**Adapting APSIM-AgPasture to simulate soil water, nitrogen and plant growth dynamics of multi-species reconstructed prairies in the Midwestern USA**

Tallgrass prairies once covered the United States, but have been replaced by row-crop systems such that only 1% remains. Prairie, consisting of a mix of perennial, deep-rooting species contrasts sharply with current annual monocultures in terms of both biomass allocation and biogeochemical processes. The substitution of cropping systems which differ so greatly from the native vegetation has resulted in a multitude of environmental problems. Field quality is degraded as soil, carbon (C), nutrients, and pesticides are lost and the water which gains these elements suffers in turn.

Many characteristics of a prairie would also be desirable for a cropping system if we are to reduce the detrimental effects of current production practices. Prairies have been shown to reduce the amount of nitrogen (N) leached from the soil, restore soil C in low-C soils, reduce greenhouse gas emissions, prevent soil loss through erosion, improve aggregate stability, reduce runoff, provide pollinator and insect habitat, and increase plant diversity. At the same time, prairies produce a large amount of biomass, xx-xx Mg/ha/yr. Many of the advantages that prairies have over cropping systems can be generally explained by perenniality and diversity, but many of the specific mechanisms underlying how prairies function are not well understood. For example, long-term prairie sites in England and Kansas have been harvested annually for many years with no reduction in production despite receiving no external inputs. Understanding how this happens requires a systems approach that examines the soil, plants, climate, and interactions therein. The best way to do this is through mechanistic simulation modeling.

There are many systems models that attempt to simulate soil and plant processes, but none that do so successfully for prairies. DAYCENT

A functioning prairie model will not only allow us to examine biogeochemical mechanisms, but also be useful at a number of levels. The environmental impact of food and energy production systems is receiving more and more attention from both consumers and industrial middlemen, and how to credit changes in management practices is often dependent upon modeled outcomes. In many cases, management plans should include the reconstruction of prairie for CRP or as incorporated strips. However, without a good prairie model, the uncertainty of the impact of additional prairie is large.

APSIM (Agricultural Production Systems sIMulator, Keatings, Holzworth) is a mechanistic modeling platform with over 80 different models available, including full soil and plant models. One of the models available in APSIM is AgPasture, a model developed in New Zealand for grazing systems. One unique component of AgPasture is the opportunity for three different plant functional groups which compete for resources aboveground, which is much more similar to how prairies function than a single-species model. However, the plant species used to create AgPasture are commonly used in grazing systems and so are much less productive than plants found in reconstructed prairie. We aimed to provide a mechanistic prairie model representative of multi-species prairie that can be used to study possible biogeochemical mechanisms, provide estimates of management effects, and be used to simulate long-term changes for slow processes, such as soil C dynamics. Therefore, we had two objectives: 1) customize APSIM AgPasture for prairies in central Iowa by developing appropriate crop and soil parameters; and 2) provide a systems-level performance assessment of the modified model.

Materials and Methods

Experimental data description

**APSIM configuration**

APSIM as an agricultural systems model contains several soil-plant-atmosphere models in to allow simulation of various aspects of cropping systems. In this study we connected in the APSIM software platform (version 7.5) the following models: (1) The AgPasture crop model for the simulation of intercropping perennial species (a description follows below); (2) The SoilN model for the simulation of soil organic matter and mineral nitrogen dynamics (Probert et al., 1998); (3) The SWIM, Soil Water Infiltration Model, for the simulation of the water balance (Huth et al., 2012). This model was preferred over the default SoilWat model because of its capacity to simulate fluctuating groundwater table and water flow in subsurface (tile) drainage, since both were present at the COBS site; (4) The SurfaceOM model for the simulation of residue dynamics (Probert et al., 1998; Thorburn et al., 2001; 2005); (5) the SoilTemperature2 model for the simulation of temperature along the soil profile. This model preferred over the default APSIM soil temperature model because reproduced experimental observation more accurately (see results); (6) the Micromet model for the computation of potential transpiration for multiple competing canopies (Snow and Huth, 2004); (7) the Manager model to specify fertilization and surface organic matter harvesting events (Keating et al., 2003).

**The AgPasture multi-species crop model**

The APSIM AgPasture crop model follows the principles of plant growth outlined by Thorney and Johnson (2000) and Johnson (2013). Its structure is very different from other APSIM models such as maize, wheat and soybean. Carbon assimilation is calculated at leaf level using photosynthesis-respiration equations and then is integrated to the canopy level using leaf area index and canopy architecture parameters. Most of the parameters are species specific and user defined (Table 1). The daily rate of biomass accumulation is affected by radiation, temperature, nitrogen, water, CO2 and extreme temperature response functions. For example, water and nitrogen limitations on crop growth are based on soil supply and plant-climate demand functions. The carbon produced every day is partitioned to shoot and roots using dynamics functions that the rate of partitioning is affected by water and nitrogen limitations also. If water is limiting, the plants will partition a greater portion of carbon to the roots to attempt to increase water uptake. The shoot carbon is further partitioned to leaf and stems (and stolon when a legume is present). The amount of carbon allocated to green leaves is used to calculate leaf area index using a user defined specific leaf area coefficient (Table 1). A key feature in the model is the shoot tissue turnover framework (net carbon assimilation 🡪 growing tissues 🡪 live tissue 🡪 standing dead/senesced tissue 🡪 litter), which accounts for N remobilization from senescing tissues to live tissues. The turnover rate is determined by a flux parameter, which is mediated by temperature and water. This turnover mechanism drives crop development and largely determines the end of the growing cycle. There is no specific plant development model (i.e. thermal time) in the model. The initiation or re-growth in the simulated perennial species starts as soon as weather variables are favorable for leaf photosynthesis and soil water and nitrogen reserves are adequate to support carbon assimilation. When multiple species are considered in the simulation, the main interaction that occurs between species is through the interception of light which drives leaf photosynthesis. For below growth processes, each species accesses water and nitrogen and interaction occurs because other species present in the simulation cause resource to be depleted rapidly or may access different regions of the soil profile. For each species, the maximum depth of the roots and its distribution along the profile is user defined.

**Model parameterization and validation**

Soil profile parameters were taken from Dietzel et al. (2016) and shown in Table 2. These parameters were derived at the same site for corn-based systems and used here as the soil is the same. Therefore, we focused on estimating the crop model parameters. It should be noted that the AgPasture model originally developed to simulate growth of high-nutritional perennial species used for animal grazing with multiple harvests over the season in New Zealand, which is a very different situation from the prairies growth and management in Midwestern US. Our strategy to adapt AgPasture to simulate prairies were: (1) the management protocol used in the experiment was incorporated into the model, i.e. dates and amount of annual residue removal for bioenergy production; (2) we specified three functional plants groups in the model that can compete each other on a daily basis for resources in order to represent reconstructed prairies growth situation in Midwest. A C3 grass, a C4 grass and a C3 herb was defined based on experimental findings at the site (Mengan et al., 2012); (3) we reviewed literature and used expert judgment and sensitivity techniques to develop initial parameters for these functional plant groups as a starting point (model parameterization); (4) then we used PEST to optimize some of those parameters (model calibration).

Johnson IR (2013). PlantMod: exploring the physiology of plant canopies. IMJ Software, Dorrigo, NSW, Australia. [www.imj.com.au/software/plantmod](http://www.imj.com.au/software/plantmod).

Thornley JHM & Johnson IR (2000). *Plant and crop modelling*. Blackburn Press, Caldwell, New Jersey, USA.

**Table 1 with calibrated parameter**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |
| # | Parameter | Range | C3 grass | C4 grass | C3 herb |
| 1 | Optimum temp for growth | 20–30 | 25.3 ± 0.2 | 26.3 ± 0.2 | 28.3 ± 0.2 |
| 2 | Specific leaf area | 10–40 | 18 | 18 | 18 |
| 3 |  |  |  |  |  |
| 4 |  |  |  |  |  |
|  |  |  |  |  |  |

What an experienced reviewer (modeler) wants to see and what I want to see in R/D:

1. Measured vs simulated and statistics for a number of variables – we have discussed this
2. A sensitivity analysis of all AgPasture parameters (Table 1) and rank them by importance. Then in the discussion we should say that the most important for further ticking is the …, the … and the …. To make a sensitivity there are different ways, I hope Isaiah can make that via PEST will add extra value, and then we present a bar plot showing the sensitivity of each (use # in Table). We can focus on biomass production for the sensitivity analysis and/or root growth for a specific year, or cumulative biomass over 3 years as a reference to judge sensitivity. Not sure which is the best way to follow here.
3. What new did we learn: a) use the model to estimate some variables that have never been measured such as ET, soil N mineralization, etc., and some text on how these compare with corn in the D. b) is the high measured root mass due to high DM allocation to roots of low decomposition of the old roots, what did we learn; c) what problems did we face in the calibration (we changed the source code to allow decomposition of FOM, also the N-stress and allocation root/shoot did not work and we change that manually, so different set of params for P and PF); d) stability test of the model (we ran the model for the next 20-years to ensure that it works fine, not shown but mentioned); e) text on calibration strategy and how we deal with the classical problem of model parameter compensation (Jim Jones et al., 2011); f) impact of this work (first time ever to simulate prairie mechanistically), why is important for publication; g) gaps for further work.

Some terminology which might be useful to consider:

Parameterization = start from zero and develop new parameters

Calibration = change existing parameters to fit data

Some notes:

* LAI should be below 10, change SLA from 20 to 18 everywhere
* Find which param we changed in the source code
* I would love to see a simulated plot of multi-species composition (average from 4 years)

JanRun2, check for ranae.

Sept 17, 2016. Sotirios re-started the calibration process.

I used my laptop and the SWIM version (7.6, r3731) to run the sim. I continued from where Isaiah stopped (sim name = JanRun2, check for ranae; new name the sample plus SVA1 at the end.

C:\Users\sarchont\Dropbox\Ranae\Ranae SWIM corn-soybean\000\_prairies for publication

Changes/improvements:

1. Used profile from FACTS (Fbiom/Finert partitioning, SOC, profile layer to 240 mm depth, no bbc condition and starting WT at 1070). These settings match up well SC, CS, CC, CCW simulations of yields, tile drainage and leaching which we might use for comparison later on.

Regarding the respiration there were many trade-offs in the systems. Respiration is a function of biomass, temperature and nitrogen. The higher the root biomass the more respiration but in the same time less N which means lower respiration. The lower the growth efficiency parameter it means more Rgrowth but in the same time less root biomass so lower respiration.

The first objective is to adapt APSIM agpasture to simulate prairies plant and soil dynamics. The second objective is threefold. Use of the model to 1) deeper understand of how prairie are functioning, 2) explore how the soil system will change if we had removed 100% or 0% prairie biomass and 3) compare prairie indices such as WUE, root distribution, leaching to corn/soybean?