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# Evaluation of keyline design using the simplified triangle method in Mediterranean agroecosystems

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## ABSTRACT

Extreme weather events and increased aridity pose a serious risk to agricultural production. Keyline design has been proposed as a water harvesting technique to promote plant production and overall ecosystem functioning, yet there is a lack of evidence about its effectiveness. The aim of this study was to evaluate the effect of keyline design on surface wetness properties in Mediterranean agroecosystems. The simplified triangle methodology was used to estimate moisture availability (Mo) and evapotranspiration fraction (EF) using Landsat 8 images. We compared tree-grass and grasslands where keyline have been implemented, with over 1,000 control plots across the 2018–2025 period. Keyline plots showed higher surface moisture (Mo), especially during winter and spring in tree-grass, but not in grasslands. EF values were significantly lower in keyline areas across all seasons compared to control areas for all systems. These results suggest a limited effect of the key line restricted to certain periods of the year and types of land use.

**Keywords:** *Nature-based solution, rainwater harvesting, simplified triangle, soil moisture availability, dehesa.*

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***Abstract**: Extreme weather events and increased aridity pose a serious risk to agricultural production. Keyline design has been proposed as a water harvesting technique to promote plant production and overall ecosystem functioning, yet there is a lack of evidence about its effectiveness. The aim of this study was to evaluate the effect of keyline design on surface wetness properties in Mediterranean agroecosystems. The simplified triangle methodology was used to estimate moisture availability (Mo) and evapotranspiration fraction (EF) using Landsat 8 images. We compared tree-grass and grasslands where keyline have been implemented, with over 1,000 control plots across the 2018–2025 period. Keyline plots showed higher surface moisture (Mo), especially during winter and spring in tree-grass, but not in grasslands. EF values were significantly lower in keyline areas across all seasons compared to control areas for all systems. These results suggest a limited effect of the key line restricted to certain periods of the year and types of land use.*

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**Resumen:** Los eventos climáticos extremos y el aumento de la aridez constituyen un grave riesgo para la producción agronómica. El diseño de línea clave se ha propuesto como una técnica de captación de agua que mejora la producción vegetal y el funcionamiento general del ecosistema, aunque la evidencia sobre su eficacia es limitada. El objetivo de este estudio fue evaluar el efecto del diseño de línea clave en las propiedades de humedad superficial en agroecosistemas Mediterráneos. Se utilizó la metodología del triángulo simplificado para estimar la disponibilidad de humedad (Mo) y la fracción de evapotranspiración (EF) utilizando imágenes de Landsat 8. Se compararon parcelas con línea clave frente a más de 1.000 parcelas de control para dos coberturas vegetales (pastos y dehesa) durante el periodo 2018–2025. Las parcelas con línea clave mostraron mayor humedad del suelo (Mo), especialmente durante el invierno y la primavera en la dehesa, pero no en las zonas de pastos. Los valores de EF fueron significativamente más bajos en zonas de línea clave a lo largo de todas las estaciones en comparación con las áreas de control para todos los sistemas. Estos resultados sugieren un efecto limitado de la línea clave restringido a ciertos periodos del año y tipos de uso del suelo.

**Palabras clave:** Soluciones basadas en la naturaleza, línea clave, método triángulo simplificado, humedad edáfica dehesa.

## 1. INTRODUCTION

Future climate projection predicts an increase in the frequency and severity of extreme weather events (Calvin *et al*., 2023), posing further challenges to agricultural systems in the coming decades (Vermeulen *et al*., 2012). This situation is particularly evident in the southwestern part of the Iberian Peninsula, where a reduction in soil moisture is foreseen (Calvin *et al*., 2023), with acute consequences for plant production, that rely in a great extent on soil moisture, a main limiting factor in these ecosystems (Joffre *et al*., 1999). Several nature-based solutions have been proposed to address these challenges (Griscom *et al*., 2017). Among them, the keyline design is advocated as a water harvesting technique that can promote plant production and overall ecosystem functioning. The keyline design was introduced in the mid-twentieth century in Australia to build effective water catchment areas. The main principle is to reduce surface water flow and distribute water from the valleys towards the ridges. Despite increasing practitioner interest in implementing this design, there is still a lack of scientific support (Giambastiani *et al*., 2023). Confounding factors, such as other regenerative practices implemented at the same time, lack of rigorous control areas, or high spatial and temporal variability in

its implementation can hamper the evaluation of its effectiveness.

Remote sensing can alleviate some of the limitations in the evaluation of the keyline design by, for instance, providing information on changes in vegetation properties or soil moisture in space and time, across different spatial scales. Among the various approaches provided by Earth Observation products, the simplified triangle technique has been proposed as an effective methodology to assess surface wetness properties. This technique only requires information on surface temperature and vegetation indices, allowing its application almost anywhere (Carlson & Petropoulos, 2019).

The aim of this work was to evaluate the effectiveness of a keyline design in Mediterranean tree-grass agroecosystems. The simplified triangle technique was used to assess the effect of the keyline on surface wetness properties.

## 2. MATERIAL AND METHODS

### 2.1. Study area

The study took place on the Mundos Nuevos farm, located in the town of Retamal de Llerena (38°34′43" N, 5°50′18" W, Badajoz), and the surroundings. The climate of the area is Mediterranean with an average annual temperature of 14.2 ºC and a rainfall of 390 mm. The vegetation of the Mundos Nuevos estate is a typical Mediterranean tree-grass ecosystem, locally called *Dehesa*, composed of a grassland layer scattered with trees. Tree species are dominated by holm oaks (*Quercus ilex*) and annual herbaceous pastures. The implementation of the keyline system took placed progressively between 2021-23. First, the entire farm was tilled following the keyline model (Fig. 1). This pattern reduces the flow of surface runoff parallel to the slope. After the tillage, in subsequent years, a network of water collection channels and connected ponds was built to maximize surface water catchment.

**Figure 1**. Detail of the keyline design in Mundos Nuevos farm.

### 2.2. Image acquisition and the simplified triangle methodology

To evaluate the effect of the interventions, the simplified triangle methodology was followed (Carlson & Petropoulos, 2019). This method allows estimating evapotranspiration fraction (EF) and moisture availability (Mo) of the soil surface. To implement it, it is necessary to know the radiometric surface temperature ($T_{ir}$) and the normalized vegetation index (NDVI). Both measurements were obtained from Landsat 8 OLI/TIRS Collection 2 after applying a bitmask for cloud and shadow removal. For the calculation of NDVI, bands 5 and 4 were used and band 10 for temperature. Images were obtained from 2018 till 2025, including the year prior to the intervention and after it. For each acquisition date, the following parameters were calculated: Fractional vegetation cover:

$$Fr = \left(\frac{NDVI - NDVI_o}{NDVI_s - NDVI_o}\right)^2 \quad (1)$$

Where $NDVI_s$ and $NDVI_o$ represents full cover and bare soil, respectively. And scaled infrared temperature:

$$T^* = \frac{T_{ir} - T_{min}}{T_{max} - T_{min}} \quad (2)$$

Both indices were obtained for 19 paddocks in the farm, where the keyline method has been implemented. Two types of paddocks were distinguished: with (TG-KL, n=19) and without trees (GS-KL, n=4). As control areas, plots classified as wooded pasture (TG-CT) or pastures (GS-CT) in the SIGPAC catalogue (SIGPAC, 2025) within a 10 km radius of the farm were used. Only parcels that were at least one ha in size and as similar as possible than keylined paddocks were selected from the SIGPAC system (n = 1118). Maximum and minimum values of each index were selected from the full scene before subsequent processing. Images were processed in Google Earth Engine (Gorelick *et al*., 2017).

To build the triangle, values of $T^*$ and $F_r$ were plotted and the *warm edge* was calculated as the linear regression between $T^*$ and $F_r$ for the pixels located in the vertex and at the bottom right of the triangle for each date. Values of surface moisture availability (Mo) and evapotranspiration fraction (EF), varying between 0 and 1, were computed as follows:

$$M_o = 1 - T^*/T_{warm\ edge} \quad (3)$$

And

$$EF = M_o\,(1 - Fr) + Fr \quad (4)$$

### 2.3. Data analysis

To assess the effect of the keyline methodology on surface moisture availability (Mo) and evapotranspiration fraction (EF), linear mixed models were used. Models included Mo or EF as response variables land cover (tree-grass and grassland with and without keyline), season and their interaction as predictors and year as a random factor. All analyses were conducted in R v4.4.2 (R Core Team, 2024).

## 3. RESULTS AND DISCUSSION

Surface moisture (Mo) and evaporative fraction (EF) were, on average, significantly different among land covers types over the studied period (Table 1). Tree-grass land cover showed higher Mo than grasslands. The keyline increased Mo in tree-grass but not in grasslands. A similar pattern was found for EF, except for the lower EF values in the keyline for both land cover types.

Higher moisture and evaporative fraction in tree-grass could be driven by the higher coverage of woody vegetation that would be active during longer periods, where annual herbaceous species dry-off, and therefore show lower infrared temperatures. This situation is particularly evident when plotting both Fr and T* to build the simplified triangle (Fig. 2). Points located in the upper part indicate continuous vegetation, whereas at the bottom, in the base of the triangle, depict bare soil. Moreover, those points close to the right border (the warm edge) indicate minimum transpiration. Tree-grass systems tend to lay at the top of the space, particularly during dry-down, pointing to areas with green vegetation cover. On the other hand, areas covered with herbaceous vegetation (GS) showed the greatest spread in this space, laying at the top during the green-up phase (i.e., autumn-winter) and taking the lowest position during the summer. Plots of the keyline farm, were in between and showed the lowest variability, indicating moderate cover of tree vegetation.

**Table 1**. Average values (% ±S.E.) of evapotranspiration fraction (EF) and moisture availability (Mo) in the keyline farm and the surroundings for tree-grass systems (TG-KL and TG-CT) and grasslands (GS-KL and GS-CT, respectively) for the whole study period (2018-2025).

| Land Cover | EF | Mo |
|---|---|---|
| TG-KL (n=15) | 13.5 ± 0.3 b | 12.7 ± 0.3 d |
| TG-CT (n=635) | 14.7 ± 0.1 d | 11.3 ± 0.1 c |
| GS-KL (n=4) | 10.4 ± 0.7 a | 8.2 ± 0.6 a |
| GS-CT (353) | 13.9 ± 0.1 c | 9.4 ± 0.1 b |

Evapotranspiration fraction (EF) and moisture availability (Mo) of the soil surface showed similar temporal dynamics during the studied period (Fig. 3). Both peaked during winter, and the lowest values were found in mid-summer, showing a declining trend during the dry down period. This pattern agrees with those reported by Petropoulos *et al*. (2020) who validated the simplified triangle technique in the same region as our study area using data from an Eddy-covariance tower. The authors showed an adequate agreement between measured and predicted EF.


**Figure 2**. Simplified triangle for the hydrological year 2023-24. Note that the complete triangle was constructed based on the whole Landsat scene, but only tree-grass (TG), grasslands (GS) and with keylines (KL) and without (CT) are depicted for clarity.

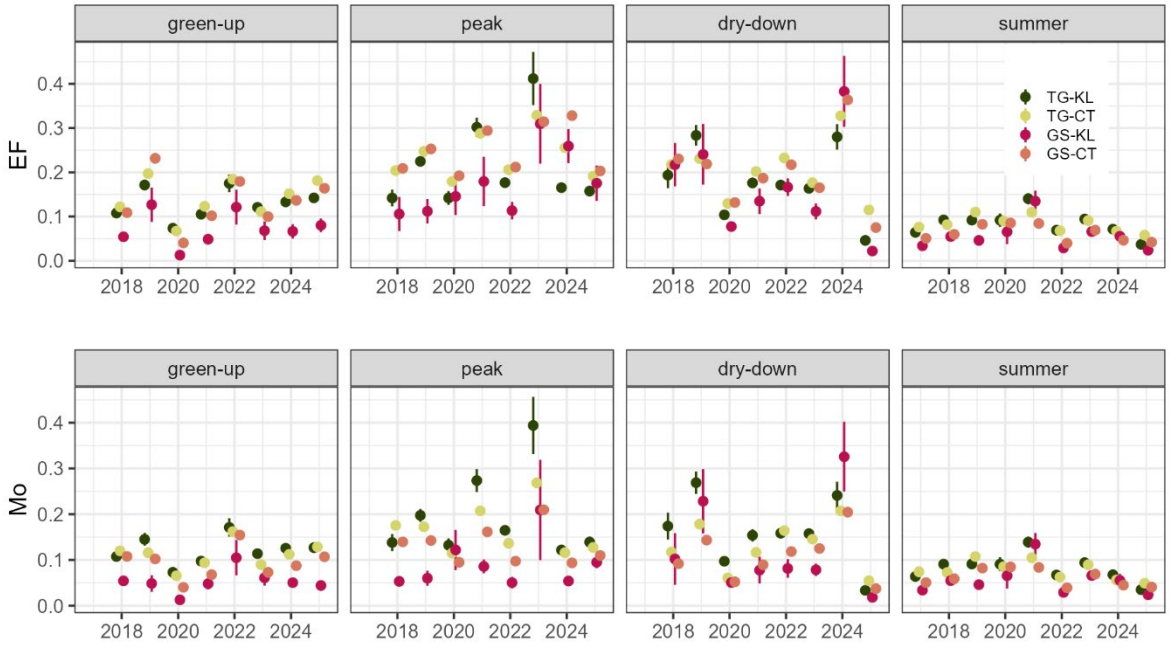


**Figure 3.** Seasonal dynamic of evapotranspiration fraction (EF) and moisture availability (Mo) in the keyline farm and the surroundings for tree-grass systems (TG-KL and TG-CT) and grasslands (GS-KL and GS-CT, respectively) for the whole study period (2018-2025)

Overall, EF values were significantly lower in the keyline than in the control for both land covers and all seasons, with the GS-KL showing the lowest values. By contrast, TG-KL increased Mo values, particularly during the peak and dry-down seasons when they were significantly different from TG-CT. Interestingly, this increase in Mo in the TG-KL was not accompanied by an increase in Fr, which together with the lowest values of GS-KL, suggests a limited effect of the keyline system for plant production. Further studies should be conducted to disentangle the net contribution of this nature-based solution as a climate-smart adaptation in Mediterranean tree-grass agroecosystems.

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## 5. REFERENCES

Calvin, K., Dasgupta, D., Krinner, G., … Ha, M. (with Lee, H.). (2023). *IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* https://doi.org/10.59327/IPCC/AR6-9789291691647

Carlson, T. N., & Petropoulos, G. P. (2019). A new method for estimating of evapotranspiration and surface soil moisture from optical and thermal infrared measurements: The simplified triangle. *International Journal of Remote Sensing*, *40*(20), 7716–7729.

Giambastiani, Y., Biancofiore, G., Mancini, M., Di Giorgio, A., Giusti, R., Cecchi, S., Gardin, L., & Errico, A. (2023). Modelling the Effect of Keyline Practice on Soil Erosion Control. *Land*, *12*(1), 100. https://doi.org/10.3390/land12010100

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*, *202*, 18–27. https://doi.org/10.1016/j.rse.2017.06.031

Griscom, B. W., Adams, J., Ellis, … Fargione, J. (2017). Natural climate solutions. *Proceedings of the National Academy of Sciences*, *114*(44), 11645–11650. https://doi.org/10.1073/pnas.1710465114

Joffre, R., Rambal, S., & Ratte, JP. (1999). The dehesa system of southern Spain and Portugal as a natural ecosystem mimic. *Agroforestry Systems*, *45*, 57–79.

Petropoulos, G. P., Sandric, I., Hristopulos, D., & Nahum Carlson, T. (2020). Evaporative Fluxes and Surface Soil Moisture Retrievals in a Mediterranean Setting from Sentinel-3 and the "Simplified Triangle". *Remote Sensing*, *12*(19), Article 19.

R Core Team. (2024). *R: A language and environment for statistical computing* R Foundation for Statistical Computing. http://www.R-project.org/

SIGPAC. (2025). *Visor del SIGPAC Nacional*. https://www.mapa.gob.es/es/agricultura/temas/sistema-de-informacion-geografica-de-parcelas-agricolas-sigpac-/visor-sigpac

Vermeulen, S. J., Campbell, B. M., & Ingram, J. S. I. (2012). Climate Change and Food Systems. *Annual Review of Environment and Resources*, *37*(1), 195–222.