Simulation of herbage yield and growth components of Cock’s foot (*Dactylis glomerata* L.) in Jablje using the calibrated LINGRA-N model

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**ABSTRACT**

In the study the previously calibrated LINGRA-N model was used for a long term simulation (1964–2013) of the herbage dry matter yield (*GRASS*) and growth analysis of Cock’s foot (*Dactylis glomerata* L.) in Jablje. Changes in the yearly *GRASS* variability are reflected in the appearance of outliers in the second half of the study period. The biggest reductions in *GRASS* are seen in the years 1992, 1993 and 2003. These are the driest years according to meteorological variables (high maximum and minimum air temperatures, low precipitation) and also according to the simulations, with the lowest reduction factor for crop growth due to drought. The potential yield (*YIELD*) is not linearly dependent on meteorological variables. Some growth components were compared on a daily basis in a dry year (1993) and an average year (1994). In 1993, for instance, 53 % of photosynthetically active radiation was intercepted, against 75 % in 1994. Seasonal development of the actual soil moisture content was linked to the development of the leaf area index and consequently to the mass of green leaves, to the mass of dead leaves and to *GRASS*. The results highlight the need for further research, on field and with simulations. As regards the latter, we have to keep in mind that they inevitably involve various uncertainties.

**Key words:** simulation, LINGRA-N, cock’s foot, herbage yield, drought, growth analysis

**IZVLEČEK**

Simulacija prideleka zelina in komponent rasti navadne pasje trave (*Dactylis glomerata* L.) v Jabljah z umerjenim modelom LINGRA-N


**Ključne besede:** modeliranje, LINGRA-N, navadna pasja trava, pridelek travne ruše, suša, analiza rasti
1 INTRODUCTION

Annual grass production varies widely, even under standard management conditions (Laidlaw, 2009). The considerable year-to-year and seasonal variation in grassland production is of major importance, as production systems must allow for the risk of unfavourable weather conditions (Trnka et al., 2006). The dependence of grassland herbage dry matter (DM) production on weather factors and their interaction with soil conditions, sward composition and management have been shown in many analyses (Trnka et al., 2006; Barrett et al., 2005; Čop, 1992).

Even individual variables important in the description of grassland growth like leaf area index (LAI) are strongly weather dependent. For example, when there are sufficient mineral nutrients in the soil, the development of the canopy (with LAI < 4) of a perennial ryegrass crop during regrowth after winter or after a cut in spring time, essentially depends on the temperature (Lambert et al., 1999).

Drought is one of the most important weather phenomena, having a major impact on grass sward growth and herbage yield. In contrast to majority field crops, grasses which constitute major part of seminatural grasslands are perennial plants and grow for several years. According to Tehnološka priporočila ... (2008), the consequences of severe droughts affect grassland sward productivity over the next years through the changes in the botanical composition of the sward, which is adapting to new growth conditions. This effect is long term and it is not obvious in monocultures, which are sown every few years. Another problem is that when rain returns after a period of drought precipitation may not be in excess of evapotranspiration so soil moisture content may not increase significantly (Laidlaw, 2009). So grassland sward makes use of periods when enough water is available and the abundant spring growth is often followed by summer hibernation. Laidlaw (2009) states that early summer droughts may not have a long term impact on yield.

In Slovenia, periods of drought are becoming increasingly problematic for forage production in summer months, especially on lighter soils (Dolničar, 2013). For example, in 2006 74 % of agricultural area damaged by drought was under permanent grasslands and pastures (Sušnik, 2006). According to climate change scenarios for Slovenia by the middle of the century (Prihodnje ... , 2014) we can expect continuous problems with drought stress due to higher air temperatures and, at least in the southern part of the country, lower summer precipitation rates.

Appropriate knowledge and understanding of the impact of climate variability on agricultural production is therefore essential for devising an adaptation strategy (Ceglar and Kajfež-Bogataj, 2012). From this point of view, crop modelling is very important for studies of the impacts of weather and climate on production. In this paper the work with the calibrated LINGRA-N model (Wolf, 2012), is described. The aim was to use the model for a long term simulation (50-year period) of the herbage dry matter (DM) yield of a grass monoculture, which brings the opportunity to observe the year-to-year variability and yield declines in years of drought. Furthermore, the growth analysis was undertaken with the intention of better understanding the interactions between growth components. This has an important role in grassland management science, as growth analyses of grass crop are rare in Slovenia, on the field or in the lab. Even if there is one, the experiment cannot be maintained for such a long period of time. Additionally, some variables of water balance were studied – their influence on the yield, its year-to-year variability or their development during average and dry years. The comparison was made with year-to-year variability of meteorological data for the central Slovenia (meteorological station Brnik).
2 METHODS AND DATA

The simulations were made with the LINGRA-N model, which was previously calibrated with herbage DM yield data for cock’s foot (Dactylis glomerata L.) in Jablje from the experiment (KIS, 2014) that was performed in the periods 1998–2003 and 2008–2013. The average measured herbage DM yield for both periods together was 9525 kgDM ha⁻¹ with the standard deviation of 1742 kgDM ha⁻¹ (Figure 1). The performance of LINGRA-N was good, with RMSE% = 12 % and with the index of agreement (Willmott, 1982) \( d = 0.84 \) (Pogačar et al., 2015).

![Figure 1: Average measured yearly herbage DM yield of cock's foot in Jablje for the periods 1998–2003 and 2008–2013 (data: KIS, 2014)](image)


2.1 Input data

The 50-year period of the simulation was set to 1964–2013 due to the availability of the meteorological data. For Jablje, the most representative meteorological station is Airport Ljubljana (Bmik). However, the distance of 12 km between the two brings some uncertainty to the modelling results, especially in the case of summer local convective events. The input for LINGRA-N includes daily data on minimum and maximum air temperatures (°C), precipitation (mm), mean wind speed (m s⁻¹), global radiation (kJ m⁻²) and early morning vapour pressure (kPa), all obtained from the Slovenian Environment Agency (ARSO, 2014).

Air temperatures were lower at the beginning of the 50-year period (Figure 2, left) and so was global radiation (Figure 2, right). For the whole period, the average of average minimum daily air temperatures for the vegetation period (April-September) (\( T_{minVP} \)) is 9.3°C, the average of average summer (June-August) minimum daily air temperatures (\( T_{minS} \)) is 12.1°C, the average of average maximum daily air temperatures for the vegetation period (\( T_{maxVP} \)) is 22°C, and the average of average summer maximum daily air temperatures (\( T_{maxS} \)) is 25°C. In the second half of the period \( T_{maxS} \) dropped below this average in just seven years. \( T_{maxS} \) was extremely high in the years 2003, 2013, 2012, 1992 and 1983. It is clear that not only air temperatures but also their year-to-year variability are increasing. Something very similar holds true for the other presented air temperatures. However, the year-to-year variability of \( T_{minVP} \) and \( T_{minS} \) was higher in the first half of the period, due to a possibly non-climatic jump around the year 1978. Global radiation is increasing even more notably. Very high values were all reached after the year 2000: in 2011, 2003, 2009, 2000, 2007, 2012 and 2013.

The 50-year average of precipitation during the vegetation period (\( RR_{vp} \)) is 734 mm, of which on average 396 mm fell in the summer time (\( RR_{s} \)) (Figure 2, right). The decrease in precipitation is not obvious, but the variability increased in the second half of the 50-year period in both cases. There have lately been more years with low \( RR_{vp} \) and especially with low \( RR_{s} \). \( RR_{vp} \) was less than 500 mm in the years 1992, 2003, 1983 and 1993, while \( RR_{s} \) was less than 250 mm in the years 1983, 1992, 2001, 2003, 2013 and 1993.
The used soil type in Jablje is pseudogley-gley, deep and moderate, the texture is silty clay. The description can be found in Tajnšek (2003). Soil moisture content at saturation is 0.5 cm$^3$ cm$^{-3}$, soil moisture content at field capacity is 0.36 cm$^3$ cm$^{-3}$ and soil moisture content at wilting point is 0.14 cm$^3$ cm$^{-3}$. The initial soil water content is set to field capacity (Pogačar et al., 2015). The rooted zone is changing with the growth of roots, every year from 30 to 40 cm. Four mowings are assumed and are set on fixed dates: 12 May, 1 July, 30 August and 17 October. The grass sward is fertilized on 1 April (60 kgN ha$^{-1}$) and on the first day after the first (50 kg N ha$^{-1}$) and the second (46 kgN ha$^{-1}$) mowing.

Furthermore, calibrated crop and soil parameters are required as input. There are 27 of them, the most influential (Pogačar et al., 2015) are the thresholds for reductions of radiation use efficiency due to low minimum temperature ($TMNFTB = -3^\circ C$) or high soil temperature ($TMPFTB = 25^\circ C$), the leaf area index after mowing ($CLAI = 0.8$ m$^2$ m$^{-2}$), the maximum light use efficiency ($RUETB = 2.6$ g$_{DM}$ MJ$^{-1}$ PAR), the fraction of precipitation lost by surface runoff ($RUNFR = 0.08$), the initial number of tillers ($TILLI = 7000$ m$^{-2}$), the mineral soil nitrogen (N) available at the start of the growth period ($NMINS = 400$ kgN ha$^{-1}$), the fraction of total biomass to roots under stressed conditions ($FRT = 0.2$) and the recovery fractions of fertiliser N applications ($NRFTAB = 0.7$).

2.2 Overview of output variables in the LINGRA-N model

From each simulation run two output files are obtained. One gives the daily results (as model time step is 1 day) for each simulated year (Table 1). The other contains yearly cumulative or average (depending on the characteristics of the variable) values for most of the variables (exceptions are marked grey in Table 1).
Table 1: Output variables of LINGRA-N simulated for each day (DM: dry matter, N: nitrogen). Variables for which model does not calculate yearly cumulative or average values are marked grey

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water balance variables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRAIN</td>
<td>mm</td>
<td>cumulative drainage</td>
</tr>
<tr>
<td>ESOIL</td>
<td>mm</td>
<td>cumulative soil evaporation</td>
</tr>
<tr>
<td>IRR</td>
<td>mm</td>
<td>cumulative irrigation</td>
</tr>
<tr>
<td>RAIN</td>
<td>mm</td>
<td>cumulative precipitation</td>
</tr>
<tr>
<td>RUNOF</td>
<td>mm</td>
<td>cumulative runoff</td>
</tr>
<tr>
<td>SMACT</td>
<td>cm(^3) cm(^{-3})</td>
<td>actual soil moisture content in rooted zone</td>
</tr>
<tr>
<td>WAVT</td>
<td>mm</td>
<td>available water in rooted zone</td>
</tr>
<tr>
<td>WTOT</td>
<td>mm</td>
<td>water in rooted zone</td>
</tr>
<tr>
<td>TRANS</td>
<td>mm</td>
<td>cumulative crop transpiration</td>
</tr>
<tr>
<td>Variables based on nitrogen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NLIV</td>
<td>kg(_N) ha(^{-1})</td>
<td>amount of N in living crop organs</td>
</tr>
<tr>
<td>NLOSS</td>
<td>kg(_N) ha(^{-1})</td>
<td>N loss in dead crop organs and cut grass</td>
</tr>
<tr>
<td>NMIN</td>
<td>kg(_N) ha(^{-1})</td>
<td>amount of organic N potentially available by mineralization from the soil</td>
</tr>
<tr>
<td>NMINT</td>
<td>kg(_N) ha(^{-1})</td>
<td>mineral N directly available from soil and fertiliser</td>
</tr>
<tr>
<td>NNI</td>
<td></td>
<td>nitrogen nutrition index (range 0-1)</td>
</tr>
<tr>
<td>NUPT</td>
<td>kg(_N) ha(^{-1})</td>
<td>N uptake by crop from soil</td>
</tr>
<tr>
<td>Crop variables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DVS</td>
<td></td>
<td>development stage</td>
</tr>
<tr>
<td>LAI</td>
<td>m(^2) m(^{-2})</td>
<td>leaf area index</td>
</tr>
<tr>
<td>PAR</td>
<td>MJ m(^{-2})d(^{-1})</td>
<td>daily amount of photosynthetically active radiation</td>
</tr>
<tr>
<td>PARAB</td>
<td>MJ m(^{-2})d(^{-1})</td>
<td>daily amount of PAR as intercepted by the crop canopy</td>
</tr>
<tr>
<td>TILLER</td>
<td>m(^2)</td>
<td>number of tillers</td>
</tr>
<tr>
<td>TRANRF</td>
<td>/</td>
<td>reduction factor for crop growth due to drought/wetness (range 0-1)</td>
</tr>
<tr>
<td>WLVD</td>
<td>kg(_{DM}) ha(^{-1})</td>
<td>mass of dead leaves in the field</td>
</tr>
<tr>
<td>WLVG</td>
<td>kg(_{DM}) ha(^{-1})</td>
<td>mass of green leaves in the field</td>
</tr>
<tr>
<td>WRE</td>
<td>kg(_{DM}) ha(^{-1})</td>
<td>mass of reserves (storage carbohydrates)</td>
</tr>
<tr>
<td>WRT</td>
<td>kg(_{DM}) ha(^{-1})</td>
<td>roots mass</td>
</tr>
<tr>
<td>TSUML</td>
<td>°C</td>
<td>temperature sum from emergence</td>
</tr>
<tr>
<td>TADRW</td>
<td>kg(_{DM}) ha(^{-1})</td>
<td>mass of green and dead leaves in the field plus herbage DM yield</td>
</tr>
<tr>
<td>GRASS</td>
<td>kg(_{DM}) ha(^{-1})</td>
<td>herbage DM yield</td>
</tr>
<tr>
<td>YIELD</td>
<td>kg(_{DM}) ha(^{-1})</td>
<td>mass of harvestable leaves in the field plus herbage DM yield</td>
</tr>
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In the second output file there are also yearly values of nitrogen use efficiency (NUE, kgDM kg⁻¹N), radiation use efficiency (RUE, gDM MJ⁻¹ PAR) and water use efficiency (WUE, gDM kg⁻¹water).

In this paper some of the simulated variables are studied. In the first place the herbage DM yield of grassland (GRASS) and the potential yield (YIELD), in connection with input weather variables and the reduction factor for crop growth due to drought (TRANRF) on a yearly basis. The dependence of RUE on TRANRF is shown. To further describe the water status, the yearly development of the actual soil moisture content in the rooted zone (SMART) is examined during a dry year (1993) and an average year (1994), in which GRASS is very close to the average GRASS for the whole period. Also, the daily amount of photosynthetically active radiation (PAR) and the daily amount of PAR as intercepted by the grass crop canopy (PARAB) are compared with each other in the two years. This kind of a comparison is also made for the variables of the daily growth of the grass crop like the mass of green leaves (WLVG), the roots mass (WRT) and the mass of dead leaves (WLVD). Furthermore, the leaf area index (LAI) progress during dry and average years is presented.

To better understand the simulation of those variables there is a short description based on Wolf (2012) of how they are calculated in the LINGRA-N model (sections 2.3 to 2.5).

### 2.3 Growth variables

Growth variable PARAB (MJ m⁻²d⁻¹) is calculated as the daily amount of incoming PAR (MJ m⁻²d⁻¹) times the fractional light interception:

\[
PARAB = PAR(1 - e^{-K_{DIF} \cdot L_d})
\]

where \(K_{DIF}\) is the extinction function for visible incoming radiation with the calibrated value of 0.6.

The daily assimilate production of the crop (GTWSO₁, kgDM ha⁻¹d⁻¹) is dependent on PARAB, RUE, correction factors for temperature, high radiation levels, and atmospheric CO₂ and reduction factors for water and N stress (via TRANRF and nitrogen nutrition index NNI). The sum of GTWSO₁ and the available amount of reserves (WRE, kgDM ha⁻¹) is labeled as GTWSO₂ (kgDM ha⁻¹d⁻¹).

The sink limited increase in leaf area (GLAISI, ha⁻¹d⁻¹) is calculated from the number of tillers and the leaf elongation rate. The sink limited increase in total biomass (GTWSI, kgDM ha⁻¹d⁻¹) is calculated as

\[
GTWSI = \frac{GLAISI}{SLA \cdot (1 - FRT)}
\]

where SLA (with the calibrated value of 0.0025 ha kg⁻¹DM) is a specific leaf area and 1-FRT (with the calibrated value of 0.8) is the above ground allocation fraction.

The actual grass growth may switch between sink and source limited growth limitation. If \(GTWSO₂ > GTWSI\), the growth rate (GTW, kgDM ha⁻¹d⁻¹) is equal to GTWSI and the additional amount of assimilates results in an increase in reserves. If \(GTWSO₂ ≤ GTWSI\) then GTW is equal to GTWSO₂. The increase in leaf mass (GLV, kgDM ha⁻¹d⁻¹) is calculated from the total growth rate GTW and the partitioning factor (1-FRT), to determine the mass of green leaves (WLVG, kgDM ha⁻¹).

The sink limited increase in leaf area (LAI) (GLAI, d⁻¹) is simulated as

\[
GLAI = GLV \cdot SLA,
\]

with SLA as in (2).

Furthermore, the relative death rates of the leaves (RDR, d⁻¹) due to N shortage (with NNI < 1; RDRₙ, d⁻¹) and due to ageing as dependent on the mean daily temperature (RDRₜ, d⁻¹), due to shading (with high LAI values; RDRₛₑ, d⁻¹) or due to drought (as dependent on TRANRF; RDRₛₜ, d⁻¹) are determined:

\[
RDR = RDRₙ + \max (RDRₛₑ, RDRₛₜ, RDRₛₜ). \quad 4)
\]

Next, the death rate of leaves (DLV, kgDM ha⁻¹d⁻¹) is calculated from RDR, followed by the calculation of the mass of the dead leaves (WLVD, kgDM ha⁻¹). The decrease in LAI (DLAI, d⁻¹) is calculated practically in the same way as the leaf death rate. Only to allow regrowth after, for example, a period of severe drought stress, LAI (m² m⁻²) remains during the growth period always at least on the value of predefined CLAI. The change in the leaf area (RLAI, d⁻¹) is equal to GLAI minus DLAI.
2.4 Herbage DM yield, potential yield and crop efficiency

For the calculation of the herbage DM yield ($GRASS$, kg$_{DM}$ ha$^{-1}$), the harvestable leaf mass ($HRVBL$, kg$_{DM}$ ha$^{-1}$) has to be determined first. It is equal to the green leaf mass in the field ($WLG$) minus the leaf mass that remains in the field after mowing:

$$HRVBL = WLG - \frac{CLAI}{SLA}$$ (5)

where $CLAI$ is the leaf area index after mowing (0.8 m$^2$ m$^{-2}$) and $SLA$ is as in (2). $GRASS$ increases at every mowing by the value of $HRVBL$ on the mowing day. Potential yield ($YIELD$, kg$_{DM}$ ha$^{-1}$) is determined by the equation:

$$YIELD = GRASS + HRVBL.$$ (6)

For the crop efficiency simulations another variable $TADRW$ (kg$_{DM}$ ha$^{-1}$) is determined as

$$TADRW = GRASS + WLG + WLVD.$$ (7)

It presents the mass of green and dead leaves in the field together with the herbage DM yield. Radiation use efficiency ($RUE$, g$_{DM}$ MJ$^{-1}$ PAR) is derived at the end of the growth period from $TADRW$ divided by the total intercepted solar radiation during the growth period. The calculation of water use efficiency ($WUE$, g$_{DM}$ kg$^{-1}$ water) is similar: at the end of the growth period $TADRW$ is divided by the total water amount used by evapotranspiration during the growth period.

2.5 Water balance

LINGRA-N calculates evapotranspiration and water balance in the same way as the WOFOST model (Supit and Van der Goot, 2003). The processes directly affecting the root zone soil moisture content are percolation, surface runoff, infiltration, crop transpiration and soil evaporation. The actual soil moisture content ($SMACT$, cm$^3$ cm$^{-3}$) can be established according to Driessen (1986 op. cit. Supit and Van der Goot, 2003):

$$SMACT = \frac{IN_{up} + (IN_{low} - T_a)}{RD} \Delta t$$ (8)

where the rate of net influx through the upper root zone boundary ($IN_{up}$, cm d$^{-1}$) is

$$IN_{up} = P + I_e - E_s - SR$$ (9)

and the rate of net influx through the lower root zone boundary ($IN_{low}$, cm d$^{-1}$) is

$$IN_{low} = -PERC$$ (10)

and $T_a$ (cm d$^{-1}$) is the calculated actual transpiration rate of crop, $RD$ (cm) the calculated actual rooting depth, $\Delta t$ the determined time step (1 d), $P$ (cm d$^{-1}$) input daily precipitations, $I_e$ (cm d$^{-1}$) from input recalculated effective daily irrigation (not used – it is not a common practice to irrigate grass swards), $E_s$ (cm d$^{-1}$) the calculated soil evaporation rate, $SR$ (cm d$^{-1}$) the calculated rate of surface runoff and $PERC$ (cm d$^{-1}$) the calculated percolation rate.

The method, introduced by Penman (1956, 1948 op. cit. Supit and Van der Goot, 2003) and adapted according to Choisnel et al. (1992 op. cit. Supit and Van der Goot, 2003), is used for daily totals of canopy transpiration and soil evaporation and is described in Supit and Van der Goot (2003). The reduction of the grass growth rate and the transpiration rate due to drought stress is calculated via:

$$TRANRF = T_a / T_p = \frac{SMACT - SMW}{SMCR - SMW}$$ (11)

where $T_a$ and $SMACT$ are defined as in (8), $T_p$ (cm d$^{-1}$) is the potential transpiration rate of crop, $SMW$ (cm$^3$ cm$^{-3}$) soil moisture content at wilting point and $SMCR$ (cm$^3$ cm$^{-3}$) critical soil moisture content. $SMCR$ is defined as the quantity of stored soil moisture below which water uptake is impaired and the plant closes its stomata. $TRANRF$ affects $RUE$ and the growth rate of the crop, the leaf death rate and the distribution of assimilates to the roots.

3 RESULTS AND DISCUSSION

As previously mentioned, there is great year-to-year variation of grassland herbage DM yields. Coefficient of variation for experimental herbage DM yield data in Jablje is 18%. For instance, measured annual grassland herbage DM yields in Austria tend to vary within ±10-20%, but during some years (e.g. 2003) these deviations can be much greater (Schaumberger et al., 2007). In the period 1995–2004, the average coefficient of variation for experimental grassland herbage DM
yields in France was about 16% (Smit et al., 2008).

The simulated GRASS (Figure 3) has about the same variability throughout the 50-year period, however, in the second half outliers start to appear, which can be alarming in terms of the negative effect of climate change.


The biggest reductions in the simulated herbage DM yield are seen in the years 1992, 1993 and 2003 (approximately 4 t ha⁻¹ year⁻¹). As it is seen in Figure 2, these are also years with very low precipitation in the summer and in the vegetation period. Only 47% of average summer precipitation for the period 1964–2013 was measured in 1992, 53% in 2003 and 59% in 1993. For the vegetation period proportions were a little higher, 55, 59 and 62%, respectively. Also, in the years 1992 and 2003 extremely high minimum and maximum daily air temperature averages were recorded for both the summer and the vegetation period. As regards global radiation, it was extremely high in the vegetation period of 2003. Altogether, it is clear that the GRASS reductions were due to drought conditions.

Sušnik and Pogačar (2010) studied indicators like the number of dry days and soil moisture deficit to define drought years for grass sward in six locations across Slovenia for the period 1973–2009, and compared them to drought reports published in Agrometeorological bulletins, which can be found in the archive of the Slovenian Environment Agency. In years 1992, 1993 and
2003 the most intense and the longest droughts were detected in all locations, which correspond to the simulation results.

Furthermore, the observed connections led to the testing of \( YIELD \) dependence on weather variables. \( YIELD \) was used in this case instead of \( GRASS \) to avoid a direct influence of the mowing dates on the final result. Among all input weather variables, calculated as the average or sum for the summer and for the vegetation period, there is none linearly related to \( YIELD \). However, it can be again seen (Figure 4) that very low \( YIELD \) is connected to very high (maximum) air temperatures and very low precipitation. Smit et al. (2008) claim the grass sward production in Europe to be strongly correlated with the annual precipitation and less with the annual temperature sum or the length of the growth period. On the other hand, the 20-year experiment on permanent grassland in Ljubljana also showed only very small positive correlation between the annual precipitation and the herbage DM yield (Lekšan, 1995).

\[ \text{Figure 4: Scatterplots of the potential yield (YIELD) versus the summer average of maximum daily air temperature (left) and YIELD versus the vegetation period sum of precipitation (right) for cock’s foot in Jablje for the whole period 1964–2013} \]

The given years with the lowest \( GRASS \) were also the years with the lowest \( TRANRF \) (Figure 5). As \( TRANRF \) is the model’s measure of drought conditions, these were detected as the driest years in the simulation. Also, in the years 1971, 1983, 1994, 2001, 2006, 2007, 2011, 2012 and 2013 \( TRANRF \) fell under 0.95, denoting dry years.

\[ \text{Figure 5: Simulated reduction factor for crop growth due to drought (TRANRF) for cock’s foot in Jablje for the whole period 1964–2013} \]
Smit et al. (2008) also claim that are herbage DM yields especially affected by droughts. Also similar as in our case, in Ireland, herbage DM yield reductions of 1.4 to 4.0 t ha\(^{-1}\) year\(^{-1}\) have been estimated to be lost for intensively managed grassland in the driest regions due to limiting soil moisture availability (Brereton and Keane, 1982 op. cit. Laidlaw, 2009).

Drought stress has a major influence on \(RUE\) (Bonesmo and Belanger, 2002). This can be seen in Jablje as the course of \(RUE\) is very similar to the course of \(TRANRF\) (Figure 6). For \(RUE\) versus \(TRANRF\) (not presented) the coefficient of determination is \(r^2 = 0.84\), which means that 84% of \(RUE\) variability can be explained with the changing \(TRANRF\).

Figure 6: Simulated radiation use efficiency \((RUE)\) of cock’s foot in Jablje for the whole period 1964–2013

Water status can be also monitored as actual soil moisture content on a daily scale with variable \(SMACT\). Figure 7 (upper right) shows a pattern of \(SMACT\) in the dry year of 1993 and in the average year of 1994. In 1993 \(SMACT\) stayed on a very low level from the beginning of May to the end of the August, while in 1994 it only fell to this level twice in the whole year. This is reflected very strongly in other variables. \(YIELD\) (Figure 7, upper left) was not increasing at all in the dry period of 1993, the same happened in 2003. In contrast, for example in the years 1994 and 2010 \(YIELD\) was increasing almost steadily throughout the vegetation period, only a little more slowly in the summer time. Naturally, \(YIELD\) depends on \(LAI\) (Figure 7, lower left), which remained under 2 m\(^2\) m\(^{-2}\) during the dry period of 1993. In 1994 \(LAI\) was below this value just at the beginning and at the end of the year, and on mowing days (four extreme falls of \(LAI\) can be seen). Otherwise it rose as high as 5 to 9 m\(^2\) m\(^{-2}\).

Cumulative \(PARAB\) in Jablje was 1100 MJ\(_{\text{PAR}}\) m\(^{-2}\) year\(^{-1}\) in the dry year of 1993, which is 53 % of \(PAR\), and 1650 MJ\(_{\text{PAR}}\) m\(^{-2}\) year\(^{-1}\) in 1994, which is 75 % of \(PAR\) (Figure 7, lower right). For example, in the research of Wolf (2006), who made simulations of rye grass growth with LINGRA for five years for optimal water and nutrient supply, \(YIELD\) appears to increase from Wageningen (The Netherlands) to Bologna (Italy) to Sevilla (Spain). He claims this was caused by the length of the growing season and by cumulative \(PARAB\), which increased for the three locations from 1200–1600 MJ\(_{\text{PAR}}\) m\(^{-2}\) year\(^{-1}\) to 1700–2000 MJ\(_{\text{PAR}}\) m\(^{-2}\) year\(^{-1}\) and 2700–2800 MJ\(_{\text{PAR}}\) m\(^{-2}\) year\(^{-1}\), respectively.
Simulation of herbage yield and growth components … in Jablje using the calibrated LINGRA-N model

Figure 7: Simulated potential yield (YIELD, upper left), soil moisture content (SMACT, upper right), leaf area index (LAI, lower left), cumulative amount of photosynthetically active radiation (PAR) and cumulative amount of PAR as intercepted by the crop canopy (PARAB) (lower right) of cock’s foot in Jablje in the dry year of 1993 and the average year of 1994 (YIELD also in 2003 and 2010)

Slika 7: Simuliran potencialni pridelek (YIELD, zgoraj levo), vsebnost vode v tleh (SMACT, zgoraj desno), indeks listne površine (LAI, spodaj levo) ter kumulativno fotosintetško aktivno sevanje (PAR) in prestreženo fotosintetško aktivno sevanje (PARAB) (spodaj desno) za navadno pasjo travo v Jabljah za suho leto 1993 in povprečno leto 1994 (YIELD tudi za leti 2003 in 2010)

According to Wolf (2006), the increase in PARAB results in a higher YIELD and in a much higher WLVD, because the higher biomass production results on average in a higher LAI and thus in more leaf senescence due to self-shading. The same can be said for the simulations in Jablje (Figure 7, Figure 8).

Figure 8: Simulated mass of green leaves (WLVG), mass of dead leaves (WLVD) and roots mass (WRT) of cock’s foot in Jablje in the dry year 1993 (left) and in the average year of 1994 (right)

Slika 8: Simulirana masa zelenih listov (WLVG), masa odmrlih listov (WLVD) in masa korenin (WRT) navadne pasje trave v Jabljah v suhem letu 1993 (levo) in v povprečnem letu 1994 (desno)
As expected from the definition, the shape of the $WLVG$ curve is the same as the shape of the $LAI$ curve, due to constant $SLA$. In 1993, during the long summer drought $WLVG$ was almost 0 all the time, so two intermediate mowings cannot be seen (Figure 8, left). On the other hand, four mowings are clearly seen in four extreme decreases of $WLVG$ in 1994 (Figure 8, right). Because of the drought, roots also grew very slowly in 1993 and at the end of the growth period reached only half of the $WRT$ that was reached at the end of 1994. What is more, the mass of dead leaves ($WLVD$) in 1993 was only 44 % of the $WLVD$ in 1994, due to low available green biomass.

4 CONCLUSIONS

Fundamentally, this research shows the value of applying the calibrated LINGRA-N model for a 50-year (1964–2013) herbage yield simulation and growth analysis. It provides insights in the interactions between several weather and crop variables or their seasonal development and herbage yield variability. It is important to have an opportunity to better understand the growth components, and simulations can reveal their dynamics and impacts on herbage yield, based on weather and soil conditions. Overall, crop models are a very useful and important tool for this kind of research.

As regards the simulated herbage DM yield ($GRASS$), recent changes in its variability are reflected in the appearance of outliers in the second half of the study period. The biggest reductions in $GRASS$ were detected in the years 1992, 1993 and 2003. These years were also recognised as years with very low precipitation and very high minimum and maximum daily air temperature averages in the summer and in the vegetation period, so we were able to conclude that the $GRASS$ reductions were due to drought conditions. The given years with the lowest $GRASS$ were also the years with the lowest reduction factor for crop growth due to drought ($TRANRF$). As the latter is the model’s measure of drought conditions, these were detected as the driest years in the simulation, too.

Radiation use efficiency variability was strongly dependent on $TRANRF$. Drought had a major impact on the cumulative amount of $PAR$ as intercepted by the crop canopy ($PARAB$), which reached just 53 % of $PAR$ in the dry year of 1993. Seasonal development of the actual soil moisture content ($SMACT$) was linked to the development of the leaf area index and consequently to the mass of green leaves, to the roots mass, to the mass of dead leaves and to $GRASS$.

However, some of the obtained results remain indicative without confirmation of the simulated values through field measurements. Angulo et al. (2013) also recommend that future work should focus on obtaining more comprehensive, high quality data allowing application of improved methods for model calibration. For modelling it would be of great importance to plan grassland field experiments multiple years in advance that would, in addition to measurements of herbage yield, include measurements of variables or parameters like leaf area index, specific leaf area, leaf appearance rate, tiller density or mass of green leaves. Measurements of soil moisture content would also be useful. Further important factors include the vicinity of the meteorological station, the availability of soil data and, possibly, swards to be one to two years old. Naturally, this would be a major project with a great need of financial support.

The results highlight the need for further research, on field and with simulations. As regards the latter, we have to keep in mind that they inevitably involve various uncertainties. These uncertainties originate from input (meteorological, soil, management) data, from calibrated (for a specific period) model parameters, from model structure and concept. In order to identify potential problems caused by seasonal weather variability, which is increasing due to climate change, and to objectively assess its impact on the grassland production, it is necessary to perform various different simulations. For Slovenia, it would be of greater importance to make such simulations for permanent grasslands, but as for now the calibration has not been successful (Pogačar et al., 2015) we need to first obtain results for various grass monocultures and various locations, and try to proceed from there.
5 REFERENCES


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


