COBISS Code 1.01

DOI: 10.14720/aas.2015.105.1.12
**Agrovoc descriptors:** grasses, gramineae, dry matter content, crop yield, statistical data, statistical methods, models, simulation, weather data

**Agris category code**: u10, f01

# Calibration of the LINGRA-N model to simulate herbage yield of grass monocultures and permanent grassland in Slovenia

Tjaša POGAČAR[1], Domen IPAVEC[2], Janko VERBIČ[3], Lučka KAJFEŽ-BOGATAJ[4]

Received January 30, 2015; accepted March 09, 2015.
Delo je prispelo 30. januarja 2015, sprejeto 09. marca 2015.

**ABSTRACT**

In this study, we calibrated the LINGRA-N model using the minimization of *RMSE*, and proceeded to evaluate its performance. We simulated herbage dry matter yield of cock's foot (*Dactylis glomerata* L.) and perennial ryegrass (*Lolium perenne* L.) in Jablje in the period 1998–2013, and multiple-species grassland in Ljubljana (S72) in 1974–1993. The overall performance of LINGRA-N is fair for perennial ryegrass (*RMSE%* < 25%) and good for cock’s foot and S72 (*RMSE%* < 15%). The index of agreement (*d*) suggests that LINGRA-N is not calibrated well enough to simulate the interannual herbage yield variability for S72, so the model cannot yet be used for the simulation of multi-species grassland herbage yield. In contrast, the herbage yields of cock’s foot and perennial ryegrass in Jablje are simulated correctly (with *d* values 0.84 and 0.78, respectively). One of our further goals is to use the calibrated model on a specific location for the simulation of the herbage yield of grass monocultures under various weather conditions as well as for the simulation of climate change effect on it.

**Key words:** grassland herbage yield, simulation, LINGRA-N, calibration, evaluation, variability, cock’s foot, perennial ryegrass

**IZVLEČEK**

**UMERJANJE MODELA LINGRA-N ZA SIMULACIJO PRIDELKA POSAMEZNIH VRST TRAV IN TRAJNEGA TRAVINJA V SLOVENIJI**

V raziskavi smo model LINGRA-N umerjali na podlagi minimizacije kvadratnega korena napake (*RMSE*) ter ocenjevali kakovost umerjenega modela. Uporabili smo podatke o pridelku suhe snovi navadne pasje trave (*Dactylis glomerata* L.) in trpežne ljuljke (*Lolium perenne* L.) v Jabljah v obdobju 1998–2013 ter trajnega travinja v Ljubljani (S72) v obdobju 1974–1993. Glede na *RMSE* se je izkazalo, da je bilo umerjanje primerno (*RMSE%* < 25 %) za trpežno ljuljko in dobro za navadno pasjo travo ter trajno travinje (*RMSE%* < 15 %). Vendar pa je indeks ujemanja (*d*) pokazal, da za S72 model ni dovolj dobro umerjen, da bi sledil medletni variabilnosti pridelka, kar pomeni, da ga v taki obliki ne moremo uporabiti za nadaljnje modeliranje pridelka trajnega travinja. Za navadno pasjo travo (*d* = 0,84) in trpežno ljuljko (*d* = 0,78) so rezultati dobri. Umerjen model bomo zato uporabili za simulacijo pridelka posamezne vrste trave pri različnih vremenskih razmerah in pod vplivom podnebnih sprememb na specifični lokaciji.

**Ključne besede:** pridelek travne ruše, modeliranje, LINGRA-N, umerjanje, ocena kakovosti, variabilnost, navadna pasja trava, trpežna ljuljka

[1] univ. dipl. meteorol., University of Ljubljana, Biotechnical Faculty, Jamnikarjeva 101, SI-1000 Ljubljana, tjasa.pogacar@bf.uni-lj.si

[2] student, University of Ljubljana, Faculty of Mathematics and Physics, Jadranska 19, SI-1000 Ljubljana, domen.ipavec@gmail.com

[3] univ. dipl. inž. agr., Agricultural Institute of Slovenia, Hacquetova 17, SI-1000 Ljubljana, janko.verbic@kis.si

[4] prof. dr., University of Ljubljana, Biotechnical Faculty, Jamnikarjeva 101, SI-1000 Ljubljana, lucka.kajfez.bogataj@bf.uni-lj.si

This article is based on research undertaken for a doctoral dissertation by Tjaša Pogačar. Supervisor: prof. dr. Lučka Kajfež-Bogataj.

Članek je nastal na osnovi raziskav v okviru doktorske disertacije Tjaše Pogačar. Mentorica: prof. dr. Lučka Kajfež-Bogataj.

## 1 INTRODUCTION

Grasslands are an important agroecosystem in Europe with essential functions for fodder and ecosystem service supply. Impact assessment modelling of European agriculture and the environment needs to consider grasslands and requires spatially explicit information on grassland distribution and productivity, which is not available (Smit et al., 2008). As grassland budgeting must precede production of the grass, its effectiveness is severely limited by the uncertainty of future herbage supply. This is due to grass growth rates being highly variable both in time, i.e. within and between seasons at one location, and in space, i.e. between locations at any one time (Barrett et al., 2005).

According to SURS (2014), in Slovenia the area of permanent grasslands has changed very little in last 10 years: from 285,410 ha in 2000 to 277,492 ha in 2010 (excluding common grassland: 22,786 ha in 2000 and 8221 ha in 2010). This accounts for the biggest share of utilised agricultural area, 58.5 % (SURS, 2014). On the other hand, the area of sown grassland has been increasing lately to provide enough quality forage (Tehnološka priporočila ... , 2008). Although the area of sown grassland has not changed (7632 ha, compared to 7702 ha previously), the area of grass-clover and clover-grass mixtures increased from 3918 ha in 2000 to 16,675 ha in 2010 (SURS, 2014).

A considerable number of models dealing with various agronomical and ecological aspects of grassland have been developed in the past decades (Herrmann et al., 2005). Process-based models can be used to study the interactions between soil and weather conditions, and management and crop growth, thereby facilitating harvest decisions that require optimization of forage yield and nutritive value (Jego et al., 2013). One of the main advantages of crop model application is the possibility to use the models under various weather and soil conditions and in various environments in various regions of the world (Žalud et al., 2006). We can use data from archives or future scenarios to run the model (Barrett and Laidlaw, 2005). Hence crop simulation models have lately become an essential tool to study climate change impacts and to perform other scenario analyses with the aim of determining crop yield and production security. Furthermore, the awareness of a potential use of models in decision support systems for livestock grazing and forage supply planning has increased (Barrett and Laidlaw, 2005; Barrett et al., 2005).

The most complex model is not necessarily the most appropriate one to simulate grass sward growth and grassland herbage yield, because we may need input data that are not easily available. There are two modelling approaches: a simple static model without a description of process rates, and a dynamic model where state variables change in accordance to fluctuating process rates (Bouman et al., 1996).

However, in Slovenia there is no simulation model in use that would serve to monitor or forecast grass sward growth and grassland herbage yield. Our long-term objective is to develop a tool that is sensitive to climatic variation, soil properties and management practices for simulating and evaluating the growth and herbage yield of sown or permanent grasslands. In this paper we describe the first steps of our work with the LINGRA-N model. The aim of the present optimisation was to obtain a common parameter set that will serve as input for LINGRA-N in order to use it for simulations under varied input climate conditions. We expect the calibrated model to explain the major part of interannual grassland herbage yield variability in Slovenia (on a specific location) and as such to be useful for further simulations. This is also strategically important for the planning of forage supply and the adaptation of Slovene grasslands to various weather conditions.

## 2 METHODS AND DATA

### 2.1 The LINGRA-N model

The LINGRA model (Bouman et al., 1996; Schapendonk et al., 1998; Wolf, 2006; Pogačar and Kajfež-Bogataj, 2011) is an intermediate type of model in which both static and dynamic descriptions are used. Only a small number of processes involving the key parameters are simulated dynamically. On the other hand, parameters that have relatively little impact on crop growth, or of which knowledge is scarce, have been treated using the static approach. The simulated key processes are light utilization, leaf formation, leaf elongation, tillering, and carbon partitioning. LINGRA was designed for applications such as forecasting of (regional) grassland herbage yield and quantitative land-use evaluation and to study the effects of climate change on grassland herbage yields (Schapendonk et al., 1998).

Our research is based on a new version of the model, LINGRA-N (Wolf, 2012). It is an extension of LINGRA for forage production under sub-optimal nutrient availability. It can be used for potential, water limited and nitrogen (N) limited growing conditions, but it has not yet been widely used for research. LINGRA-N is largely equal to LINGRA, but the new model structure allows simulations for different grass sward types growing under a large range of soil and weather conditions with different management regimes (Wolf, 2012). For performing land use studies at the regional scale the possibility to do simulations for all these combinations is essential and is made possible by putting all the input data in separate input files (Wolf, 2012). In both models, crop growth after the winter period is initialized when a 10-day moving average of daily air temperatures is higher than the given base temperature. Growth only takes place when the supply (photosynthesis plus reallocation from the reserve pool) exceeds or equals the demand function. Conversely, carbohydrates will be stored in the reserve pool when the photosynthetic supply exceeds the demand. To calculate the grassland herbage yield, $Y$ (g dry matter m$^{-2}$) can be calculated by multiplying total biomass by dynamic grass specific partitioning factors, $HI$:

$$Y = \int (f_t PAR_t E_t) HI \qquad (1)$$

where $f_t$ is the fraction of photosynthetically active radiation (*PAR*) intercepted by the foliage, $PAR_t$ the incoming amount of *PAR* (MJ m$^{-2}$ d$^{-1}$), and $E_t$ the light utilisation efficiency (g dry matter (MJ PAR)$^{-1}$). Intercepted radiation is calculated from the leaf area index. Light use efficiency is made dependent on air temperature, level of *PAR* and possibly occurring water (Bouman et al., 1996) or nitrogen stress (new for LINGRA-N).

As others (e.g. Merot et al., 2008) we did not take into account the complex processes occurring on the crop during winter. It is assumed that the crop is also optimally protected against pests, diseases and weeds (Bouman et al., 1996). Water and nutrient availability are both subject to change by management but, in contrast with the extensive use of fertilizers, irrigation of agricultural grasslands is not widely practised.

As input for LINGRA-N user has to prepare meteorological, soil and grass crop data. The following daily weather data are used to run the model: minimum and maximum temperatures, irradiation, precipitation, mean wind speed, and early morning vapour pressure. Two output files are produced from each simulation run. One gives the soil and grass crop status at a defined regular interval during the crop growth period. The other gives mainly the total amount of cut grass, the cumulative components of the water balance, the cumulated crop's nitrogen (N) uptake and N losses (Wolf, 2012).

### 2.2 Calibration and performance evaluation of the model

Most studies on the agronomic performance of grassland are restricted to a few years, which is too short to allow for an analysis of production stability or for an estimation of the probable range of grassland productivity at a given site (Herrmann et al., 2005). Ideally, experiments used for grass model development should include detailed repetitive measurements of crop performance over the growing season, in addition to exact information about the weather and soil conditions at the experimental site (Persson et al., 2014). The lack of long-term experimental data limits the use of grassland models, as reliable and sufficiently extensive data are essential for their calibration and verification (Trnka et al., 2006). Grassland herbage yield data over at least 10 year period are needed for the LINGRA or LINGRA-N calibration, to indicate both the mean yield level and yield variation (Wolf, 2006).

Parameter estimation and model evaluation are essential phases in every modelling project. Most of the studies are based on a "trial and error" approach whereby different values of the parameters are tested until the simulation fits the data reasonably well (Merot et al., 2008; Shibu et al., 2010). We conducted a simple sensitivity analysis (without interaction taken into account) in order to identify non-influential parameters that can be omitted from the calibration. Values of non-influential parameters were then set as default values in LINGRA-N. Influential parameters were calibrated by minimizing the difference (minimization of *RMSE*, e.g. Jego et al., 2013) between the simulated and measured forage dry matter yield. At first in four groups of parameters changing simultaneously (around 40,000 iterations for each group), secondly in six groups (parameters changing with higher precision) and finally in two more groups, depending on previous results. Together, this made 12 steps of the calibration procedure.

The commonly used correlation measures such as Pearson's correlation coefficient ($r$) and its square, coefficient of determination ($r^2$), and tests of statistical significance in general are often inappropriate or misleading when used to compare model predicted and observed variables. Difference measures, however, seem to contain appropriate and insightful information (Willmott, 1982). So we decided to use the root mean square error ($RMSE$) and its relative value in % (*RMSE%*) to evaluate the model performance (e.g. Willmott, 1982; Jego et al., 2013):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - P_i)^2}\ , \qquad (2)$$

$$RMSE\% = \frac{RMSE}{\overline{O}} \times 100 \qquad (3)$$

where $n$ is the number of measurements, $O_i$ the measured value, $\overline{O}$ the mean of the measured values and $P_i$ the value simulated by the model. The simulation is considered to be excellent when $RMSE\% \leq 10\%$, good when $10\% < RMSE\% \leq 20\%$, fair when $20\% < RMSE\% \leq 30\%$, and poor when $RMSE\% > 30\%$ (Jamieson et al., 1991 op. cit. Jego et al., 2013).

Also according to Willmott (1982) we should determine how much of $RMSE$ is systematic in nature and what portion is unsystematic. The systematic part can be described by $RMSE_s$ and the unsystematic part takes the form of $RMSE_u$:

$$RMSE_s = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\hat{P}_i - O_i)^2} \qquad (4)$$

$$RMSE_u = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - \hat{P}_i)^2} \qquad (5)$$

where $\hat{P}_i$ is derived from the least-squares regression, $\hat{P}_i = a + bO_i$ ($a$ is the intercept and $b$ is the slope).

Moreover, the difference between the simulated and observed dry matter was evaluated by means of Willmott's index of agreement (Willmott, 1982):

$$d = 1 - \frac{\sum_{i=1}^{n}(Pi - Oi)^2}{\sum_{i=1}^{n}(|P_i'| + |O_i'|)^2} \qquad (6)$$

where $n$, $P_i$, and $O_i$ are defined as in (2). $P_i'$ and $O_i'$ are $P_i - \overline{O}$ and $O_i - \overline{O}$, respectively. $d$ is intended to be a descriptive measure, and is both a relative and bounded measure which can be widely applied in order to make a cross-comparison of models (Willmott, 1982).

## 2.3 Input data

The application of LINGRA-N in Slovenia brought along major challenges regarding input parameters. During our research we came across two extensive collections of grassland herbage yield data.

Firstly, measurements of herbage yield of sown grassland have been performed since 1998 (at some locations even since 1983) on several locations as part of the research of the Agricultural Institute of Slovenia (KIS, 2014). Taking into consideration the available nearby meteorological and soil data we decided to use the experiments in Jablje and Rakičan. Only the results for Jablje are presented in the article. The advantage of the experiments is that the measurements were performed for grass monocultures. We used cock's foot (*Dactylis glomerata* L., DG), as it is said to be more drought resistant (Kapun, 2005), and perennial ryegrass (*Lolium perenne* L., LP), which was often used abroad for the calibration of LINGRA. The experiment was carried out from 1998 to 2013, except in 2005 and 2006 for DG, and except in 2000, 2005 and 2008 for LP.

The herbage yield of sown grass sward is usually considerably lower in the seeding year (development is still in progress, the first mowing is only to remove the weeds) and reaches its optimum in the second (LP) or third (DG) year. Afterwards the herbage yield starts to diminish: faster for LP, which usually disappears from stands in the fourth year. DG still grows even in the sixth year; the herbage yield is decreasing more slowly. Weather conditions can outweigh the development significance for grass growth, but only in extremes like severe drought. Consequently, it would be ideal to have herbage yield data on the grasses sown every year; otherwise this has substantial implications for a general model to predict grass production. On this ground, because of a significant deviation from our expectations, in view of weather conditions and other herbage yield measurements we had to eliminate the years 2004 and 2007 for DG, and 2001 and 2004 for LP. In 2004 DG was in its fifth year and the herbage yield was extremely low. On the other hand, in 2007 the ley was in the second year and the herbage yield was very high. Something similar could be seen with LP, where 2001 was the first year and 2004 the fourth. For other years herbage yields were averaged for leys of various age to minimize the effect of younger and older leys.

Both experiments were carried out in randomized block design in four replicates with a plot size of 6 $m^2$. There were in average five varieties of cock's foot (from 2 to 8) and nine varieties of perennial ryegrass (from 5 to 14). We calculated the minimum, average and maximum herbage yields for each year from all replicates. Total datasets of averages for 12 years (11 for LP) were divided into two parts, the odd six years for calibration and the even six (five for LP) for validation. Some simplifications were made to arrange the data for the use in the model. Average cutting days were used (Table 2), although not all years of the experiment involved four mowings, but between two and five. Additionally, the fertilization amount of nitrogen (N) is averaged for LP.

Secondly, we studied the whole unpublished paper archive of prof. dr. Mirko Leskošek from the Biotechnical Faculty (BF) at the University of Ljubljana. He had done an exceptional job, performing fertilizing experiments on permanent grassland, starting from the year 1955. Some experiments contain 10 or even 20 years of data. Even though a major part of the data is not useful for us, it would be a serious loss never to use them, so we collected them in a file to be available for further studies. Basic information about the data is presented in Table 1.

**Table 1:** The base of experiments carried out by prof. dr. Mirko Leskošek, now arranged in a file
**Preglednica 1:** Preged poskusov prof. dr. Mirka Leskoška, ki smo jih uredili v elektronski obliki

| Experiment number | Period | Number of mowings | Variants of fertilization | Location |
|---|---|---|---|---|
| S2 | 1955–1966 | 2 | 6 | Hoče |
| S5 | 1955–1969 | 2 | 6 | Pristava near Mestinje |
| S6 | 1955–1960 | 2 | 6 | Imeno |
| S7 | 1955–1970 | 2 | 4 | Sela near Podčetrtek |
| S8 | 1955–1968 | 2 | 6 | Brestanica |
| S9 | 1955–1970 | 2 | 4 | Rožno near Brestanica |
| S10 | 1955–1970 | 2 | 4 | Arto near Sevnica |
| S11 | 1955–1968 | 2 | 4 | Škofljica |
| S12 | 1955–1968 | 2 | 6 | Blatna Brezovica near Vrhnika |
| S13 | 1956–1965 | 2 | 7 | Predoslje near Kranj |
| S18 | 1958–1963 | 2 | 9 | Litija |
| S26 | 1960–1970 | 2 | 6 | Horjul |
| S27 | 1961–1970 | 1, 2 | 5 | Dragatuš |
| S34 | 1963–1968 | 2 | 5 | Rožno near Brestanica |
| S35 | 1963–1968 | 2 | 5 | Vnanje Gorice |
| S40 | 1972–1981 | 2 | 6 | Rožno near Brestanica |
| S42 | 1972–1980 | 2 | 6 | Gabrovčec near Krka |
| S44 | 1969–1973 | 2 | 5 | Polšnik above Litija |
| S45 | 1969–1973 | 2 | 5 | Nova vas – Bloke |
| S46 | 1969–1973 | 2 | 6 | Lome above Idrija |
| S47 | 1969–1973 | 2 | 5 | Preska above Litija |
| S48 | 1969–1973 | 2 | 6 | Sorica above Škofja Loka |
| S49 | 1969–1973 | 2 | 5 | Cerknica |
| S50 | 1969–1973 | 2 | 6 | Gorjuše above Bohinj |
| **S72** | **1974–1993** | **2, 3, 4** | **11** | **Ljubljana BF** |
| S77 | 1975–1980 | 5 | 11 | Bašelj |
| S78 | 1975–1978 | 4 | 9 | Letenice |
| S79 | 1975–1979 | 3 | 11 | Ljubljana BF |
| S80 | 1981–1988 | 3 | 7 | Ljubljana BF |
| S87 | 1984–1989 | 3 | 8 | Ljubljana BF |

This article presents the results for the experiment S72 in Ljubljana. It was carried out on multi-species permanent grassland of the laboratory field of the Biotechnical Faculty in Ljubljana from 1974 to 1993. The meadow is situated in the Pre-Alpine area at an altitude of about 300 m. Despite a relatively large amount of rainfall the habitat is quite dry, which is also reflected in the grassland plant community, which can be found on the unfertilized *Bromo-Plantaginetum mediae* (Žitek, 1991). The experiment was carried out on 64 parcels with an area of 14 $m^2$ each in 16 variants of fertilization and three cutting regimes (two, three or four mowings). The data are already averaged for each fertilization and cutting variant. We used the data from the following treatment combination: three mowings and the fertilization application of 180 kg N $ha^{-1}$, 120 kg $P_2O_5$ $ha^{-1}$ and 165 kg $K_2O$ $ha^{-1}$. Again, total dataset was divided into two parts, the odd 10 years for calibration and the even 10 for validation. Management practices such as the date and rate of N fertilization as well as cutting dates (Table 2) were used to create the management file.

**Table 2:** Average cutting days for four mowings in Jablje (DG and LP) and for three mowings in Ljubljana (S72) used at the beginning of calibration and N fertilization rates for all experiments

**Preglednica 2:** Povprečni datumi za štiri košnje v Jabljah (DG in LP) in tri v Ljubljani (S72) ter stopnja gnojenja z dušikom za vse poskuse

| Experiment | Average cutting days $1^{st}$-$2^{nd}$-$3^{rd}$-$4^{th}$ mowing (Julian day) | Fertilization rate $1^{st}$-$2^{nd}$-$3^{rd}$ (kg N $ha^{-1}$) |
|---|---:|---:|
| DG | 136-187-242-287 | 60-50-46 |
| LP | 135-176-237-280 | 60-50-46 |
| S72 | 145-206-267 | 60-60-60 |

For all three experiments day 91 was set as the date of the first fertilization; it is a simplified marker of the beginning of the vegetation period. The first days after the first and second mowing were set as the dates of the second and third fertilization. At the beginning, crop specific parameters were set as default. For more common parameters (16) the calibration range was determined from the literature, and for the others (11) as a 30 % range around the default value. In the paper the statistic criteria (averages, standard deviations, the root mean square error, its systematic and unsystematic part, the index of agreement) are calculated for the whole datasets.

We acquired the meteorological data from the Slovenian Environment Agency (ARSO, 2014). Minimum and maximum air temperatures (°C), and precipitation (mm) are measured, mean wind speed (m $s^{-1}$) is averaged, whereas irradiation (kJ $m^{-2}$) and early morning vapour pressure (kPa) are calculated. Jablje and Ljubljana both have the moderate continental climate of the central Slovenia. For Jablje we can use the nearest meteorological station Airport Jože Pučnik Ljubljana (Brnik) and for Ljubljana the station Ljubljana Bežigrad (Ljubljana). This of course brings some uncertainty to the modelling results, because the data from Brnik are not representative for Jablje in every meteorological situation. Particularly in the summer time, the water balance can vary due to local convective events that do not occur at both locations. The missing values for less than five days were interpolated as part of model calculations (this is not possible for precipitation, but no precipitation data were missing). More data were missing for early morning vapour pressure in Brnik and were replaced with the data for Ljubljana.

In Brnik, in the period 1981–2010 the average summer (June to August) maximum air temperature was 25.0 °C and the annual 14.7 °C. For the minimum air temperature the summer average was 12.4 °C and the annual 4.0 °C. The average annual precipitation was 1363 mm. Temperature conditions in Ljubljana are warmer. Temperatures in the reference period (1961–1990) are closer to the ones in the period 1981–2010 in Brnik. The average summer maximum air temperature was 25.0 °C and the average annual maximum air temperature 14.8 °C in the reference period. In the period 1981–2010 these average air temperatures were higher by 1.2 °C and 0.8 °C, respectively. The average summer minimum air temperature was 13.4 °C and the annual 5.5 °C in the reference period. In the second period those averages were higher by 1.4 °C and 1.1 °C, respectively. The average annual precipitation was practically the same as in Brnik, 1393 mm in the reference period and 31 mm less in the second period.

The soil type in Jablje is pseudogley-gley, deep and moderate, the texture is silty clay. Soils are described in the proceedings of the conference about IOSDV experiments (Tajnšek, 2003). The basic soil data for the experiment in Ljubljana are from the Centre of soil and environmental science (CPVO, 2014). The experiment had similar conditions than the ones in Jablje: pseudogley on gravel, the texture is silty clay. Soils are medium deep and brown. Soil input parameters (Table 3) were derived from the basic soil data using the SPAW model, version 6.02.75, developed by Saxton (Saxton and Rawls, 2006).

**Table 3:** Soil data for Jablje (DG and LP) and Ljubljana (S72)
**Preglednica 3:** Podatki o tleh za Jablje (DG in LP) in Ljubljano (S72)

| Experiment | Soil moisture content at field capacity ($cm^3\ cm^{-3}$) | Soil moisture content at wilting point ($cm^3\ cm^{-3}$) | Soil moisture content at saturation ($cm^3\ cm^{-3}$) | Maximal percolation rate to deeper soil layers ($cm\ d^{-1}$) |
|---|---|---|---|---|
| DG and LP | 0.36 | 0.14 | 0.50 | 30 |
| S72 | 0.29 | 0.13 | 0.49 | 39 |

The initial soil water content was set to field capacity, which is representative of soil water status when simulations start during winter or at the beginning of spring (Schapendonk et al., 1998; Lazzarotto et al., 2009; Jego et al., 2013).

## 3 RESULTS AND DISCUSSION

After conducting the sensitivity analysis, we eliminated 10 non-influential parameters and continued the calibration with 27 parameters. From the much simpler LINGRA model evaluation and sensitivity analysis conducted by Bouman et al. (1996), only four influential parameters were selected for calibration: minimum threshold temperature for photosynthesis, threshold temperature after which photosynthesis reaches a maximum value, leaf area index after cutting, and maximum light use efficiency. Besides those the most important in the LINGRA-N model are the fraction of precipitation lost by surface runoff, the initial number of tillers, dates of mowing, the total mineral soil N available at the start of the growth period, the fraction of total biomass to roots under stressed conditions and the recovery fractions of fertiliser N applications.

In the calibration using the data for Jablje, 16 out of 27 default parameters were changed for cock's foot (DG), and 22 for perennial ryegrass (LP). For S72 (the experiment in Ljubljana) there were 19 such parameters. For DG and LP the meteorological, soil and management data are the same (except the mowing dates), so differently calibrated parameters only mean variation in their crop characteristics. The difference between the predicted herbage yields for both grass species can be seen in Figure 1. The interannual variability due to weather conditions is similar, but in general the herbage yields are lower for LP. The simulations are for instance the same for the year 2009, but on the other hand the difference between the observed values for the year 2009 is 3000 kg DM ha$^{-1}$, and it is unfortunately practically impossible to determine the reason.

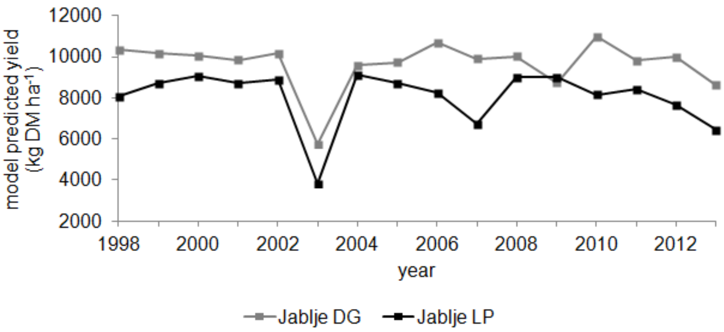


**Figure 1:** Model predicted herbage yield after the calibration for cock's foot (Jablje DG) and perennial ryegrass (Jablje LP) in Jablje
**Slika 1:** Z umerjenim modelom izračunan pridelek za navadno pasjo travo (Jablje DG) in trpežno ljuljko (Jablje LP) v Jabljah

As Figure 2 demonstrates, the dynamics of herbage yield are quite well fitted for DG. As an illustration we can additionally see some intermediate steps in the calibration procedure. Throughout the period, the final model predicted herbage yield is firmly inside the minimum-maximum frame of observed values. The simulation is excellent for the year 2003, when extreme drought reduced the herbage yield to a considerable extent. The simulation is also very good for the years 2001, 2011, 2012, and 2013.

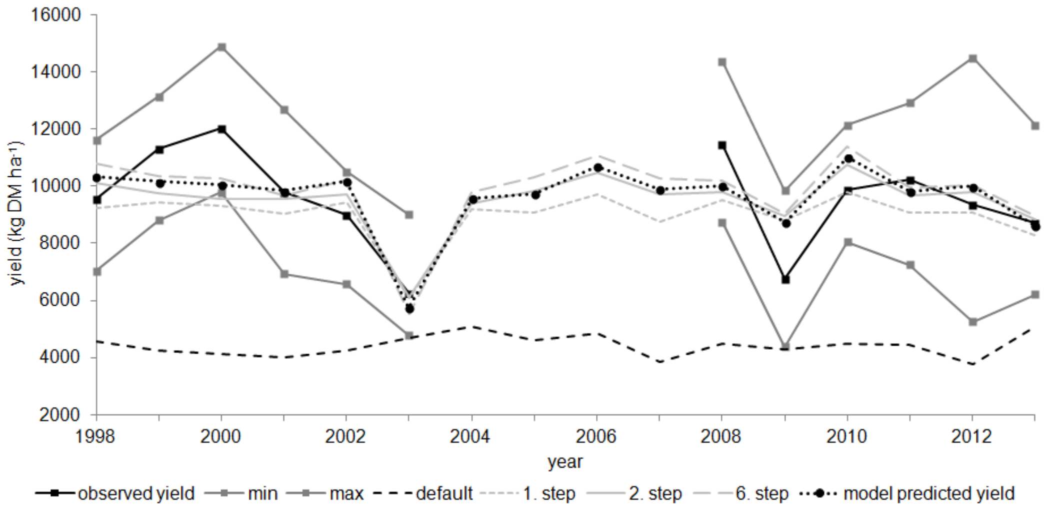


**Figure 2:** The herbage yield of cock's foot in Jablje: average (observed yield), minimum (min) and maximum (max) values of observed herbage yield, the default output of the model without calibration (default), 1st, 2nd, and 6th step herbage yield results of the calibration procedure, and model predicted herbage yield at the end of calibration
**Slika 2:** Pridelek navadne pasje trave v Jabljah: povprečne (observed yield), najmanjše (min) in največje (max) izmerjene vrednosti pridelka, modelska simulacija pridelka pred umerjanjem modela (default), rezultat simulacije 1., 2. in 6. koraka pri umerjanju modela in simulacija pridelka z umerjenim modelom

As regards the other years we have to keep in mind that there can be bigger differences because of the aging of the grass sward. In the year 2000 the ley was in the second year, so the observed herbage yield of cock's foot is much higher than predicted. A similar situation was seen in the year 2008. In contrast, the year 2009 was the ley's fourth year, grass sward growth slowed down, weeds started to overgrow it. Thus the observed herbage yield is much lower than predicted.

For LP, the predicted herbage yields are very close to observed ones in the years 2002, 2003, 2009, 2011 (figure not presented). The fit altogether is not as good as for DG, but it exceeds the maximum observed herbage yield only a little in 1999. The reason could be the same as with DG; the ley was in the third year, which is past the optimum for LP, and due to weeds there were also only two mowings. Furthermore, the observed herbage yields in the years 2007 and 2010 were quite low (so the simulation is too high). A comment for both years could be that sometimes already after its second overwintering LP stops to grow well and becomes very sensitive to high summer temperatures and soil moisture deficit.

Additionally, on the scatter plots (Figure 3) we can clearly see the relationship between the observed and predicted values for both grass species in Jablje. The plots alone indicate that the model is more variable in the case of LP.

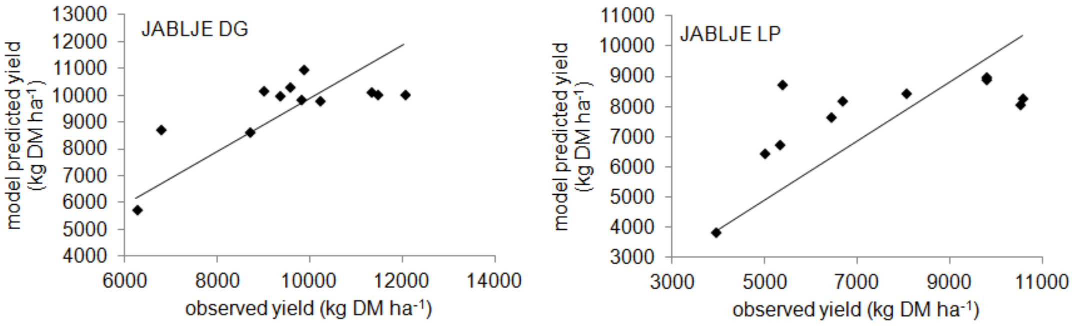


**Figure 3:** Scatterplots of the observed versus model predicted herbage yield for two grass species on the same location (Jablje). Left: cock's foot (DG), right: perennial ryegrass (LP)

**Slika 3:** Razsevna diagrama (izmerjeni vs. simulirani pridelek) za obe vrsti trave na isti lokaciji, v Jabljah. Levo: navadna pasja trava (DG), desno: trpežna ljuljka (LP)

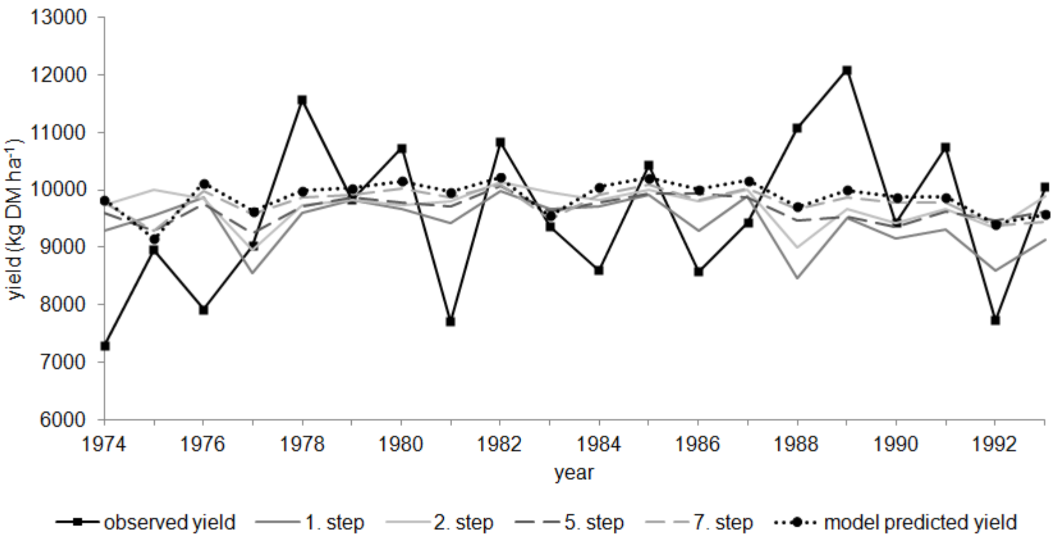


**Figure 4:** The herbage yield of multi-species grassland in the experiment S72 in Ljubljana: observed herbage yield, 1st, 2nd, 5th and 7th step herbage yield results of the calibration procedure, and model predicted herbage yield at the end of calibration

**Slika 4:** Pridelek poskusa S72 na travniku v Ljubljani: izmerjene vrednosti pridelka (observed yield), rezultat simulacije 1., 2., 5. in 7. koraka pri umerjanju modela in simulacija pridelka z umerjenim modelom

Even though calibration results for Jablje are good, we have a problem with S72 in Ljubljana (Figure 4). We may say the trouble is in the multi-species grassland. If there are already quite big differences between DG and LP (Figure 1), the difficulty caused by multi-species grass is only greater. So it seems as if the model can only be fully calibrated if we have a monoculture.

However, Figure 4 demonstrates that in this case the model may be able to reproduce the overall herbage yield level (the production potential) of the site, whereas the representation of interannual herbage yield variability is inaccurate. This can only have limited benefits in modelling in general, e.g. for overall grassland herbage yield levels on many locations in Slovenia or even in one part of Europe.

An examination of averages indicates that for each experiment the average predicted herbage yield ($\overline{P}$) overestimates the corresponding average observed herbage yield ($\overline{O}$) (Table 4). In contrast, according to Schapendonk et al. (1998) LINGRA grassland herbage yield simulations underestimated observations on most of 35 locations around Europe. Nevertheless, the differences are not big: 308 kg DM ha$^{-1}$ between the average predicted and average observed herbage yield for S72, 251 kg DM ha$^{-1}$ for LP and only 23 kg DM ha$^{-1}$ for DG. On the other hand for each experiment the standard deviation of the observed herbage yields ($\sigma_O$) is higher than the standard deviation of predictions ($\sigma_P$) (Table 4). The biggest problem is in the standard deviation of predictions for S72, which is only 289 kg DM ha$^{-1}$ and does not correspond to the variability of the observed herbage yield.

**Table 4:** Number of measurements ($n$), the average observed herbage yield ($\overline{O}$) and its standard deviation ($\sigma_O$), the average predicted herbage yield ($\overline{P}$) and its standard deviation ($\sigma_P$) for the performance evaluation of LINGRA-N for three study experiments (DG and LP in Jablje, S72 in Ljubljana)

**Preglednica 4:** Število meritev ($n$), povprečni izmerjeni pridelek ($\overline{O}$) in standardni odklon ($\sigma_O$) ter povprečni simulirani pridelek ($\overline{P}$) in standardni odklon ($\sigma_P$) za oceno kakovosti modela LINGRA-N pri treh obravnavanih poskusih (DG in LP v Jabljah, S72 v Ljubljani)

| Experiment | $n$ | $\overline{O}$ (kg DM ha$^{-1}$) | $\sigma_O$ (kg DM ha$^{-1}$) | $\overline{P}$ (kg DM ha$^{-1}$) | $\sigma_P$ (kg DM ha$^{-1}$) |
|---|---|---|---|---|---|
| DG | 12 | 9525 | 1742 | 9548 | 1359 |
| LP | 11 | 7398 | 2439 | 7649 | 1512 |
| S72 | 20 | 9569 | 1368 | 9877 | 289 |

The most interesting result of the statistical analysis (Table 5) is that with respect to *RMSE*, no meaningful distinction can be made between the goodness of fit of model predictions for DG and S72. The overall performance of LINGRA-N is fair for LP (*RMSE%* = 23 %) and good for DG (*RMSE%* = 12 %) and S72 (*RMSE%* = 14 %). For example, in Scandinavia *RMSE%* for timothy was 43 % after the calibration (Van Oijen et al., 2005). However, good evaluation is needed that includes several statistical criteria. Regarding the systematic and unsystematic errors we can say that only for S72 the systematic error prevails over the unsystematic one. The index of agreement for S72 ($d$ = 0.37) suggests that LINGRA-N is not calibrated well enough to simulate a multi-species grassland herbage yield, so for now we will not be able to use it for this purpose. Meanwhile the index of agreement is much higher for DG and LP, 0.84 and 0.78, respectively. For illustration, Persson *et al.* (2014) outlined the difference between leys of various age. For the first ley year were *RMSE%* 31 % and $d$ 0.36, while for the second ley year both were much better, *RMSE%* 22 % and $d$ 0.98. Considering both *RMSE* and $d$, we can be satisfied with the calibration of LINGRA-N for DG and a little less for LP.

**Table 5:** Statistical criteria: the root mean square error (*RMSE*), its relative value in % (*RMSE%*), its systematic ($RMSE_s$) and unsystematic ($RMSE_u$) part and the index of agreement ($d$) for additional performance evaluation of LINGRA-N for three study experiments (DG and LP in Jablje, S72 in Ljubljana)

**Preglednica 5:** Statistični kriteriji: kvadratni koren napake (*RMSE*), njegova relativna vrednost v % (*RMSE%*), njegov sistematični ($RMSE_s$) in nesistematični ($RMSE_u$) del ter indeks ujemanja ($d$) za nadaljnjo oceno kakovosti modela LINGRA-N pri treh obravnavanih poskusih (DG in LP v Jabljah, S72 v Ljubljani)

| Experiment | *RMSE%* (%) | *RMSE* (kg DM ha$^{-1}$) | $RMSE_s$ (kg DM ha$^{-1}$) | $RMSE_u$ (kg DM ha$^{-1}$) | $d$ |
|---|---|---|---|---|---|
| DG | 12 | 1134 | 711 | 882 | 0.84 |
| LP | 23 | 1709 | 1353 | 1043 | 0.78 |
| S72 | 14 | 1329 | 1199 | 249 | 0.37 |

## 4 CONCLUSIONS

We have to concur with Barrett et al. (2005) that as grass sward growth is determined by the interaction of many environmental and management factors, forecasting grass sward growth rates is particularly difficult. Unfortunately we do not have datasets consisting of multiple years of observations from sequential measurements of grassland herbage yield, together with e.g. leaf area, tiller density, reserve carbohydrates, leaf appearance rate, leaf elongation rate, or specific leaf area, possibly during spring growth and first summer regrowth, in swards of one to two years of age (likewise e.g. Persson et al., 2014). That would improve calibration by dividing it in several stages. Considering the simplifications we made, we can conclude that the herbage yield of cock's foot and perennial ryegrass in Jablje is correctly simulated by the calibrated LINGRA-N. Two sets of parameters were defined: one for DG and one for LP. The best results are for DG in Jablje, with *RMSE%* = 12 % and with the index of agreement $d$ = 0.84. The results for S72 in Ljubljana are far from optimal. As the interannual variability is not simulated well, we cannot use the model for further analyses in S72.

Calibration was the first step in preparing a tool to simulate grass sward growth and grassland herbage yield on specific locations in Slovenia. The degree of complexity of LINGRA-N construction is appropriate for its intended application, rather than for process understanding. Our further goal is to use the calibrated model for the simulation of the herbage yield of grass monocultures under various weather conditions as well as for the simulation of climate change effect on it. However, further parameterization and validation would be required for locations where the model will be operated using well-monitored swards under realistic parameters.

## 5 REFERENCES

ARSO – climatological data. 2014. Slovenian Environment Agency (http://www.arso.gov.si/): database output

Barrett P.D., Laidlaw A.S. 2005. Grass growth modelling: to increase understanding and aid decisionmaking on-farm. V: Utilization of grazed grass in temperate animal systems. Murphy J.J. (ed.). Wageningen, Wageningen Academic Publishers: 79-88

Barrett P.D., Laidlaw A.S., Mayne C.S. 2005. GrazeGro: a European herbage growth model to predict pasture production in perennial ryegrass swards for decision support. European Journal of Agronomy, 23: 37-56; DOI: 10.1016/j.eja.2004.09.006

Bouman B.A.M., Schapendonk A.H.C.M., Stol W., Van Kraalingen D.W.G. 1996. Description of the growth model LINGRA as implemented in CGMS. Quantitative Approaches in Systems Analysis, 7: 11-56

CPVO – soil data. 2014. Centre of soil and environmental science, Biotechnical Faculty, University of Ljubljana (http://web.bf.uni-lj.si/cpvo/): database output

Herrmann A., Michael K., Kornher A. 2005. Performance of grassland under different cutting regimes as affected by sward composition, nitrogen input, soil conditions and weather – a simulation study. European Journal of Agronomy, 22: 141-158; DOI: 10.1016/j.eja.2004.02.002

Jego G., Belanger G., Tremblay G.F., Jing Q., Baron V.S. 2013. Calibration and performance evaluation of the STICS crop model for simulating timothy growth and nutritive value. Field Crops Research, 151: 65-77; DOI: 10.1016/j.fcr.2013.07.003

Kapun S. 2005. Pridelovanje pasje trave. Naše travinje 1, 1: 10-11

KIS – herbage yield data of grass monocultures. 2014. Agricultural Institute of Slovenia (http://www.kis.si/): database output

Lazzarotto P., Calanca P., Fuhrer J. 2009. Dynamics of grass-clover mixtures – An analysis of the response to management with the PROductive GRASsland Simulator (PROGRASS). Ecological Modelling, 220: 703-724; DOI: 10.1016/j.ecolmodel.2008.11.023

Merot A., Bergez J.E., Wallach D., Duru M. 2008. Adaptation of a functional model of grassland to simulate the behaviour of irrigated grasslands under a Mediterranean climate: The Crau case. European Journal of Agronomy, 29: 163-174; DOI: 10.1016/j.eja.2008.05.006

Persson T., Höglind M., Gustavsson A.M., Halling M., Jauhiainen L. et al. 2014. Evaluation of the LINGRA timothy model under Nordic conditions. Field Crops Research, 161: 87-97; DOI: 10.1016/j.fcr.2014.02.012

Pogačar T., Kajfež-Bogataj L. 2011. LINGRA: model za simulacijo rasti in pridelka travne ruše. Acta agriculturae Slovenica, 97, 3: 319-327

Saxton K.E., Rawls W.J. 2006. Soil water characteristic estimates by texture and organic matter for hydrologic solutions. Soil Science Society of America Journal, 70: 1569-1578 ; DOI: 10.2136/sssaj2005.0117

Schapendonk A.H.C.M., Stol W., Van Kraalingen D.W.G., Bouman B.A.M. 1998. LINGRA, a sink/source model to simulate grassland productivity in Europe. European Journal of Agronomy, 9: 87-100; DOI: 10.1016/S1161-0301(98)00027-6

Shibu M.E., Leffelaar P.A., Van Keulen H., Aggarwal P.K. 2010. LINTUL3, a simulation model for nitrogen-limited situations: Application to rice. European Journal of Agronomy, 32: 255-271; DOI: 10.1016/j.eja.2010.01.003

Smit H.J., Metzger M.J., Ewert F. 2008. Spatial distribution of grassland productivity and land use in Europe. Agricultural Systems, 98: 208-219; DOI: 10.1016/j.agsy.2008.07.004

SURS – grassland data. 2014. Statistical office of the Republic of Slovenia. http://pxweb.stat.si/pxweb/Database/Okolje/Okolje.asp (17. 12. 2014)

Tajnšek A. 2003. Deset let trajnih poskusov IOSDV v Sloveniji, Jable in Rakičan 1993–2003. In: Namen in cilj trajnih poljskih poskusov IOSDV Jable in IOSDV Rakičan. Žalec, 12. 12. 2003. Tajnšek A., Čeh Brežnik B., Kocjan Ačko D. (eds.). Proceedings of the conference, Slovensko agronomsko društvo: 7-24

Tehnološka priporočila za zmanjšanje občutljivosti kmetijske pridelave na sušo: poljedelstvo, travništvo, zelenjadarstvo in hmeljarstvo. 2008. Ljubljana, Ministry of Agriculture, Forestry and Food: 44 p. http://www.arsktrp.gov.si/fileadmin/arsktrp.gov.si/pageuploads/Aktualno/Aktualno/2013/Tehnoloska_priporocila_za_zmanjsanje_obcutljivosti_na_suso.pdf (18. 11. 2013)

Trnka M., Eitzinger J., Gruszczynsk G., Buchgraber K., Resch R., Schaumberger A. 2006. A simple statistical model for predicting herbage production from permanent grassland. Grass and Forage S cience, 61: 253-271; DOI: 10.1111/j.1365-2494.2006.00530.x

Van Oijen M., Höglind M., Hanslin H.M., Caldwell N. 2005. Process-based modeling of Timothy regrowth. Agronomy Journal, 97: 1295-1303; DOI: 10.1111/j.1365-2494.2006.00530.x

Willmott C.J. 1982. Some comments on the evaluation of model performance. Bulletin of the American Meteorological Society, 63: 1309-1313; DOI: 10.1175/1520-0477(1982)063<1309:SCOTEO>2.0.CO;2

Wolf J. 2006. Grassland data from PASK study and testing of LINGRA in CGMS. ASEMARS Project report no. 2. Wageningen, Alterra: 38 p.

Wolf J. 2012. LINGRA-N: Simple generic model for simulation of grass growth under potential, water limited and nitrogen limited conditions. User guide for LINGRA-N. Wageningen, Wageningen University (available on agreement): 65 p.

Žalud Z., Trnka M., Ruget F., Hlavinka P., Eitzinger J., Schaumberger A. 2006. Evaluation of crop model STICS in the conditions of the Czech Republic and Austria. In: Proceedings of the conference Bioclimatology and water in the land (poster), Strecno, 11.-14. 9. 2006: 7 p. http://www.cbks.cz/sbornikStrecno06/prispevky/PosterII_clanky/P2-16.pdf (11. 11. 2013)

Žitek D. 1991. Dinamika razvoja pridelka travne ruše pri različnem gnojenju v enem letu. Bachelor thesis. Ljubljana, University of Ljubljana, Biotechnical Faculty, Department of Agronomy: 128 p.