TECNOLOGIAS DA INFORMAÇÃO PARA DETERMINAR O PERÍODO ÓTIMO DE PREPARAÇÃO DE ALIMENTOS A PARTIR DE ERVAS DE CEREAIS PERENES**INFORMATION TECHNOLOGIES FOR DETERMINATION THE OPTIMAL PERIOD OF PREPARING FODDER FROM PERENNIAL GRASSES****ИНФОРМАЦИОННЫЕ ТЕХНОЛОГИИ ОПРЕДЕЛЕНИЯ ОПТИМАЛЬНЫХ СРОКОВ ЗАГОТОВКИ КОРМОВ ИЗ МНОГОЛЕТНИХ ЗЛАКОВЫХ ТРАВ**

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RESUMO

A eficácia da criação de gado é amplamente determinada por uma base sólida de alimentação. Atualmente, a produtividade do gado na Federação Russa está aumentando e isso requer uma abordagem mais cuidadosa para avaliar a qualidade da alimentação. Isso, em primeiro lugar, diz respeito a tipos de alimentos como feno, silagem, haylage, que representam 60-85% da dieta diária média dos animais. O valor nutricional desses tipos de alimentos depende em grande parte do conteúdo e da proporção de proteína bruta e fibra bruta nas ervas perenes quando são colhidas. Nos estágios iniciais do desenvolvimento da planta, a proteína bruta predomina em sua composição e o teor de fibras é insuficiente. Portanto, cortar ervas perenes nesse período é irracionalmente. Com o crescimento e desenvolvimento da planta, sua transição para o estágio da emergência da espiga, o teor de proteína bruta diminui com o aumento do teor de fibras. A colheita de ervas perenes durante o período em que contêm uma grande quantidade de fibras e baixa proteína também é irracional, uma vez que o baixo teor de proteína nos alimentos não contribui para o crescimento da produtividade animal. O momento ideal para a colheita das ervas é considerado o momento em que o teor de proteína bruta é de 14 a 16% e da fibra bruta – 26 a 28%. Determinar o conteúdo desses elementos é um processo bastante trabalhoso e caro, a análise dura cerca de 3 dias. Somente grandes empresas agrícolas podem se dar ao luxo de realizar essas análises. Ao mesmo tempo, hoje existem tecnologias para exame remoto de culturas, que neste caso podem ser realizadas usando veículos aéreos não tripulados (VANTs). Atualmente, com a ajuda deles, determina-se o teor de nitrogênio nas plantas. Os autores deste artigo propõem uma técnica digital para determinação remota de fibra bruta e proteína bruta, que determina o momento ideal da preparação de alimentos.

Palavras-chave: *composição dos alimentos, análise remota, composição química das plantas, veículos aéreos não tripulados, sensores infravermelhos de nitrogênio.*

ABSTRACT

The effectiveness of cattle breeding is mostly determined Forage base. Currently, cattle productivity in the Russian Federation is increasing, and this requires a more careful approach to assessing the quality of feed. This primarily applies to such types of feed like hay, silage, haylage, which make up 60-85% in the average daily diet of livestock. The nutritional value of these types of feed depends mostly on the content and ratio of crude protein and crude fiber in perennial grasses when they are harvested. In the early phases of plant development, crude protein predominates in its composition, and the fiber content is insufficient. Therefore, mowing perennial grasses in these terms is irrational. With the growth and development of the plant, its transition to the heading stage, the crude protein content decreases with increasing fiber content. Harvesting perennial grasses at a time when they contain a large amount of fiber and low protein is also irrational since the low protein content in feed does not contribute to the growth of animal productivity. The optimum time for harvesting herbs is considered to be the time when the crude protein content is 14-16%, and crude fiber – 26-28%. Determination the content of these elements is a rather laborious and expensive process, the analysis lasts about three days. Only large agricultural enterprises can afford to carry out such analyses. At the same time, today, there are technologies for remote sensing of crops, which in this case can be carried out using unmanned aerial vehicles (UAVs). Currently, with their help, the nitrogen content in plants is determined. The authors of this paper propose a digital technique for remote determination of crude fiber and crude protein, which determines the optimal timing of the harvesting herbs.

Keywords: *feed composition, remote analysis, chemical composition of plants, unmanned aerial vehicles, infrared nitrogen sensors.*

АННОТАЦИЯ

Эффективность скотоводства во многом определяется прочной кормовой базой. В настоящее время продуктивность крупного рогатого скота в Российской Федерации возрастает и это требует более внимательного подхода к оценке качества кормов. Это, прежде всего, касается таких видов кормов, как сено, силос, сенаж, которые составляют в среднесуточном рационе скота 60-85%. Питательность этих видов кормов во многом зависит от содержания и соотношения сырого протеина и сырой клетчатки в многолетних травах при их заготовке. На ранних фазах развития растения в его составе преобладает сырой протеин, а содержание клетчатки недостаточно. Поэтому скашивание многолетних трав в эти сроки нерационально. С ростом и развитием растения, переходом его в фазу колошения содержание сырого протеина уменьшается при увеличении содержания клетчатки. Заготовка многолетних трав в период, когда в них содержится большое количество клетчатки и мало протеина – также нерациональна, так как низкое содержание протеина в кормах не способствует росту продуктивности животных. Оптимальными сроками заготовки трав считаются те сроки, когда содержание сырого протеина составляет 14-16%, а сырой клетчатки – 26-28%. Определение содержания данных элементов – довольно трудоемкий и дорогостоящий процесс, анализ длится около 3 дней. Только крупные сельскохозяйственные предприятия могут позволить себе производить такие анализы. В то же время сегодня существуют технологии дистанционного зондирования посевов, которые могут в данном случае осуществляться при помощи беспилотных летательных аппаратов (БПЛА). В настоящее время с их помощью определяется содержание азота в растениях. Авторы данной статьи предлагают цифровую методику дистанционного определения содержания сырой клетчатки и сырого протеина, что определяет оптимальные сроки заготовки корма.

Ключевые слова: *состав кормов, дистанционный анализ, химический состав растений, беспилотные летательные аппараты, инфракрасные датчики азота.*

1. INTRODUCTION

At the present moment, the meat and dairy cattle breeding industry in the Russian Federation continues to reduce production volumes. Among the main reasons are the long production cycle in these sub-sectors and the need to develop a related industry such as feed production with significant sown areas of fodder crops and fodder

land, a long train of equipment, which determines a significant investment and a low rate of return on investment (Khudyakova *et al.*, 2018). This reduces the food security of the Russian Federation in milk and dairy products, as well as in beef. In this regard, the search for ways to increase the efficiency of animal husbandry is very urgent, one of these ways is to strengthen the feed base – providing livestock with high-quality feed,

increasing feed output while reducing the cost of feed production (Shuai *et al.*, 2019). This can be achieved in many ways due to adherence to feeding production technology. In particular – due to the procurement of feed in optimal terms (Karydas *et al.*, 2020).

In the structure of the feed ration of livestock, a significant part (60-85%) consists of feed produced from perennial grasses – hay, silage, haylage. This paper is devoted to the chemical analysis of the quality of perennial grasses in order to determine the optimal term for their mowing. Large agricultural enterprises, agricultural holdings, which have their laboratories for the analysis of feed, analyse the content of crude protein daily to determine the optimal harvesting time (Schmidhuber and Tubiello, 2007; Misselhorn *et al.*, 2012). This is a time consuming and expensive process. About 1% of agricultural enterprises in the Russian Federation have such laboratories, which is not enough. Moreover, this issue is being resolved in the Russian Federation for significant sown areas of perennial and annual grasses. Currently, the grass area is 18.3% of the cultivated area of the Russian Federation and 90.2% of the cultivated area of fodder crops (Agriculture in Russia, 2019). Despite the determined tendency to reduce the area under forage crops in general, and forage grasses, in particular, they occupy a relatively large area – 14544 thousand hectares (Table 1).

Determining the optimal harvesting time for perennial grasses is an important task. As the herbs grow, the collection of dry matter increases. However, at the same time, their quality may deteriorate in terms of feed value (Kasakova *et al.*, 2019; Tynybekov *et al.*, 2013; Pashtetsky *et al.*, 2018). As a rule, this is expressed in a decrease in the content of crude protein and the accumulation of the fibrous fraction – crude fiber, which leads to a deterioration in the digestibility of the resulting feed and its energy value. In this regard, it is necessary to choose the harvesting dates when the quality would be high enough, at the same time, without compromising yield (Laliberte *et al.*, 2011; Astor *et al.*, 2018).

The nutritional value of perennial herbs is primarily determined by the content of crude protein and fiber. The digestibility of the feed and energy content depends on the fiber content. The productivity of animals directly depends on the amount of protein (Pashtetsky *et al.*, 2018; Pashtetskiy *et al.*, 2020). And therefore, these two criteria should be in the optimal combination to establish the timing of cleaning. It is believed that under production conditions, these parameters

correlate with each other. So, the content of crude fiber in the silage and haylage of the 1st class should not exceed 26-28 in dry matter, with a crude protein level of at least 14-16% (Stepanova, 2019).

2. MATERIALS AND METHODS

The main suggestion of the study is to determine protein and fiber in plants by remote sensing of perennial grass crops using unmanned aerial vehicles equipped with special nitrogen sensors. The operation of sensors for non-contact measurement of nitrogen in plant leaves is based on taking into account the degree of light or laser beams reflection from the plant leaf. The more chlorophyll in the leaf, the higher the nitrogen content and the higher the degree of reflection. Sensors can be mounted, for example, on the roof of a tractor or on an UAVs. Such sensors are widely marketed. For example, sensors such as the CropSpec™ Vegetation Level Sensor or the YARA N-Sensor (AgriCon company). And the principle of operation of the N-sensor MiniVeg N system is based on the excitation of chlorophyll by laser beams. This sensor is mounted on the front of the tractor. Sensors can also be portable and displaceable, as for example CCM-200 PLUS sensor (USA). Information technologies such as satellite navigation, unmanned vehicles, and aircraft (UAVs) equipped with all kinds of sensors, IoT-platforms, and Big Data are actively being introduced into agriculture today (Khudyakova *et al.*, 2018). In particular, in solving the problem posed above, technologies for remote sensing of crops can be used. Determination of the critical phase of growth of fodder culture can be carried out using special sensors that are mounted on static installations or UAVs. Together with the analysis of weather data carried out by other sensors mounted on the same devices, they can help determine the optimal harvesting time for forage crops concerning a specific place on the field.

This is the task of precision farming (Karydas *et al.*, 2020; Ismailova *et al.*, 2016; Tarshilova *et al.*, 2016). The International Precision Agriculture Society (ISPA) defined this term as “a management strategy that collects, processes and analyses temporal, spatial and other data, and combines them with other information to support management decisions to improve the use of resources to increase efficiency, productivity, quality, profitability and sustainability of agriculture (International society of precision..., 2019). Precision farming can

significantly increase the efficiency of agricultural production, both due to resource-saving and due to the implementation of a host of measures in optimal terms, which, as in this case, ensures the optimal content of nutrients in the feed and contributes to the growth of livestock productivity by increasing the rate of feed output (Bongiovanni and Lowenberg-DeBoer, 2004; Schmidhuber and Tubiello, 2007; Misselhorn *et al.*, 2012; Lowenberg-DeBoer and Erickson, 2019). The results of multispectral remote sensing from unmanned aerial vehicles and their application in pasture conditions, including low-flying drones, were described in (Laliberte *et al.*, 2011; Astor *et al.*, 2018). Characterisation of plant growth parameters and yield forecasting was done in (Zhou *et al.*, 2017; Shuai *et al.*, 2019; Yudaev *et al.*, 2019).

To solve the problem of non-contact determination of the crude protein content in perennial grasses, we can also use the method of reconnaissance diagnostics of plant conditions using unmanned aerial vehicles (The technique of remote..., 2011). The method involves the formation of a specific reference area of a homogeneous surface next to the field to be tested; the establishment of the boundaries of several control sites in a field with varying degrees of plant density; aerial photography of the field with UAVs with multispectral images. Next, the nitrogen content in plants is measured at control sites using a nitrogen tester, and a spectroradiometer is used to perform ground-based measurements of the spectral brightness of point objects on a reference site and the spectral brightness of a calibration panel. The ground-based spectral brightness coefficients (GSB) are determined by dividing the results of measuring the areas on the reference site with a spectroradiometer by the measurement result of the calibration panel, with the result reduced to the range 0-1 (0-100%). Further, the obtained results are transferred to a computer, where, using special processing, a multispectral orthophoto map of the diagnosed field is formed. Next, atmospheric-corrected GSBs for each pixel of the orthomosaic are calculated by regressing the initial brightness values of the pixels obtained directly during aerial photography to the GSB obtained from ground-based measurements of the reference sites included in the orthomosaic. A normalised difference vegetation index (NDVI) map is constructed, showing the nitrogen content in the plants of the diagnosed field. Calibrate the resulting maps using ground measurement data from reference sites.

To obtain images of crops of perennial grasses to determine the content of nitrogen and digestible protein in plants, UAVs of both airplane, helicopter, and multicopters types can be used. At the same time, the last two species are considered the most acceptable option, since they do not require special take-off space and are able to "hover" over the object. Specialists recommend using the following UAVs for these purposes (Table 2). Today, the market offers several dozen types of UAVs that can be used for the above purposes (Korotaev and Novopashin; 2018 RoboTrends, 2018).

The operation of sensors for non-contact measurement of nitrogen in plant leaves is based on taking into account the degree of light or laser beams reflection from the plant leaf. The more chlorophyll in the leaf, the higher the nitrogen content and the higher the degree of reflection. Such sensors are widely marketed. So, for example, Figure 1 shows the Resonon Pika-L hyperspectral sensor, which has 281 spectral channels (spectral range 400-1000 nm), a lens with a field of view of 17.6 degrees. The camera is mounted on the DJI S1000 octocopter. Sensors can also be mounted on the roof of the tractor (Figure 2).

Compared to static field stations, UAVs have a number of advantages such as high quality of collected data, high quality of image resolution, relatively low price, the ability to select and integrate various sensors. The drones are equipped with various modern technologies such as infrared cameras, GPS, and LASER. UAVs monitor the state of nitrogen to establish the adequacy of its concentration. An analysis of the ripeness of crops and grass using UAVs was carried out in (Honkavaara *et al.*, 2012; Tlesova *et al.*, 2018). The advantages of Spatio-temporal sounding of UAVs in comparison with remote sensing are shown in (Berni *et al.*, 2009; Schwarzbach *et al.*, 2009).

To determine the content of structural carbohydrates, empirical methods are usually used to ensure the separation of carbohydrates according to their digestibility in the process of animal nutrition. So, in the framework of the analysis of feed according to the Weende analysis, the level of structural substances is estimated by the content of crude fiber (CF). However, CF does not represent the sum of indigestible substances, as well as the whole amount of structural carbohydrates (SC), some of which, as well as part of lignin, are removed during its determination and enter, along with non-structural carbohydrates, in the fraction of nitrogen-free extractive substances

(NFE), which includes carbohydrates, significantly different in their digestibility. At the same time, knowledge of the entire amount of SC and its individual components is necessary for a more accurate prediction of feed consumption and digestibility. Neutral-detergent fiber (NDF), representing the total amount of SC and lignin, is one of the most important indicators of feed quality. The feed consumption (Mertens, 2010), its nutritional value (Weiss, 1998), and, ultimately, the productive effect, depending on its level and digestibility. Since the end of the last century, the assessment of feed and rations for the content of detergent forms of fiber in them has become widespread throughout the world. Analysis methods are standardised at the international and interstate levels (GOST ISO 13906-2013, 2013; GOST ISO 16472-2014, 2014). In Russian Federation, some forages and forage grasses were also examined by the level of acid-detergent fiber (ADF) and NDF in the conditions of the Moscow, Kaluga, and Orenburg regions (Vorobyova, 2002; Kharitonov *et al.*, 2008; Levakhin *et al.*, 2015) and Tatarstan (Bykova and Gibadullina, 2010), studies were carried out to study the digestion in bull calves (Levakhin *et al.*, 2007; Bykova and Gibadullina, 2010) and cows (Kharitonov and Khotmirova, 2009) depending on the content of structural carbohydrates in the diet. However, there is still insufficient information on the levels of ADF and NDF in different types of forage grasses, depending on the phase of vegetation and other conditions. Partly in connection with this, forages feed standards (GOST R 55986-2014, 2014) contain standards for CF content, but there are no requirements for levels of detergent forms of fiber.

3. RESULTS AND DISCUSSION:

In practical activities, the harvesting time is set based on the phase of growth of plants. For example, for preparing silage, it is recommended to mow grass in the phase of the beginning of the heading, for haylage – in the phase of the end of going booting and the beginning of heading. But the problem is that this or that phase does not occur simultaneously and can last quite a long time – depending on the type of grass. For example, the booting phase lasts up to 20 days. The heading and flowering phase is 7-10 days. During the same phase, the composition of plants changes. The composition of plants can be different in the same phase of development, depending on weather conditions. For example, with a lack of moisture in combination with adverse temperature conditions, even in the phase of the

beginning of booting, the content of crude fiber can reach the level of the earing phase - 30% or more. Therefore, the optimal harvesting time is determined by daily analyses during the harvesting period.

The crude protein content in the feed is related to the nitrogen content. Currently, the nitrogen content in herbs is determined as follows. Herbal samples are taken by a special method. Further, herbs dried at a temperature of 60-65°C in an oven with forced ventilation are grounded until they pass through a sieve with 1 mm openings. A portion of the feed is burned in concentrated sulfuric acid in the presence of a catalyst, and the amount of ammonia formed is determined in one way or another. The ammonia content is determined by the nitrogen content.

Large farms that have reached a high level of animal productivity are forced to conduct such analyses in order to procure high-quality feed daily. But it is quite laborious and expensive. Analysis by conventional chemical methods takes at least three days. Therefore, special studies are carried out in order to develop methods for optimal timing of grass harvesting without analysis. So, sometimes regression equations are used that relate the composition of the plants to their height, the sum of the temperatures, and the amount of rainfall during the growing season of grass. But this requires lengthy research over several years with field trials. The quality of the statistical prediction of the composition is poor.

Precision farming is based on information management and has been made possible thanks to many technological innovations based on information technology. These technologies allow the farmer to receive large amounts of information regarding the state of the soil (moisture content of nutrients in it), the state of crops, and the state of the environment. With this information, management decisions become more appropriate and effective. Information technologies used directly in the field make it possible to isolate from the whole set of factors precisely those whose impact will give the highest results, in particular the yield of forage crops. Ultimately, this increases the profitability of production and its stability (Plant *et al.*, 2000). In particular, remote sensing of crops can be used to determine the crude protein content in feed crops. The ability to determine crude protein (crude protein) in a plant provides a determination of its nitrogen content. It can be determined by multiplying the nitrogen content by 6.25 since the nitrogen concentration in most proteins is, on average, 16%.

Currently, the most common form of remote sensing, including for determining the nitrogen content in plant leaves, is electromagnetic radiation, which is detected by sensors installed on a variety of media - satellites, drones, agricultural machinery, various static installations in the field. Most widely used in agriculture are wavelengths, such as visible light, near-infrared, and thermal infrared. And if thermal infrared radiation is mainly used to remotely determine the stress level of a plant as a result of a lack of nutrients, moisture, etc., then near-infrared radiation can be used to test the content of nutrients in the plant.

Currently, many different sensors have been developed for smart crop production. For example, CLAAS today offers the CROP SENSOR sensor for the biomass and nitrogen index, equipped with a measuring system with four high-power LEDs (How do drones work..., 2019). The measurement frequency of such a sensor is 800 units per second, regardless of the time of day or the nature of the lighting. Such sensors are manufactured by the company for subsequent mounting on equipment traveling in the field, but similar sensors can be installed on low-flying UAVs.

The UAVs listed above and several dozen similar ones using a multispectral camera make it possible to obtain accurate maps of the vegetation index (NDVI), which can serve as the basis for determining the digestible protein content in forage grasses, in increments of up to several centimeters (Figure 3).

An interesting solution was developed by the German company Fritzmeier, which offers agricultural producers the ISARIA plant stand sensor (Sergeev, 2019). Similar tasks are performed by, for example, the Topcon CropSpec sensor system. Sensors installed on this system scan plants in order to detect chlorophyll content, since this indicator correlates with the nitrogen content in plant leaves (CropSpec™ vegetation..., 2019). Such sensors are used to determine the amount of nitrogen in plants in order to determine the doses of accurate fertilizer application. However, we propose the use of such systems to determine the optimal timing of grass harvesting for fodder storage. The flight control system communicates with an assistant installed on a personal computer (PC) via a Micro-USB cable. This allows us to configure UAVs and update their firmware (Agriculture in Russia, 2019). The architecture of a remote monitoring system for crude protein content in perennial grasses (determining the optimal mowing time for

perennial grasses) may include subsystems traditional for similar monitoring (Lupyan *et al.*, 2015): data acquisition subsystem; data processing subsystem; subsystem for maintaining data archives; subsystem of data presentation and analysis; system control and monitoring unit.

Knowing the content of nitrogen (protein) in plants, we can determine the fiber content. This term is called structural carbohydrates (SC) together with lignin, which makes up the cell walls of plants. Structural carbohydrates include pectin, hemicellulose (HC), and cellulose (C) (Bailey, 1973). They are a source of energy for ruminants, which, with the help of the microflora of the gastrointestinal tract, are able to partially digest them. It should also be noted the physiological role of structural substances, which consists in ensuring the normal functioning of the rumination and motor function of the gastrointestinal tract.

How to determine the content of crude fiber in plants? There is an inverse relationship between the crude protein content in plants and the crude fiber content. So, for example, experiments conducted at the V.R. Williams All-Russian Research Institute of Feed on alfalfa showed the following regression equation between the content of crude fiber and crude protein in alfalfa in the flowering phase (Stepanova, 2019): $Y = -1.5x + 56.6$ (correlation coefficient $r = -0.83 \pm 0.15$ ($tr = 5.4$ $9 > t_{01} = 2.98$)). In the non-chernozem zone of Russia, in the crops of perennial grasses, a significant proportion of cereal grasses such as brome, meadow fescue, and timothy grass meadow occupy a significant share. This species of grasses and feed from them occupy a high share in the feed balance of ruminants. The content of crude fiber and crude protein in these grasses in the conditions of central Russia, depending on the vegetation phase, obtained by the authors of this article, are given in Table 3.

The correlation between crude protein and crude fiber in these grasses are close (Figure 4) (Equation 1):

$$Y = 43.41 - 1.13X \quad (R^2 = 0.844), \quad (\text{Eq. 1})$$

where X – crude protein content in plants, %; Y – crude fiber content in plants, %.

4. CONCLUSIONS:

Thus, the nitrogen content determined using remote technology in perennial grasses can serve as a starting point for determining the crude protein content in them, which in turn can serve as the basis for determining the amount of crude fiber

(based on the use of the above regression equation). The period of time when the crude protein content is 16-18%, and the fiber content 26-28% will be the optimal mowing period for perennial grasses.

Digital technologies are firmly entering our lives and are more often being used in field agriculture. The use of unmanned aerial vehicles equipped with powerful infrared sensors allows us to quickly, within a few hours, determine not only the nitrogen content but also the crude protein content in feed crops. Using the correlation and regression dependencies between the content of crude protein and crude fiber in plants, it is possible to determine the optimal harvesting time of perennial grasses for hay, silage, and haylage, which will increase the efficiency of feed use, reduce the unit costs of meat and dairy cattle breeding, and increase their efficiency.

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Table 1. The sown area of forage grasses in the Russian Federation, thous. ha.

Forage grasses	2000 year	2014 year	2015 year	2016 year	2017 year	2018 year
Perennial grasses	18046	10849	10760	10717	10588	10558
Annual grasses	5946	4571	4536	4187	4107	3986

Table 2. UAVs that are best for using to take pictures of crops of perennial grasses

Name	Distinctive features
BirdsEyeView FireFLY6 Pro	the possibility of vertical take-off and landing, the possibility of reverse motion coverage - up to 2.42 km ² payload weight - 0.7 kg time of flight - up to 1 hour
Honeycomb AgDrone	surveying speed - 3.47 km ² /h speed - up to 82 km/h time in the air - up to 1 hour coverage radius - 344 ha/hour resolution - 2.5 cm/pixel flight altitude - about 130 m
eBee SQ, senseFly Ag 360	coverage radius - up to 200 ha time in the air - 55 minutes flight altitude - 120 meters resolution - 12 cm/pixel
The Sentera PHX	time in the air - 59 minutes coverage radius - up to 280 ha flight altitude - 130 meters resolution - 3.8 cm/pixel

Table 3. The content of crude fiber and crude protein by the phases of vegetation, % of dry matter

Culture and vegetation phase	Crude fiber content,%	Crude protein content,%
Brome		
booting phase	20.07	22.23
heading phase	24.8	14.69
initial blossom	30.42	8.88
Festuca		
booting phase	19.67	18.45
heading phase	29.04	13.12
initial blossom	34.35	10.81
Timothy		
booting phase	23.69	16.90
heading phase	30.98	12.87
initial blossom	33.99	8.56

Source: data by Khudyakova Kh.K., V.R. Williams All-Russian Research Institute of Feed.

a)

b)

Figure 1. Octocopter with camera (a) and triaxial cardan-joint for camera and inertial measuring unit (IMU) (b) (Kanning et al., 2019)

Figure 2. Tractor roof with CropSpecTM vegetation level sensor mounted on it

Figure 3. Crop monitoring (vegetation index NDVI) from UAV images converted to map in Drone2Map for ArcGIS (Nagornyuk, 2016)

Figure 4. *Dependence between the content of crude protein and crude fiber in the dry matter of perennial grasses*