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Research paper

Carbon dioxide emissions from switchgrass and cottonwood grown as bioenergy crops in the Lower Mississippi River Alluvial Valley

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A B S T R A C T

Marginal land of the Lower Mississippi Alluvial Valley (LMAV) has the potential to be utilized for substantial production of bioenergy feedstocks. However, resulting ecosystem services associated with dedicated bioenergy crop production, such as soil respiration and carbon dioxide (CO_2) emissions, which play an important role in global carbon (C) cycling, are not well understood. The objective of this study was to evaluate the effects of land use [i.e., switchgrass (*Panicum virgatum*) and eastern cottonwood (*Populus deltoides*) grown as dedicated bioenergy crops and a soybean (*Glycine max*)-grain sorghum (*Sorghum bicolor*) agroecosystem rotation] on monthly respiration and estimated annual CO_2 emissions for 2012 and 2013 from a silt -loam soil in east-central Arkansas. Peak monthly fluxes achieved each year differed ($p < 0.05$) somewhat among ecosystems. Annual CO_2 emissions differed among ecosystems ($p < 0.001$), but not between years ($p = 0.45$). Cottonwood emitted less CO_2 in both years (7.3 and 7.4 Mg ha^{-1} for 2012 and 2013, respectively) compared to the other two ecosystems, while emissions from the switchgrass did not differ from those from the soybean in 2012 (10.3 and 9.5 Mg ha^{-1}, respectively) or grain sorghum in 2013 (9.7 and 9.2 Mg ha^{-1}, respectively). Results showed established bioenergy feedstock cropping systems do not have greater soil CO_2 emissions compared with a traditional soybean-grain sorghum crop rotation. Results also indicated that different bioenergy feedstocks can produce different quantities of CO_2 emissions, which may be important to consider when converting marginal lands to bioenergy feedstock cropping systems.

1. Introduction

To meet the expected demand for feedstock mandated by the Energy Independence and Security Act, it has been estimated that ~169,000 km^2, ~10% of the total US agricultural land, would be required [1]. The majority of this area is expected to come from marginal lands too poor to profitably support row-crop production and from land coming out of the Conservation Reserve Program (CRP) [2]. Oak Ridge National Laboratory defined marginal land for agriculture as that whose productivity is limited by erosiveness, excessive wetness, soil chemistry constraints, rooting constraints, and/or climate factors [3]. This describes many areas in the Lower Mississippi Alluvial Valley (LMAV) of the mid-southern and southern United States.

The LMAV encompasses southeastern Missouri, western Tennessee and Mississippi, and eastern Arkansas and Louisiana. Alluvial floodplains, bottomland forests, and swamps in the LMAV were drained and converted into agricultural land dominated by cotton (*Gossypium* ssp) during the nineteenth century. Currently, the main crops grown in the LMAV are soybean (*Glycine max*), rice (*Oryza sativa*), grain sorghum (*Sorghum bicolor*), and corn (*Zea mays*) [4]. Despite their history of intensive cropping, many areas in the LMAV are poorly suited for cultivated crops because of susceptibility to soil erosion, poor drainage during rainfall events, and yield-limiting

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water supply during summer growing seasons. In contrast, the LMAV has been identified as an area that can support large switchgrass (*Panicum virgatum*) biomass yields [5].

Lowland-type switchgrass populations native to the southern US provide the source genetics for cultivars such as 'Alamo' and 'Kanlow', which can attain yields greater than 28 Mg ha^{-1} of dry biomass [6]. Furthermore, switchgrass is an attractive bioenergy crop for the LMAV area because switchgrass can persist in somewhat poorly drained soil conditions [7,8].

Eastern cottonwood (*Populus deltoids*) was once a part of the native bottomland forests in the LMAV before large-scale conversions of forests to cropland occurred in the 1960s and 1970s to meet the growing demand for soybean. In recent years, there has been an effort to restore a portion of the converted cropland back to bottomland forest [9]. Planting of eastern cottonwood has been targeted as a first step in reforestation of the LMAV since cottonwood is native to the region [10]. Cottonwood in general, and eastern cottonwood in particular, have been shown to have the fastest growth rate (i.e., 1.5–2.0 m y^{-1}) of all woody crops identified by the Department of Energy (DOE) as potential bioenergy crops on soils in the LMAV [11].

Bioenergy feedstocks, including switchgrass and cottonwood, may provide additional ecosystem services beyond being large biomass producers on marginal lands with relatively low-level inputs. The critical role of greenhouse gas emissions in driving climate change calls for a better understanding of soil respiration and carbon dioxide (CO_2) emissions from biofuel cropping systems, especially since such crops can reassimilate carbon (C) which is released during their combustion. Soil respiration, or the production of CO_2 by soil organisms and plant roots [12], is considered one of the largest C fluxes in the global C cycle, amounting to 68 to 77 Pg of carbon per year [13]. Root respiration accounts for roughly 50% of total soil respiration, but this fraction can vary widely depending on vegetation type and age, soil texture, and climatic regime [12]. Environmental factors, such as soil temperature and soil moisture, strongly regulate soil respiration and the resulting diffusion of CO_2 from the soil to the atmosphere [12]. Other factors associated with vegetation type and management, such as tillage and fertilization, can exacerbate CO_2 fluxes and emissions [14].

The type and magnitude of ecosystem services involving C cycling potentially provided by bioenergy cropping systems can provide and differences that may exist compared to more traditional cropping systems need to be measured in relation to traditional cropping systems to inform life-cycle assessments and guide the economics of potential greenhouse gas credits. Specifically, such measurements aimed at the LMAV could open up a new industry that can combine ecosystem improvement with economic development. Therefore, the objective of this study was to evaluate the effects of land use [i.e., switchgrass and cottonwood grown as dedicated bioenergy crops and a regionally representative soybean-grain sorghum crop rotation] on monthly respiration and annual CO_2 emissions from a silt-loam soil in the LMAV of east-central Arkansas. It was hypothesized that, due to more frequent soil disturbances, monthly fluctuations in soil respiration and annual emissions will be greater in the soybean-grain sorghum crop rotation than in the switchgrass or cottonwood ecosystems.

2. Materials and methods

2.1. Site description

This study was conducted at the University of Arkansas Division of Agriculture's Pine Tree Research Station (PTRS) (35°8′33.12″N, 90°44′24′66″W), near Colt, AR. The PTRS is located in the LMAV in St. Francis County in east-central Arkansas. The approximately 12-ha study site is poorly drained land that was previously used for row-crop production. The study area is surrounded on the north, south, and west by forest and by other cropping systems to the east (Fig. 1). St. Francis County is located in the Southern Mississippi Valley Loess area, which is Major Land Resource Area (MLRA) 134 [15].

The study area is comprised of Calloway silt loam (~45%), Henry silt loam (~30%), and Loring silt loam (~17%) [16]. The Calloway silt loam (fine-silty, mixed, active, thermic Glossaquic Fragiudalf) is somewhat poorly drained with 30–60 cm to the water table and contains a fragipan at 40–60 cm [16]. The Henry silt loam (coarse-silty, mixed, active, thermic Typic Fragiaqualf) is poorly drained with the water table at 0–30 cm and a fragipan at 35–56 cm [16]. The Loring silt loam (fine-silty, mixed, active, thermic Typic Fragiudalf) is moderately well-drained with the water table at 46–76 cm and a fragipan at 60–81 cm [16].

The climate of the region is warm and wet with a 30-y mean annual temperature minimum of −11.9 °C in January and a 30-y mean annual maximum of 37.6 °C in August [17]. The 30-y mean annual precipitation is 127 cm [17].

2.2. Field treatments and establishment

Eastern cottonwood and switchgrass were selected as bioenergy feedstock for this study. A soybean-grain sorghum rotation was selected as a control treatment to represent the common upland row-crop rotation throughout the region. A set of three plots was used for each treatment. Two plots measured 30 m × 90 m, and the third plot measured 90 m × 90 m. A 17 m × 45 m subplot area was established as the measurement area within each plot (Fig. 1). The 90 m × 90 m plots served to provide more accurate production and wildlife data, as primary goals of the overall project, for which this specific study was a part, were a complete economic and

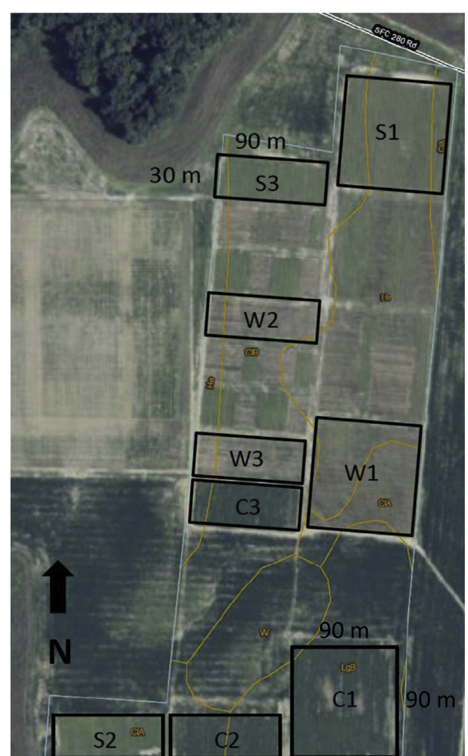

Fig. 1. Aerial image of the study site at the Pine Tree Research Station near Colt, AR. Switchgrass (S1, S2, S3), cottonwood (W1, W2, W3), and soybean-grain sorghum crop rotation (C1, C2, C3) treatments, individual plot locations, and dimensions are noted.