A remote sensing approach assessment for water use estimation in alfalfa hay and seed yield in a semiarid region under irrigation

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The **hay dry matter** (Y_h) and **seed yield** (Y_s) of **alfalfa (*Medicago sativa L.*)** under field conditions may vary depending on management practices. However, the acquisition of timely field-scale information can be replaced by remote sensing techniques, given their potential to provide data at field scale, provided that the acquisition interval is appropriate.

Remote sensing approaches for routine estimation of evapotranspiration (ET) are becoming more readily available. One approach is based on the method of the FAO to calculate ET, which uses the crop coefficients (K_c) that can be related to vegetation indices (VIs) – transformations of surface reflectance measured in specific bands of the electromagnetic spectrum, typically the red and near infrared bands, obtained by remote sensing.

This study aimed to validate a remote sensing approach for estimating first-year water use of alfalfa grown for hay and seed production, using a field dataset.

Materials and Methods

Location:

The experiment was executed in the National Institute of Agricultural Technology (INTA) located in the Río Dulce Irrigation Scheme (SRRD), Santiago del Estero (SE) province, NW Argentina (28°03' S; 64°15' W).

Climate:

- Mesothermal, semi-arid type climate.
- Mean annual rainfall: 594 mm,
- Mean annual reference evapotranspiration (ET_o): 1,300 mm.
- Mean annual maximum temperature: 29.1 °C.
- Mean annual minimum temperature: 14.2 °C.

Soil Characteristics:

- Silty loam texture.
- Water holding capacity: 176 mm m^{-1}.
- Soil water content at field capacity: 270 mm m^{-1}.
- Soil water content at permanent wilting point: 92 mm m^{-1}.

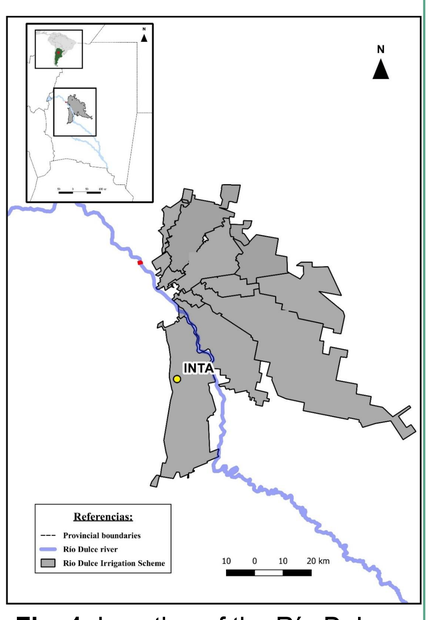

Fig. 1. Location of the Río Dulce irrigation scheme (Santiago del Estero, Argentina),

Remote sensing approach:

The method proposed by the FAO to estimate ET is based on the concepts of ET_o and K_c (**$ET = K_c\ ET_o$**). The approach used to estimate crop evapotranspiration assisted by remote sensing technique (**ET_{cVI}**) is based on the ability of multispectral VI to trace the crop's growth and estimate Kc (a) and generates spatially-distributed Kc that provide estimates of field-specific ET (b). A daily water balance in the soil root zone was compute.

Measurements and determinations:

To validate the **ET_{cVI}**, gravimetric sampling was conducted monthly at two sites (**S1: hay production; S2: seed production**) to determine soil moisture content down to a depth of 2 meters. A root zone soil water balance was calculated using soil moisture content (**ET_r**), and results were compared to **$ET_{c,VI}$**.

Hay yield **(Yh)** in S1 was estimated from the number of bales (25kg each at 16% moisture content) (Fig.2a), while seed yield **(Ys)** in S2 was calculated as the harvested seed weight (Fig.2b).

Fig. 2. **a) Site 1: view of field hay production**
b) Site 2: view of field seed production

Water use efficiency was calculated using the soil moisture content at S1 **(WUEhr)** and S2 **(WUEsr)**, as well as the remote sensing approach at S1 **(WUEhVI)** and S2 **(WUEsVI)**.

The remote sensing approach was evaluated of the root mean square error (RMSE) between ETr and ETcVI for each harvest (of hay and seed production).

Results

The total season rainfall was 567 mm (May.24/May.25). In S1, four irrigations were applied, with an average of 95 mm (±19) each, totaling 380 mm. In S2, only one irrigation of 80 mm was applied 90 days before the first harvest.

For validation of the remote sensing approach, a time series of 38 Sentinel-2 satellite images was used. Scatterplot of measured moisture soil content, representing the "truth", vs. estimated moisture soil content, running a water balance, shows very good agreement when the remote sensing approach was used (Fig. 3).

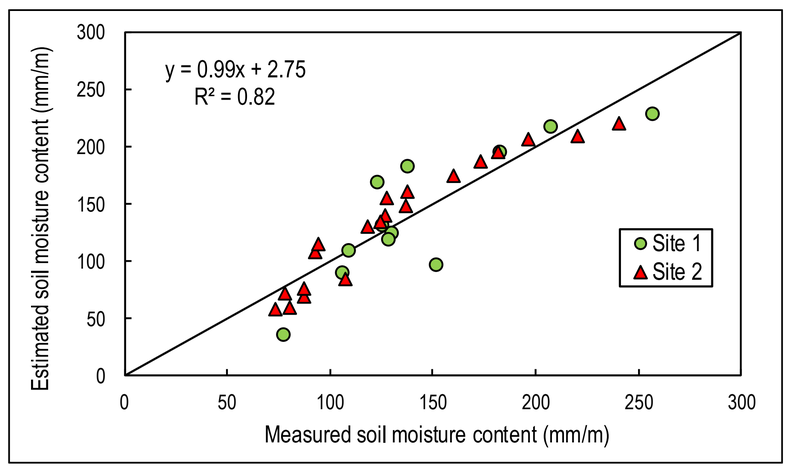

Fig.3. Relationship between soil moisture content estimated with the remote sensing approach and measured with gravimetric sampling was conducted monthly at two sites (S1: hay production; S2: seed production).

Table.1. Hay dry mater and seed yield, crop evapotranspiration using measured moisture soil content (ET_r) and remote sensing approach (ET_{cVI}), and water use efficiency (WUE) to each harvest of alfalfa at two sites during the 2024-2025 growing season.

Site	Production	Harvest (dd/mm/yy)	Bales -25 Kg- (un)	Yield* (Kg ha^{-1})	ET_r (mm ha^{-1})	ET_{cVI} (mm ha^{-1})	WUE_r (Kg mm^{-1})	WUE_{VI} (Kg mm^{-1})
S1	Hay	13/09/24	117	2925	192	181	15	16
	Hay	25/10/24	98	2450	201	157	12	16
	Hay	02/12/24	68	1700	129	166	13	10
	Hay	10/01/25	67	1675	190	116	9	14
	Hay	17/02/25	115	2875	155	150	19	19
	Hay	31/03/25	56	1400	183	105	8	13
	Hay	12/05/25	34	850	83	70	10	12
S2								
	Seed	15/12/24		144	214	270	0.7	0.5
	Seed	17/03/25		150	244	188	0.6	0.8

*Number of rectangular hay bales × 25 kg per bale

In **S1** (seven harvests), the **total hay yield** for the **season** was **555 bales** weighing 25 kg each (**13,875 kg ha^{-1}**), while in **S2** (two harvests), the **total seed yield** was **294 kg ha^{-1}**.

The seasonal hay production **ET_r** and **ET_{cVI}** were 1135 mm and 945 mm, respectively (RMSE = 55 mm). The seed production **ET_r** and **ET_{cVI}** values were both 458 mm (RMSE = 56 mm). The remote sensing approach slightly underestimated ET (by less than 10%).

The **WUE_{hr}** and **WUE_{hVI}** were 12 Kg mm^{-1} and 15 Kg mm^{-1}, respectively, while the **WUE_{sr}** and **WUE_{sVI}** values were both **0.6 kg mm^{-1}.**

Conclusion

The correlation between evapotranspiration from the remote sensing method was relatively good, understanding that evapotranspiration obtained from the soil moisture content represents the "truth".

This study validated a remote sensing-based approach to estimate evapotranspiration in irrigated alfalfa for hay and seed. The method proved reliable for optimizing irrigation scheduling and improving water use efficiency under varying management conditions.

(a) Pôças, I., Calera, A., Campos, I., Cunha, M. (2020). Remote sensing for estimating and mapping single and basal crop coefficients: a review on spectral vegetation indices approaches. *Agricultural Water Management, 233*, 106081.

(b) Salgado, R., & Mateos, L. (2021). Evaluation of different methods of estimating ET for the performance assessment of irrigation schemes. *Agricultural Water Management*, *243*, 106450.