



Effect of planting configurations and irrigation regimes on yield, quality, and economic returns of alfalfa-grass mixtures

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Abstract

Alfalfa (*Medicago sativa* L.) is the most important forage crop grown globally. Alfalfa is often called “Queen of Forages” because of its high productivity, great animal performance, and superior nutritive value. However, producers/ranchers face several challenges such as high and inefficient use of water, alfalfa weevil infestation, and bloat problems in grazing livestock. A field study was conducted in 2020-2021 and 2021-2022 growing seasons to compare forage productivity, nutritive value, alfalfa weevil abundance, and economic returns of monocrop alfalfa and different seeding ratios of alfalfa-grass mixtures planted at different planting configurations under full and deficit irrigation. Treatments included monocrop alfalfa, 75-25% mixture, 50-50% mixed row planting, and 50-50% alternate row planting of alfalfa with each of three perennial cool-season grasses (orchardgrass, tall fescue, and meadow brome) under full and deficit irrigation. Full irrigation plots received 100% ET_c (crop evapotranspiration) for the whole season while deficit irrigation plots received 100% ET_c for the first harvest and 60% ET_c for subsequent harvests. The study design was split plot with irrigation as whole plot factor and cropping system (monoculture and mixtures) as subplot factor. Results show that intercropping alfalfa with grasses irrespective of planting configurations produces similar forage yield to monocrop alfalfa. Deficit irrigation reduced forage yield. Forage nutritive value was generally higher in monocrop alfalfa, however some mixtures produced similar nutritive value as monocrop alfalfa. Intercropping alfalfa with grasses reduced alfalfa weevil numbers. The 75-25% mixture of alfalfa and tall fescue under full irrigation produced the highest net present value. Deficit irrigation reduced costs but did not result in high net present value compared to full irrigation. Alternate row planting with orchardgrass under deficit irrigation produced similar net present value to full irrigation. Increasing unpredictability of the weather due to climate variability can make deficit irrigation a more viable and sustainable option.

Introduction

Alfalfa is the most important forage crop in the US and the fourth (6.7 million hectares) largest crop in terms of area harvested, behind corn (32.9 million hectares), soybean (30.4 million hectares.) and wheat

(15.1 million hectares) (USDA, 2020). Alfalfa has a deep taproot system allowing it to extract water from deeper depths than other forage species. It is therefore very tolerant to drought conditions. Nevertheless, alfalfa water use is high due to its long growing season and dense canopy. About 13 cm of water is required to produce 1000 kg of alfalfa (Wright, 1988). The primary consumptive use of water by alfalfa is evapotranspiration, which is a function of the crop characteristics, weather conditions and water content in the rhizosphere. Highest yield of forage is obtained when water supplied to alfalfa from precipitation and irrigation meets the evapotranspiration needs of the crop. Alfalfa-grass mixtures are recommended as a management strategy to boost forage yield and increase profitability. Mixtures utilize resources more efficiently (Liu *et al.*, 2018), resulting in higher yields compared to monocultures. Alfalfa-grass mixtures are known to improve nutritive value of forages (Adjesiwor *et al.*, 2017). The seeding ratios and planting pattern of alfalfa-grass mixtures may be one of the strategies to increase yield in mixtures, but this has not been extensively explored. Alfalfa-grass mixtures also have the potential to reduce alfalfa weevil numbers. The primary objective of the study is to investigate forage productivity, nutritive value, alfalfa weevil abundance, and economic returns of monocrop alfalfa and alfalfa-grass mixtures under different planting patterns and different irrigation regimes.

Methods

The experiment was conducted from 2020 to 2022 at the University of Wyoming James C. Hageman Sustainable Agriculture Research and Extension Center (SAREC) near Lingle, Wyoming. Most of the precipitation at the study site occurs between March and October. Soil samples were collected in the summer of 2020 before planting. Soil was analyzed for pH (8.4), OM (1.8), N-NO₃ (30 mg kg⁻¹), P (22 mg kg⁻¹), and CEC (20.4 meq/100g). Treatments included monocrop alfalfa, 75-25% mixture, 50-50% mixed row planting, and 50-50% alternate row planting of alfalfa with each of three perennial cool-season grasses (orchardgrass, tall fescue, and meadow brome) under full and deficit irrigations (Table 1). Full irrigation plots received 100% ET_c (crop evapotranspiration) for the whole season while deficit irrigation plots received 100% ET_c for the first harvest and 60% ET_c for subsequent harvests.

The study design was split plot with irrigation as whole plot factor and cropping system (monoculture and mixtures) as subplot factor. Irrigation scheduling was based on alfalfa crop evapotranspiration (ET_c). Daily ET_c values were calculated using the American Society of Civil Engineers (ASCE) Standardized Reference ET Equation (Allen *et al.*, 2005) and alfalfa crop coefficient (K_{cr}) values (Allen & Pereira, 1998) (Equations 1 and 2). Four biomass harvest samples were taken for each treatment plot and oven-dried at 60°C for at least 48 hrs. Dry weight of samples was measured and recorded as weight per unit quadrat area, which was then used to estimate forage yield per hectare (kg ha⁻¹). Oven-dried samples were ground in a mill with a 1-mm mesh. Forage nutritive value parameters, including crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), and in vitro dry matter digestibility (IVDMD) were analyzed using Near-Infrared Reflectance Spectroscopy. Alfalfa weevils were collected using a sweep net, with ten sweeps taken from each plot. The economic value (dollar per hectare) of each treatment was determined through a net present value (NPV) analysis. Analysis of variance (ANOVA) was performed on forage dry matter yield and nutritive value data. A mixed effect model with alfalfa-grass mixtures with irrigation regime as fixed effects and block as random effect was used. Significance was declared at α = 0.05, and post hoc mean separations were made using Tukey HSD test.

$$ET_c = K_{cr} \times ET_{rs} \dots \dots \dots 1$$

$$ET_{rs} = \frac{0.408 \Delta (R_n - G) + \gamma \frac{C_n}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + C_d u_2)} \dots \dots \dots 2$$

where, ETrs = reference evapotranspiration (mm d⁻¹); Rn = calculated net radiation at the crop surface (MJ m⁻² d⁻¹); G = soil heat flux density at the soil surface (MJ m⁻² d⁻¹); T = mean daily temperature at 1.5 to 2.5-m height (°C); u₂ = mean daily wind speed at 2-m height (m s⁻¹); es = saturation vapor pressure at 1.5 to 2.5-m height (kPa), calculated for daily time steps as the average of saturation vapor pressure at maximum and minimum air temperature; ea = mean actual vapor pressure at 1.5 to 2.5-m height (kPa); Δ = slope of the saturation vapor pressure-temperature curve (kPa °C⁻¹); γ = psychrometric constant (kPa °C⁻¹); Cn = numerator constant (K mm s³ Mg⁻¹ d⁻¹) and Cd = denominator constant (s m⁻¹). Units for the 0.408 coefficient are m² mm MJ⁻¹.

Results

All mixtures produced forage yield similar to the monocrop (Table 1). Intercropping with 25% grass increased forage yield by 8% compared to monocrop alfalfa under full irrigation. Under deficit irrigation, the 50Alf+50OG-AR mixture had the highest forage yield (Table 1). Full irrigation resulted in higher forage yield (Table 1). Although alternate row plantings were not significantly different from mixed row plantings under deficit irrigation, they generally yielded more for all grass species. Monocrop alfalfa had the highest CP content, significantly higher than all mixtures except 50Alf+50TF-AR (Table 1). Monocrop alfalfa had lower NDF concentration than all mixtures except 50Alf+50TF-AR. Monocrop alfalfa recorded similar dry matter digestibility as all mixtures except 50Alf+50MB and 50Alf+50OG_AR. All mixtures recorded lower alfalfa weevil count compared to the monocrop alfalfa (Table 1). The highest count of alfalfa weevil was observed in the monocrop alfalfa while the lowest count was found in alternate row planting of mixtures. The 75Alf-25TF mixture under full irrigation yielded the highest NPV, while the lowest NPV was observed in the 50-50 alfalfa and meadow brome grass mixture under deficit irrigation (Table 1).

Table 1. Forage yield, forage nutritive value and alfalfa weevil count of different proportions of alfalfa-grass mixtures under full and deficit irrigations at SAREC from 2021 to 2022.

†Alf, Alfalfa; OG, Orchardgrass; TF, Tall fescue; MB, Meadow brome grass; AR, Alternate row planting; FI, Full Irrigation; DI, Deficit Irrigation; CP, Crude Protein; NDF, Neutral detergent fiber; ADF, Acid detergent fiber;

Alfalfa-grass mixtures	2-yr average forage yield		CP	NDF	IVDMD	Alfalfa weevil count		Net present value	
	FI	DI				2021	2022	FI	DI
	kg ha ⁻¹					g kg ⁻¹		# per sweep	
100Alf [†]	8845 abcd	7826 ab	266 a	360 b	792 a	10.8 a	41.4 a	\$3260 abcd	\$3144 abcd
75Alf+25OG	9456 ab	7009 ab	247 bc	380 ab	775 ab	8.3 bc	31.7 b	\$3583 abc	\$2486 bcd
75Alf+25TF	9729 a	6372 ab	251 b	401 a	775 ab	8.3 bc	33.1 ab	\$3853 a	\$2142 d
75Alf+25MB	9528 ab	6706 ab	248 bc	397 a	774 ab	9.7 ab	35.1 ab	\$3692 ab	\$2410 bcd
50Alf+50OG	8998 abc	7337 ab	244 bc	399 a	775 ab	7.8 cd	28.3 bc	\$3311 abcd	\$2792 abcd
50Alf+50TF	8185 bcd	6405 ab	246 bc	384 ab	779 ab	6.6 de	26.3 bcd	\$2852 abcd	\$2271 d
50Alf+50MB	8956 abcd	6226 b	250 b	396 a	743 c	5.5 e	27.0 bcd	\$3299 abcd	\$2066 d
50Alf+50OG-AR	7595 cd	7930 a	235 c	397 a	770 b	5.5 e	20.8 cd	\$2448 bcd	\$3153 abcd
50Alf+50TF-AR	7448 d	6902 ab	255 ab	360 b	779 ab	5.9 e	21.3 cd	\$2363 cd	\$2537 bcd
50Alf+50MB-AR	8708 abcd	7337 ab	245 bc	386 ab	774 ab	6.9 cde	18.0 d	\$3176 abcd	\$2833 abcd

IVDMD, Invitro dry matter digestibility. Within columns, means followed by the same letter are not different at α= 0.05.

Discussion

The superior yield of orchardgrass mixtures compared to other mixtures under deficit irrigation may stem from its compatibility with alfalfa. Casler (1988) noted that alfalfa-orchardgrass combinations exhibit greater vigor, ground cover, and regrowth compared to mixtures with smooth brome or ryegrass. This compatibility enhances resource use efficiency, contributing to the superior performance of the orchardgrass mixture under deficit irrigation. Full irrigation resulted in higher forage yield compared to deficit irrigation due to better leaf growth and photosynthesis (Zargar *et al.*, 2017). Under water stress, stomatal closure and reduced leaf expansion limit photosynthesis (Zargar *et al.*, 2017), lowering forage accumulation. Although alternate row plantings were not significantly different from mixed row plantings under deficit irrigation, they generally yielded more for all grass species, likely due to reduced interspecies competition for resources like water (Lafrenière & Drapeau, 2011). The similarity in CP levels between monocrop alfalfa and 50Alf+50TF-AR is likely due to the decreased grass proportion in the 50Alf+50TF-AR mixture. Forage grasses such as meadow bromegrass, tall fescue and orchardgrass typically have higher NDF concentrations than alfalfa (Adjesiwor *et al.*, 2017; Aponte *et al.*, 2019). As a result, mixing these grasses with alfalfa increased the NDF content in the mixtures. The lower weevil counts in mixtures may result from grasses interfering with the insects' visual cues (Meyer and Raffensperger, 1974) or due to emigration of the insect from the mixed stands (Roda *et al.*, 1997). This emigration might also be driven by volatile compounds produced by the grasses (Smith *et al.*, 1992). The high NPV in the 75-25 alfalfa-tall fescue mixture was mainly driven by significant total revenue, which compensated for the higher costs.

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