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Effects of Short Season Irrigation on Pasture Yield and Predicting Yield with Sentinel-2 Satellite

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EFFECT OF SHORT SEASON IRRIGATION ON PASTURE YIELD AND PREDICTING YIELD WITH SENTINEL-2 SATELLITE

By

Ihsan Bugra Bugdayci

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Civil and Environmental Engineering

with

Emphasis in Irrigation and Water Management

Approved:

Niel Allen, Ph.D. Major Professor	Alfonso Torres-Rua, Ph.D. Committee Member
Matt Yost, Ph.D. Committee Member	Janis L. Boettinger, Ph.D. Vice Provost for Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2020

ABSTRACT

Effects of Short Season Irrigation on Pasture Yield and Predicting Yield with Sentinel-2 Satellite By

Ihsan Bugra Bugdayci, Master of Science

Utah State University, 2020

Major Professor: Dr. Niel Allen
Department: Civil and Environmental Engineering

The main objectives of this research were to determine the correlation between UAV and Sentinel-2 Satellite, predict pasture yield using UAV and Satellite images, and observe deficit irrigation effects for pasture yield. This study was conducted at Lewiston and Panguitch, Utah. UAV images before each harvest in 2017 and one harvest in 2018 were used to find the correlation. Normalized difference vegetation index (NDVI) calculated with UAV data and Sentinel-2 Satellite data were used to determine the correlation. The results of this study indicated that Sentinel-2 and UAV had good correlations with $R^2 = 0.90$ for all observations. This relationship makes it possible to extend datasets to predict the yield. NDVI analysis were made using UAV on small and larger areas. Yield estimations for pastures in Panguitch and Lewiston, Utah were made using NDVI from UAV and Sentinel-2 data. For Panguitch, highest correlation was found 49 days before the harvest with $R^2 = 0.96$ and RMSE = 0.04 tons/acre, but in general good correlations were found 15 days before the harvest with $R^2=0.80$ or higher. The second highest correlation was 10 days before harvest with $R^2 = 0.86$ and RMSE = 0.07 tons/acre for Panguitch. At Lewiston, the highest correlation was found 21 days before the harvest with R^2= 0.93 and RMSE = 0.04 tons/acre. At Lewiston research plots with full season irrigation and irrigation until August had more yield than no irrigation, irrigation through May, and irrigation through July plots. The less irrigation had lower yield. Full season irrigated plots had almost 20 percent more yield than non-irrigated plots in average of the years in this study, whereas irrigation until August had 6 percent less yield than full season irrigated plots. However, deficit irrigation did not matter in terms of yield apart from non-irrigated plots in Panguitch, Utah. The effects of deficit irrigation after 5 years were assessed visually using NDVI and there was no impact on crop health in the Lewiston study area.

(72 pages)

PUBLIC ABSTRACT

Effects of Short Season Irrigation on Pasture Yield and Predicting Yield with Sentinel-2 Satellite

Ihsan Bugra Bugdayci

Deficit irrigation can reduce agriculture water use making additional water available for other uses. This study looked at multi-year impacts of deficit irrigation on pasture yield. The results show that that early irrigation provides the most benefit to cool season pastures and late season irrigation only had small impacts on yield. According to this research, irrigation water can be saved without impacting the yield importantly.

Remote sensing techniques are becoming a part of agriculture. Yield predictions are important for the farmers and others involved with agriculture. In this research, relationships between the normalized difference vegetation index (NDVI) calculated from remotely sensed data and pasture yields were developed. Additionally, un-maned aerial vehicle (UAV) and Sentinel-2 Satellite images were compared finding a strong correlation between them. This means that Sentinel-2 data which is readily available to the public on 5-day intervals can be used to predict pasture yield. This study was one of the rare studies that UAV and Satellite Images were compared. The correlation between them very high and helped to expand the dataset. The research was sponsored by Utah Agriculture Experiment Station and the cost was about $15,000 per year.

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Ihsan Bugra Bugdayci

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ACRONYMS

SM	Soil Moisture
Kc	Crop Coefficient
ET	Evapotranspiration
VIs	Vegetation Indices
NDVI	Normalized Difference Vegetation Index
GEE	Google Earth Engine
GIS	Geographic Information System
WUE	Water Use Efficiency
RDI	Regulated Deficit Irrigation

INTRODUCTION

Food demand increases as the population of the world increases (Wallace, 2000). This results in an increased demand for both non-agriculture and agriculture water use, requiring more water management options. About 70 percent of freshwater withdrawals worldwide is used for agriculture (FAO, 2020). In Utah, agricultural irrigation uses about 80 percent of the fresh water withdrawals to irrigate about 1.2 million acres, about 2% of the state's area (Dieter et al., 2018). Because of the limited water resources and increasing population agricultural production should be maximized with minimal water usage.

Methods to use water effectively in agriculture include water-saving irrigation technologies, water harvesting methods, waste-water reuse, and deficit irrigation (Çiftci, et al., 2014). Due to the possibility of the water scarcity in the future, deficit irrigation is a good way to reduce irrigation water. The key factor of deficit irrigation is to maximize water use efficiency of a crop by decreasing the irrigations with small effects on yield (Kirda, 2002).

Utah is the second driest state in the United States (NOAA National Climatic Data Center, 2020; Bingham and Pool, 2015) therefore the amount of water for irrigation is the highest compared with other water uses in the state. The efficient use of water is important to help and meet the many demands for the limited water supply. Figure 1 shows the average monthly annual precipitation in UTAH from 2010 to 2019. Figure 2 indicates annual state precipitation averages in the USA for each state.

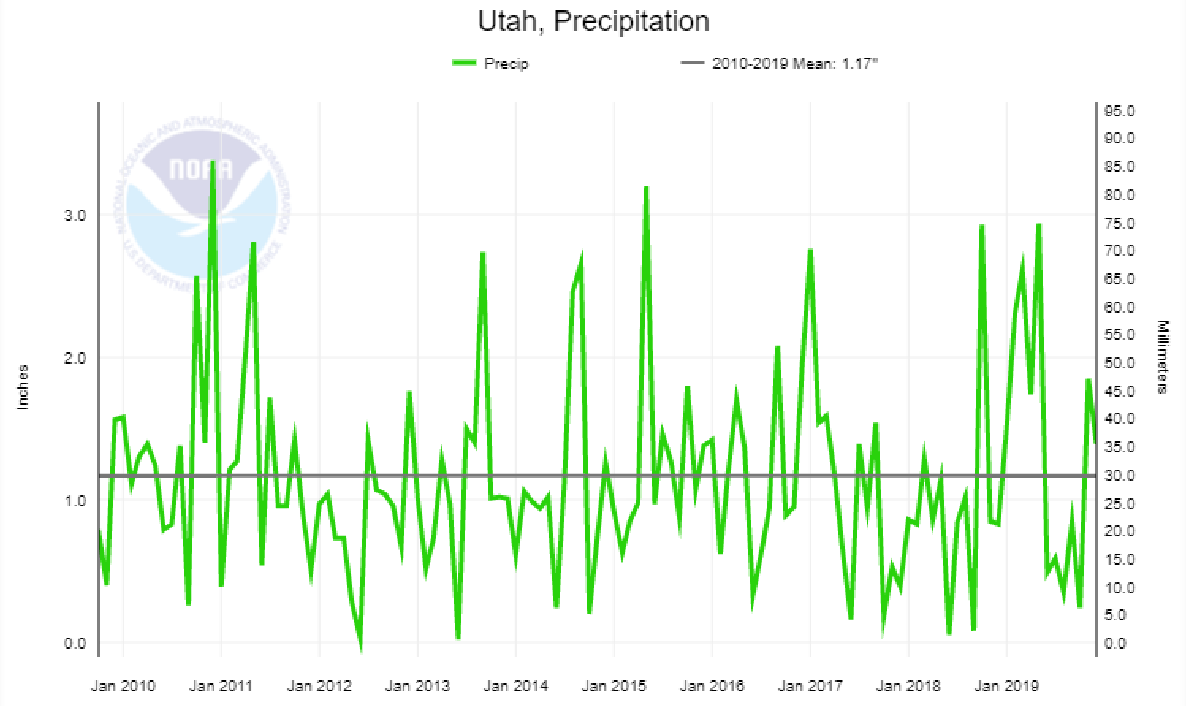


Figure 1. Monthly Utah Precipitation Data in inches between 2010 and 2019.

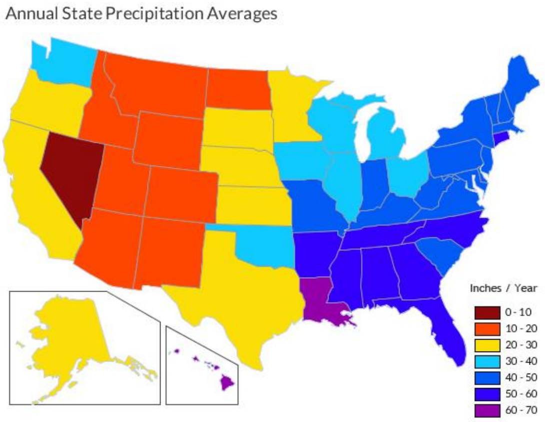


Figure 2. Annual State Precipitation Averages (NOAA National Climatic Data Center,2020).

Most of the irrigated crop production in Utah is perennial forage crops (alfalfa and grasses) which support livestock, dairy, and export markets. Figure 3 represents Utah crop income percentages in 2018. Hay (pasture and grass) and alfalfa constitute 85 percent in terms of income (Figure 3) and comprise 73 percent of total acres in Utah in 2018 (Figure

4) (USDA National Agricultural Statistics Service, 2018). Figure 4 shows the percentage of crop in acre in Utah in 2018, For arid Utah, drought-tolerant crops like alfalfa and pasture are a good choice to withstand drought and water stress. During water shortages, deficit irrigation of forages can provide water for other crops or other uses.

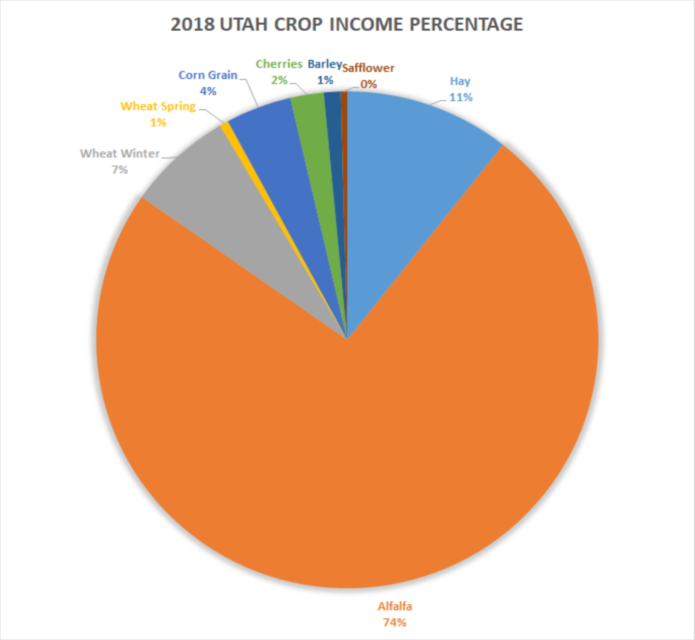


Figure 3. Utah Crop Income Percentage in 2018.

Irrigation water shortages are generally occurring due to climate change, drought and increase in population. Understanding already occurring deficit irrigation effects on yield pastures can provide valuable information to mitigate decreasing water supplies.

Remote sensing technology is becoming a part of agriculture. An agricultural field and field conditions of plants can be observed and assessed without physically touching by remote sensing (Nowatzki, Andres, & Kyllo, 2004). Satellite remote sensing can provide data from large areas at lower cost (no cost for some public data) than field sampling (field sampling is always needed) and can provide full spatial coverage.

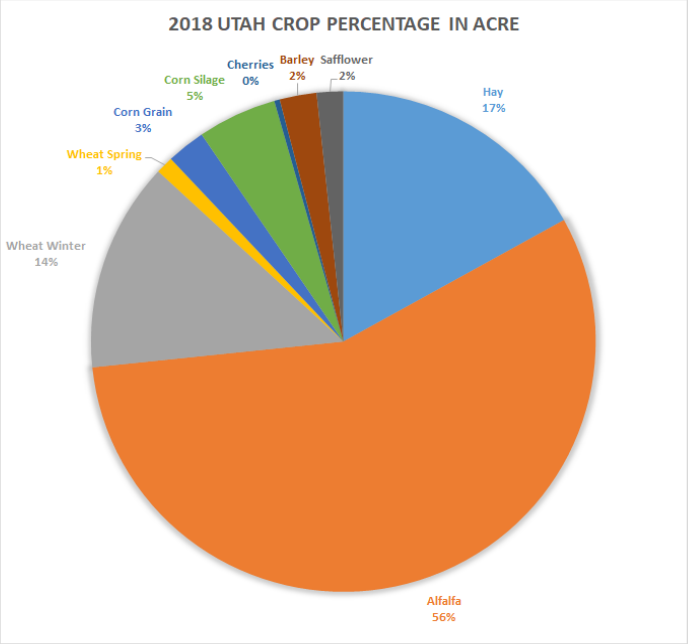


Figure 4. Utah Crop Percentage in Acre in 2018.

Remote sensing also be used for yield estimations in agriculture (Tunca et al., 2019; Çetin et al., 2018). Early yield estimations can help farmers to make early decisions. Yield predictions are important to set a price for a product. Insurance companies also use yield estimation. If any disaster happens, these companies can predict the possible yield loss and compensate insured farmers more accurately. Some remote sensing techniques have been developed to estimate yield giving successful results. With the help of these methods, it is easy, fast and cheaper to predict yield (Bach, 1998). Vegetation indices are the major inputs for yield predictions and crop water use. Statistically significant correlations have been found between spectral vegetation indices and crop coefficient (Kc) in some studies. (Fitzgerald and et al. 2003; Poss et al. 2006; Koksal, 2008; Aboutalebi, Torres-Rua, and Allen (2018).

OBJECTIVES

The objectives of the research are to:

1. Determine the radiometric relationship between Unmanned Aerial Vehicle (UAV) and Sentinel-2 Satellite Images.

Compare UAV images and Sentinel-2 satellite optical images to determine the correlations of spectral data at 60 by 160 feet plots. Satellite images can expand the data obtained by UAV images because of higher frequency at a lower cost. While the resolution of the UAV images is smaller than the Satellite images, obtaining UAV images every 5 days or 10 days is not practical due to costs and effort. Normalized Difference Vegetation Index (NDVI) values from UAV and Sentinel-2 images were calculated and compared to determine the relationships.

2. Determine whether yield can be predicted with remotely sensed data.

Correlate plot yield with Sentinel-2 normalized difference vegetation index (NDVI) to determine if yield can be spatially predicted from Sentinel-2 data.

3. Determine the impact of short-season and full season irrigation scenarios on pasture yield.

Measure pasture yield for short-season irrigation scenarios for different years and locations. Determine whether differences in water use and yield for irrigation levels can be assessed using satellite images.

LITERATURE REVIEW

Deficit Irrigation

Deficit irrigation methods are commonly used in the regions where water supply is limited. (Fereres and Soriano, 2006). Yield of pastures as affected by irrigation amount has been studied for decades. Most cool season pasture grasses use the highest amount of water in the early portion of the growing season (Volesky and Berger, 2010). Researchers compared pasture yields and found that yields of Tall Fescue and Meadow Brome were higher than Orchardgrass and perennial Ryegrass at low irrigation levels based on five irrigation levels ranging between 41 and 91 cm (Kevin B. Jensen et al., March 2001). Smeal et. al (2005) conducted research about cool-season pasture grasses for forage production with different irrigation levels during three years on the Colorado Plateau. They found that Orchardgrass, Meadow Brome, and Tall Fescue had more yield than intermediate Wheat Grasses, crested Wheat Grass, perennial Ryegrass, and Smooth Brome under highest irrigation. Dr. Steve Orloff conducted research from 2005 to 2008 in northern California with 26 species of pasture grasses using three different irrigation cut-off times; June 1st, July 15th and full-season irrigation. According to his research, tall fescue had the highest yield within those 26 different grasses for both full irrigation and deficit irrigation. The research indicated that with deficit irrigation brome, fescue, and wheatgrass maintained good stands (Orloff et al., 2005, and Orloff, 2010). Deficit irrigation scenarios is important to sustain the health of pasture. Research has indicated that the most critical time to provide enough water to grasses for sustaining a healthy crop is from early spring to first harvest (Kirkpatrick, et. al, 2006)

There have also been many studies on deficit irrigation of alfalfa. Sam Geerts and Dirk Raes (2009) did research about the benefits and drawbacks of deficit irrigation, they found that deficit irrigation reduces yields but can increase water use productivity. In another study, research on the effect of soil moisture on alfalfa forage quality and yield showed that growing alfalfa at low soil moisture stress (adequate soil water) yielded more dry matter than at high soil stress (low soil moisture). The results indicated that low soil moisture stress and high temperatures had less yield and less quality forage impact than low soil moisture stress and low temperatures (Vough et al., 1971). Bauder, Bauer, Ramirez, and Cassel (1978) conducted a research where annual precipitation is 500 mm in North Dakota. Their research showed the yields reached 5 tons/ha in dryland, 9.7 tons/ha with deficit irrigation and 10.2 tons/ha with full irrigation.

Carter and Sheaffer (1983) conducted research about alfalfa response to four water supply levels (no irrigation, medium low irrigation, medium high irrigation, and high irrigation) and found that high irrigation and medium high irrigation had an increase in dry matter yield compared to medium low irrigation and no irrigation. Donovan and Meek (1983) conducted research about alfalfa responses to irrigation treatments at 56(dry), 66(semidry) ,75(optimum), and 84(wet) percent of pan evaporation (Ep). Alfalfa protein concentration was lower in wet treatments than dry treatments. The yields increased with the amount of water applied. Petit, Pesant, Barnett, Mason, and Dionne (1992) conducted research about the effects of soil moisture, pH, and phosphorus fertilization on alfalfa quality. There were three different soil moisture levels; semi-dry(between 100 percent available water and field capacity), optimal (between field capacity and 70 percent of available water), and wet (between field capacity and saturation point). They found that the quality of alfalfa increased with water deficit. Wet soil moisture and high temperature had less quality, whereas low soil moisture and low temperature had higher quality alfalfa.

Saeed and El-Nadi (1997) conducted a research about irrigation impacts on the alfalfa yield, growth and water use efficiency in northern Sudan in 1993. There were three treatments with 65 mm water every 7 days, 80 mm water every 10 days, and 104 mm water every 13 days. The yields were 15.3, 12.9 and 11.2 tons/ha ,whereas water use efficiency values were 0.12, 0.10, 0.08 ton/ha/cm for each treatments respectively(65mm 7 days, 80mm 10 days, 104 mm 13 days). The linear correlation between water use and dry matter yield was very consistent (R^2=0.99). The research suggested that alfalfa should be irrigated slightly and often to get more yield and more water use efficiency.

Blaine Hanson and Putnam ; (Blaine Hanson & Putnam, 2000) expressed that alfalfa can be produced with less water than normal irrigation but there would be some decreases on the yield. Also, they determined that higher yield could be obtained with better irrigation water use efficiency. One of the studies in their research indicated that regulated deficit irrigation could enhance the profit for alfalfa.

Takele and Kallenbach (2001) conducted a research about water conservation on alfalfa in California and Arizona. They analyzed four summer dry-down periods 0 days, 35 days, 70 days and 105 days and found that for the first 35 days there was little yield loss. After 70 days of dry down period, the yield losses increased. The potential water conservation would be between 254 and 944 million m^3 in the region and the agricultural income would decrease about 16 million dollars to 73 million dollars. Their research suggested that the water conservation would be useful in areas where water prices higher than \$0.045 m^{-3} in California and \$ 0.036 m^{-3} in Arizona.

B Hanson, Putnam, and Snyder (2007) conducted a research about the deficit irrigation impacts on alfalfa yield and evapotranspiraton in California to transfer the saved water from alfalfa to water-short areas. There is no irrigation in July, August and September. Alfalfa yields decreased by 4.68–6.47 Mg ha^{-1} in July and August and seasonal evapotranspiration was between 1249 mm to 1381 mm. Fully irrigated alfalfa ET was 224-230 mm higher than deficit irrigated alfalfa ET.

A research conducted by Kuslu, Sahin, Tunc, and Kiziloglu (2010) to detect alfalfa yield and water use efficiency with seasonal deficit irrigation effects. Five irrigation treatments were applied with 0, 20, 40, 60, and 80 percent of full irrigation. As soon as the water deficits increased, water use efficiency values and yield decreased.

Lindenmayer, Hansen, Brummer, and Pritchett (2011) published a paper about alfalfa deficit irrigation to identify water savings with deficit irrigation and maximize the water use efficiency. They suggested that water deficits would be more effective when it is applied with less efficient water-use growth periods rather than seasonal-long water deficits.

Holman, Min, Klocke, Kisekka, and Currie (2016) conducted a research about alfalfa nutritive value with effects of irrigation amount. Four different irrigation (0, 200, 380, 610 mm) amount were used during the growing season. The research results showed that highest irrigation amount was concluded with the lowest forage nutritive value. The yield decreased with irrigation amount, whereas relative feed value increased. Compared to 380 mm and 610 mm growing season irrigation amount, 13 percent product value increased in less irrigation, however yield decreased about 19 percent.

Cavero, Faci, Medina, and Martínez-Cob (2017) studied about effects of six different irrigation treatments (55, 75, 85, 100, 115, 130 percent of crop irrigation requirement) on alfalfa yield. For the first year of study, the forage yield increased linearly but for the other years it has increased until 115 percent of crop irrigation requirement. While the yield is increasing with applied irrigation amount, the N content of alfalfa decreased. The water-use efficiency, ET, and alfalfa forage yield increased with applied water until 115 percent of crop irrigation requirement for all years, however, the N content was lower with high irrigation amount.

The cited studies show that providing enough water during early growing season (until first harvest) is important for the crop health. In some areas where the rainfall is high until the first harvest, the yield results were close between full irrigated and deficit irrigated areas because most of the yield for forage is produced in the first harvest. Water use efficiency is increased with deficit irrigation. The studies also suggest that deficit irrigation should be used in areas where the water prices high and water supplies limited.

In summary from the all literature, the location of research areas, soil types, crop types, irrigation methods, irrigation times, the climate of the areas have effects on the results for deficit irrigation studies. This study will help to determine short season effects on pasture yield and give an information about better water management.

Yield Estimation with Remote Sensing

Remote sensing data and technology is commonly used in agriculture and is becoming more important. Multispectral bands and vegetation indices (VIs) from satellite and unmanned aerial vehicle (UAV) imagery are used to help manage crop production. Vegetation health, amount of biomass and water stress can be predicted using UAV imagery. Vegetation Indices can be used to estimate chlorophyl content. Many studies have shown relationships between crop yield and vegetation indices. As reported by Aboutalebi, the NIR band had the best relationship with the pasture yield (R^2=0.92) among the individual bands. Vegetation indices RVI and NDVI also provided an important correlation with the yield with R^2= 0.90, and R^2=0.85, respectively (Aboutalebi et. al 2018).

Research conducted by B. Rudorff and Batista (1990) studied three different wheat types to assess the spectral response of wheat to determine the correlation between vegetation indices and yield. The research indicated that the vegetation index and the yield correlation coefficient was very high (r = 0.82 to 0.93). Another study by Rudorff and Batista concerned yield estimation by using Landsat Satellite, and agrometeorological data. The results showed that 40 and 60 percent of wheat yield variability can be stated with vegetation index derived from Landsat. According to their model wheat yield estimation was acceptable with $R^2 = 0.65$ (Rudorff, B., & Batista, G. , 1990).

Taylor et al. (1997) did a research about mapping yield potential with NDVI for different plots. They used the NDVI values with a linear regression model to compare yield values for different plots in the research area. The research is concluded with a significant correlation between NDVI and yield (r = 0.77).

Ferencz and Ferencz-Arkos (2004) completed a study about crop yield prediction with satellite images. They used two different ways to estimate the yield with Landsat Thematic Mapper (TM), GYURI (General Yield Unified Reference Index), NOAA (National Oceanic and Atmospheric Administration) and AVHRR (Advanced Very High-Resolution Radiometer). For the TM and GYURI, the correlation was R^2=0.75 and R^2=0.93 for the county-average yield, for the NOAA AVHRR the correlation was R^2=0.846 to 0.872. A research conducted by Prasad et al. (2005) used NDVI (normalized difference vegetation index) to predict the crop yield. The research results showed R^2=0.78, and R^2=0.86 correlation for corn and soybean crop respectively.

A research about yield estimation of cotton and spectral monitoring by Ansari et al. (2006) indicated that total dry matter, plant height and leaf area index are considerably correlated with spectral indices. The cotton was the best correlated with NDVI. The research found that the lowest difference between actual yield and estimated yield was 81-110 days after sowing. The difference was less than 5 percent from the actual yield.

Remote sensing techniques were used to estimate potential forage yield loss due to deficit irrigation in a research in 2006. Vegetation indices were used to predict the yield. They found successfull yield estimations at 75 percent. The yield estimation percent was 72 for wheatgrass, whereas 92 percent for alfalfa (Poss, Russell, & Grieve, 2006).

Satir and Berberoglu (2016) used Landsat TM/ETM satellite images to estimate corn yield before the harvest by using Remote Sensing and GIS techniques in the Cukurova Region. According the analyses, the corn yield was estimated about 2 months ago with 8.8 percent error rate.

Aboutalebi et al. (2018) conducted a research about yield estimation by using unmanned aerial vehicle (UAV). Vegetation indices have been used to predict to yield. A strong correlation was found between the amount of biomass and vegetation indices.

Tunca et al. (2018b) estimated sunflower yield and leaf area index by using multispectral UAV images. Linear relationship was found between sunflower yield and NDVI for all measurement days. They conclude that sunflower yield can be estimated successfully between days after sowing 85-92.

Khaliq et al. (2019) compared the unmanned aerial vehicle (UAV) and Satellite Multispectral Imagery for vineyard field. They calculated the NDVI values from Sentinel-2 Satellite and UAV with three different environment, the whole cropland surface, only the vine canopies, and only the inter-row terrain. They could not find a good correlation between UAV and Satellite Imagery in a vineyard. This study will compare the UAV and Sentinel-2 satellite and predict the yield with Satellite Images by using normalized difference vegetation index (NDVI). Some other studies from the literature could not found a good correlation between UAV and Satellite images, however other studies found a good correlation between yield and vegetation indices.

Definitions

Water Use Efficiency: It is described as yield divided by consumptive water use (e.g. tons of production per acre-foot of water use). This research considers water use efficiency for different deficit levels resulting from different irrigation periods.

Evaporation: Evaporation is the process of liquid water changing to water vapor by of energy from atmosphere or sun (Monteith, 1965).

Transpiration: It is described as the evaporation of internal plant water, generally through the leaves (USGS, Water Science School, 2020).

Evapotranspiration: It is generally described as the sum of evaporation from the land surfaces and canopy, and transpiration from the plants (USGS, Water Science School ,2020).

Vegetation Indices: Vegetation Indices were developed to evaluate the vegetative covers with spectral measurements. More than 40 vegetation indices have been developed to decrease the effects of environment such as shadow, soil color and moisture (Bannari, Morin, Bonn, & Huete, 1995).

Normalized Difference Vegetation Index (NDVI): It is one of the most used Vegetation Indices. Quantification of the vegetation greenness and vegetation density and plant health changes can be observed with NDVI. The ratio between near infrared (NIR) and red (R) values give the NDVI value. (NIR-R)/(NIR+R) **(**USGS, Landsat Surface Reflectance-Derived Spectral Indices, 2020).

METHODOLOGY

Relationships between yield, water use, and remotely sensed data were evaluated based on measured yield and soil moisture data from pasture plots with different irrigation levels in Lewiston and Panguitch, Utah. Yield data were gathered at the Lewiston, Utah from 2014 – 2018, soil moisture and remote sensing data from 2016 through 2018. Yield, soil moisture, and remote sensing data were gathered from Panguitch, Utah plots from 2018-2019. The Methodology and Results sections use English units which are well known to potential users of the data and results.

Study Area

This study was conducted at Lewiston and Panguitch both located in Utah (Figure 5). Figure 6 shows the location of the Lewiston site located in northern Utah. The coordinates are 41° 57’ 04” N 111° 52’ 20” W with an elevation of 4508 feet above the sea level. The location receives an average annual precipitation of 12.31 inches (U. S. Climate Data, 2019). The soil type at the study area is a fine sandy loam with a fluctuating water table about 36 inches below the ground surface. Tall fescue was the main crop but there was also a small amount of alfalfa and birdsfoot trefoil. The field is irrigated with impact sprinklers spaced 40 by 60 feet. Figure 7 is the layout of the research site in Lewiston. The Lewiston research includes four replications of five irrigation levels (no irrigation, irrigation through May, June, July and full-season irrigation). Each pasture was planted into 160 feet by 60 feet subplots in twenty replications separated by 60 feet buffer strip and the entire plot is 637 ft x 574.7 ft. Table 1 is a summary of Lewiston’s climate data.

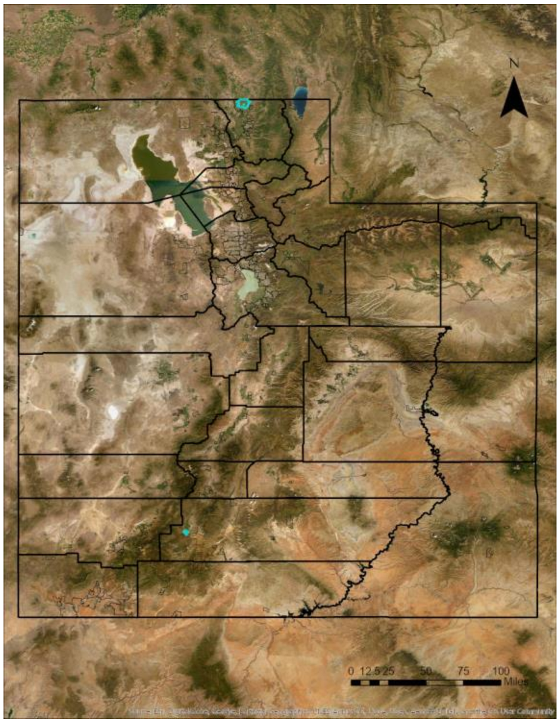


Figure 5. Lewiston and Panguitch study areas in Utah.

Figure 6. Study area in Lewiston, Utah.

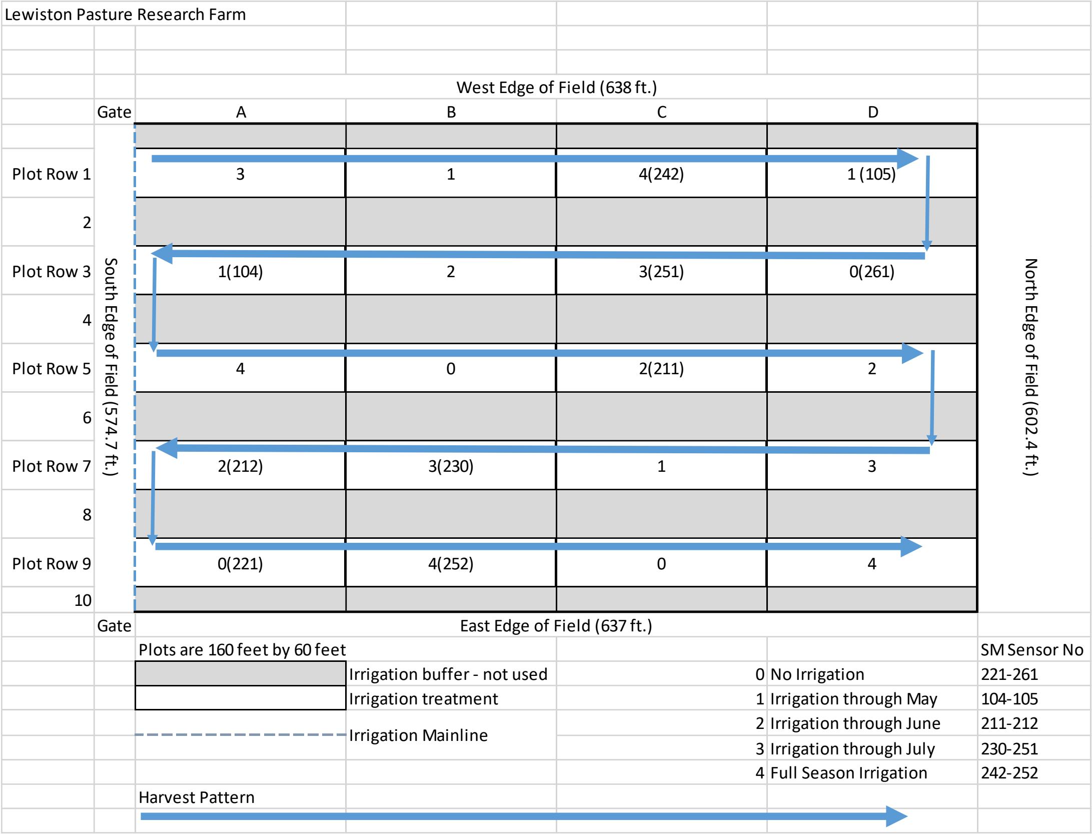


Figure 7. Lewiston pasture research area plot layout.

Table 1: Lewiston climate annual averages.

Climate Averages		
	Lewiston,Utah	United States
Rainfall	18.5 inches	38.1 inches
Snowfall	56.8 inches	27.8 inches
Precipitation	101 days	106.2 days
Sunny	219 days	205 days
Avg. July High	89.1°	85.8°
Avh. Jan. Low	15°	21.7°
Elevation	4508 ft.	2443 ft.

Retrieved in 06/13/2020 https://www.bestplaces.net/climate/city/utah/lewiston

The Panguitch site is located in the southern part of Utah with 37.868948° latitude and -112.436556° longitude with an elevation of 6624 feet above the sea level (see Figure 8). The average annual precipitation in the Panguitch site is 9.72 inches (U. S. Climate

Data, 2019). The texture of the soil is a loam with some gravelly bands and the water table is below 16 feet. Tall Fescue and Cache Meadow Brome are used for that research area. The field is irrigated by wheel lines with impact sprinklers spaced 40 by 60 feet. For both sites, there are electronic weather stations maintained by the Utah Climate Center. Soil moisture measurements were made at 10 locations in each field with 3 Acclima TDR-315l true waveform digitizing Time Domain Reflectometer (TDR) soil moisture sensors.

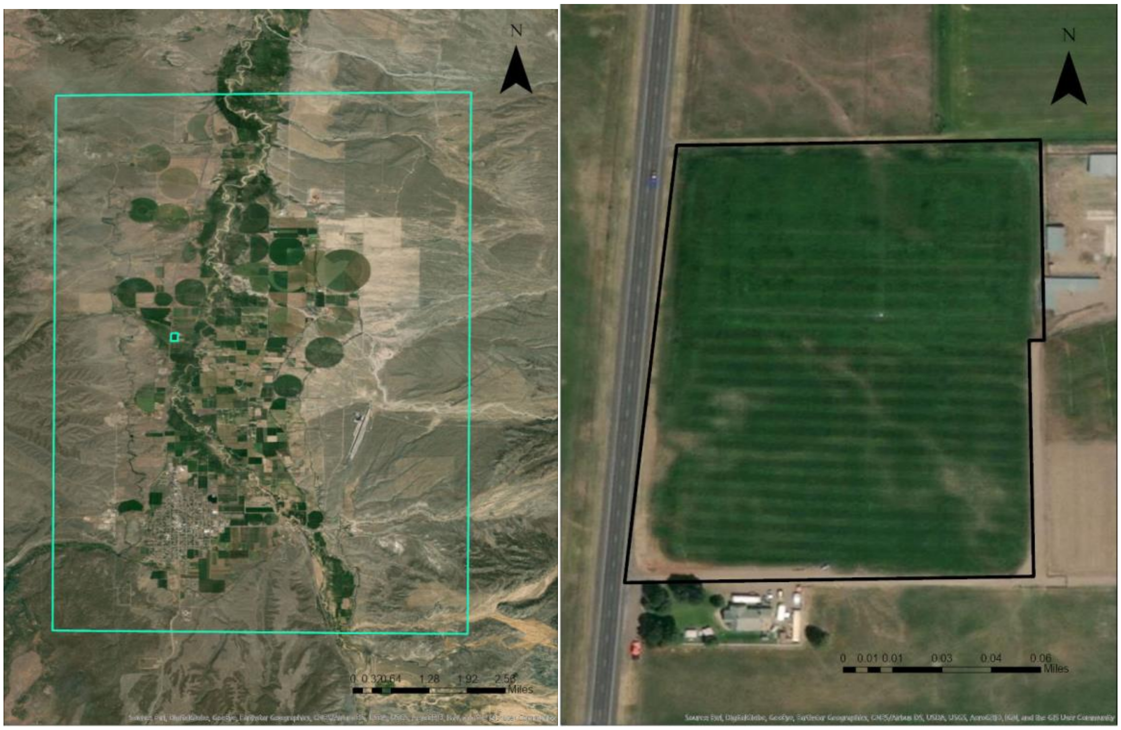
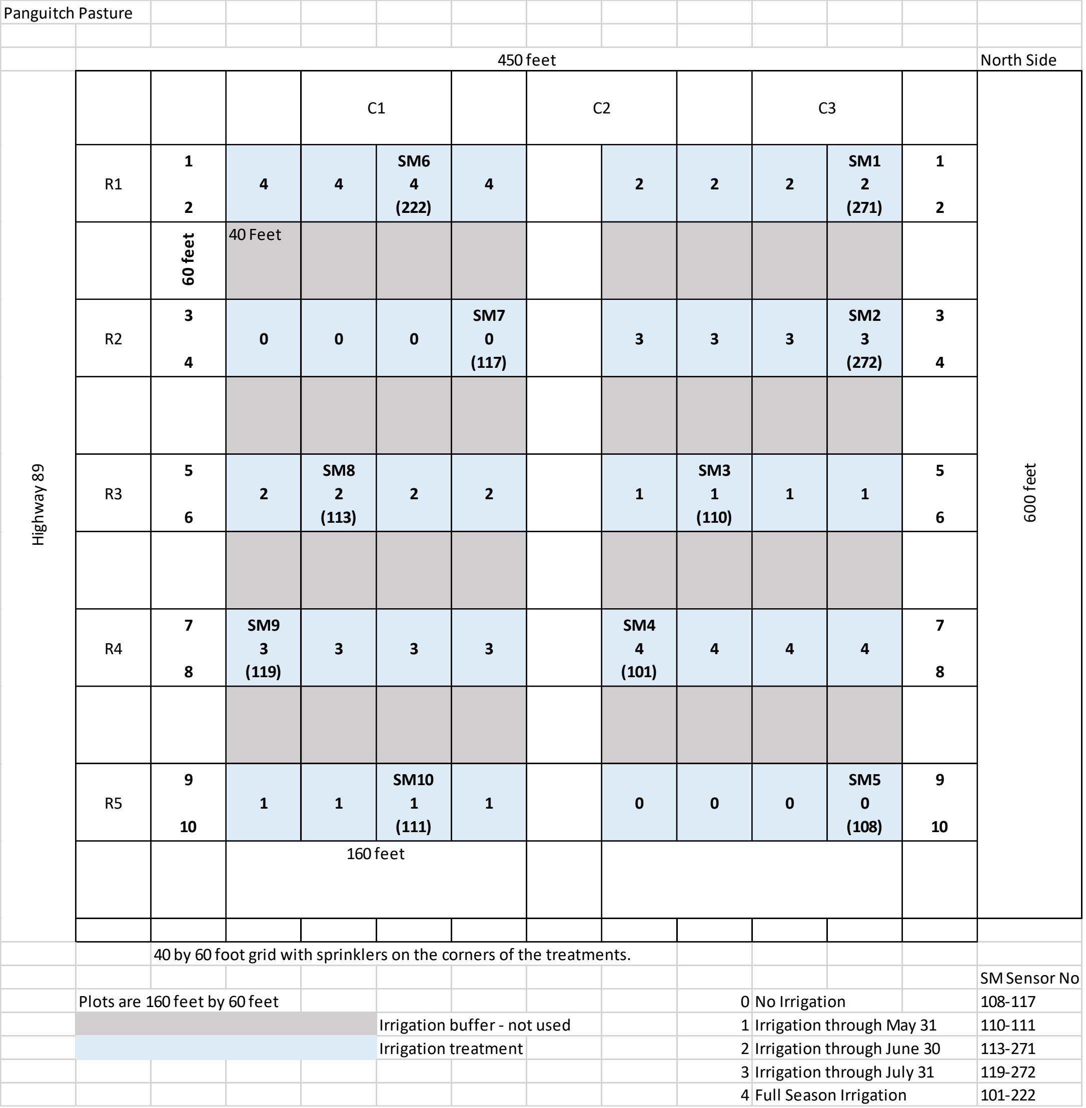


Figure 8. Study area in Panguitch, Utah.

The Panguitch study area includes two replications of five irrigation levels (no irrigation, irrigation through May, June, July and full-season irrigation). In 2017, the research site had 25 plots that were 40 feet by 60 feet separated by 60 feet buffer strip. In 2018 the site was changed to 10 plots 160 feet by 60 feet separated by 60 feet buffer strip in 2018, due to difficulty irrigating the smaller plots precisely with a wheel line sprinkler system (Figure 9). Table 2 is a summary of the climate data.



Panguitch Pasture

450 feet — North Side

Highway 89 — 600 feet

			C1			C2			C3		
R1	1 2	4	4	SM6 4 (222)	4		2	2	2	SM1 2 (271)	1 2
	60 feet	40 Feet									
R2	3 4	0	0	0	SM7 0 (117)		3	3	3	SM2 3 (272)	3 4
R3	5 6	2	SM8 2 (113)	2	2		1	SM3 1 (110)	1	1	5 6
R4	7 8	SM9 3 (119)	3	3	3		SM4 4 (101)	4	4	4	7 8
R5	9 10	1	1	SM10 1 (111)	1		0	0	0	SM5 0 (108)	9 10
		160 feet									

40 by 60 foot grid with sprinklers on the corners of the treatments.

			SM Sensor No
Plots are 160 feet by 60 feet		0 No Irrigation	108-117
▨	Irrigation buffer - not used	1 Irrigation through May 31	110-111
▨	Irrigation treatment	2 Irrigation through June 30	113-271
		3 Irrigation through July 31	119-272
		4 Full Season Irrigation	101-222

Figure 9. Panguitch pasture research area plot layout.

Study area features have been indicated in Table 3. Sentinel-2 Satellite Band Features are presented in Table 4. Pixel resolution of the Sentinel-2 for Red, Green, Blue and NIR was

10 meters (393.7 inches or 32.81 feet), whereas the pixel resolution is 2 cm (1 inch or 0.07 feet) for UAV.

Table 2. Panguitch climate annual averages.

Climate Averages		
	Panguitch,Utah	United States
Rainfall	12.3 inches	38.1 inches
Snowfall	45.4 inches	27.8 inches
Precipitation	68.6 days	106.2 days
Sunny	252 days	205 days
Avg. July High	85.2°	85.8°
Avh. Jan. Low	11.5°	21.7°
Elevation	6624 ft.	2443 ft.

Retrieved in 06/13/2020 https://www.bestplaces.net/climate/city/utah/panguitch

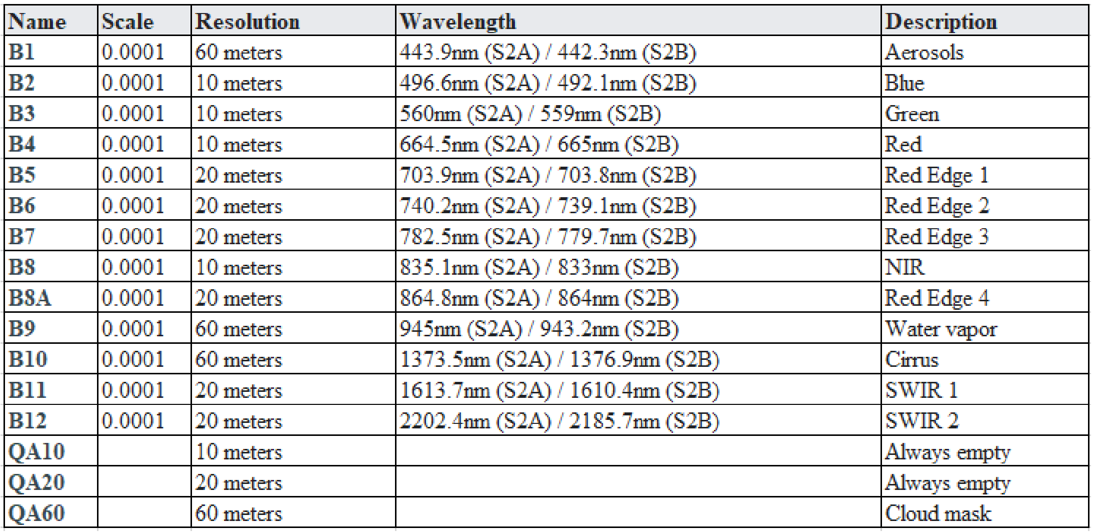
Table 3. Lewiston and Panguitch Study Area Features.

Study Area	Lewiston	Panguitch
Total Plot	20	10
Soil Moisture Sensor	10	10
Size	160 ft x 60 ft	160 ft x 60 ft
Buffer	Yes	Yes
Irrigation Type	Sprinkler Irrigation	Sprinkler Irrigation
Crop Type	Tall Fescue	Tall Fescue and Meadow Brome
Soil Type	Fine Sandy Loam	Loam with Gravel
Annual Precipitation	12.31 inches	9.72 inches

Methods

This research compares pasture yields at different irrigation levels. Yield data from 2013 to 2018 were used for the Lewiston site. In Panguitch, data obtained in 2018 and 2019 were used. The research is conducted for multiple years in order to evaluate and compare the effects of deficit irrigation on the pasture yield.

Table 4. Sentinel-2 imagery bands.



Name	Scale	Resolution	Wavelength	Description
B1	0.0001	60 meters	443.9nm (S2A) / 442.3nm (S2B)	Aerosols
B2	0.0001	10 meters	496.6nm (S2A) / 492.1nm (S2B)	Blue
B3	0.0001	10 meters	560nm (S2A) / 559nm (S2B)	Green
B4	0.0001	10 meters	664.5nm (S2A) / 665nm (S2B)	Red
B5	0.0001	20 meters	703.9nm (S2A) / 703.8nm (S2B)	Red Edge 1
B6	0.0001	20 meters	740.2nm (S2A) / 739.1nm (S2B)	Red Edge 2
B7	0.0001	20 meters	782.5nm (S2A) / 779.7nm (S2B)	Red Edge 3
B8	0.0001	10 meters	835.1nm (S2A) / 833nm (S2B)	NIR
B8A	0.0001	20 meters	864.8nm (S2A) / 864nm (S2B)	Red Edge 4
B9	0.0001	60 meters	945nm (S2A) / 943.2nm (S2B)	Water vapor
B10	0.0001	60 meters	1373.5nm (S2A) / 1376.9nm (S2B)	Cirrus
B11	0.0001	20 meters	1613.7nm (S2A) / 1610.4nm (S2B)	SWIR 1
B12	0.0001	20 meters	2202.4nm (S2A) / 2185.7nm (S2B)	SWIR 2
QA10		10 meters		Always empty
QA20		20 meters		Always empty
QA60		60 meters		Cloud mask

https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S2#bands

Retrieved on 06/13/2020

Remotely sensed data was used to compare the effects of the deficit irrigation on the pasture health. The UAV images including Red, Green, Blue and Near Infrared Bands were taken by Aggie Air and include three sets of UAV images, one before each cutting during 2017 at Lewiston, one during 2018 at Lewiston, and one during 2018 at Panguitch. The UAV images were compared to Sentinel-2 satellite images. There was a significant correlation between UAV images and satellite images; therefore, Sentinel-2 data taken every 5 days were used. The resolution of the UAV Images for this research ranged from 2 cm to 10 cm due to the red, green, blue and near infrared bands. The resolution for Sentinel-2 is 10 meters (393.7 inches or 32.81 feet). The research plots minimum dimension was 60 feet with 60 feet buffers, so the Sentinel-2 was used with careful selection of pixels at the same locations with UAV images. Landsat-8 data was not used in this research due to the pixel resolution of 30 meters (98.42 feet), too large for the research plots.

The UAV images from Aggie Air were compared to satellite image results and statistical relations have been established. The multi-year 5-day interval Sentinel-2 data has been used to determine differences in NDVI between irrigation management strategies. The Sentinel-2 data was used for multiple years in the analysis. Since the research data is more than a year, we had a time-series data to compare the results.

Statistical Analysis

After multiple years of deficit irrigation on pasture, yield results were analyzed. Yield results were compared to each other at all irrigation levels to see the differences. The data were analyzed by site and cut at $P \leq 0.05$ using the MIXED procedure of SAS (SAS Institute, 2016). The dependent variable was forage yield. Site, irrigation treatment, crop type (fescue or brome at Panguitch only), and their interactions were considered fixed effects, whereas replicate (nested within site), and interactions involving replicate were considered random effects. Year was also considered a repeated effect using the first-order autoregressive covariance structure. The UNIVARIATE procedure of SAS was used to inspect the residuals for normality, and scatterplots of the residuals vs. predicted values were used to assess common variance. When fixed effects were significant, Fisher's protected LSD test ($P \leq 0.05$) was used for mean comparisons utilizing the PDIFF procedure of SAS. ArcGIS Pro was used for data management and analysis. Google Earth Engine is used for calculations of the NDVI values and to predict the yield. Python is used for data management.

RESULTS

UAV and Sentinel-2 NDVI Comparisons for Lewiston

In Lewiston, Utah there were three UAV flights conducted before each harvesting during 2017 and one flight during 2018. The Sentinel-2 images taken closest in date to UAV flights were used to determine correlations between the UAV and Sentinel-2 images for plots with soil moisture sensor and the same irrigation level. Table 5 lists the dates of the imagery; the paired UAV and Sentinel-2 images were within a couple of days of each other. NDVI was calculated using UAV and Sentinel-2 data for the plots with soil moisture sensors. Summaries of regression analyses for the 4 sets of data for each plot are listed in Table 6 along with the regression of all the data and the data for August 14, 2018. The UAV data pixel resolution is 2 cm therefore it has more detailed images than the satellite images. The pixel size for Sentinel-2 is 10 meters (32.81 feet), smaller polygons have been created inside the plots and the averaged values have been used. The same polygons were used to calculate NDVI values for UAV data. The only difference was the number of pixels inside the polygons. Crop NDVI values are assumed more accurate with better pixel resolution, thus the correlation between UAV and Sentinel-2 satellite is more important to get better results. The analysis shows a good correlation between the data sets and allows the Sentinel-2 data to be used in along with UAV data. Since the correlations between the satellites might be different due to the band width and wavelength, 90 percent correlation was used without any adjustment. Figure 10 includes plot of the data used in the regression analysis showing the correlation of the variable sets. The correlation between NDVI calculated with Sentinel-2 and UAV data is strong, only one correlation had and R^2 below 0.90.

Table 5. UAV and Sentinel-2 flights dates.

UAV	**Sentinel-2**
6/18/2017	6/20/2017
8/22/2017	8/21/2017
10/17/2017	10/18/2017
8/14/2018	8/14/2018

Table 6. Regression correlation of NDVI calculated from UAV and Sentinel-2 data (y=ax + b), where Sentinel-2 NDVI values are a function of UAV NDVI values.

Soil Moisture Sensors in Lewiston	**Irrigation Level**	**Number of Data Pairs**	**Equation**	**R^2**
221	No Irrigation	4	$y = 1.15x - 0.17$	$R^2 = 0.95$
261	No Irrigation	4	$y = 1.04x - 0.09$	$R^2 = 0.94$
104	Irrigation until June	4	$y = 1.26x - 0.27$	$R^2 = 0.97$
105	Irrigation until June	4	$y = 1.03x - 0.12$	$R^2 = 0.83$
211	Irrigation until July	4	$y = 0.95x - 0.02$	$R^2 = 0.96$
212	Irrigation until July	4	$y = 1.05x - 0.10$	$R^2 = 0.97$
230	Irrigation until August	4	$y = 1.02x - 0.07$	$R^2 = 0.97$
251	Irrigation until August	4	$y = 0.92x + 0$	$R^2 = 0.91$
242	Full Season Irrigation	4	$y = 0.93x - 0.00$	$R^2 = 0.94$
252	Full Season Irrigation	4	$y = 1.27x - 0.30$	$R^2 = 0.94$
All Data	All Irrigation Types	40	$y = 0.99x - 0.06$	$R^2 = 0.91$
Same Day	All Irrigation Types	10	$y = 0.69x + 0.15$	$R^2 = 0.95$

Figure 11 indicated the correlation between UAV and Sentinel-2 Satellite NDVI values for all irrigation level plots. For 2017, there was 3 flights before each harvest and for 2017 there was one flight before the harvest. Those flights and the closest date satellite images have been used to make the comparison and find the correlation. Overall correlation was very high with $R^2 = 0.90$.

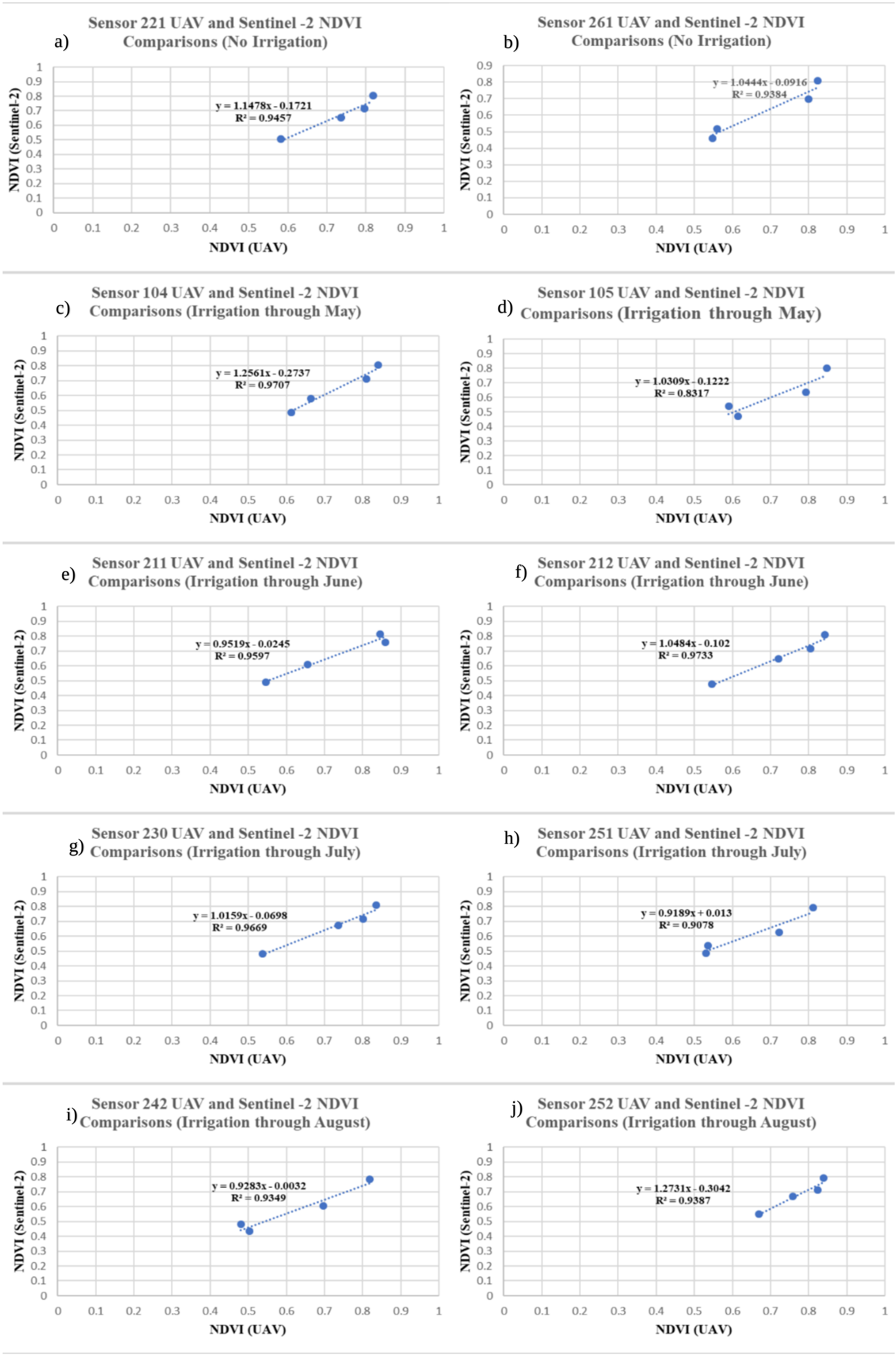


Figure 10. UAV and Sentinel-2 NDVI Comparison.

This correlation is the most useful, because it includes more data pairs and data over multiple locations with wider range of values than the correlations for the single locations.

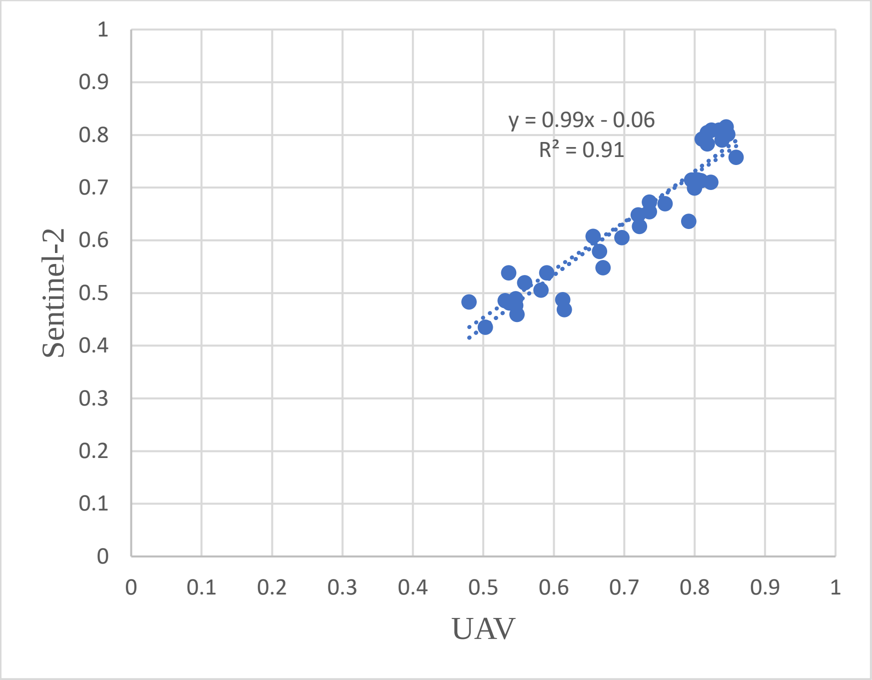


Figure 11. UAV and closest Sentinel-2 NDVI correlation for all sensor locations.

Figure 12 shows the correlation between UAV and Sentinel-2 Satellite NDVI values for each plot for same day flight with UAV and Sentinel-2 Satellite. Same day flight had a little better result compared to all NDVI comparisons. That means, the correlation values for other figures would be better when they have same day flight with UAV and Sentinel-2.

The results of the NDVI comparisons from UAV and Sentinel-2 show that NDVI are very close each other and Sentinel-2 data can be used for NDVI. While the correlation is around 90 percent in some images, same day images for UAV and Sentinel-2 correlation was above the 95 percent, therefore Sentinel-2 images were used for the research area to expand the dataset. Since UAV flights are costly and not easy to process the data and equipment, satellite images are a good choice for agricultural areas. The wavelength is different between each satellite or cameras so the correlation between UAV and Sentinel-2 was very accurate, therefore the adjustment between them was not needed.

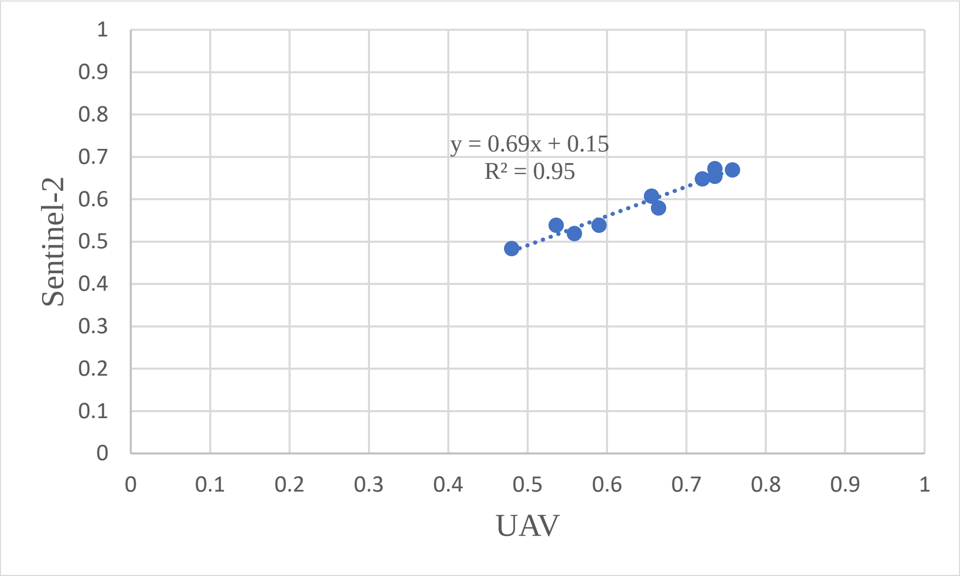


Figure 12. Correlation of the same day NDVIs for UAV and Sentinel-2 for all sensor locations.

Pasture Yield Predicted by NDVI

Table 7 lists the yield predictions before harvests using NDVI as an indicator with the correlation values. Yield predictons have been shown in the Table 7. For three different years, yield predictions have been made. The equations obtained from the yield and NDVI values were used to create yield maps. Y value in equation represents the predicted yield and X value is the NDVI value. Predicted yield is obtained by the equation by using NDVI values. Actual yield values have been used to find the correlation between yield and NDVI values. Figure 13 represents the approximate location of the plots by irrigation levels. Red color shows no irrigation (0), yellow indicates irrigation until June (1), green color represents irrigation until July (2), turquois color shows irrigation until August (3), and blue color indicates full season irrigation (4) . The locations of the plots have been put approximately. Figure 13 can be used to find the location of irrigation levels for the other predicted yield maps in Lewiston. The number of total plots are 20 in Lewiston with 5 differen irrigation level numbered from 0 to 4. Yield predictions were made with the help of Sentinel-2 data. The predicted correlation values have been put Figure 14 by choosing the best correlations before each harvest. The number of yield prediction correlations can be different than other images because Sentinel-2 images cannot be usable due to cloudy days so it changes the number of images obtained from Sentinel-2. It is possible not to have same number of images between each harvest due to climate conditons. Figure 14 shows the correlation between NDVI and yield for the second cutting on August 25, 2016 harvest (plots a-d) and October 20, 2016 (plot e). The correlation becomes stronger the closer to the date of harvest. Figure 15 is the 2016 predicted yield map for Lewiston study area. The map has been created by using the equation from Table 7.

(https://code.earthengine.google.com/b819fd2de689b2ed0a54a0f9e2c07241)

The yield map has been created by using the respective formulas from Figure 14 b). This map represents the yield 21 days before the harvest. The code is available here:

(https://code.earthengine.google.com/67ff06cf29e46a5c74af1a43582e289a)

The yield map in Figure 15 c) has been created from the Figure 14 d) formula to predict the yield one day before the harvest for Lewiston study area.

https://code.earthengine.google.com/d7be2456c1b4511ad97a7e430f59b39c

Figure 15 d) shows the yield map that has been calculated from Figure 14 e) formula. This map indicates the yield 30 days before the harvest.

(https://code.earthengine.google.com/1e9ed18fe3398de5e2a743fe0a6b4a28)

Provided website links show the predicted yield maps and the code that has been used to create yield maps. The estimated yield values can be seen from the inspector module on Google Earth Engine. After selecting the inspector module, whenever the map is clicked, the predicted yield values will appear on the right of the page.

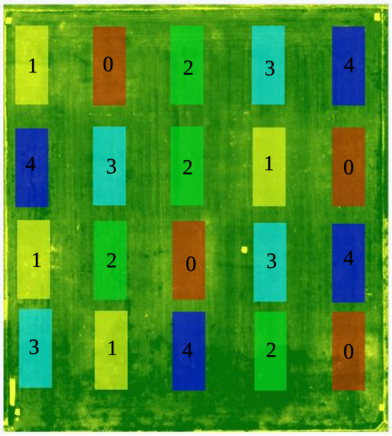


Figure 13. Approximate plot locations by irrigation levels in Lewiston.

Lewiston 2017

Figure 16 a) represents the correlation between NDVI and yield 21 days before the harvest. The correlation was $R^2 = 0.80$ and the $RMSE = 0.07$. The correlation between yield and NDVI have been found 4 days before the harvest in Figure 16 b) with $R^2 = 0.84$ and RMSE = 0.06.

Table 7. Lewiston yield predictions.

Lewiston					
NDVI Date	**Harvest Date**	**Days Before Harvest**	**Equation**	**R^2**	**RMSE (tons/acre)**
7/22/2016	8/25/2016	34	$y = 2.36x - 0.83$	$R^2 = 0.85$	RMSE = 0.06
8/4/2016	8/25/2016	21	$y = 2.63x - 1.20$	$R^2 = 0.9$	RMSE = 0.04
8/11/2016	8/25/2016	14	$y = 2.73x - 1.23$	$R^2 = 0.93$	RMSE = 0.04
8/24/2016	8/25/2016	1	$y = 4.55x - 1.93$	$R^2 = 0.97$	RMSE = 0.03
9/20/2016	10/20/2016	30	$y = 0.88x - 0.37$	$R^2 = 0.82$	RMSE = 0.01
8/4/2017	8/25/2017	21	$y = 2.57x - 1.10$	$R^2 = 0.80$	RMSE = 0.07
8/21/2017	8/25/2017	4	$y = 3.04x - 1.61$	$R^2 = 0.84$	RMSE = 0.06
10/3/2017	10/19/2017	16	$y = 0.86x - 0.39$	$R^2 = 0.69$	RMSE = 0.01
10/18/2017	10/19/2017	1	$y = 1.35x - 0.56$	$R^2 = 0.87$	RMSE = 0.01
7/27/2018	8/15/2018	19	$y = 3.72x - 1.33$	$R^2 = 0.72$	RMSE = 0.11
8/6/2018	8/15/2018	9	$y = 2.70x - 1.20$	$R^2 = 0.82$	RMSE = 0.09
8/9/2018	8/15/2018	6	$y = 3.32x - 1.42$	$R^2 = 0.86$	RMSE = 0.08

Figure 16 c) was the correlation between third cutting yield and NDVI values 16 days before the harvest. The correlation was $R^2 = 0.69$ and the RMSE = 0.01. Yield and NDVI correlation has been shown in Figure 16 d). The correlation between them was $R^2 = 0.87$ and RMSE = 0.01 one day before the harvest. It was the last harvest for Lewiston study area in 2017.

Lewiston 2016

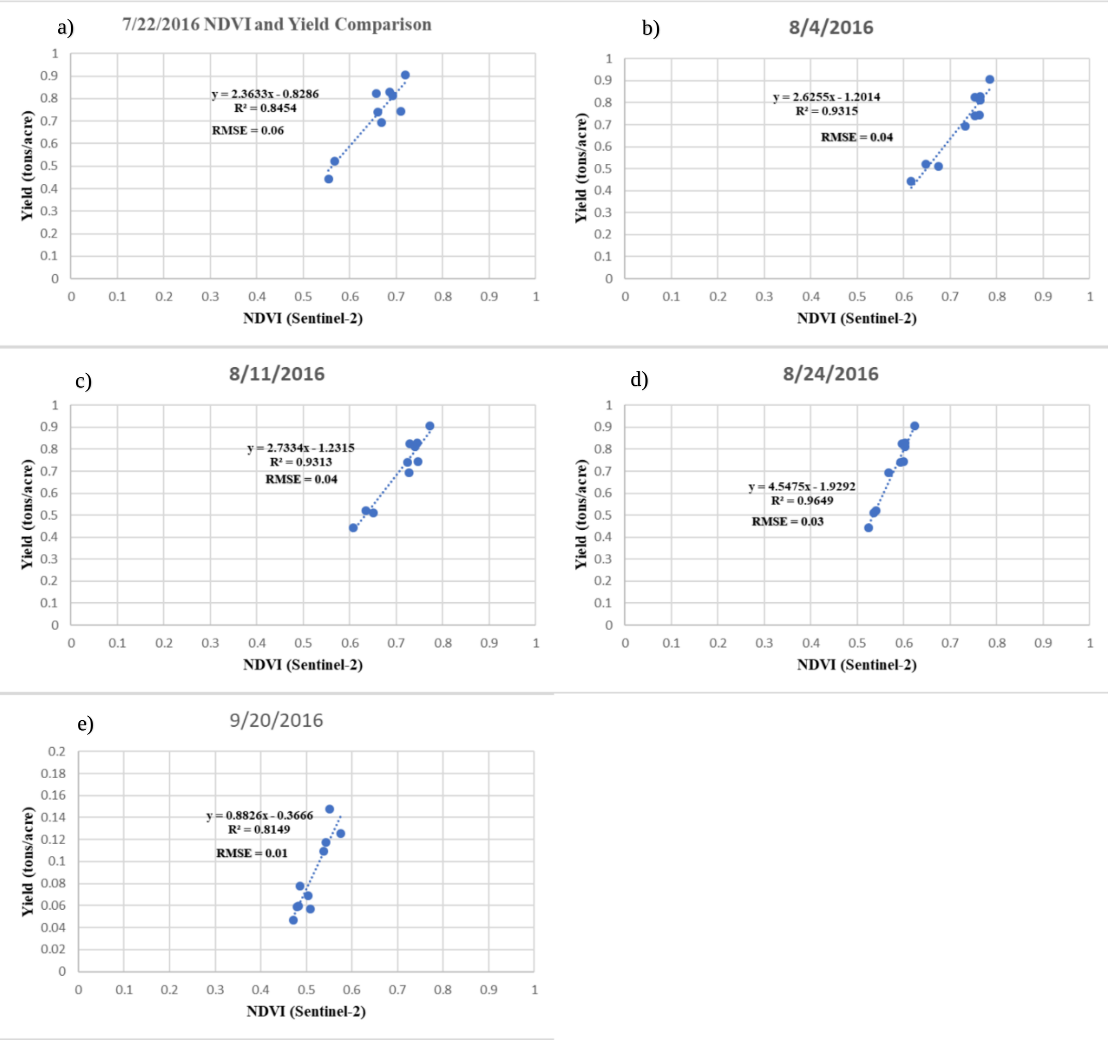


Figure 14. NDVI and yield correlation for Lewiston in 2016.

Figure 17 a) is the yield map 21 days before the harvest. The map has been created by using the formula from the Figure 16 a). The formula (y = 2.5733x – 1.0969) has been used for NDVI values to get the yield map.

(https://code.earthengine.google.com/f6490fa176a2081a3dd8b6cd6925ef6a)

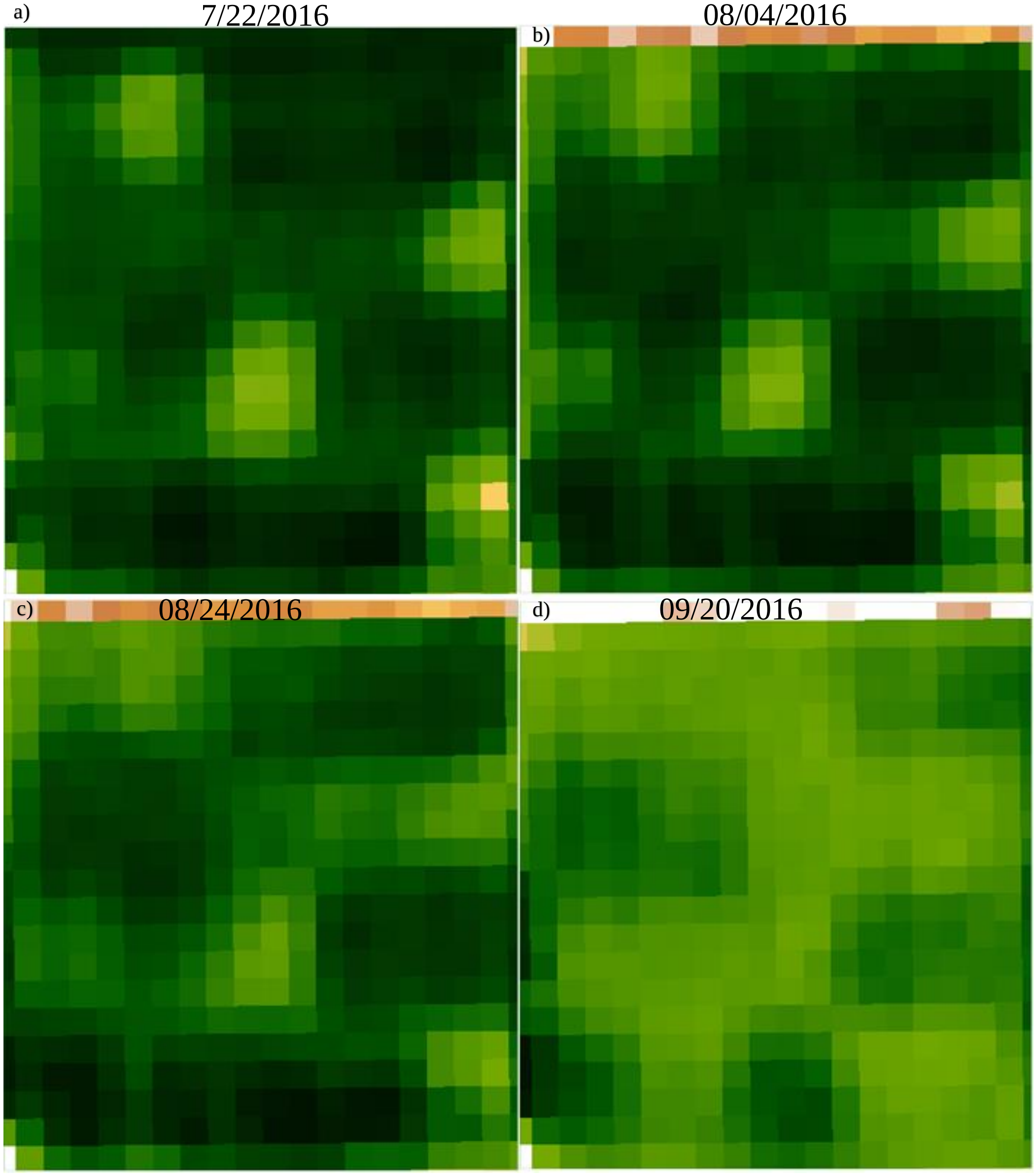


Figure 15. Yield map for Lewiston in 2016.

Yield map has been obtained in Figure 17 b) by using the Figure 16 b) formula. The map shows the yield 4 days before the harvest.

(https://code.earthengine.google.com/b3be99b54f9119b6f15ad80d93e0505d)

Figure 17 c) is the yield map for third cutting in 2017 for Lewiston study area. The formula from Figure 16 c) has been used to get yield map.

(https://code.earthengine.google.com/5adf738a264b8fae98e55e927e319641)

The yield map in figure 40 was obtained from the formula in Figure 16 d). Figure 17 d) shows the yield map one day before the harvest. The effects of deficit irrigation is more obvious than the other yield maps here in Figure 17 d).

https://code.earthengine.google.com/b820df51bf6bd8fed5f7fed51d6053bc

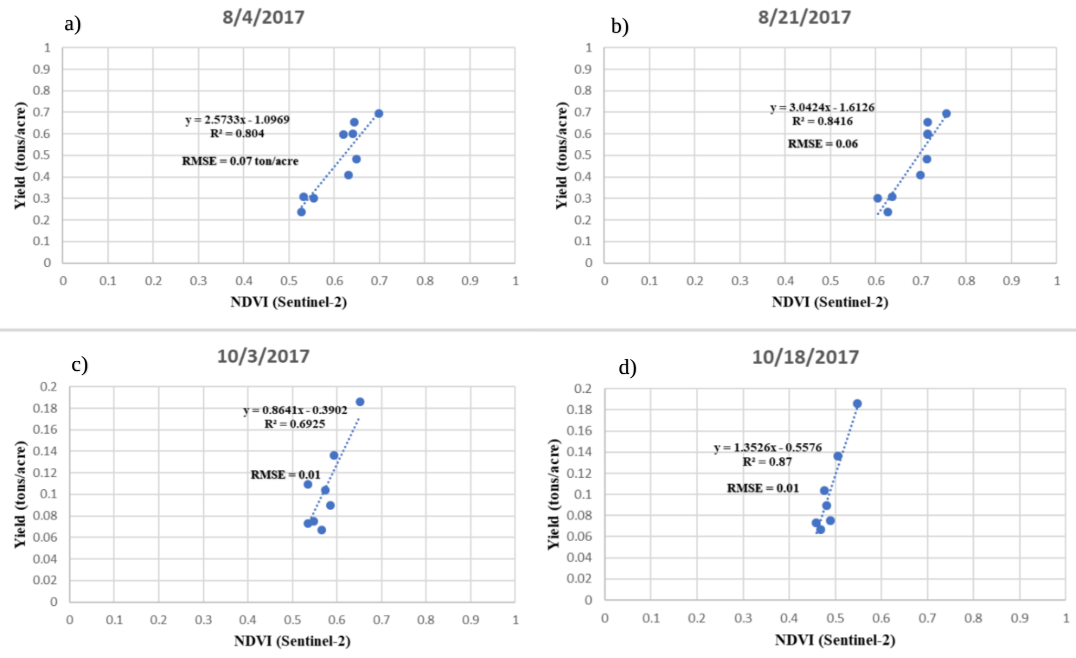


Figure 16. NDVI and yield correlation for Lewiston in 2017.

Lewiston 2018

Figure 18 a) is the yield and NDVI correlation 19 days before the harvest. The correlation values were $R^2 = 0.72$ and RMSE = 0.11. The correlation was high in Figure

18 b) representing the comparison of the NDVI and yield. The NDVI values were 9 days before the harvest. R² = 0.82 and RMSE = 0.09 in 8/6/2018. The correlation in Figure 18 c) has been found between yield and NDVI values in 08/09/2018 in Lewiston study area 6 days before the harvest with R² = 0.86 and RMSE = 0.08.

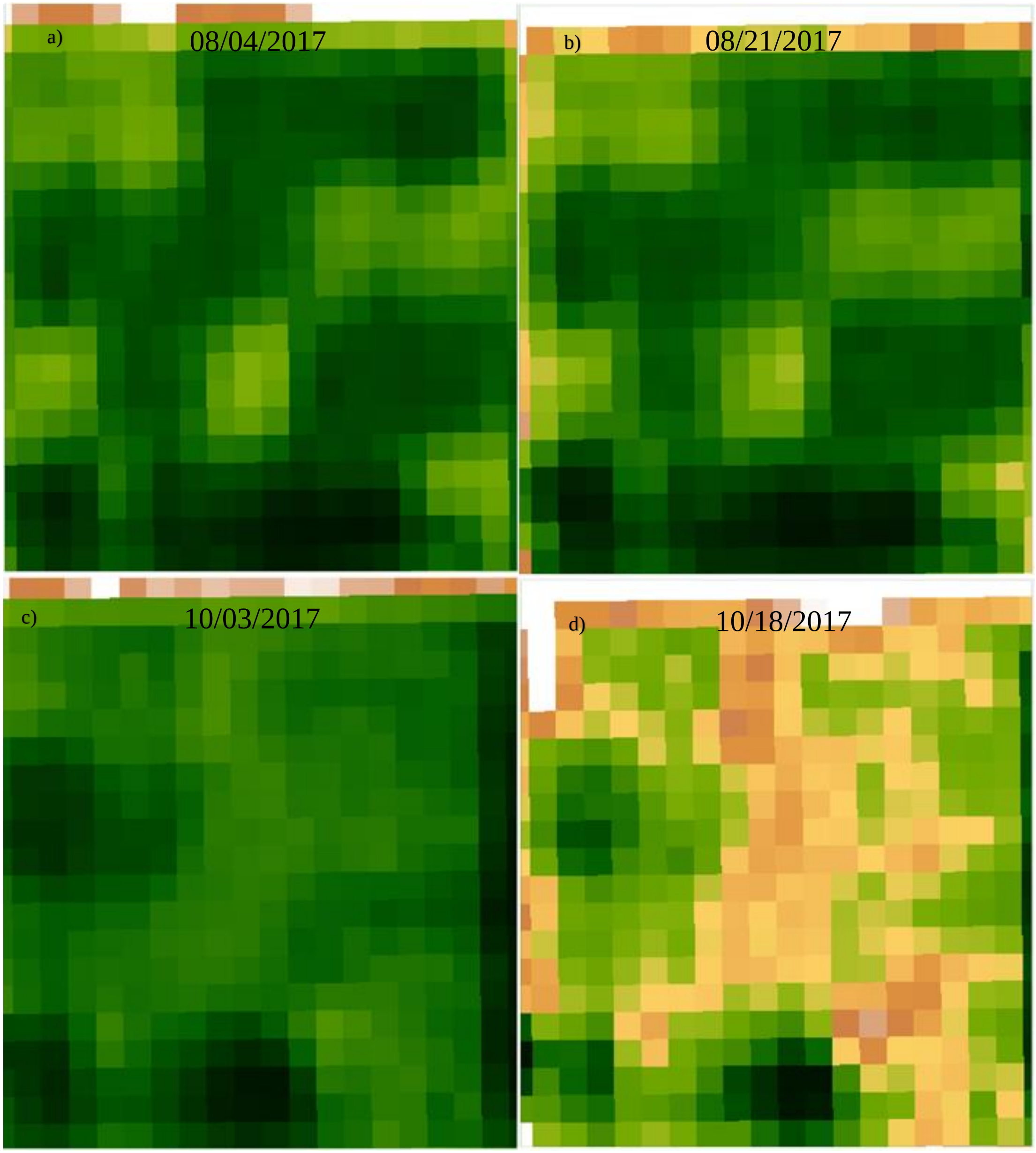


Figure 17. Yield Map for Lewiston in 08/04/2017.

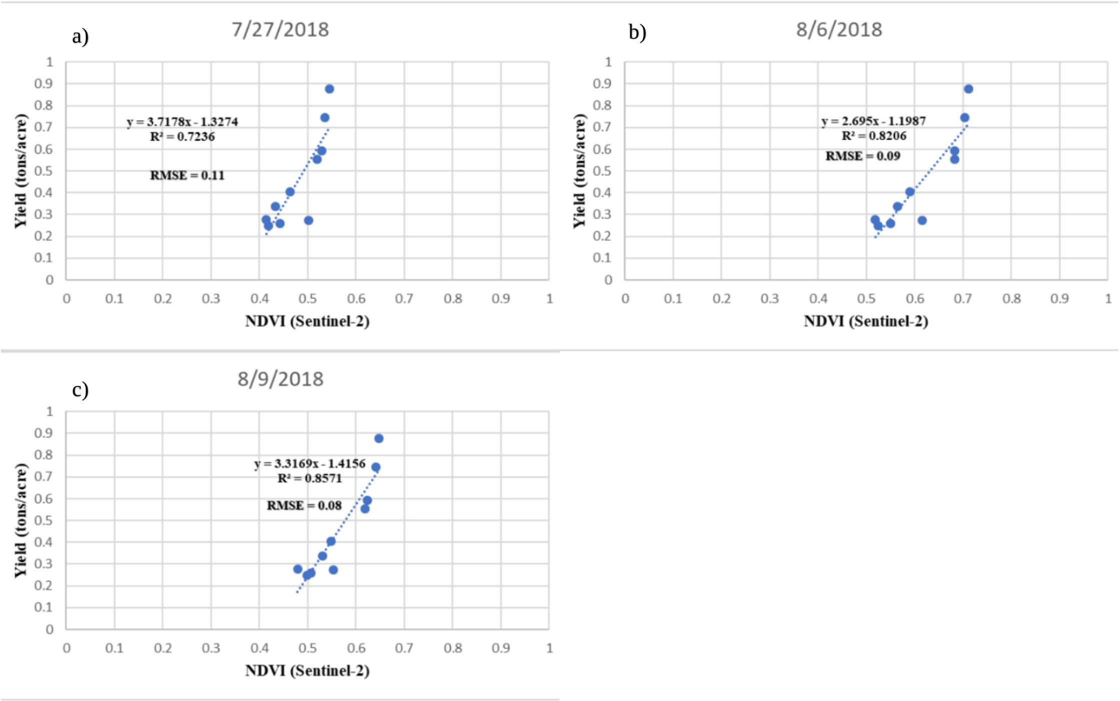


Figure 18. NDVI and yield correlation for Lewiston in 2018.

Figure 19 a) is obtained from formula in Figure 18 a). The formula and NDVI values have been used to get the yield map in 07/27/2018. From the yield map we can see the effects of deficit irrigation and irrigated and non-irrigated plots.

https://code.earthengine.google.com/061e755135f4ce664c979b957e5c84bf

Figure 19 b) is the yield map 9 days before the harvest and it shows the impacts of deficit irrigation on the plots. The yield map has been obtained by using the formula in Figure 18 b).

https://code.earthengine.google.com/c21f130221adf324b73b1d0ec5dd9c49

Figure 46 has been obtained by using the formula from the Figure 18 c). The changes in yield can be seen between Figure 19 c) and 20 b) in terms of yield and effect of deficit irrigation. Non-irrigated ares yield was little bit more lower than 3 days ago.

https://code.earthengine.google.com/6edfdf017c13920f3fd06c2ca9780514

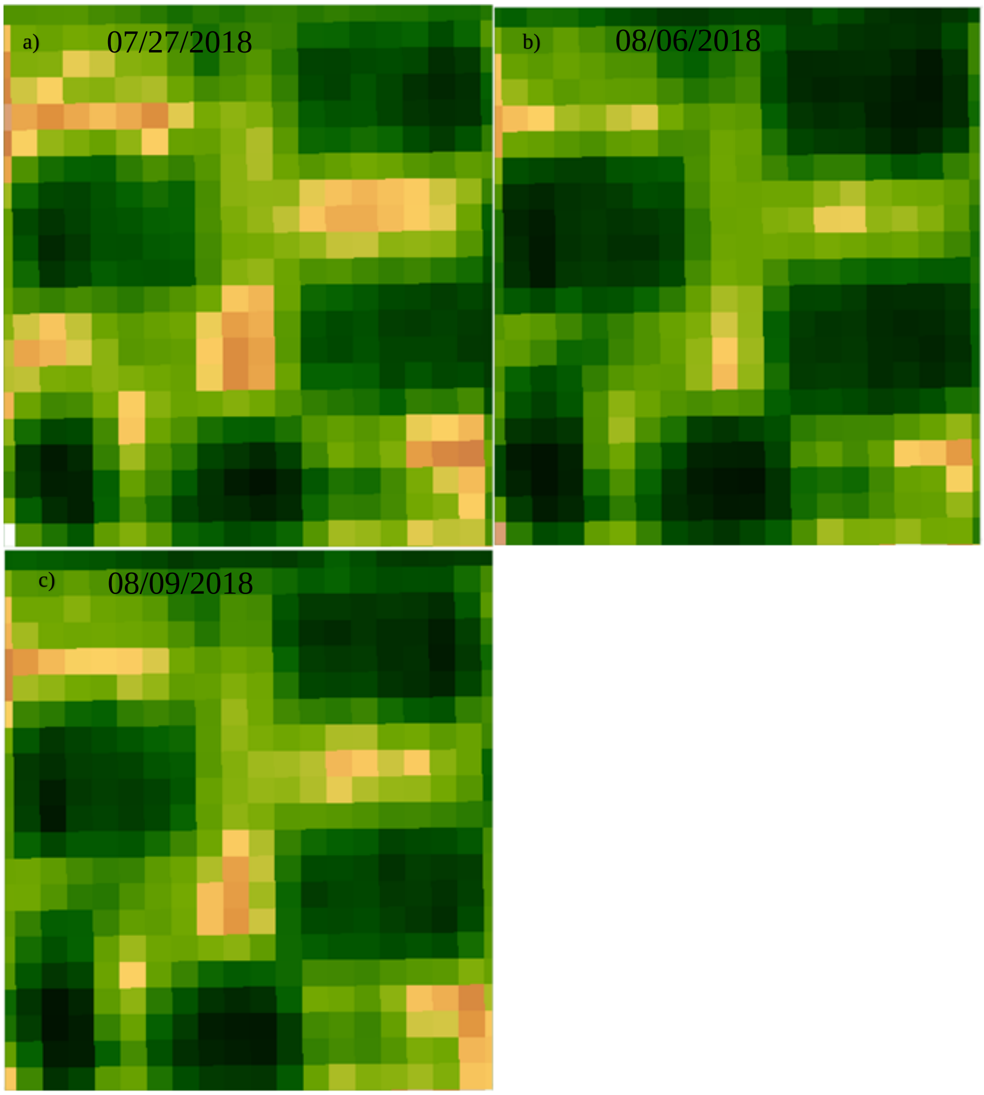


Figure 19. Yield map for Lewiston in 2018.

Panguitch 2018

Table 8 shows the yield estimations for two years. The equations obtained from NDVI and yield correlation have been used to get yield maps.

Figure 20 shows the location of the plots approximately by irrigation levels. Red color represents no irrigation (0), yellow shows irrigation through May (1), green color indicates irrigation through June (2), turquois color shows irrigation through July (3), and blue color indicates full season irrigation (4) . The locations of the plots have been shown approximately. Figure 20 can be used to find the location of irrigation levels for the other predicted yield maps in Panguitch.Figure 21 a) is the correlation between NDVI values and the yield in Panguitch study area for the first harvest. The NDVI values have been obtained in 04/28/2018 and the yield has been cut in 07/06/2018. The yield estimation was made 69 days before the harvest with $R^2 = 0.75$ and RMSE = 0.09. Figure 21 b) is the correlation of the NDVI and yield in 05/18/2018 for Panguitch study area 49 days before the harvest. The correlation was very high with $R^2 = 0.96$ and RMSE = 0.04. Figure 21 c) is the yield and NDVI comparison in 06/17/2018 for Panguitch study area. The correlation was good 19 days before the harvest with $R^2 = 0.84$ and RMSE = 0.07. NDVI and yield values comparisons have been shown in Figure 21 d) with $R^2 = 0.85$ and RMSE 0.07 for Panguitch study area 9 days before the harvest. Figure 21 e) is the correlation between yield and NDVI values 4 days before the harvest. $R^2= 0.84$ and RMSE = 0.07 Panguitch study area. The formula is used to get yield values from the NDVI values. Figure 21 f) is comparison of the second harvest yield and NDVI values 38 days before the harvest. Correlation was $R^2 = 0.64$ and RMSE = 0.1. Figure 21 g) shows the correlation between yield and NDVI values for Panguitch study area 28 days before the harvest with R² = 0.65 and RMSE = 0.09. Figure 21 h) indicates the NDVI and yield correlation 8 days before the harvest in Pangutich with R² = 0.87 and RMSE = 0.06. Figure 21 i) is the correlation between yield and NDVI value in 09/10/2018 for Panguitch study area 3 days before the second harvest. R² = 0.82 and RMSE = 0.07 have been found from the correlation.

Table 8. Panguitch yield prediction analyses.

Panguitch					
NDVI Date	**Harvest Date**	**Days Before Harvest**	**Equation**	**R²**	**RMSE (tons/acre)**
4/28/2018	7/6/2018	69	y = 4.76x - 0.12	R² = 0.75	RMSE = 0.09
5/18/2018	7/6/2018	49	y = 2.34x + 0.39	R² = 0.96	RMSE = 0.04
6/17/2018	7/6/2018	19	y = 1.51x + 0.48	R² = 0.84	RMSE = 0.07
6/27/2018	7/6/2018	9	y = 1.50x + 0.50	R² = 0.85	RMSE = 0.07
7/2/2018	7/6/2018	4	y = 1.44x + 0.57	R² = 0.84	RMSE = 0.07
8/6/2018	9/13/2018	38	y = 2.52x - 0.88	R² = 0.64	RMSE = 0.1
8/16/2018	9/13/2018	28	y = 2.03x - 0.62	R² = 0.65	RMSE = 0.09
9/5/2018	9/13/2018	8	y = 2.32x - 0.84	R² = 0.87	RMSE = 0.06
9/10/2018	9/13/2018	3	y = 2.08x - 0.69	R² = 0.82	RMSE = 0.07
6/22/2019	7/1/2019	9	y = 4.05x - 1.31	R² = 0.86	RMSE = 0.07
6/27/2019	7/1/2019	4	y = 3.18x - 0.66	R² = 0.84	RMSE = 0.07
8/21/2019	9/19/2019	29	y = 2.26x - 0.90	R² = 0.74	RMSE = 0.09
8/31/2019	9/19/2019	19	y = 2.36x - 0.94	R² = 0.79	RMSE = 0.08
9/15/2019	9/19/2019	4	y = 2.66x - 0.57	R² = 0.66	RMSE = 0.1

Figure 22 a) is the yield map for Panguith study area 69 days before the harvest. It has been obtained by using the formula in Figure 21 a).

https://code.earthengine.google.com/09220d029ff3a1b3f68bf1bf9ab79cac

The yield map in Figure 22 b) was calculated from the formula in Figure 21 b). It shows the predicted yield 49 days before the harvest with very high accuracy for the Panguitch study area.

https://code.earthengine.google.com/1b839474e51f2751687193843f69d9bd

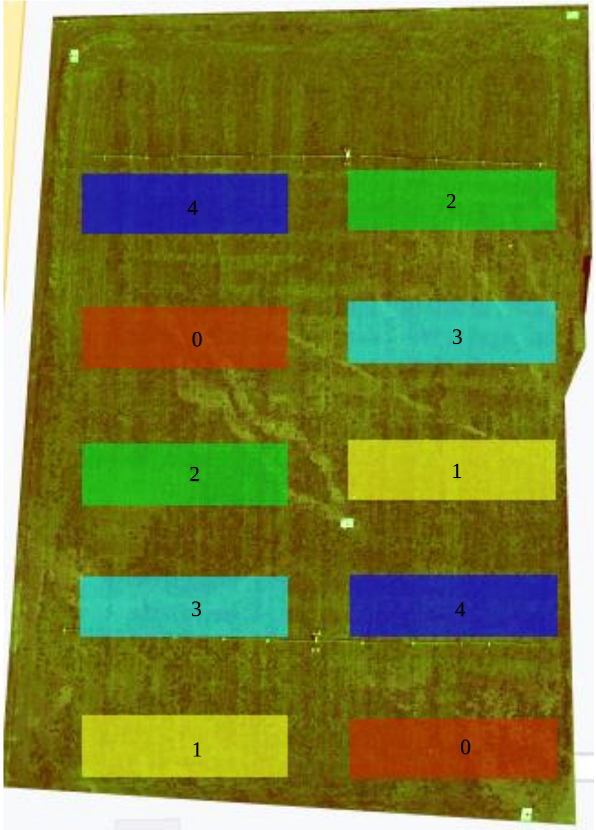


Figure 20. Approximate plot locations by irrigation levels in Panguitch.

The predicted yield map is shown in Figure 22 c) for Panguitch study area 19 days before the harvest. The map has been created by using the NDVI values and the formula from the Figure 21 c).

https://code.earthengine.google.com/861e35b8893861c4604e8174724e03a9

The yield map in Figure 22 d) indicates the predicted yield 9 days before the first harvest in Panguitch. The NDVI values and formula in Figure 21 d) have been used to obtain the yield map.

https://code.earthengine.google.com/875802d3a10a5a66d07d6a13b6a67725

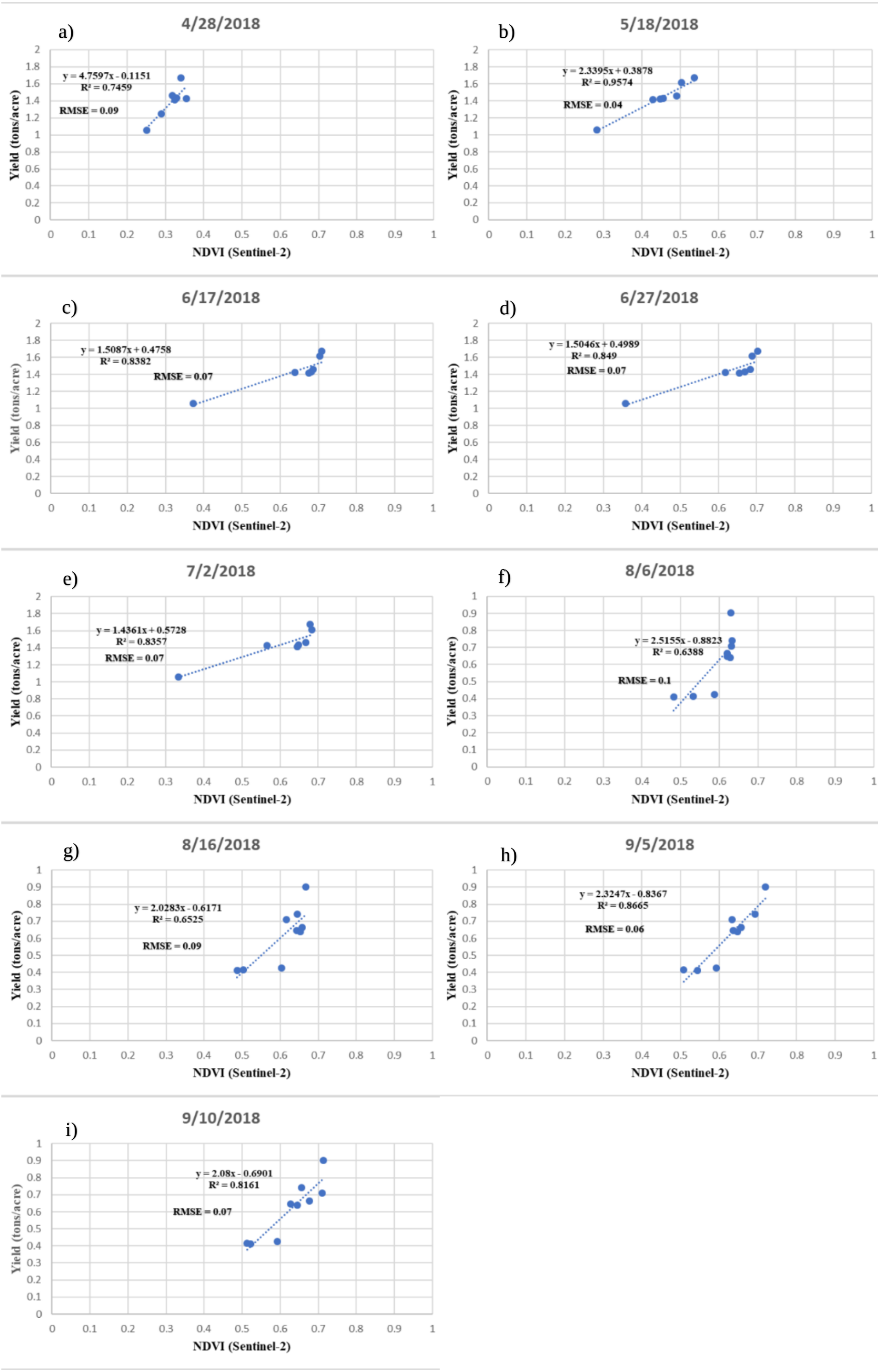


Figure 21. NDVI and yield correlation for Panguitch in 2018.

Yield map in Figure 22 e) has been obtained from the formula from Figure 21 e). The map shows the predicted yield 4 days before the harvest.

https://code.earthengine.google.com/84deeadafc30c736131ba29d6a5c4955

Figure 22 f) is the yield map in Panguitch study area. The map was created using formula from Figure 21 f) and NDVI values in 08/06/2018.

https://code.earthengine.google.com/6bd9de162d9ced82458a34126a397ddc

Figure 22 g) is the yield map 28 days before the harvest for Panguitch. The map has been created in Google Earth Engine by using NDVI values and the formula from Figure 21 g).

https://code.earthengine.google.com/3be05bbb4334fe6ec525ef3ee74ea0ab

Figure 22 h) shows the yield map in Panguitch 8 days before the harvest. The map was created by using the formula in Figure 21 h) and NDVI values. GEE has been used to obtain the yield map.

https://code.earthengine.google.com/4b683654a47dcf1a1bb32c2b0fb32d04

The predicted yield map in Figure 22 i) has been created from formula in Figure 21 i). This map shows how the yield look like 3 days before the harvest with a good correlation.

https://code.earthengine.google.com/fadd447a993cc54559d551597853e874

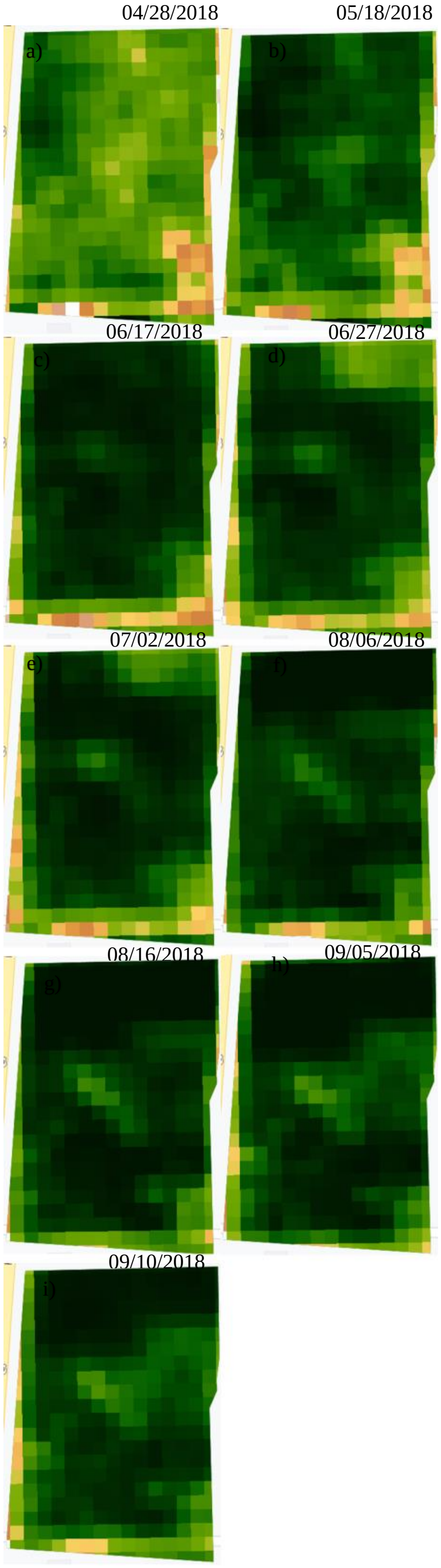


Figure 22. Yield map for Panguitch in 2018.

Panguitch 2019

Figure 23 a) is the correlation between NDVI and yield for Panguitch study area in 2019 nine days before the harvest. $R^2 = 0.86$ and RMSE was 0.07 for this day. Figure 23 b) shows the NDVI and yield correlation in Panguitch study area 4 days before the first harvest with $R^2 = 0.84$ and RMSE = 0.07. The correlation of NDVI and yield have been shown in Figure 23 c). It is for Panguitch study area yield estimation correlation 29 days before the harvest. The correlation result was good with $R^2 = 0.74$ and RMSE = 0.09. The correlation between yield and NDVI have been indicated in Figure 23 d) for Panguitch study area 19 days before the second harvest with $R^2 = 0.79$ and RMSE = 0.08. Figure 23 f) is the correlation of NDVI and the yield 4 days before the harvest. The yield estimation correlation was $R^2 = 0.66$ and RMSE = 0.1

The created map in Figure 24 a) is the yield map of the Panguitch study area 9 days before the harvest. The yield map has been obtained by using the formula from Figure 23 a). GEE has been used to create the yield map.

(https://code.earthengine.google.com/1adf66f506269003ae7eb774aa0696c5)

Figure 24 b) indicates the yield map that has been calculated from the formula in Figure 23 b). This map shows the predicted yield 4 days before the first harvest in Panguitch study area.

(https://code.earthengine.google.com/716e4656b037bcf74fec76447e62b25f)

The yield map in Figure 24 c) was obtained from the NDVI values and the formula in Figure 23 c). The map represents the predicted yield with NDVI in Panguitch study area 29 days before the second harvest.

([https://code.earthengine.google.com/c22a9acf06f0705c52a77b8d757c6aee)](https://code.earthengine.google.com/c22a9acf06f0705c52a77b8d757c6aee)

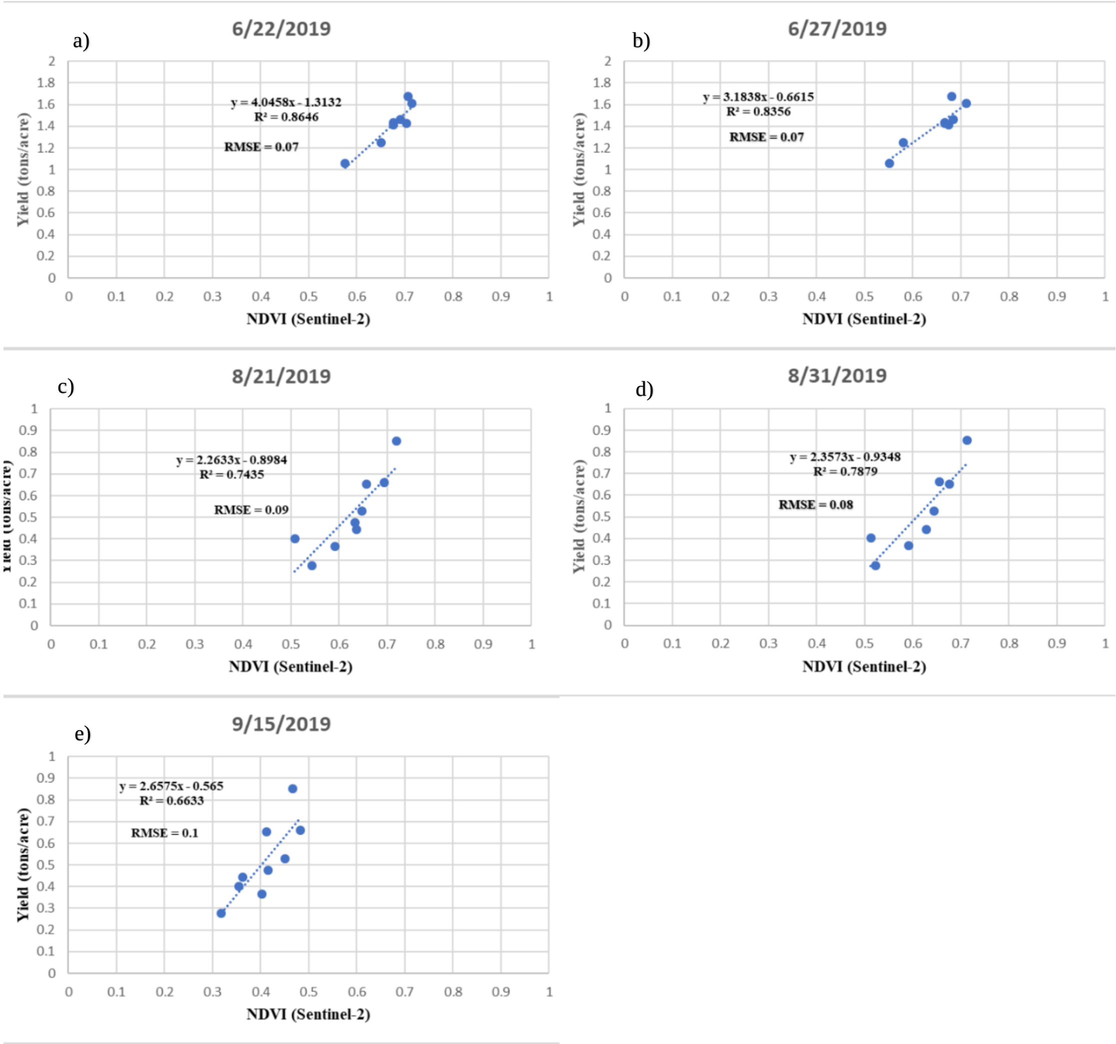


Figure 23. NDVI and yield correlation for Panguitch in 2019

Figure 24 d) represents the yield map for Panguitch study area 19 days before the second harvest. The map was created from the formula in Figure 23 d) by using NDVI values with GEE.

(https://code.earthengine.google.com/ca6520da239c570ab4058e61e581e89f)

The yield map in Figure 24 e) has been obtained from the formula in Figure 23 e). The map shows the predicted yield four days before the harvest in Panguitch study area in 2019 for the last cutting.

(https://code.earthengine.google.com/70b4f36cbb112eff5140f155b0e70578)

Irrigation Season Length and Yield in Lewiston

Figure 25 shows that average yield in 2014 through 2018was affected by irrigation level. Non-irrigated area had less yield than full-season area. Full-season irrigated area and irrigated until August areas always had the most yield compared to other irrigation levels. There was effects of rainfall and climate on yield, therefore there have been fluctuations on the yields. There was no big difference between non-irrigated and irrigated through May plots. They produced yield close each other.

Lewiston Yield

Table 9 indicates the first cut average yield analysis by irrigation treatments. Irrigation treatment did not matter in terms of yield results for each treatment due to earliest harvest and rainfall. Table 10 shows the statistical analysis of the second cuttings and treatments for average yields during the years. According to the results, both full season irrigation and irrigation through July had yields each other. The areas with no irrigation had the lowest yield response, whereas irrigation through May and June had close yield results.

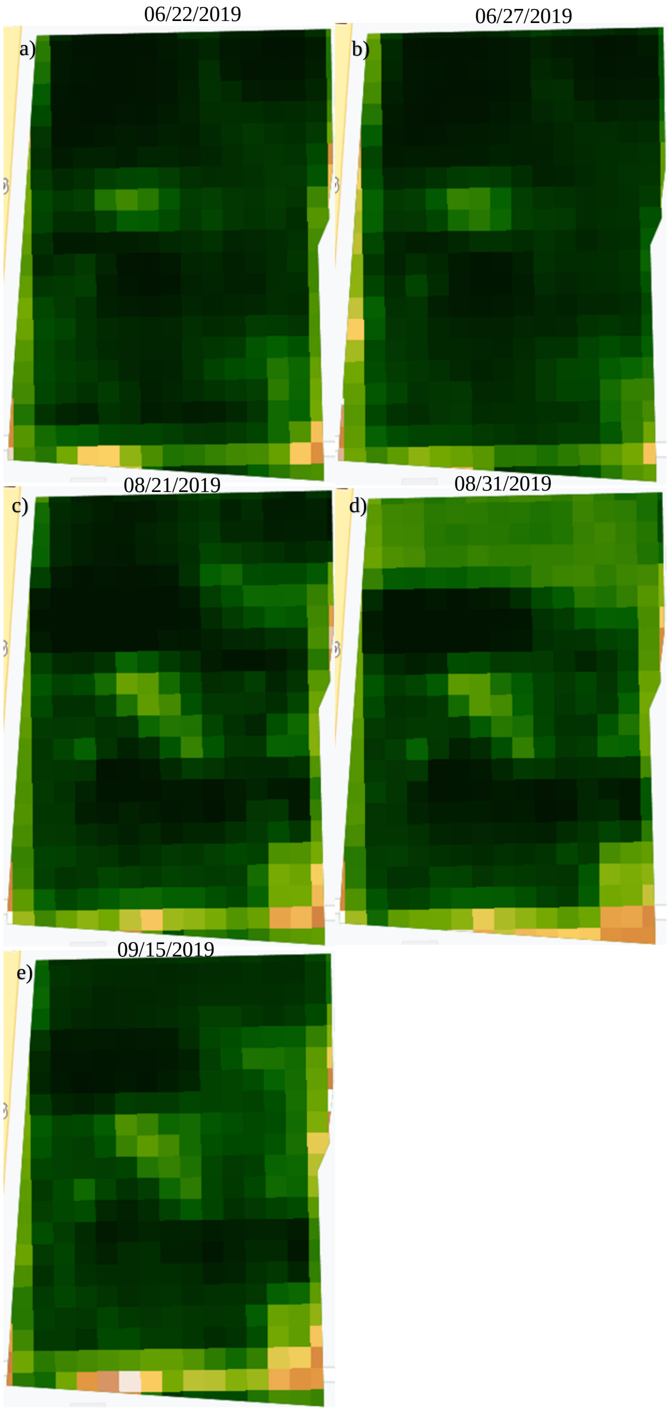


Figure 24. Yield Map for Panguitch in 2019.

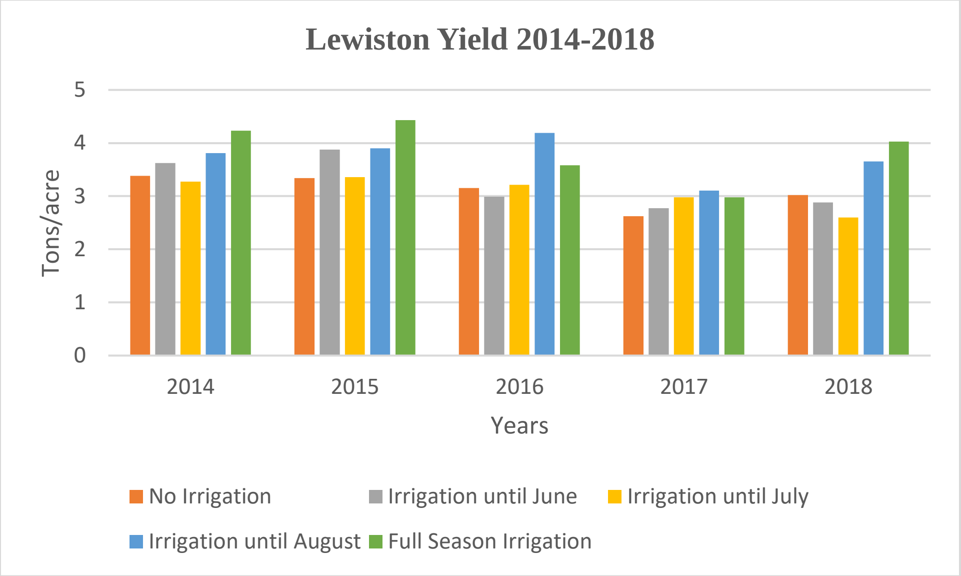


Figure 25. Lewiston Yield (2014-2018).

Table 11 represents the analysis of 3rd cuttings by irrigation levels. Yield differed by irrigation levels. Highest irrigations had highest yields compared to non-irrigated area and other deficit irrigated areas. Table 12 indicates the analysis of irrigation treatments by total yield of all year average in Lewiston study area. The results showed that the irrigation levels mattered in terms of yield. Plots with longer irrigation periods had more yields than short-season irrigated plots. Table 13 shows that the ratio of the yield to maximum yield mattered by irrigation treatments. In general, longer irrigation season resulted in higher yields although there was not a significant yield difference between all irrigation levels irrigated areas had more yields than others. There was no difference between irrigation treatment 1 and 2. Irrigation treatment 1 was irrigation through June and treatment 2 was irrigation through July. If we will use deficit irrigation for the pasture we can choose the irrigation treatment 1 for this area and we can save more water, because irrigation treatment 1 and 2 did not have a difference.

Table 9. Statistical analysis of the first cut by irrigation treatment in Lewiston.

Cut	**Irrigation Treatment**	**Average Yield (tons/acre)**	**Standard Error (tons/acre)**	**Letter Group**
1	No Irrigation	2.231	0.105	AB
1	Irrigation Until June	2.3115	0.105	AB
1	Irrigation Until July	2.154	0.105	B
1	Irrigation Until August	2.44	0.105	A
1	Full Season Irrigation	2.4008	0.105	AB

Table 10. Statistical Analysis of the second cut by irrigation treatment in Lewiston.

Cut	**Irrigation Treatment**	**Average Yield (tons/acre)**	**Standard Error (tons/acre)**	**Letter Group**
2	No Irrigation	0.5097	0.05592	C
2	Irrigation Until June	0.656	0.05592	B
2	Irrigation Until July	0.7392	0.05592	B
2	Irrigation Until August	0.8953	0.05592	A
2	Full Season Irrigation	0.9068	0.05592	A

Table 11. Statistical analysis of third cut by irrigation treatment in Lewiston.

Cut	**Irrigation Treatment**	**Average Yield (tons/acre)**	**Standard Error (tons/acre)**	**Letter Group**
3	No Irrigation	0.3414	0.0161	C
3	Irrigation Until June	0.3486	0.0161	BC
3	Irrigation Until July	0.3228	0.0161	C
3	Irrigation Until August	0.3894	0.0161	B
3	Full Season Irrigation	0.4479	0.0161	A

Table 12. Statistical analysis of average total yield of the years by irrigation treatment in Lewiston.

Irrigation Treatment	Average Yield (tons/acre)	Standard Error (tons/acre)	Letter Group
No Irrigation	3.0821	0.1764	C
Irrigation Until June	3.3161	0.1764	BC
Irrigation Until July	3.216	0.1764	BC
Irrigation Until August	3.5279	0.174	AB
Full Season Irrigation	3.7555	0.1764	A

Table 13. Statistical analysis of the yield ratio to maximum yield by irrigation treatment in Lewiston.

Irrigation Treatment	Average Yield (tons/acre)	Standard Error (tons/acre)	Letter Group
No Irrigation	0.7005	0.038	C
Irrigation Until June	0.754	0.038	BC
Irrigation Until July	0.7362	0.038	BC
Irrigation Until August	0.8046	0.03749	AB
Full Season Irrigation	0.8499	0.038	A

In conclusion, the overall statistical analysis of the Lewiston study area shows that irrigation levels effect yield. More irrigation had higher yields than lower irrigation yields. The second cut, third cut, total yield and ratio of the yield indicated that irrigation amount has an impact on yield. When we less irrigate the pasture, we can still get some yield but less than the full season irrigated pasture.

Irrigation Season Length and Yield in Panguitch

Figure 26 indicates the effects of deficit irrigation on Brome and Fescue yield. Each irrigation level and yields for the crops have been shown in the figure for 2018 and 2019.

For all irrigation levels and years apart from no irrigation and irrigation until August in 2018, Meadow Brome had more yield than Tall Fescue. Tall Fescue and Meadow Brome had almost same yield results for full season irrigated plots in 2018 and non-irrigated plots in 2019.Panguitch yield results between 2018 and 2019 have been shown in Figure 27. Non-irrigated plots had the lowest yield compared to others for both years, whereas irrigation until June plots had the most yields. All other plots (irrigation until July, irrigation until August, and full season irrigation) produced very close yields each other. The graph shows that the irrigation level did not matter for that area for those crops (Fescue, Brome).

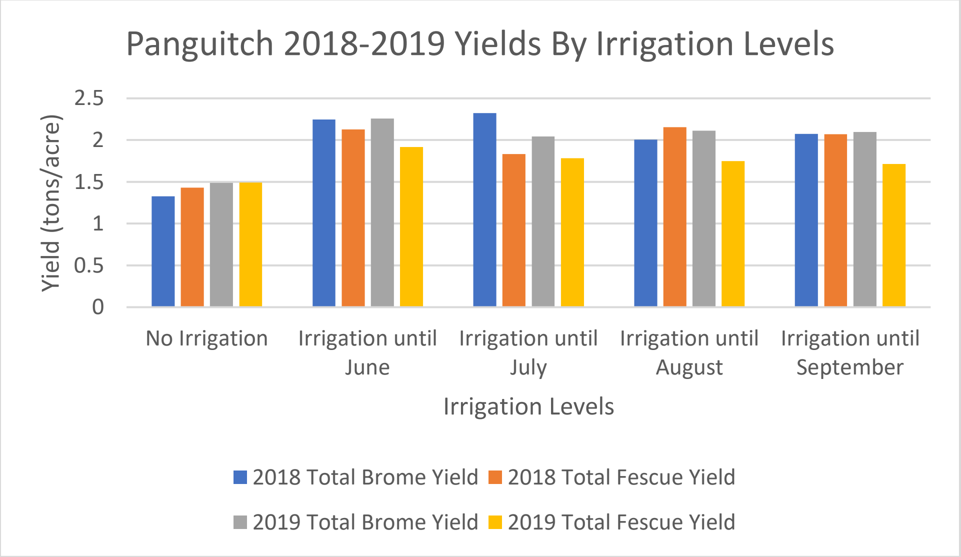


Figure 26. Panguitch 2018-2019 yields by irrigation levels of the pastures.

Panguitch Yield

Table 14 shows that brome had better yield than fescue in first cutting in the Panguitch study area. Table 15 shows the comparison of the two different crops (brome and fescue) in terms of yield in two different years.

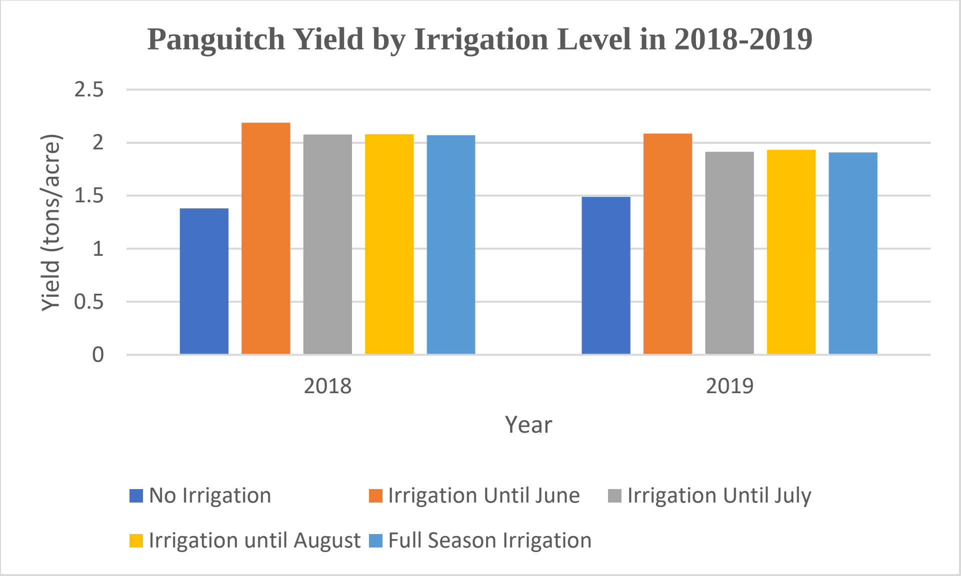


Figure 27. Panguitch yield (2018-2019).

In Panguitch study area, brome produced higher yields than fescue. Table 16 represents that Fescue had more yield than Brome in the second cut in average of the years, however, brome had better yield than fescue in terms of total yield in Table 16. So, the first yield has more impact on the total yield than the second yield. Table 17 indicates the comparison of the total yield in average by treatments. The analysis represents that the irrigation treatment did not matter for the yield in terms of irrigation level apart from the non-irrigated plots. This happens because the yield for the pasture was the highest for the first cutting so when the plots are irrigated once they produce the yield with the help of rainfall and it helps to produce more yield. For the other cuts, the amount of yield is lower than the first cutting and it affects the results. Table 18 shows the statistical analyses of the treatments by ratio for the years in Panguitch study area. It looks there is no difference by treatments apart from the non-irrigated plots.

Table 14. Statistical analysis of first cut by crop in Panguitch.

Cut	**Irrigation Treatment**	**Average Yield (tons/acre)**	**Standard Error (tons/acre)**	**Letter Group**
1	Brome	1.4935	0.05318	A
1	Fescue	1.2139	0.05318	B

Table 15. Statistical analysis of first cut by crop and years in Panguitch.

Cut	**Year**	**Crop**	**Average Yield (tons/acre)**	**Standard Error (tons/acre)**	**Letter Group**
1	2019	Brome	1.5834	0.0752	A
1	2018	Brome	1.4036	0.0752	AB
1	2018	Fescue	1.2977	0.0752	BC
1	2019	Fescue	1.13	0.0752	C

Table 16. Statistical analysis of second cut by crop in Panguitch.

Cut	**Crop**	**Average Yield (tons/acre)**	**Standard Error (tons/acre)**	**Letter Group**
2	Fescue	0.6134	0.03914	A
2	Brome	0.5044	0.03914	B

Table 17. Statistical analysis of total yield by irrigation treatment in Panguitch.

Irrigation Treatment	**Average Yield (tons/acre)**	**Standard Error (tons/acre)**	**Letter Group**
No Irrigation	1.4348	0.1333	B
Irrigation Until June	2.1368	0.1333	A
Irrigation Until July	1.9963	0.1333	A
Irrigation Until August	2.0055	0.1333	A
Full Season Irrigation	1.9896	0.1333	A

Table 18. Statistical analysis of yield ratio by irrigation treatment in Panguitch.

Irrigation Treatment	**Average Yield (tons/acre)**	**Standard Error (tons/acre)**	**Letter Group**
No Irrigation	0.6133	0.05669	B
Irrigation Until June	0.9103	0.05669	A
Irrigation Until July	0.8497	0.05669	A
Irrigation Until August	0.8364	0.05669	A
Full Season Irrigation	0.848	0.05669	A

To summarize, brome had higher yield for the first cut in 2018 and 2019, whereas fescue had higher yield for the second cut. In terms of total yield and ratio of the yield, irrigation level did influence the yield apart from non-irrigated plots. Due to rainfall, the irrigated areas produced the yield closer each other however, non-irrigated area was affected by the drought and did not produce yield as much as others did.

RESEARCH CONTRIBUTIONS

The results from the study show that water can be conserved on pastures with cool-season grasses in northern and central Utah by short-season deficit irrigation without a large decrease in yield. The relationship between yield and short-season irrigation provides information for irrigation and water management. The information is useful in areas where pasture irrigation is prevalent and water leases or water conservation is important.

The changes in the pasture health from the beginning until the end of the research helps provide management options. The results show that in Lewiston deficit irrigation has no long-term impact on the health of the pasture. However, in Panguitch where it is drier and there are areas with gravelly soils, no irrigation and irrigation through May has some plant mortality and highly stressed plants. The research shows how pasture crops in the research areas respond to different irrigation levels and provides yield reduction expectation for short-season irrigation and drought years.

CONCLUSION

In this study, comparison of NDVI data from UAV and Sentinel-2 were made and it was found that Sentinel-2 data could be used to spatially and temporally expand detailed studies made using UAV data and ground-based yields. A good correlation (R^2 = 0.90 across all conditions) between Sentinel-2 and UAV images were observed and applied to expand the dataset. This high correlation provided a good dataset for the research area. UAV images were only 4 days before each harvest in 2017 and one harvest in 2018. With the help of Sentinel-2 images, research has been completed with almost every 5 days images. NDVI values have been calculated by using Sentinel-2 and UAV images and the correlation has been found from those values. Yield predictions have been made from NDVI values in both study areas and very good correlation values have been found. The correlation values for yield prediction was higher than R^2 = 0.90 and RMSE = 0.03 in general. Yield has been predicted 30 days, 20 days, 15 days before the harvest. The good correlation values for yield prediction has been found until 49 days before the harvest. For different days and different correlation values yield estimation have been made. The formulas from yield predictions have been used to create the yield maps from NDVI maps. For all irrigation plots and for both sides, predicted yield maps have been created. Statistical analysis of irrigation treatments has been made for Lewiston, UTAH and Panguitch, UTAH. In Lewiston study area, irrigation level mattered in terms of yield, however, irrigation treatment for Panguitch study area did not matter in terms of yield apart from non-irrigated area. In Lewiston, longer season irrigation had higher yields than shorter-season irrigation. In Panguitch, if plots were irrigation through May the yield differences were not significantly different than the other short-season irrigation levels. This may be due to monsoons moisture in later months and generally low yields after first cutting. However, the non-irrigated plots did have significantly lower yields. Lastly, the pasture health was not impacted due to short-season irrigation after five years in Lewiston.

The results of UAV and Sentinel-2 comparison show that Sentinel-2 data can be used along with UAV data if the data sets are adjusted based on correlated data sets. Deficit/short-season irrigation can be decreased by irrigation application. The yield from a short-season irrigation can be estimated based on the measured yields. Yield can be predicted with some degree of confidence up to one month prior to harvest using Sentinel-2 NDVI vs. yield relationships. Determine the water depletion or consumptive use differences between the different levels of irrigation. The consumptive use could then be used to determine water use efficiency based on the yields of the different irrigation levels.

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