AMBAWA: an Agent-Based Model of Biomass flows in Agropastoral areas of West Africa

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The description of AMBAWA (Agent-Based Model of Biomass flows in Agropastoral areas of West Africa) is based on the ODD protocol (Overview, Design concepts and details,) proposed in 2006 and revised in 2010 by Grimm and colleagues.

Overview

Purpose

AMBAWA has been built with the aim to contribute to the analysis of resource flows (organic and mineral fertilizers, crop residues) between crop and livestock systems for agropastoral areas of West Africa and Burkina Faso in particular. The objective is to compare the effects of different prospective scenarios on biomass productivity at the field, farm, and village scales.

Entities, state variables, and scales

The main entities represented in the model are described below:

- *the **farm*** is managed according to one of four predefined strategies based on typology of farmers found in the study area (Diarisso et al., 2015, see table 1).

Type	Farm area (ha)	Animal corralling on field	UBT min-max	Animal fostering	Supply of organic N (kg/ha)	Supply of mineral N (kg/ha)	Harvest rate of crop residues (%)
SO	4	No	2-5	No	3	51	31
AP	8	Yes	12-20	No	13	31	54
MO	10	No	4-8	Yes	12	45	29
PA	6	Yes	50-60	No	39	45	100

Table 1: The four types of farms (SO: subsistence-oriented crop farmers; AP: Agro-pastoralists; PA: pastoralists; MO: market-oriented crop farmers) and their characteristics (source: investigations in 2012-2013 cropping seasons).

The farm is made-up of fields, animals, the homestead, and an animal park (where animal manure is accumulated) located spatially. The farm is also a decision-making entity managing the animal fostering (traditional practice of entrusting the animals of the farm to another type of farm during all or part of the year), animal dislocation, supply of mineral and organic nitrogen to maize crop, and the harvest of maize stalks;

- the ***field***, represented by a cell in a spatial grid, is characterized by a surface area (1 ha), a location, and a type of coverage (road, corral, building, water dam, grass, crop, crop residue, fallow, forest, lowland). A single crop, maize, is simulated in the current version of the model, crop residues are consequently maize stalks;
- the ***grazing area is*** an aggregation of fields, characterized by an amount of grass that can be grazed by animals, and by a period of accessibility;
- *the* ***animals*** (aggregated in herds) are described by two types (draught oxen and breeding cattle), which differ in their seasonal movements (between grazing and cropping areas). Each animal (converted into a tropical livestock unit of 250 kg) has a daily forage need and a daily production of feces;
- the ***climate*** set the rainfall conditions (low, normal, good) for a given year.

Process overview and scheduling

Two seasons are represented in the model: a wet season from June 1 to October 31 and a dry season from November 1 to May 31. These seasons influence the biophysical (the production of feces and crop production) and decisional (the movements of animals, supplies of nitrogen, and harvest of maize stalks) processes in the model.

During the wet season, maize is grown taking into account the supplies of mineral and organic nitrogen specific to each type of farmers (see table above). Breeding cattle are affected to the grazing area until the end of the rainy season. Draught oxen are kept on their own farm and fed on the fallow fields of the cropping area. During the day, animals (of both types) produce manure on the fields they are assigned to (cropping or grazing area), and at night on the parks of their own farm or of the grazing area according to the type of animal.

In the dry season, each type of farmer harvests fodder stocks using the maize stalks produced in the rainy season on his/her farm. Breeding cattle leave the grazing area and with the draught oxen are assigned to the cropping area in order to be fed on the stalks left in the fields (unharvested fraction) of their farm on the day, while at night they are corralled. Animals move randomly throughout the cropping area and consume maize stalks. When the stalks are exhausted on the cropping area, the animals are fed on the fodder stocks of their own farm. Once the fodder stocks of their farm are consumed, the animals leave the simulation until the end of the dry season. It represents the transhumance practice (traditional practice corresponding to the search for new fodder out of the village).

The balance of inputs (nitrogen supplied by the farmer and by animals during grazing) and exports (harvests of grain and stalks) of nitrogen is calculated for each field of the cropping area, the nitrogen balance being used as a fertility indicator. An update of the nitrogen content of each field of the cropping area is made at the beginning of each rainy season.

The time step of the simulation is a half day. The distinction between night and day period allows taking into account animal movements to simulate production of manure and fodder consumption. Some processes, such as grain production, have a seasonal temporality.

Design concepts

Basic principles

The model was designed to analyze flows of biomass and nitrogen between different locations (cropping and grazing areas) and types of farmers at the village scale. Each farm is made-up of animals and fields (based on actual survey data). The animal plays a key role in the flows of biomass. It consumes biomass on some fields (in the pasture and the cropping area) and deposits organic manure in the parks (located on the farm or in the grazing area).

Interaction

The model simulates the interactions between different types of farms within a village. Direct interactions are simulated through animal fostering that links two farms via the temporary pooling of their animals. Indirect interactions are also considered through competition of animals of each type of farm for the access and use of a common resource (crop residues). Herds consume residues of other farms and deposit feces in the night corral of their own farms. Consequently farms with large animal numbers accumulate large amounts of animal manure using the biomass produced by other farmers.

Stochasticity

The decisions of farmers in the AMBAWA model are deterministic. However, animals on both the grazing area and the cropping area move randomly so as to avoid a crowd on some fields while others are unoccupied.

Details

Initialisation

Data used to describe the types of farms come from surveys conducted in the region site. Data on crop and animal production come from the literature (Defoer et al., 1998; Landais & Lhoste, 1993). The simulation begins June 1st, beginning of the rainy season. The simulated village has an area of 900 ha made-up of 7 % of grazing area, 85 % of cropping area, 5 % of natural protected area, and 3 % occupied by buildings, water dams, and roads (according to our field investigations). 94 farms representing the four types of farms in the proportions found in the region study (24 MO, PA 12, PA 16 and 42 SO), are simulated in the model.

Submodels

Grazing area

We assumed that the grass production in the grazing area is not a constraint for animal feeding during the rainy season (Vall & Diallo, 2009). During this period, satiety of animals is always satisfied. In the dry season, grass is significantly reduced in the grazing area. This biomass is below the threshold of a satiety estimated at 0.72 kg of dry matter per day per UBT (Vall et al, personal communication 2014). Consequently the animals do not use the grazing area during the dry season.

Fertility

The fertility of each field of the cropping area is determined at the beginning of each rainy season:

Fertility = CoefFert * ((MinN + Org N) / ConsN) (eq.1)

ConsN= ((GrainYield* CGA)/100) + ((StalkYield* CPA)/100) (eq.2)

With

- Fertility, the fertility of the field
- CoefFert, the coefficient of fertility of the field (from 0 to 1)
- MinN, the amount of mineral nitrogen applied by the farmer (kg/ha),
- OrgN, the amount of organic nitrogen applied by the farmer (kg/ha)
- ConsN, amount of nitrogen consumed by the crop (kg / ha)
- GrainYield, grain yield (kg / ha)
- StalkYield, the stalk yield (kg/ha)
- CGA, grain nitrogen conversion factor
- CPA, straw nitrogen conversion factor

Crop

Yields are calculated using the following equations :

GrainYield = BasicYield * fertility + (MinN + OrgN) * NAE (eq.3)

StalkYield= GrainYield /GSR (eq.4)

With :

- BasicYield, the average maize yield observed in the study site when no organic or mineral fertilizers are applied (400 kg / ha).
- NAE, the agronomic N use efficiency of fertilizers (14 kg/ha/kgN),
- GSR, ratio between grain and stalk (1.4)

The produced biomass changes according to the harvests made by the farmer (grain and fodder stock) and the uptake of crop residues by animals while grazing.

Animals

This submodel simulates the movements, fodder consumption, and production of feces by animals. The maximal amount of fodder that can be consumed per UBT per day is of 6.25 satiety threshold). The minimal amount of fodder that can be consumed per UBT per day is of 0.72 of dry matter per day (Defoer et al., 1998). Below this threshold, we assumed that the physiological needs of the animal are inhibited. The fecal production is closely related to the amount of biomass consumed. It does not exceed the maximum threshold set in the model, which is equal to 2.8 of feces per day (Landais & Lhoste, 1993). The amount of feces produced by an animal is higher at night than during the day (Rufino et al., 2006) representing 70% of the daily production (eq.5).

FecalProduction = satiety * RatioNightDay * fecesMax * nbHeads (eq.5)

with

- satiety, daily coverage of fodder need (depending on the amount of fodder ingested)
- RatioNightDay: Fraction of feces produced during the night (0.7) and the day (0.3)
- fecesMax: Maximal production of feces per day per UBT (2.8 kg)
- nbHeads, the size of the herd

The movements, consumption of biomass, and production of feces by animals vary seasonally. Breeding cattle are assigned to the two grazing areas of the village where the amount of forage is not a limiting factor for the whole rainy season. In the current version of the model, fecal restitution by animals in the grazing area is not considered, since they are not collected by farmers (observations from field surveys). Draught oxen use the fallow fields of the cropping area during the day and sleep on their own farms at night. Part of the animal manure produced during the rainy season is consequently harvested. During this period, MO farmers entrust their animals to AP farmers that receives their fecal production.

In the dry season, just after harvests (grain and part of stalks), animals produce manure during the day on the field while they are grazing the unharvested fraction of maize stalks. At night, they return to their own farms where they produce larger amount of animal manure.

When fodder supplies (first from the unharvested fraction of maize stalks of all farms, , and then from fodder stocks of their own farms) of animals do not meet their fodder requirements (below the fodder satiety), they go on transhumance and disappear temporarily of the simulation (they will return the following rainy season).

References

Defoer, Toon Budelmann, Arnoud Toulmin, C. Carter, Simon E., J. T. (1998). Building common knowledge : Participatory learning and action research Chapter 3 : Sources and flows of nutrients in farming. In Soil fertility management in Africa : A resource guide for participatory learning and action research. *Royal Tropical Institute, Amsterdam, The Netherlands / International Institute for Environment and Development, London, U.K,.*

Diarisso, T., Corbeels, M., Andrieu N, Vayssières J, Corbeels M, Blanchard M, Vall E, T. P., Djamen, P., & Tittonell, P. (2014). Biomass transfers and nutrient budgets of the agro-pastoral systems in a village territory in south-western Burkina Faso. *Nutrient Cycling in Agroecosystems*.

Grimm V., Berger U., Bastiansen F., Eliassen S., Ginot V., Giske J., Goss-Custard J., Grand T., Heinz S.K., Huse G., Huth A., Jepsen J.U., Jørgensen C., Mooij W.M., Müller B., Pe'er G., Piou C., Railsback S.F., Robbins A.M., Robbins M.M., Rossmanith E., Rüger N., Strand E., Souissi S., Stillman R.A., Vabø R., Visser U., DeAngelis D.L. 2006. A standard protocol for describing individual-based and agent-based models. *Ecological Modelling* 198: 115-126.

Grimm V., Berger U., DeAngelis D.L., Polhill J.G., Giske J., Railsback S.F. 2010. The ODD protocol: A review and first update. *Ecological Modelling* 221: 2760-2768.

Landais, É., & Lhoste, P. (1993). Systèmes d'élévage et transferts de fertilité dans la zone de savanes africaines. *Cahiers Agricultures*, *2*, 17.

Rufino, M., Rowe, E. C., Delve, R. J., & Giller, K. (2006). Nitrogen cycling efficiencies through resource-poor African crop–livestock systems. *Agriculture, Ecosystems & Environment*, *112*(4), 261–282. doi:10.1016/j.agee.2005.08.028

Vall, E., Diallo, M.A., 2009. Savoirs techniques locaux et pratiques : la conduite des troupeaux aux pâturages (Ouest du Burkina Faso). *Natures Sciences Sociétés*. 17, 122-135.