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Modeling poplar growth as a short rotation woody crop for biofuels in the Pacific Northwest

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ABSTRACT

Predicting the economic viability and environmental sustainability of a biofuels industry based on intensively cultivated short rotation woody crops (SRWC) requires spatial predictions of growth and yield under various environmental conditions and across large regions. The Physiological Principles in Predicting Growth (3PG) model was modified to evaluate the growth and yield of coppiced poplar (*Populus spp*). This included an additional biomass partitioning method and developing a sub-model which takes into account the impact of coppicing on post harvest regeneration, extending the applicability of the 3PG model to coppice management regimes.

The parameterized model was applied to the entire Pacific Northwest of the United States, using appropriate climate and soil input data. Results predict the yield of poplar cultivation at a spatial resolution of $\approx 64\ km^2$ throughout the $\approx 8{,}000{,}000\ km^2$ of the study region. Existing agricultural cultivation patterns were used to estimate regional water availability for irrigation, and for non-irrigated regions, land cover features including ownership, slope, soil salinity and water table depth where used to select areas with a real potential to support a SRWC plantation.

Results can be integrated with other models that allow for optimizing crop selection and biorefinery site selection. Important results include; an updated 3PG model for coppiced SRWC plantings, estimates of biomass feedstock yields under different irrigation patterns and weather conditions, and estimates for feedstock availability when combined with crop adoption scenarios.

1. Introduction

The Advanced Hardwood Biofuels Northwest (AHB-PNW) is a consortium of university and industry partners investigating the development of a sustainable hardwood biofuels industry in Washington, Oregon, northern California, Idaho, and western Montana in the United States. Inspired in part by the U.S. Energy Independence and Security Act 2022 targets for renewable fuel, AHB-PNW is carrying out research and development to support a system for growing and converting hardwoods, such as hybrid poplars, into liquid biofuels. This

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research and development initiative has focused on fuels fully compatible with existing liquid transportation fuel infrastructure.

To support economic and environmental models for a biofuels industry, spatial predictions of yield for short rotation woody crops(SRWC) under various environmental conditions are required throughout the entire Pacific Northwest (PNW) region. The Physiological Principles in Predicting Growth (3PG) [1–3] model was utilized for this purpose. Empirically based growth and yield models for hybrid poplar have been used with some success in the region [4], however the samples used to develop allometric relationships did not include coppice management. Stand to Ecosystem CaRbon and EvapoTranspiration Simulator (SECRETS) [5] is another process based model, differing from 3PG in a number of ways, including biomass production and aboveground partitioning [6].

The 3PG model was modified for SRWC, particularly for poplar plantation methodologies. The motivation for the use of spatially resolved yield estimates is two-fold:

1.1. Biofuels production system optimization

Substantial investment is required to construct facilities capable of producing drop-in fuels [7]. Capitalization of these facilities will depend upon a demonstrated consistent supply of feedstock. While spot or commodity markets may emerge to supply the demand for these facilities via bulk rail or marine supply chains, first mover facilities will likely depend on contracts with regional producers to supply a substantial percent of the facility demand. This analysis helps identify locations likely to have access to substantial local supply.

1.2. Land use

The potential for displacement of food crops from agricultural lands is a possible outcome of expanding biofuel markets. The impacts associated with an increase in food prices on global food security raises ethical issues that relatively developed and food-secure societies must consider [8]. This exercise helps identify land not currently in food production that is potentially viable for SRWC production.

3PG predicts total carbon based on photosynthetically active radiation and is parameterized by variables relating to the tree, soil (water availability) and weather data. It produces monthly estimates of foliage stem and root biomass. In this analysis 3PG is run for each pixel within a grid of the PNW. Each pixel is modeled as a stand with input parameters that vary with geography (soil, weather) are used to parameterize the model. Modifications to the original 3PG model include changes to the biomass partitioning, and the inclusion of a root contribution to regrowth after coppicing.

A physiological growth model such as 3PG is advantageous because it allows variation of growth parameters and assumptions regarding management practices for poplar species. In addition to biomass growth and yield estimations, allocations for both above and below ground biomass can be tracked for more complete life-cycle analysis of the carbon budget related to the fuels.

The 3PG model has been used previously to model SRWC production. One [9] used the 3PG to predict growth of the Walker poplar hybrid (*Populus deltoides* x *Populus nigra*) in Saskatchewan, Canada. This analysis did not investigate the growth dynamics related to coppicing. In a separate study [10] the SECRETS model was modified and evaluated for coppice poplar production from two varieties under a range of soil fertility conditions. The SECRETS coppice modified partitioning fractions with the presence of a large root mass, one of the outcomes of the coppicing model described here for 3PG.

The 3PG model [11] has been deployed across several states in the northern Midwest United States to predict growth and yield of hybrid poplar but did not evaluate the impact of coppice management. To date, the use of physiological growth models such as the 3PG to evaluate spatial variability in yields of coppiced SRWC at the scale and extent of the results presented here has not been attempted.

The original 3PG model does not include coppicing as a management practice, which is problematic as it cannot reasonably account for post-coppicing regrowth. Coppicing of SRWC has been widely demonstrated to increase growth rates post-coppice in comparison to un-coppiced stands [12–14]. The extensions presented in this paper include coppicing with a general sub-model that allows a monthly growth contribution from an existing root mass. The model specifies a relatively small contribution of aboveground growth from the accumulated root mass after coppicing in order to initiate the next cycle of production [10].

With appropriate input information, the 3PG model can predict yields for the entire Pacific Northwest study region, under various irrigation scenarios. When linked with models of crop adoption, biofuel feedstock estimates are possible.

2. Methods and calculation

The main goal of this study was to create spatially explicit poplar growth potential for the PNW that can reliably predict yield from SRWC plantations in the region.

The study area, the Pacific Northwest of the United States, includes Washington, Oregon, northern California, Idaho, and western Montana. A regular grid partitions the region. The individual pixel size is a relatively coarse 8192 m $\times$ 8192 m. The spatial aggregation will necessarily result in yield estimates that do not capture local variability. However, the intent of the study is to identify areas of high productivity within the study region. A coarse geographic unit was selected to strike a balance between geographic specificity and complexity of subsequent modeling steps not covered in this paper. Another similar study [11] used 32 km^2 spatial resolution.

An Albers equal area projection with reference longitude 120° W, latitude 44° N and parallels at 41° N and 47° N was utilized [15]. Other input datasets (eg. climate, soils) were scaled to match the base pixel size and raster projection. For example, the National Land Cover Dataset (NLCD) used in this study, was originally imported and projected at a much finer scale, 32 $\times$ 32 m, then aggregated upwards and used to determine proportion of landcover types within each 64 km^2 unit. Section 2.2 provides additional exemplary detail.

Data processing was carried out within a postgresql database, with the postgis geospatial extensions [16–18]. The 3PG model was implemented directly in the postgresql database