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Estimation of green water footprint of animal feed for beef cattle production in Southern Great Plains

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ABSTRACT

The goal of our study is to safeguard and promote regional beef production while mitigating its environmental footprint. Conducting a Life Cycle Analysis (LCA) including green water footprint (GWF) is one of the objectives. This manuscript describes the estimation of GWF of animal feed crops including grasses of native range and introduced pasture, winter pasture and small grains typical to Southern Great Plains. The estimates are based on modeled evapotranspiration from Agricultural Policy Environmental Extender (APEX) model under Nutrient Tracking Tool (NTT) framework. NTT simulated crop growth, water balance, animal grazing, and manure management using 47 years of weather data from 1960. Our results aggregated by county indicate grasses in the native range and field crops used as winter pasture show smaller GWF than grasses in the introduced pasture and small grains. Animal stocking rate appears to be directly correlated with water requirement to produce a unit quantity of forage.

1. Introduction

On an average, every American is consuming 27.7 kg (61.1 lbs) of beef each year [1]. Although per capita consumption has gone down from 33.8 kg (74.7 lbs) in 1985 [1], the demand for beef is steadily increasing because of increase in population and increased availability of safe and good quality meat. Beef animal production is important in the United States from the standpoints of food production, export potential and economic impact ($ 44 billion industry [2]). Although the market forces drive the production of beef, most producers wish to make sure beef cattle production is eco-friendly as much as possible. Also, the consumers should be aware of the ecological consequences of beef animal production.

About 50% of total beef cattle and calf production in the United States occurs in the five states of Texas, Nebraska, Kansas, Oklahoma and California [3,4] of which Texas, Kansas, and Oklahoma are in the Southern Great Plains (SGP). This outlines the importance of SGP for beef cattle production in the nation. Because of this importance, and the vulnerability of animal production arising from changing climate a five-year USDA-funded study titled “Resilience and vulnerability of beef cattle production in the Southern Great Plains under changing climate, land use and markets” was initiated as a multi-institutional and multidisciplinary collaboration involving four universities and three research centers. The collaborating institutions include the Texas Institute for Applied Environmental Research (TIAER)-Tarleton State University, United States Department of Agriculture (USDA)-Agricultural Research Service (ARS) in El Reno, Oklahoma, USDA-ARS in Bushland, Texas, Kansas State University, Oklahoma State University, University of Oklahoma, and the Samuel R. Noble Foundation in Ardmore, Oklahoma [5,6].

The project goal is to safeguard and promote regional beef production while mitigating its environmental footprint. The project is focused on the vulnerability and resilience of beef cattle – forage - rangeland – winter wheat production system in the SGP under changing climate. Conducting a full Life Cycle Analysis (LCA) is one of the major objectives of the study in addition to field experiments, extension, outreach and education [5,6]. Estimation of all inputs and outputs of water, energy, and greenhouse emissions in beef cattle production are parts of the LCA.

A typical beef animal production has three phases a) cow-calf b) backgrounding or stocking and c) feedlot before it is harvested for meat. The production begins with a cow-calf phase where a breeding

Abbreviations: **LCA**, Life Cycle Analysis; **APEX**, Agricultural Policy Environmental Extender; **USDA**, United States Department of Agriculture; **NASS**, National Agricultural Statistical Service; **SGP**, Southern Great Plains; **TIAER**, Texas Institute for Applied Environmental Research; **ARS**, Agricultural Research Service; **NRCS**, Natural Resource Conservation Service; **NTT**, Nutrient Tracking Tool; **CP**, Conservation Practice; **AU**, Animal Unit; **ASABE**, American Society of Agricultural and Biological Engineers; **ET**, Evapotranspiration; **NRC**, National Research Council; **OFPF** guide, Oklahoma forage and pasture fertilization guide

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herd of cows is raised that give birth to calves each year. Beef calves are weaned about six to ten months of age when they weigh 204–317 kg (450–700 lbs). Standing forage is the main diet of animals in the cow-calf phase. Weaned calves are sent to backgrounding or stocking where they graze on grass and forage until they are 12–16 months old along with their mother cows. As well some of the weaned calves are sold in the market. After back-grounding and before harvest the cattle spend four to six months in a feedlot receiving a balanced ration of a grain-based diet. This study focuses on the cow-calf and backgrounding phases only.

In the chain of beef animal production from calving to slaughtering the animal for meat, water is used in all the different phases. Water is used for producing grains for animal feed, raising pasture and forage crops, provision of water for drinking and servicing (cleaning the animals and their shelter) to animals. Also, water is used in the slaughter of the animals [7].

This manuscript deals with estimation of green water (green water is the water received from precipitation and stored in the soil which is available for the plants to use) footprint of animal feed production in beef cattle production in the study area.

Although there are a few previous studies on estimating green water footprint for beef cattle production, this study is unique because of a) the use of a physically-based model that simulates crop growth, water balance, animal grazing, manure management along with observations of real weather data for estimating water footprints, b) very detailed level of analysis involving aggregation of results of many model runs for different types of soil, slope combinations occurring in each county (about 2,400 km^2 land area), c) estimation of water footprints for each specific type of forage crop and grain typical of the study area, and d) establishment of relationships between water footprint and stocking rates, types of grazing animals and types of grasses.

2. Materials and methods

2.1. Description study area

The study area spans from north-central Texas, through Central Oklahoma, into south-central Kansas (Fig. 1). It comes under Natural Resource Conservation Service (NRCS) land resource areas of 80A and 78C. The landscape is composed of a vibrant forage-based beef cattle production system, which is one of the most productive yet temporally variable agricultural systems in the United States. This land use mosaic provides abundant ecosystem services. Similar to the rest of the conterminous United States, the study area experiences the North-South temperature gradient and East-West precipitation gradient.

The animal feed crops typical to the region include native range, introduced pasture, winter pasture and grains as detailed in Table 1. The native range and introduced pasture include both warm-season and cool-season grasses. The native range grasses are neither fertilized nor irrigated. The introduced pasture, winter pasture, and grains are fertilized but rarely irrigated.

2.2. Modeling tool and framework for analysis of results

The modeling tool used in the study is the Nutrient Tracking Tool (NTT). It is the enhanced version of the Nitrogen Trading Tool, an earlier model that was developed by the USDA [8]. NTT provides farmers, government officials, researchers, and others an efficient, web-based, and user-friendly method of evaluating the impacts of land management and conservation practices (CPs) on water quality and quantity. Both structural and cultural CPs can be evaluated in NTT with a few key strokes after selecting the user's field of interest. NTT estimates the impacts of each practice, or a combination of practices, on sediment, nutrient, and runoff, as well as farm production indicators such as crop yield. Agricultural Policy Environmental Extender (APEX) [9,10] is the computer model driving NTT. Through its interface with APEX, NTT simulates all CPs using rigorous algorithms while providing the user with a simple web-based interface for accessing the results.

The APEX model was developed to simulate the impacts of land management practices for small-medium watersheds and heterogeneous farms. The model can simulate runoff, sediment, nutrient transport (including its soluble and sediment-bound constituents), crop growth, animal grazing and manure management using physically based mechanisms. The land management operations simulated include tillage, planting, application of fertilizer and pesticides, irrigation, and harvest. Also simulated are many structural and cultural BMPs typical of agricultural areas.

The model can simulate a variety of crops including grasses in native range and introduced pasture, field crops, small grains, fruits, and vegetables. Crop rotation, multiple cropping, and crop competition can also be simulated by APEX. The existing capabilities of the model relevant to this study are animal grazing, feed intake on grazing land, deposition of solid and liquid manure by grazing animals, provision to have different stocking rates and animal types, and fate and transport of the manure and applied fertilizer on the landscape. The model uses the growing degree-days concept using real weather data to simulate crop growth. The routing of water, sediment, nutrient, and pesticide capabilities are comprehensive and similar to the procedures employed in some of the widely used watershed-scale models. The routing of constituents can be simulated between subareas and channel systems within the model.

The model simulations were carried out for different soil and slope combinations found in each county. About 47 years of observed daily temperature and precipitation were used to drive the model results. The long period of weather data in the study had many incidents of deviations from the temperature and precipitation patterns of normal years [11–13]. The model setup with 47 years of weather data is expected to capture the variations in the growth of animal feed crops and the associated water balance components. The initial two years of data and results were not included in the analysis of model output since it takes that long for the model state variables to assume realistic initial values. The modeling framework was pre-calibrated for crop yields, runoff and pollutant loads and therefore additional calibration was not carried out. The model runs at a daily time step. However, the results were aggregated at an annual time step by county and for the entire study region, which is adequate for the purpose of this study. It should be noted that the model results represent the edge of field/farm values for counties in Oklahoma only.

2.3. Definition of land management operations for the animal feed crops

The growth of grasses in native range and introduced pasture were initiated at the beginning of model simulations [14–16]. For grains and winter pasture, typical planting and harvest operations were taken from the agricultural handbook [2]. All the crops raised for animal feed in the region are rain-fed except an insignificant proportion ($<$ 2%) of grasses in the introduced pasture. Therefore, irrigation was not simulated in the model set up used for estimating GWF. However, APEX has the capabilities to model irrigation of crops.

2.4. Modeling cattle grazing

Some assumptions were made to enable realistic simulation of beef grazing operations. Cow-calf and stocker operations are cattle operations that graze cattle on rangeland and pasture. In the model simulations, only stockers were allowed to graze in winter pasture. However, all types of beef cattle were allowed to graze grasses in native range and introduced pasture. The number of animals allowed to graze (stocking rate) varies with (a) type of animal and (b) type of forage as outlined in Table 2 (Personal communication with project collaborators