Water Use Efficiency and Land Cover Variability on a Native Grassland Ranch on the Pampa Biome of Uruguay

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Abstract
Global efforts towards sustainable cattle ranching should be based on comprehensive approaches, targeting physical variables of the ranching process, as well as, the socioeconomic dimensions. Alianza del Pastizal is a non-profit conservation organization that works to preserve the temperate grasslands of the Southern Cone of South America by promoting conservation practices among ranching communities in Uruguay, Paraguay, Argentina, and Brazil. Alianza has become a mediator for ranchers exchanging information, resources, and education. Ranchers associated with the Alliance take pride in their property management as they aim to improve the community wellbeing and natural resource sustainability. In a previous study, producers from the four countries in the Alliance engaged in focus groups and participatory workshops where they identified water cycle regulation and water quality, as the most important ecosystem services provided by natural grasslands on their properties. With this information, our ultimate goal is to determine if the producers actual land use management activities align with the importance they placed on water. For this purpose, we chose the properties located in the floodplain of the Queguay River, northwestern Uruguay. We used a Google Earth Engine platform to inventory the vegetation types and corresponding Water Use Efficiency (WUE) values per vegetation type in the Colonia Juan Gutierrez. Our results indicate the presence of various vegetation types in the Colonia properties, which follow the seasonal rainfall and temperature patterns of the region, and display variability in WUE values. We plan to carry out the same analysis in the Rincon de Perez conservation area, and the managed forests west of the Colonia. Ultimately, we plan to compare these results to properties that do not subscribe to the Alianza's ideas to determine whether the stated preferences of Alianza ranchers align with differences in practice that improve environmental outcomes.

Introduction and Literature Review
Ranchers in the Colonia Juan Gutiérrez face significant seasonal challenges with water management for livestock watering due to the drought events of summer and flooding events of winter. These situations are predicted to worsen due to climate change, in addition to, the negative effects that expanding managed forests in the headwaters of the Queguay Grande river tributaries will have on the water cycle of the watershed (Restrepo-Osorio, 2020, Ch 3). In this paper we inventoried the land cover vegetation types in the Colonia properties and investigated if there were differences in water use efficiency (WUE) among the vegetation types. This information may provide insights regarding the vegetation types that could have an important effect on the regulation of the water cycle in the watershed and therefore play an important role in the drought and flood cycles affecting ranching communities in the area. Water use efficiency (WUE) is defined as the ratio of carbon assimilated for gross primary production (GPP) to water loss from the system through seasonal or annual evapotranspiration (ET) (de Oliveira et al., 2018; Tang et al., 2014). We used the equation proposed in Beer et al. (2009); WUE=GPP/ET. Above ground GPP is the gross primary productivity in g cm^{-2} and ET is the evapotranspiration in kg H_2O (Beer et al., 2009; Oliveira et al., 2018). According to Brunsell et al. (2014) this equation is commonly used to explore relationships between the water cycle and terrestrial carbon (Brunsell et al., 2014; de Oliveira et al., 2018). Evaporation, which is dependent on solar radiation, can be separated into three elements: 1) water that infiltrates into the soil, then is absorbed by plants and transpired to the atmosphere, 2) water intercepted by foliage which then evaporates into the air, and 3) water which is intercepted by litter on the soil surface, then infiltrates into the litter, then into the soil, and then evaporates (de Oliveira et al., 2017; Wilcox et al., 2017). Transpiration is the main factor of evapotranspiration over land and it is connected to vegetative productivity (Monteith, 1988; Nosetto et al., 2011). GPP is directly proportional to carbon assimilation (Beer et al., 2009). WUE values change with annual seasonal variability typically displaying higher values during the wet seasons and lower values during the dry season, dependent on ET patterns (de Oliveira et al., 2017). Given that GPP is directly proportional to WUE, it also follows seasonal precipitation patterns. A study carried out in the Amazonia of Brazil indicated that during the low water availability and high ET of the dry season, GPP decreased due to increased stomatal closure and therefore

decreased photosynthetic rates (de Oliveira et al., 2017). In a different study, Bathurst (2018) found that during the winter season, watersheds become saturated, there is little infiltration, and evapotranspiration is low (Bathurst et al., 2018), therefore biomass production and WUE decreases.

Study Site and Methods

Uruguay is part of the southern cone of South America and it is located between the latitudes 30º and 35º South. Uruguayan temperatures increase from the southeastern coast of the country to the northwestern departments. According to 1961-1990 records from the Uruguayan Meteorological Institute, the thirty-year normal temperature for the country is 63.5^0F with an average maximum temperature of 66.2^0F over the Artigas department, and an average minimum temperature of 60.8^0F over the Atlantic coast of the Rocha department (INUMET, n.d.-a). Annual average precipitation ranges from approximately 43.3in in the southwestern departments to approximately 63in in the Rivera department (INUMET, n.d.-a). The center of the Paysandú department is approximately located in the -32.34^0 latitude and -58.0^0 longitude in the northwestern area of Uruguay. According to records from 1961-1990, Paysandú's 30-year normal annual temperature is 64.2^0F, with an annual maximum temperature of 108.3^0F and an annual minimum temperature of 23.9^0F. According to INUMET records from 1961 to 1990, the annual average precipitation in Paysandú during those years was 48in with a maximum 5.8in in the month of March and a minimum of 2.7in in the month of June (INUMET, n.d.-a). Precipitation patterns in Colonia Juan Gutiérrez from 1901 to 2016[1] follow the general national seasonal trend but deviate in magnitude. Records show a maximum of 5in in April and a minimum of 3.2in in July. Uruguay has two high precipitation periods during the year. The period of precipitation with most rainfall occurs during the fall, and another period with lower rainfall occurs during the spring. The first period reaches its peak in April, which is halfway through fall, and the second period reaches its peak in October, which is halfway through spring. Precipitation in the Colonia Juan Gutiérrez follows this pattern; however, the precipitation events present a larger magnitude than the national monthly mean average. Temperature in the Colonia closely follows the national temperature deviating minimally in the summer when temperatures go up to 76.55ºF. Winter temperatures in the Colonia do not seem to deviate much from national temperatures and go as low as 52.86ºF.

Temporal Evapotranspiration Aggregation Method (TEAM) Tool

TEAM is a Google Earth Engine tool developed in 2019 by Jim Coll in collaboration with Gabriel de Oliveira. Both coauthors assisted in the development of this project as it is the second application of the TEAM tool in an academic setting, and the first time the tool will be used in the temperate grassland habitat of South America. Previous studies have validated MOD16A2 and MOD17A2H data sets using flux towers in the Brazilian Amazonia to compare WUE, GPP, and ET values in agricultural, primary and secondary tropical forests, and pastureland cover types (de Oliveira et al., 2017). The data presented an average error of ~11% for MODIS16A2 and ~13% for MODIS17A2H when compared to flux tower ground measurements. De Oliveira et al. (2017) found that MODIS presents higher accuracy for forest land cover compared to pasture land cover type (de Oliveira et al., 2017). We used TEAM to assess the land cover composition and distribution surrounding the Colonia Juan Gutiérrez, and to obtain the WUE values. Water Use Efficiency is defined as the ratio of carbon assimilated as biomass production Gross Primary Productivity (GPP), to the units of water used by vegetation Evapotranspiration (ET). TEAM uses MOD16A2 and MOD17A2H (500 m pixel) data sets to carry out its functions (Coll, 2019). TEAM calculates WUE using MOD16A2 for an 8-day composite of GPP and an 8-day composite for ET using MOD17A2H from 2001-2018. For this purpose, the shapefiles of the property boundaries and paddock distribution were obtained from the president of the Sociedad de Fomento Rural de la Colonia Juan Gutiérrez (*Development Society of the Juan Gutiérrez Colony*). These shapefiles were imported into the TEAM platform and made them available as a *custom shapefile* under the *unit to aggregate* feature (Coll, 2019). The IGBP land cover classification MCD12Q1 database was selected in the *land cover* feature of the TEAM tool and the *custom shapefile* under the *unit to aggregate* feature was selected.

Colonia Juan Gutiérrez Properties

The zoom feature was used to frame the polygons outlining the properties in the Colonia Juan Gutiérrez. *WUE* was chosen as the *variable to view*, the *mean* was chosen for the *temporal stat to aggregate*, the *spatial stat to aggregate*, and the *table stat to aggregate*. The *year-to-view* was left as default, the *images to animate* were left as the default of 24, and the *timestep (ms)* was also left as the default 1000. Each one of the 145 polygons outlining the paddock distribution in the Colonia properties were selected. The WUE values for all vegetation types in the properties were displayed in time series and monthly aggregate graphs, both of which were exported as PNG and CSV files to record the WUE for all vegetation types in the ranches. All CSV files were

[1] https://climateknowledgeportal.worldbank.org/watershed/265/climate-data-historical

compiled on Google Sheets to obtain a monthly mean WUE, and create graphs of the WUE of each vegetation type in the Colonia properties.

Results

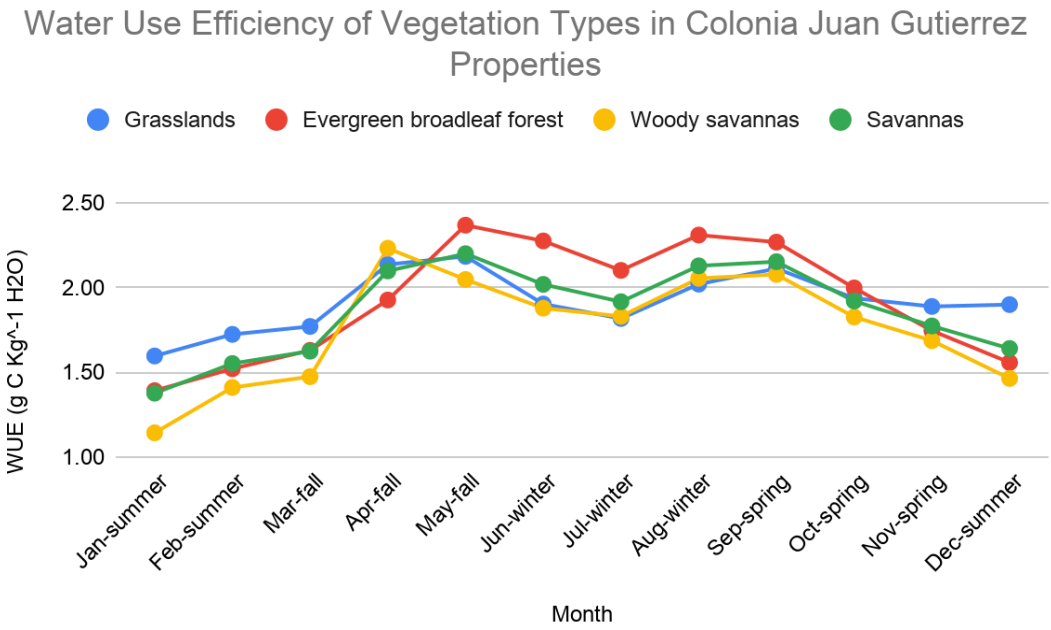

Figure 1.TEAM tool WUE aggregated values for vegetation types in Colonia Juan Gutiérrez properties from 2001-2018

COLONIA JUAN GUTIÉRREZ PROPERTIES			
Vegetation Type	**WUE (g C Kg^{-1} H_2O)**		**Monthly mean WUE**
	Min	**Max**	
Woody savannas	1.14	2.23	1.76
Savannas	1.38	2.20	1.76
Evergreen broadleaf forest	1.39	2.37	1.92
Grasses	1.60	2.18	1.92

Table 1. WUE mean of minimum values and mean of maximum values for the vegetation types in the Colonia Juan Gutiérrez properties, and overall monthly mean WUE per vegetation type.

Water use efficiency of vegetation types in Colonia Juan Gutiérrez properties

The WUE analysis of the vegetation types on the properties of the floodplain of the Queguay Grande river and the properties of the floodplain of the Queguay Chico river, both part of the Colonia Juan Gutiérrez, show that most values follow a similar pattern. WUE seems to increase from January to March where it steeply increases and decreases in July after which it increases again and then slowly decreases from October until the end of the year (Figure 1). The evergreen broadleaf forest WUE is higher than the rest of the vegetation types with a WUE of 2.37 g C Kg^{-1} H_2O, whereas woody savannas in the properties had the lowest WUE value of 1.14g C Kg^{-1} H_2O. Evergreen broadleaf forests and grasses had the highest monthly mean WUE of 1.92g C Kg^{-1} H_2O, and woody savannas and savannas had the lowest monthly mean WUE of 1.76g C Kg^{-1} H_2O (Table 1).

Discussion

Different vegetation types react differently to the seasonal variations in precipitation and temperature and therefore regulate the water cycle in different ways. This is of special interest to ranchers and other land managers in the Queguay Grande river watershed, given the history of seasonal flooding and drought that affect the ranching enterprise and the livelihood of ranching families. In general, evergreen forest species maintain their leaves during the winter; therefore, water flux processes can still occur with little disruption

compared to deciduous species that become dormant during the winter. The production of biomass by evergreen species, or GPP, is ongoing, therefore it results in higher WUE values compared to other vegetation types in the properties. Given that the relationship between GPP and WUE is directly proportional, a high GPP is often reflected in a high WUE. Therefore, since the evergreen broadleaf forest species in the Cololnia Juan Gutierrez properties remain active during the winter using water for biomass production, they could influence water cycle dynamics in the watershed during that season. Woody savanna vegetation types identified in the Colonia properties could be an indication of a serious problem involving woody encroachment of potential exotic species from nearby managed forests and having effects in the water dynamics in the watershed. This could become a threat to the efforts of several local and national conservation organizations, including the Alianza del Pastizal, which works to preserve the native grasslands of the Pampa biome. Intentional or unintentional land conversion of temperate grasslands to forests would jeopardize the livelihood of the ranching communities in the Colonia Juan Gutiérrez. Woody encroachment management should become a priority for conservation nonprofit organizations, and associated local and national governmental organizations such as the Ranching, Agriculture, and Fishing Ministry of Uruguay, to collaborate and provide the necessary tools for ranchers to adapt, mitigate and become resilient to negative effects derived from climate change.

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