 8. Observed (Obs) and simulated (Sim) soil water content and soil water storage for the validation years (2008-2009) under pasture using GPFARM-Range model in scenario 2

The calibrated water fluxes are listed in table 13. Compared with scenario 1, the water fluxes for scenario 2 were generally lower in different simulation years. The simulated water fluxes for 2006 and 2009 had larger difference with observed drainage: -18.32% of PBIAS and 0.26 of NSE.

Table 12. Water flux calibration and evaluation under pasture using GPFARM-range model in scenario 2 (all values in cm).

	Sim water flux	Obs drainage
2006	21.57	10.82
2007	44.25	43.67
2008	41.07	53.41
2009	18.35	40.28
4-year average	31.31	37.04
PBIAS	-18.32%	
NSE	0.26	
IoA	0.71	
R^2	0.63	
RMSE	13.69	
RMSE/AVG	0.37	

It was indicated that GPFARM-Range model was not sufficient to simulate both soil moisture and subsurface drainage flow at the same time. When model simulated the soil moisture well (with PBIAS 5.1% and 1%, NSE 0.67 and 0.56 for calibration years and validation years, respectively), it can only simulate the subsurface drainage with PBIAS of -18.32% and NSE of 0.26. When model simulated the subsurface drainage well (with four-year simulated water flux of 37.1 cm compared with observed four-year water flux of 37.0cm), it can only simulate the soil moisture with NSE of 0.53 and 0.38 for calibration years and validation years, respectively. The scenario 1 which simulated better on subsurface drainage might be reasonable because simulated water fluxes from last layer had better correspondence with observed drainage data. Moreover, the observed soil moisture data was not actually measured by the specific soil layers we used in this study. The scenario 2 which simulated well on soil moisture might be reasonable because the evapotranspiration for this scenario was higher than the scenario 1, which was more reasonable for pasture field. Moreover, the pasture fields were randomly selected within the whole research field, which surrounded by different corn or soybean fields. The subsurface drainage flow was measured below surface, there was possibility that subsurface water movement might be from other plots. It is hard to decide which scenario is more reasonable, further investigation is required.

One study conducted in the same research site in the same period using Root Zone Water Quality Model (RZWQM) also simulated hydrology in corn and soybean fields (Qi et al., 2011b). In this study, there were four corn and soybean fields. The model calibration was conducted in the TRT1 plot which was winter rye growth prior to corn in odd years and prior to soybean in even years, while validation plots were CTRL1 (corn in odd years and soybean in even years without cover crop), TRT2 (winter rye cover crop growth prior to soybean in odd years and prior to corn in even years) and CTRL2 (soybean in odd years and corn in even years without cover crop). The simulated soil water storage for pasture had different pattern compared with corn and soybean fields, which might due to the different growth periods. The PBIAS values for corn and soybean fields were within 5% for four plots, however, the NSE value was 0.46 for TRT1 and ranged from -0.79 to -0.04 for the validation plots. Compared with results using the RZWQM in the corn and soybean plots, the GPFARM-Range model had PBIAS values within 5.1% in calibration and validation years in both scenarios, and NSE values were all larger than 0.5 expect 0.47 for calibration years in scenario 1. In general, the simulated pasture SWS using the GPFARM-Range model proved to have better performance than SWS for corn and soybean fields using the RZWQM.

CHAPTER 5: SUMMARY AND CONCLUSIONS

5.1 Summary and conclusions

Soil moisture in 0-60 cm soil profiles, subsurface drainage flow, and biomass of grasses were monitored during the growing season of the period from 2006 through 2009 under pasture plots composed of cool season grasses and legumes in Iowa. In this study, an attempt was made to simulate soil water and subsurface drainage flow for this site using the recently updated GPFARM-Range model. After calibration and validation, we found that the GPFARM-range model was sufficient to quantify the soil water content and storage for a subsurface drained perennial pasture field near Gilmore city, Iowa. However, the model was not satisfactory in simulating both soil moisture and subsurface drainage flow at the same time. When the model simulated the soil moisture well (with PBIAS 5.1% and 1%, NSE 0.67 and 0.56 for calibration and validation years, respectively), it could only simulate the subsurface drainage with PBIAS of -18.32% and NSE of 0.26. When model adequately simulated the subsurface drainage (with four-year simulated water flux of 37.1 cm compared with observed four-year water flux of 37.0 cm), it could only simulate the soil moisture with NSE of 0.53 and 0.38 for calibration years and validation years, respectively. It is difficult to decide which scenario is more reasonable, therefore further investigation is required. Moreover, even though the simulated 4-year average water flux out of the last soil layer was in 1% error from the observed average subsurface drainage, this study suggests that adding a drainage component into the GPFARM-range model is necessary because it is not sufficient to simulate subsurface drainage in a timely manner.

5.2. Recommendations for future studies

The GPFARM-Range model simulates soil moisture and evapotranspiration in subsurface tile-drained pasture land. Some suggestions have been made to improve simulation.

1. Add drainage component into the GPFARM-Range model. In this study, we can only use water flux from last layer to mimic subsurface drainage to comparing observed data, which is not the best way to calibration. Adding drainage component into the GPFARM-Range model can improve the accuracy of hydrology simulation.
2. Lack of data on freeze-thaw process in the winter. In this study, there was no snow data to calibrate and the snow converting factor was assumed by the field geography. Testing snow data in the future would enhance the simulation performance of the model calibration.
3. It is suggested that using other field data with different climate conditions, soil types, and pasture variations to test the capability of the GPFARM-Range model.

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