# Evaluation of a decision support system for the recommendation of pasture harvest date and form

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**Abstract:** The task of generating automatic recommendations of pasture harvest date and form was previously addressed through a knowledge-based decision support system (DSS). The system follows expert rules and exploits data such as the weather history and forecast, the growth stage of grass and legumes, plant height and crude fibre content. In this paper, we present the results of our evaluation of this DSS on 26 fields in West and Northwest Germany. We compared the suggestions made by the DSS with the decisions of expert farmers and obtained an accuracy of $R^2$=0.746 and RMSE=7.83 days. The best results occurred for intensively managed fields for dairy cows, with an $R^2$ of 0.891 and RMSE of 3.20 days. We conclude our DSS and its underlying methodology have the potential to support farmers and secure high-quality fodder.

**Keywords:** expert system, grassland harvesting, forage, knowledge representation, decision-support

## 1 Introduction

The tasks of farmers have become more complex in the last decades with increasing farm size and complex legal framework conditions. Monitoring pastures includes challenges such as widely distributed fields and the uncertainty of weather forecast, which makes the decision for the right harvest date difficult. An optimised management of grassland is crucial for an economic dairy farm [In19], but currently, at many farms, a single person manages animals, crops and pasture at the same time which creates a need for widespread competence [Ro18]. One way to address this issue is through the application of artificial intelligence (AI) principles, such as a decision support system (DSS), which can make

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expert knowledge more accessible by computing large amounts of input data and producing a recommendation that helps the farmer simplify complex situations.

Many tools can support a human decision-maker by providing a series of organizational and analytical resources. We propose the use of a DSS that combines expert knowledge encoded as inference rules and exploits various types of information to generate suitable recommendations that follow a field's description, legal considerations and the principles of logic (such as coherence and consistency). Prior work suggests a DSS has the potential to increase yield and quality by optimizing the harvest date [Ha17], with examples ranging from crop-growing-models to statistical approaches [Ro18; Ha17].

In this paper, we utilize a more mature version of the DSS prototype discussed in [Ti22], but instead focus on an evaluation methodology in the context of pasture harvesting. Our results suggest that this approach has the potential to support farmers and secure high-quality fodder.

## 2 Material and methods

The DSS is based on the SEMPR framework, suitable for inference and semantic web tasks [Ni21]. Inference rules are written in a formal description language and were modelled from interviews with experts and literature research. Given a set of rules and the description of a field, the DSS infers all possible harvesting and management options while observing relevant restrictions, such as the weather conditions automatically obtained from the German weather service (DWD). In the vegetation period of 2021, the recommendations were first tested on two fields and their results were used to further tune the DSS [Ti22].

In order to find an appropriate harvesting date of silage, we consider a dry period of two days before and three days after a potential harvest date. If the dry period extends to two days before and seven days after the cutting day, hay harvesting is possible. A dry day is defined as less than 2 mm of rain per day. We then compare the recommendations from the DSS across four additional days (after each data collection date) with the weather thresholds.

Additional results include whether the harvest form "hay" or "silage" is possible, and whether the more significant part is grass or legumes. Both options can be recommended if possible, so the farmer can decide based on his needs. This requires information about the growth stage of grass and legumes, plant height and legume rate. These values are compared with specific thresholds for silage and hay. The DSS always uses the latest possible data.

- For silage harvesting:
  - Plant height must be ≥ 25 cm or
  - The growth stage of grass either "before ear emerging" or "after tillering",

  - The crude fibre content must be ≤ 22%
- For hay harvesting:
  - plant height must be ≥ 25 cm and
  - grass growth stage at "flowering" or later.

The crude fibre content $c_t$ at time $t$ is computed by a simple linear growth model [Be11]:

$$c_t = 0.3\,(d_t - d_v) \qquad (1)$$

where $d_t$ is the current date and $d_v$ is the vegetation start date.

In 2022, 13 farmers collected data from 29 fields, from which 9 are managed as organic. 26 fields are harvested in the form of silage, the rest in the form of hay. 13 fields are permanent grasslands and 16 are integrated in the crop rotation. The altitude over sea level ranges from 0 to 364 m. Sand, clay and loam soils are present. This represents different locations and environments across West and Northwest Germany. Between February 25$^{th}$ and July 28$^{th}$, a total of 198 measurements were made with a frequency of 7 to 21 days. Each farmer received instructions ahead of data collection to ensure consistency. The following data were collected by them: growing stage of grass and legumes, plant height, legume rate, harvest date and abnormalities. Fields are managed in an "intensive" or "extensive" way, where we defined extensive as harvest after May 31$^{st}$ 2022.

The recommendations of the DSS were compared with the decisions of the farmers, considered the experts in their own respective farm and fields. All statistical analyses were computed in the software environment R (V4.0.1). Differences in means between subsets (hay and silage, extensive and intensive managed) are estimated with a Wilcox Test ($\alpha$=0.05). Coefficient of determination ($R^2$) and a linear model are computed between harvest date of the farmer and harvest date recommended by the DSS for different subsets (all data, hay, silage, extensively and intensively managed). As a measure of prediction error, the means of the root mean square error (RMSE) was used:

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(d_{s,i} - d_{f,i}\right)^2} \qquad (2)$$

where, for each field $i$, $d_s$ is the harvest date recommended by the DSS and $d_f$ the farmer's, for a total of $N$ fields.

## 3 Results

The farmers provided 52 harvest dates, out of which 14 correspond exactly with the DSS. The differences in days between the farmers and DSS have a minimum of 0 and maximum of 49 with a median of 3. The maximum differences are shown in Tab. 1. The highest accuracy shows the subset of intensively managed fields with an $R^2$ of 0.891 and RMSE of 3.2. The hay subset shows a lower $R^2$ of 0.426 and higher RMSE of 20.45.

The linear regression between farmer and DSS harvest dates are shown in Fig. 1, which demonstrates an overall underestimation of the time until harvesting and also a higher accuracy for the recommendation for intensive managed fields.

| Dataset | $R^2$ | RMSE | Mean differences in days (±Standard deviation) | Max. differences in days |
|---|---|---|---|---|
| All | 0.746 | 7.83 | 7.84 (±11.92) | 49 |
| Silage | 0.792 | 5.85 | 5.97 (±10.11) a | 41 |
| Hay | 0.434 | 20.45 | 20.45 (±15.29) b | 49 |
| Intensive | 0.891 | 3.20 | 3.20 (±5.95) A | 28 |
| Extensive | 0.748 | 22.60 | 22.60 (±14.03) B | 49 |

Tab. 1: Coefficient of determination ($R^2$), root mean square error (RMSE), mean differences in days (±Standard deviation) and maximum differences in days between farmers´ decision and DSS recommendation for different subsets. Lowercase indicates significant differences between silage/hay fields, uppercase letters indicate significant differences intensive/extensive fields.

The differences between farmers and the DSS are significantly higher for extensive fields than for intensive fields, and also higher for hay fields than for silage fields. The recommended harvest form was the same as harvested. In many cases the DSS suggests both options.

## 4 Discussion

The 14 out of 52 exact matches suggest the DSS is more risk averse than the farmers, often recommending to harvest one or two days later with less rain. Another source of disagreement might be the gaps in data acquisition, since the DSS uses the latest available data, but this may be improved with crop simulation models [Ro18; Ha17]. Further, implementation of UAV-based images can also increase the accuracy of growing models [In19].

The DSS shows an appropriate accuracy with $R^2$ of 0.746 and RMSE of 7.83, but a maximum difference of 49 days with respect to farmers is not suitable in practice and may impact optimal yield and quality. This occurs primarily in “hay harvest” and “extensive” fields, without which the $R^2$ improves to 0.891 and the RMSE falls to 3.2. The differences in days are significantly smaller for intensive fields than for extensive fields. For hay, a higher amount of crude fibre than silage is needed so hay fields are harvested later. Some fields belong to programs for environmental protection and have restrictions for the harvest time. In this case, the DSS recommends a harvest date much earlier and in form of silage, because the agronomic parameters were suitable.

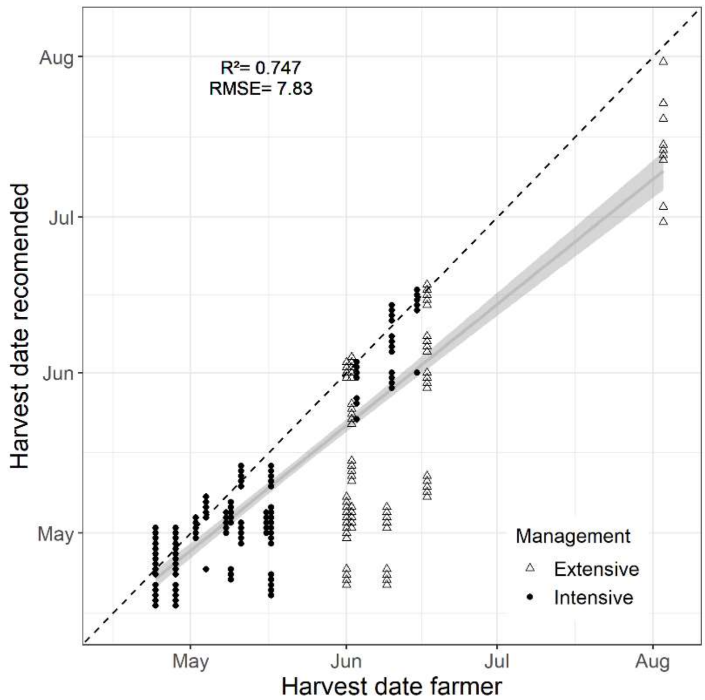


Fig. 1: Linear regression between farmer and DSS harvest dates. Shapes indicate the intensity of the field management. Solid line is the regression line with confidence interval of 95%. Dashed line is the 1:1 line (i.e., x = y). N=381.

It is important to remark that in its current form, the DSS makes inferences only at the level of fields, not farms. In practice, a farmer must often consider additional factors such as construction, equipment and the management of other crops and livestock, which may influence their chosen dates, although generally all fields of a farm share the same harvest date. Field-level suggestions can nevertheless contribute to farm-level decision making. Harvest forms were suggested correctly, often both “silage” and “hay” due to weather conditions. In such cases the farmers can simply use this information according to their specific needs.

In terms of knowledge representation, important rules are those weather-based, which determine harvest conditions, and those that determine optimal harvest quality from grass height, a measurement strongly correlated with quality parameters like protein content and digestibility [Sk09]. The growth stage is an important addition. The crude-fibre model, however, is too simplistic and is not representative, so perhaps a dynamic model may yield better accuracy. For one field, a big gap of 49 days occurred. In this case, the field was harvested in June as hay. A higher threshold for growing height could improve the recommendation for hay.

## 5 Conclusion

Our results show that despite some disagreements, the DSS recommends suitable harvest dates for pasture, the best results coming from intensively managed fields used in dairy farming. Currently, data collection in the field is sufficiently easy and fast but implementing growth models or estimating plant height via remote sensing could further relieve the farmer and contribute to higher quality measurements. Future work on the DSS includes improving result presentation and explanations, which may provide additional insight into field and farm management. With suitable refinements, a DSS has the potential to support a farmer and secure high yields and good quality even under conditions of uncertainty.

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Bibliography

[Be11] Berendonk, C.: Ermittlung der Schnittreife im ersten Aufwuchs. https://www.landwirtschaftskammer.de/landwirtschaft/ackerbau/gruenland/ermittlung-schnittreife.htm. (accessed 2020.11.30), 2011.

[Ha17] Hanrahan L. et al.: PastureBase Ireland: A grassland decision support system and national database. Comput. Electron. Agric.Vol. 136, 2017.

[In19] Insua J.R. et al.: Estimation of spatial and temporal variability of pasture growth and digestibility in grazing rotations coupling unmanned aerial vehicle (UAV) with crop simulation models. PLoS OneVol. 14, No. 3, 2019.

[Ni21] Niemann N. et al.: Wissensverarbeitung in der Landwirtschaft mit regelbasierten Inferenzsystemen und Begründungsverwaltung, in Meyer-Aurich et al.: *Informations- und Kommunikationstechnologien in kritischen Zeiten, Lecture Notes in Informatics (LNI)*, 2021, Vol. P-309, pages 229–234.

[Ro18] Rotz, C A. et al.: The Integrated Farm System Model, Session 2018.

[Sk09] Skládanka J. et al.: Influence of preparatory cut and harvest date on the yields and quality of perennial grasses, in Cagaš et al.: *Alternative functions of grassland. Proceedings of the 15th European Grassland Federation Symposium,* 2009, Vol. 14, pages 242-245.

[Ti22] Tieben C. et al.: Auf dem Weg zu einem Entscheidungsunterstützungssystem zur Pflege und Ernte von Grünlandflächen, in Gandorfer et al: *Künstliche Intelligenz in der Agrar- und Ernährungswirtschaft, Lecture Notes in Informatics (LNI)*, 2022, Vol. P-317, pages 289-294.