Effect of the hydrological keyline design on the growth and quality of the naturalized grassland in the dry central zone of Chile

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Abstract

The effect of climate change in the central, semi-arid zone of Chile has altered precipitation patterns, shortening the growing season of the naturalized annual grasslands and reducing forage yields. Water harvesting techniques such as the hydrological keyline design, may improve the distribution of precipitation, reduce erosion, and enhance soil water harvesting. It may therefore reduce the impact of climate change in rainfed areas. A trial was implemented to evaluate the effect of the keyline water harvesting practice on soil variables, and pasture production and quality in three farms of the semi-arid O'Higgins region. Rains began in April and amounted to a total of 399 mm. Pasture species germinated in August, and growth peaked in October. The keyline design influenced soil moisture and temperature, crude protein (CP), neutral detergent fiber, and acid detergent fiber of the grasses. Yields varied between months and locations. Overall, keyline management significantly increased compressed forage height and yield by 44 and 25% respectively, relative to the control. Considering that there was an effect of location it is necessary to determine the effects of variables such as soil fertility, slope, and orientation, among others.

Introduction

A large part of the central dryland zone of Chile is covered by naturalized grasslands. These grasslands are found on compacted soil with low percentages of organic matter, due to decades of wheat monoculture and poor grazing management. Furthermore, the decrease in annual rainfall due to climate change has shortened the grassland's growing season, modifying the grasses' nutritional quality throughout the year and reducing total production. In this context, increasing rainwater harvesting would likely raise yields of the naturalized annual grassland. Hydrological keyline design is a practice used worldwide to improve soil water storage and its distribution in the soil profile as shown for beans (Ponce-Rodríguez et al., 2021) and grasslands (Grill, 2014, Yeomans, 1981). The aim of this study was to evaluate the effect of the use of the keyline technique to increase soil water conservation and its effect on forage yield and its nutritional quality in the Mediterranean-like central region of Chile.

Methods and Study Site

Three experimental sites (farms) were selected in 2020 in the drylands of the O'Higgins region (34°18' S and 71°43'). Keyline zones were designed and implemented on surfaces of between 1 and 4 hectares on each farm using a Yeoman's plow. Three exclusion plots for each farm were selected within the keyline design area (WK) (Keyline Treatment). The farm Control Treatment (NK) consisted of non-altered areas with identical biophysical characteristics to the WK including as above, three exclusion plots. Monthly measurements of soil moisture and temperature and compressed height of the grass were carried out during the growing season. Samples were taken between 12:00 and 15:00 hours consisting of nine measurements per variable in each exclusion plot. An Electronic Grassland Plate Meter Jenquip model EC1 was used to estimate the compressed height. Soil water content (SWC, %) and temperature (°C) were measured using a soil moisture meter model FieldScout TDR 350, using two probe lengths (7.5 and 12 cm). Three samples were harvested to ground level in each exclusion plot to assess dry matter yields, using a 37 cm diameter ring. The samples were weighed fresh and then frozen for the subsequent determination of Dry Matter (DM), Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), and Crude Protein (CP). Meteorological data, including mean, maximum, and minimum temperatures, and precipitation, were recorded with a weather station installed in one of the farms. The statistical design corresponds to Randomized Complete Block Design (RCBD), where each farm was considered a block. The factors were the farm and the treatment. The three exclusion plots by farm were considered subsamples. The response variables were Soil water content (SWC, %), temperature (°C), Dry Matter (DM), Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), and Crude Protein (CP) estimated monthly.

Results and Discussion

In the year under study, precipitation began early in April and amounted to a total of 399 mm throughout the year. However, 65.7% of the precipitation occurred during June (Figure 1). Germination began in August when the required conditions of soil temperature and humidity were obtained. Measurements of soil water content and temperature began following germination. Measurements of compressed height and yield took place in September due to slow grassland growth.

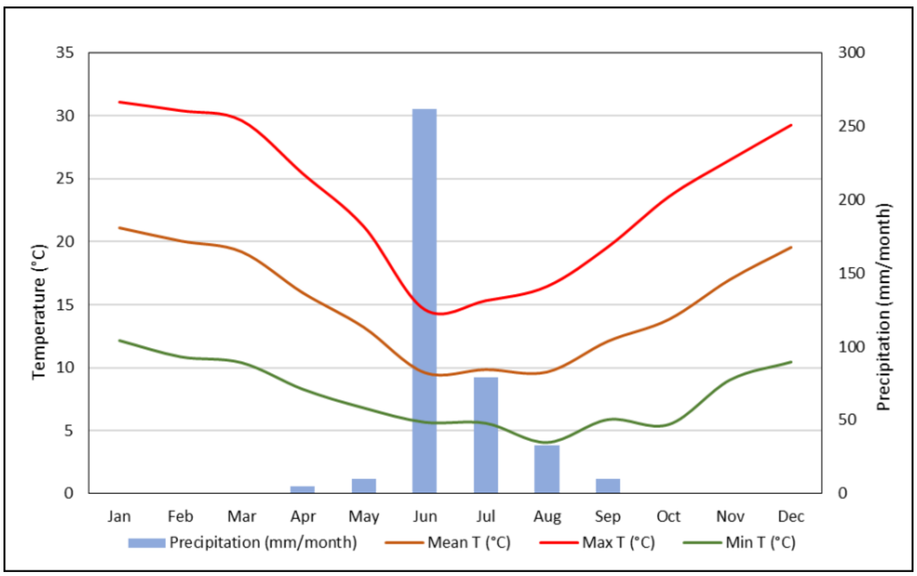

Figure 1. Ombrothermic diagram of the study region

Significant differences were observed in soil water content and temperature due to the effect of the implementation of the keyline design in the study plots ($p<0.01$). At a depth of 7.5 cm, the NK treatment presented higher humidity levels than the WK treatment. At a depth of 12 cm, significant differences were only observed in September. However, at this depth, the WK plots tended to present a more uniform distribution of soil water content (SWC, %), which is appreciated through lower standard errors. Soil temperature at 7.5 cm was lower in the WK plots in August and September but higher in October and November (Table 1). This result was explained by the higher level of aeration of the WK plots, which homogenizes the soil temperature with the ambient temperature.

Table 1. Soil water content (SWC, %) and temperature (°C) in control treatments (NK) and keyline design (WK) during the grass grown season (Mean±SE)

Variable	**August**			**September**			**October**			**November**		
Treatment	**NK**	**WK**	**p**	**NK**	**WK**	**p**	**NK**	**WK**	**p**	**NK**	**WK**	**p**
SWC 7.5 cm (%)	31.2±0.6	26.9±0.7	< 0.01	12.8±0.4	11.6±0.3	0.027	6.1±0.3	5.3±0.2	0.033	3.8±0.2	3.3±0.2	0.128
SWC 12 cm (%)	31.9±0.5	32.4±0.4	0.383	14.4±0.5	12.9±0.4	< 0.01	8.1±0.4	7.9±0.3	0.556	4.5±0.3	4.2±0.3	0.502
Temperature 7.5 cm (°C)	22.7±0.1	21.9±0.1	< 0.01	22.9±0.2	21.1±0.2	< 0.01	25.2±0.3	26.6±0.2	< 0.01	28.5±0.3	29.8±0.3	< 0.01
Temperature 12.5 cm (°C)	22.4±0.1	22±0.1	0.007	23.2±0.2	21.3±0.2	< 0.01	21.2±0.4	24.1±0.3	< 0.01	28.3±0.3	30.2±0.3	< 0.01

As a consequence of the agroclimatic variables, the growing season lasted only 4 months, beginning with the reproductive stage of the grass at the end of September and reaching senescence in November. Dry matter content in September and November was lower in the WK plots ($p<0.01$), which would indicate a prolongation of the vegetative state and would be a consequence of the better distribution and conservation of water in the soil. In the WK grass samples, a lower content of crude protein was also observed in November and a higher content of NDF and ADF, probably due to the more significant growth of the grass. The highest growth of the WK grass was observed in October and November through the variables yield of dry matter and compressed height. These results differ from those obtained in the study carried out by Ponce-Rodríguez et al., (2021), where, despite obtaining significant differences in soil water content, did not find differences in the yield of the beans crop in Durango, Mexico.

Table 2. Parameters of quality and growth of the naturalized grassland in control treatments (NK) and keyline design (WK) during the grass grown season (Mean±SE)

Variable	**September**			**October**			**November**		
Treatments	**NK**	**WK**	**p**	**NK**	**WK**	**p**	**NK**	**WK**	**p**
Dry Matter (%)	24.6±0.4	22.7±0.4	< 0.01	33.9±0.7	34.6±0.6	0.453	76.7±0.6	71.6±0.6	< 0.01
Crude Protein (%)	9.9±0.4	10.3±0.3	0.488	9±0.2	8.7±0.2	0.262	5.8±0.2	4.8±0.2	< 0.01
Acid Detergent Fiber (%)	30.8±0.7	31.5±0.5	0.420	34.3±0.4	34.4±0.4	0.817	46.6±0.5	48.3±0.5	0.030
Neutral Detergent Fiber (%)	52.8±0.9	51.5±0.8	0.296	52.7±0.6	54.7±0.6	0.019	54.5±0.5	57.3±0.6	< 0.01
Yield (kgDM/ha)	1341±233.7	1407.8±204.5	0.834	2395.1±226.1	3190.5±208.3	0.013	1902.4±119.5	2393±115.3	< 0.01
Compressed height (cm)	10.3±0.5	10.9±0.4	0.378	17.3±0.6	20.9±0.6	< 0.01	14.8±0.5	21.3±0.5	< 0.01

A significant effect of farm was observed in most of the variables analyzed (Table 3). This effect is a consequence of the variability in the grassland, soil, and topographic characteristic among the study farms, which includes the condition and species present in the grassland, orientation, slope, and soil fertility, among others.

Table 3. Average results in the variables analyzed across farms

Variable	Farm 1	Farm 2	Farm 3	p
SWC 7.5 cm (%)	21.9±0.9c	11.9±0.3a	14±0.6b	<0.01
SWC 12 cm (%)	19.3±0.8b	13.4±0.4a	24.1±1.2c	<0.01
Temperature 7.5 cm (°C)	25.3±0.2b	18.7±0.3a	27.5±0.2c	<0.01
Temperature 12.5 cm (°C)	25.1±0.3b	19.2±0.3a	26.7±0.2c	<0.01
Dry Matter (%)	27.4±0.8a	25.3±0.7a	39.6±0.8b	<0.01
Crude Protein (%)	10.9±0.3b	10.8±0.2b	8.4±0.2a	<0.01
Acid Detergent Fiber (%)	32.6±0.5a	33.2±0.5a	34.8±0.5b	<0.01
Neutral Detergent Fiber (%)	51.9±0.8a	50±0.7a	55.4±0.7b	<0.01
Yield (kgDM/ha)	2327.5±67.4a	3403.7±59.9b	2498.8±56.6a	<0.01
Compressed height (cm)	13.1±0.5a	20.8±0.4b	14.3±0.4a	<0.01

Conclusions and Implications

The use of the keyline design increased water harvesting on naturalized grasslands and produced a significant effect on soil water content and temperature. The direction of the effect concerning the control treatment was related to the humidity present in the soil; thus, with low humidity, a greater retention of humidity was observed; on the contrary, with high humidity, a better distribution of water tends to decrease the content of moisture in the soil. The compressed height and the grassland's annual yield were increased due to the use of the keyline practice. The present study corresponds to a first approximation of the effect of the keyline design in the dryland grassland of the O'Higgins Region. New studies must incorporate variables such as terrain slope and soil fertility and consider the keyline design's effect on the variables of soil temperature, water content, and pasture nutritional quality in the long term.

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