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Abstract. To determine appropriate forage species for US ecoregions, geographic information technologies (GIS) are being used to create climatic and soil factor maps. Excel spreadsheets and RStudio are used to create response functions of forage species to minimum and maximum temperature, annual precipitation, soil pH, soil salinity, and salinity. National forage data and expert opinion will evaluate quantitative tolerances, seasonal yield profiles, and pollinator suitability. These maps and agronomic and livestock use information will be shared with forage specialists and farmers to provide alternatives for improved perenniality, increased diversity, and system circularity. Future work will include development and evaluation of climate change scenarios for temperature and precipitation. Anticipated outcomes include improved species selection and decision making to develop and manage sustainable agricultural systems, improved national policies to provide incentives for agroecologically-matched agricultural systems, and improved likelihood of long-term agricultural production sustainability based on agroecological principles.

Introduction

Previous Work

China Mapping

Initial efforts on GIS-based species suitability mapping began with support from the Oregon Seed Council's USDA Foreign Agricultural Service Market Access Program and the parallel Emerging Markets Program project grant to Oregon State University with collaboration among many cooperators, agencies, organizations, universities, and commercial companies. The computer mapping project was based on the concept that new GIS-based mapping technologies and information systems could aid in developing agricultural and natural resource management systems that are economically and environmentally sustainable.

This was a collaborative effort to create a web-based comprehensive knowledge resource to assist land managers and other decision makers in choosing forage, conservation, and turfgrass species that are optimally matched with their environments. The overall goal was to apply these advanced computer technologies to improve agricultural productivity, natural resource management, environmental protection, and urban beautification.

A China Atlas (Daly and Hannaway, 2005; Daly et al., 2008) was developed with the support of the various sponsors and key collaborators. It is a hardcopy representation of digital geospatial products, with 280 maps of climate, soil, and tall fescue, orchardgrass, and perennial ryegrass suitability maps for China.

Tall Fescue Agronomy Monograph

A tall fescue monograph was developed, initially distributed online and later converted into a publication of the Agronomy Society of America (Fribourg, et al., 2009). Chapter 3 describes *Development of Suitability Maps with Examples for the United States and China*. Suitability for tall fescue refers to its potential to contribute significant annual yield to plant communities managed for forage within areas to

which it is adapted. Traditional approaches to plant species suitability mapping have been based on hand-drawn maps involving a graphic artist and a plant specialist to define qualitative, highly generalized zones with minimum temperature as the primary suitability criterion. Advanced spatial analysis approaches permit creation of quantitative, highly detailed and increasingly accurate species suitability maps. These are based on plant tolerance of edaphic and climatological characteristics of the region. Sophisticated climate modeling software (PRISM Climate Group; Daly and Bryant, 2013) created climatic grids for the United States and China, integrating digital soils information into a mapping application. These techniques provided a new approach to species suitability mapping. Landscape-level tall fescue suitability maps were created based on published and expert estimates of climatic and soil factor tolerances for tall fescue used as forage.

Clover Program

Based on the work for high-priority cool-season grass seed production (tall fescue, orchardgrass, and perennial ryegrass) in Oregon for national and international markets, a 'MatchClover' tool was developed for 13 annual and perennial clovers (Hannaway, et al., 2018). Sponsored by the Oregon Clover Commission, this is a web-based application to improve the selection of clover species, a high value Oregon crop, for specific locations, intended uses, and levels of management. It is based on research and extension information used throughout the US and the world. Information for each clover species has been developed with US and international experts and placed within a database allowing presentation in various complexities. Selection strategies are based on qualitative and quantitative tolerances to climatic and soil-based factors and species suitability for use as pasture, hay, silage, cover-crop, soil conservation and improvement, pollinators, wildlife, and beautification applications. Climatic and soil information define conditions which are then compared with the clover species tolerances, determining how well-suited each species is for the targeted location. The intended use and management level information further refine the search for the most appropriate legume.

Fostering Resilience and Ecosystem Services in Landscapes by Integrating Diverse Perennial Circular Systems.

For Objective 1.1 of the USDA-NIFA funded Sustainable Agricultural Systems project, we are expanding the GIS-based suitability maps to include additional forage species to identify current dominant and appropriate diverse perennial circular systems in major agroecoregions. Suitability factors for each species are based on literature values and forage expert experience. In place of the previous approach to define tabular values as adapted, moderately-, and marginally-suited zones, mathematical functions are developed for climatic and edaphic factors. PRISM Climate data were obtained for minimum January and maximum July long-term mean temperatures and annual precipitation for climate characterization. Soil factors include pH, soil drainage class, and salinity (NRCS, 2003.) Cultivar yield and persistence data were obtained from published and online resources by forage research and extension faculty.

Methods

Ecoregions

To identify national ecoregions, existing national and state US EPA Level III Ecoregion maps were provided to state contributors to identify their major regions of dominant agricultural systems across the USA. In collaboration with collaborating farmers and ranchers, researchers are analyzing their current crop and/or livestock production systems, developing recommendations for an improved circularity of perennial systems, and comparing traditional and improved systems for soil, plant, animal, economic and sociological factors. Optimal alternative forage systems that include livestock will contain perennial forage species with bioactive secondary metabolites proven to benefit animal health.

Species selection decisions will be informed by species suitability maps developed from quantitative climatic and edaphic tolerance response functions. These functions are applied to spatial data layers for temperature, annual precipitation, pH, soil drainage, and salinity. Forage suitability spatial data layers will be overlain on ecoregions masked for cultivated lands, thereby identifying suitable species to be considered for improved perennial circular production systems.

A Community Climate System Model (CESM4) is being used to perform a delta-change downscaled from the PRISM data to predict alternative monthly, min/max temperature and precipitation. These are based on climate change scenarios resulting from potential greenhouse gas emission rates. Species suitability maps and species selection recommendations will be adjusted according to these projected climate changes.

Species

Participating researchers and forage extension specialists across the USA have recommended grasses, legumes, and other forb species to include in this study. The ultimate objective is greater production of perennial species, but selected annual species (small grain cereals, sorghum species, and self-recurring legumes) will also be modeled.

Yield Predictions

Data for forage yield were obtained from the NASS Cropscape data portal and state forage websites from reviewing faculty nationally. These reflect various management protocols and harvest phenology; dry matter predictions will be evaluated by research and extension forage faculty.

Alfalfa - Most Difficult Situation

Most forage species have one type for nationwide use. Corn and soybean are annual forages that have numerous types based on length of growing season. For perennial forages, alfalfa has 11 types based on fall dormancy and winter survival. Initial work on one fall dormancy and winter survival index was presented at the Mongolian International Grassland Congress (Hannaway, et al., 2009). From the growth of the 11 alfalfa fall dormancy (FD) and 6 winter survival index (WSI) cultivar types, grown under differing environmental conditions, mathematical functions were created in RStudio. RStudio is an integrated development environment for R, a programming language for statistical computing and graphics. The growth response to temperature was modeled using a logistic function (S curve). Minimum temperature (the ascending curve) and maximum temperature (the descending curve) were created separately. Data used to create the functions were obtained from research papers, other online university research and extension publications, NRCS documents, and knowledge and experience of alfalfa experts.

Resources used to estimate temperature tolerances of the various FD and WSI cultivar types included Alforex and Barenbrug seed company brochures that stylistically display regions suitable for each type in the USA and People's Republic of China, respectively. These stylistic graphics were translated into quantitative temperature values by overlaying regions on PRISM Tmin and Tmax long-term mean value maps. These overlays will define northern and southern latitudes for each zone. US alfalfa Extension and research forage specialists will assist by providing their grower-focused educational publications and websites that provide their state maps and recommendations for FD and WSI cultivar classes and typical hay yields for each type and region.

Results and Discussion

Analysis, assessment, and interpretation

Previous work on tall fescue, perennial ryegrass, orchardgrass, and alfalfa were used as models for 15 clover species within the MatchClover application within Extension application species cards as part of

the Oregon State University Forage Information System (https://forages.oregonstate.edu/matchclover/). PRISM Climate Data (https://www.prism.oregonstate.edu/) was used for Tmin, Tmax, and annual precipitation. NRCS STATSGO soil data was used for pH, soil drainage, and salinity. Tolerance functions were developed for each of the six tolerance values and applied to create nine maps for each species. These are available now for the clover species and will be developed for a larger set of species with an expanded system called MatchForage. We anticipate sixty-six species total species, with annuals and perennials of both cool-season and warm-season suitability.

Communication of findings and technology transfer

Forage scientists will review tolerance values and maps. Results will be communicated via the web segment and at state, regional, national, and international forage meetings.

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