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Strategic planning of grass forage production in North-West Russia

A. Valge, A. Sukhoparov and E. Papushin*

Federal Scientific Agroengineering Center VIM, branch in Saint Petersburg, Filtrovskoje Shosse 3, p.o. Tiarlevo, RU196625 Saint Petersburg, Russia
*Correspondence: papushinea@yandex.ru

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Abstract. Energy and nutritional value of harvested forage rely heavily on grass vegetative phase and harvesting time. The study aimed to identify rational forage harvesting options in terms of harvesting time. The data for modelling were taken from the literature based on the results of many years' research. The mathematical models of variation of grass mass and quality depending on days after emergence were created. The possible options of two-step harvesting of forage grass (cocksfoot, *Dactylis glomerata*) were considered using mathematical methods of nonlinear programming: (1) obtaining maximum hay mass with maximum feed units from specified area of 400 ha and maximum forage yield at full flowering of 15.0 t ha^{-1}; and (2) identifying the harvesting timing and area to obtain the required amount of hay (2,500 t) with a target nutrient content (1,200 feed units). Problem 1 solution was harvesting 1 scheduled for the 45th day after emergence at full earing on 170 ha; harvesting 2 scheduled for the 69th day after emergence at full flowering on 230 ha. In this case, 2,066.5 t of hay with 947 feed units would be obtained. Problem 2 solution was harvesting 1 scheduled for the 43th day after emergence at middle earing on 250 ha; harvesting 2 scheduled for the 65th day after emergence at early flowering on 156 ha. The created models can be effectively applied for forage harvesting in any grassland area required and in any regions.

Key words: cereal grass, forage harvesting, forage quality, modelling, non-linear programming, strategy, yes-no decision.

INTRODUCTION

In the EU the permanent grassland occupies about 48% of agricultural area (Eurostat, 2020). In the North-West Russia forage crops are grown on above 90% of all agricultural area, with perennial grasses accounting for 88% (Agriculture, 2019).

The grass forages harvested at early maturity phases and through multiple mowings contribute to better animal performance (Jansone et al., 2010; Stypinski, 2011; Flaten et al., 2015; Meripõld et al., 2017; Bernardes et al., 2018; Pang et al., 2021). However, the agricultural enterprises have to choose the most suitable grass harvesting time limits to receive the forages of target quantity and quality (Thiessen et al., 2017).

The farms in the North-West Russia mainly use perennial forage grasses such as cocksfoot (*Dactylis glomerata*), meadow fescue (*Festuca pratensis*), timothy (*Phleum pratense*) and others. Their typical feature is that they have the greatest nutrient content in the early vegetative phases - stem elongation and early earing. These periods being over, the grass nutritive and energy value in general decrease (Valge et al., 2018). Yet the grass continues growing, and the dry matter and, subsequently, forage yield increase. Obviously, the farm specialist has to choose such a forage harvesting strategy that would ensure the maximum forage yield with the target quality per unit of the harvested area. It should also provide for making some forecasts.

The main reason for poor forage quality is non-compliance with relevant technological regulations in the part of the proper agro-technical time limits. One way to address this problem without additional material resources is to optimise the harvesting timing (Parsons et al., 1998; Valge et al., 2019).

However, the strategic planning with the use of information technologies is more expedient for this technological process as it takes into account many different scenarios under varying factors responsible for the process implementation.

We have put forward a hypothesis about the effectiveness of modelling the rational options in terms of harvesting time since the standard solution methods are inapplicable due to the specific features of forage production.

The study purpose was to identify a rational forage harvesting option in terms of harvesting time with the maximum yield in terms of quantity and quality (Problem 1) and the minimum area for receiving the target forage yield (Problem 2).

MATERIALS AND METHODS

The set problems were solved by the mathematical methods of nonlinear programming (Himmelblau,1972) based on mathematical models of variation in the forage grass mass and quality depending on the days after emergence.

The data for modelling were taken from the literature (Kosolapov & Trofimov, 2014). The data is based on the results of many years' research of agronomists. The vegetative phases, the days after emergence and the grass nutritive value are typical of the forage grasses grown in North-West Russia, the Leningrad Region, in particular.

Variation in the grass mass by vegetative phases under conditions of the Leningrad Region is shown on the example of the cocksfoot in Table 1 from (Kosolapov & Trofimov, 2014).

Table 1. Variation in the cocksfoot's mass and nutritive value by developmental phases

Grass development stages	Grass moisture content (%)	Green mass yield, (t ha^{-1})	Feed units from 1 hectare (t)	Average days emergence
Stem extension	76	8.4	5.2	30
Early heading	74	9.9	4.8	38
Full heading	72	12.1	3.9	50
Early flowering	68	14.1	3.2	62
Full flowering	64	15	2.7	70

Data analysis from Table 1 in *Microsoft Excel 2003* allowed obtaining the dependence of the cocksfoot mass in a certain vegetative phase on its mass at full flowering phase:

$$y_T = 0.0115 \cdot T + 0.232 \quad (1)$$

$$R^2 = 0.9908$$

where T – number of the days after emergence; R^2 – coefficient of determination.

The dependence of the variation in feed units for the cocksfoot harvested from 1 hectare of grassland on the days after emergence will be as follows:

$$y_{FU} = 7.23 + 0.064 \cdot T \quad (2)$$

$$R^2 = 0.9997$$

Eqs (1) and (2) are empirical.

Since an increase in the grass mass leads to a proportional decrease in the feed units, an optimisation problem can be formulated for choosing a strategy for two-step forage harvesting. In practice, to obtain the forage with high nutrient content, a part of the grassland is harvested in the early time limits - earing and early flowering phases. The main area is harvested at a full earing phase and full flowering phase.

This problem can be formalised to estimate the possible benefits from the two-step harvesting. The following possible formalisation variants of this problem were considered:

– receiving the maximum mass of hay with the maximum feed units from the specified harvesting area;

– identifying the time limits and harvesting area of perennial forage grasses to produce the required amount of hay with the target nutrient content.

The following notations were introduced: T_1 – first day of the first harvesting; T_2 – first day of the second harvesting; Q_1 – grass mass from the first harvesting, t; Q_2 – grass mass from the second harvesting, t; E_1 – mass of feed units in the grass from the first harvesting; E_2 – mass of feed units in the grass from the second harvesting; S_1 – first harvesting area, ha; S_2 – second harvesting area, ha; U – expected grass yield, t ha^{-1}; S – total grass harvesting area, ha.

Problem No. 1

To identify the forage grass harvesting strategy aimed to produce hay with the maximum mass and the maximum feed units from the specified harvesting area.

This problem belongs to the class of mathematical nonlinear programming problems and can be solved by one of the well-known numerical methods (Himmelblau,1972). The problem content is to search for the value of the maximum grass volume with the best possible quality at certain (fixed) values of the harvesting conditions of an uncontrollable nature taking into account the parameters of the constraints.

The maximum of the objective function should be found:

$$K_1 \cdot (Q_1 + Q_2) + K_2 \cdot (E_1 + E_2) = \max \quad (3)$$

under the following constraints:

$$
\begin{aligned}
&Q_1 = (0.0115 \cdot t_1 + 0.232) \cdot U \cdot S_1 > 0; \\
&Q_2 = (0.0115 \cdot t_2 + 0.232) \cdot U \cdot S_2 > 0; \\
&E_1 = (7.23 - 0.064 \cdot t_1) \cdot U \cdot S_1 > 0; \\
&E_2 = (7.23 - 0.064 \cdot t_2) \cdot U \cdot S_2 > 0; \\
&S_1 + S_2 = S; \\
&30 < t_1 < t_2 < 70.
\end{aligned} \tag{4}
$$

where K_1 – conversion factor of hay yield to grass mass (0.23–0.37); K_2 – conversion factor of feed units in hay to feed units in grass per hectare of grassland (0.42–0.52).

Problem No. 2

To determine the time limits and harvesting area of perennial forage grasses to obtain the required amount of hay with a target nutrient content. This problem also belongs to the class of mathematical programming problems and is solved by numerical methods. The minimum harvesting area is taken as an objective function:

$$S_1 + S_2 = \min \tag{5}$$

under the following constraints:

$$
\begin{aligned}
&S_1 + S_2 \le S; \\
&Q_1 + Q_2 = Q_{\text{target}}; \\
&E_1 + E_2 = E_{\text{target}}.
\end{aligned} \tag{6}
$$

where Q_{target} – target amount of harvested forage, t; E_{target} – target amount of harvested feed units, t.

RESULTS AND DISCUSSION

Both variants of problems were solved using *Flexsiplex* programme (Himmelblau, 1972).

Solution of Problem No. 1

The forage grass harvesting area was taken as 400 hectares, the maximum forage yield at full flowering phase was taken as 15.0 t ha^{-1}.

The problem-solving result was the maximum objective function for the following variables:

– the first harvesting should be scheduled for the 45th day after emergence at a full earing phase on the grassland area of 170 ha;

– the second harvesting should be scheduled for the 69th day after emergence at full flowering phase on the rest of the grassland area - 230 ha.

The calculations resulted in the maximum forage yield with the maximum nutritive value from the specified harvesting area (Table 2).

Table 2 shows that in this case 2,066.5 t of hay with 947 t of feed units will be obtained. If the harvesting takes place at full flowering phase, then 2,220.0 t of hay will be obtained, but the feed unit content will be 932 t.

Table 2. The harvesting area to receive the maximum grass yield with maximum nutrient content

Harvesting step	Hay mass (t)	Feed unit mass (t)	Harvesting area (ha)	Harvesting area (%)
First harvesting	790.5	411.1	170.0	43
Second harvesting	1,276.0	535.9	230.0	57
Total	2,066.5	947	400.0	100

Solution of Problem No. 2

The grass harvesting area and time limits need to be determined to obtain 2,500.0 t of hay with 1,200.0 t of feed units.

The problem-solving result was the following strategy:

– the first harvesting should be scheduled for the 43th day after emergence at middle earing phase on the grassland area of 250 ha;

– the second harvesting should be scheduled for the 65th day after emergence at early flowering phase on 156 ha of the grassland.

The calculations resulted in the optimal area value for two-step forage grass harvesting to obtain the required volume of high-quality hay (Table 3).

Table 3. The rational harvesting areas to obtain the high-quality hay

Harvesting step	Hay mass (t)	Feed unit mass (t)	Harvesting area (ha)	Harvesting area (%)
First harvesting	1,364.0	839.0	250.0	62%
Second harvesting	1,136.0	361.0	156.0	38%
Total	2,500.0	1,200.0	406.0	100%

This way, to make the hay in round bales of the required volume with the maximum nutrient content in natural conditions, an area of 250 ha (61.6% of the total harvested grassland) is to be harvested first. In this case, 1,364.0 of hay (54.5% of the total hay mass) with 839 t of feed units (69.9% of the total feed units in the required volume of harvested hay) will be prepared.

When deciding upon the forage harvesting strategy, the mathematical methods of both nonlinear programming and linear programming are acceptable. The former methods were illustrated by making hay from forage perennial grasses in this study and by solving the transport problem in forage harvesting (Valge et al., 2020); the latter methods were used by (Parsons et al., 1998) for silage harvesting.

However, linear programming methods are more suitable at the initial stage of work planning for the future forage grass harvesting, when the optimal technological option is formed based on the available material and technical resources on the farm. The nonlinear programming methods are more suited for choosing a rational option closer to the harvesting time based on forage grass characteristics with due account for obtaining the required forage yield and quality.

Other researchers (Sørensen et al., 2010; Flaten et al. 2015) mainly propose models for predicting the moisture content of cut grass using predicted weather data. Their models provide the decision support for harvesting time and subsequent forage quality. Typically, this decision is a simple assessment made by the individual farmer.

CONCLUSIONS

Timely harvesting allows receiving the required forage yield and quality. Knowing how the grass mass and its nutrient content change with the plant growth and development, it is possible to simulate the forage harvesting on different vegetative phases.

The study was based on the data from the literature and considered two problems - obtaining the maximum hay mass with maximum feed units from the area taken as 400 ha and identifying the harvesting timing and area to obtain the required amount of hay taken as 2,500.0 t with a target 1,200.0 feed units.

Nonlinear programming methods were found a most effective tool for identifying the best tactical scenario of two-step forage harvesting. The methods were based on mathematical models of variation of grass mass and quality depending on days after emergence. Problems were solved through target function search.

Problem 1 solution was harvesting 1 scheduled for the 45th day after emergence at a full earing phase on 170 ha; harvesting 2 scheduled for the 69th day after emergence at full flowering phase on 230 ha. In this case, 2,066.5 t of hay with 947 feed units would be obtained. Problem 2 solution was the harvesting 1 scheduled for the 43th day after emergence at a middle earing stage on 250 ha; harvesting 2 scheduled for the 65th day after emergence at an early flowering phase on 156 ha.

The created models can be effectively applied for forage harvesting in any grassland area required and in any regions. The modelling includes many calculations and factors to be considered, it must be based on information technologies. Therefore, we are currently developing a relevant software tool. The next research step will be the creation of models based on an experimental study of options for forage production.

REFERENCES

Agriculture in Russia. 2019. Moscow: Rosstat Publ. 91 pp. (in Russian)

Bernardes, T.F., Daniel, J.L.P., Adesogan, A.T., McAllister, T.A., Drouin, P., Nussio, L,G., Huhtanen, P., Tremblay, G.F., Belanger, G.& Cai, Y. 2018. Silage review: Unique challenges of silages made in hot and cold regions. *Journal of Dairy Science* **101**(5), 4001–4019. doi: 10.3168/jds.2017-13703

Eurostat 2020. Agriculture, forestry and fishery statistics - 2020 edition. 234 pp. doi: 10.2785/143455

Flaten, O., Bakken, A.K. & Randby, A.T. 2015. The profitability of harvesting grass silages at early maturity stages: An analysis of dairy farming systems in Norway. *Agricultural Systems* **136**, 85–95. doi: 10.1016/j.agsy.2015.03.001

Himmelblau, D.M. 1972. *Applied nonlinear programming*. New York: McGraw-Hill Inc. US. 416 pp.

Jansone, B., Rancane, S., Berzins, P., Stesele, V. & Jansons, A. 2010. Evaluation of perennial grass mixtures of different species and varieties in the central part of Latvia introduced from other European countries. *Agronomy Research* **8**(III), 563–572.

Kosolapov, V.M. & Trofimov, I.A. (Eds.) 2014. *Handbook of fodder production*. Russian Academy of Agricultural Sciences, Moscow, 717 pp.

Meripõld, H., Tamm, U., Tamm, S., Võsa, T. & Edesi, L. 2017. Fodder galega (*Galega orientalis Lam*) grass potential as a forage and bioenergy crop. *Agronomy Research* **15**(4), 1693–1699. doi: 10.15159/AR.17.021

Pang, D.G., Yan, T.H. & Krizsan, S. 2021. Effect of strategy for harvesting regrowth grass silage on performance in dairy cows. *Journal of Dairy Science* **104**(1), 367–380. doi: 10.3168/jds.2020-18888

Parsons, D.J. 1998. Optimising silage harvesting plans in a grass and grazing simulation using the revised simplex method and a genetic algorithm. *Agricultural Systems* **56**(1), 29–44. doi: 10.1016/S0308-521X(97)00030-9

Sørensen, C.G., Bochtis, D.D., Green, O. & Oudshorn, F.W. 2010. A scheduling model for forage harvesting. *Grassland Science in Europe* **15**, 443–445.

Stypinski, P. 2011. The effect of grassland-based forages on milk quality and quantity. *Agronomy Research* **9**(II), 479–488.

Thiessen, M., van Mourik, S. & van Evert, F.K. 2017. Modelling of strategic grass harvest management. *Acta horticulturae* **1154**, 25–32. doi:10.17660/ActaHortic.2017.1154.4

Valge, A.M., Eremin, M.A. & Sukhoparov, A.I. 2018. Modeling technique of grass fodder making process. *Technologies, machines and equipment for mechanised crop and livestock production* **4**(97), 115–126 (in Russian, English abstr.).

Valge, A.M., Sukhoparov, A.I. & Frolova, M.G. 2019. Optimization of green forage chain parameters in fodder production under conditions of Leningrad Region. *Technologies, machines and equipment for mechanised crop and livestock production* **2**(99), 222–229 (in Russian, English abstr.).

Valge, A.M., Sukhoparov, A.I. & Papushin, E.A. 2020. Grass forage transportation process modeling. In: *Engineering for Rural Development. 19th ISC ERDev*. LLU, Jelgava, Latvia, **19**, 1201–1207. doi: 10.22616/ERDev2020.19.TF288