CULTIVATION TECHNOLOGY FOR LOWBUSH BLUEBERRY CULTIVATION IN MILLED PEAT FIELD PLANTATIONS

AMMENDATUD FREESTURBAVÄLJADEL KASVATATAVA AHTALEHISE MUSTIKA MASINVILJELUSTEHNOLOOGIA

MARGUS ARAK

A Thesis
for applying for the degree of
Doctor of Philosophy in Engineering Sciences

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filosoofiadoktori kraadi taotlemiseks
tehnikateaduse erialal

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CONTENTS

LIST OF ORIGINAL PUBLICATIONS

The thesis is based on the following original publications and intellectual properties. References to them in the thesis are given with mark paper or patent and their Roman numerals.

I Olt J., **Arak M.**, Jasinskas A. 2013. Development of mechanical technology for low-bush blueberry cultivating in the plantation established on milled peat fields. Agricultural Engineering, 45 (2): 120-131.

II **Arak, M.**, Olt, J. 2017. Determination of the connection force between berries and stem in blueberry plants. Proceedings of the 45th International Symposium on Agricultural Engineering: Actual Tasks on Agricultural Engineering, Opatija, Croatia, 21-24.02.2017. Ed. Igor Kovacev. University of Zagreb, 589−595.

III **Arak, M.**, Soots, K.; Starast, M.; Olt, J. 2018. Mechanical properties of blueberry stems. Research in Agricultural Engineering (RAE), 64 (4), 202−208, doi: 10.17221/90/2017-RAE

IV **Arak, M.**, Olt, J. 2014. Constructive and kinematics parameters of the picking device of blueberry harvester. Agronomy Research, 12 (1), 25−32.

V **Arak, M.**, Olt, J. 2020. Technological description for automating the cultivation of blueberries in blueberry plantations established on depleted peat milling fields. In: Proceedings of the 7th International Scientific Conference Rural Development 2019, 98−103. Kaunas, Lithuania: Vytautas Magnus University, doi: 10.15544/RD.2019.024

VI **Arak, M.**, Liivapuu, O., Maksarov, V., Olt, J. 2021. A justification of the choice of parameters for the picking reel tooth on a lowbush blueberry harvester. Agronomy Research 19(3), 1329–1338, 2021, (in press), https://doi.org/10.15159/AR.21.133

The contributions of the authors to the papers:

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III	**MA**, JO, MS, KS	**MA**, JO, KS	**MA**, JO, KS, MS	**MA**, JO, MS
IV	**MA**, JO	**MA**, JO	**MA**, JO	**MA**, JO
V	**MA**, JO	**MA**, JO	**MA**, JO	**MA**, JO
VI	**MA**, OL, VM, JO	**MA**, OL, VM, JO	**MA**, OL, VM, JO	**MA**, OL, VM, JO

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LIST OF INTELLECTUAL PROPERTIES

I Title: Blueberry harvester
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Inventors' names: Olt, J., Arak, M.

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Inventors' names: Soots, K., Arak, M., Olt, J.

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Paper	Study design	Preparation and elaboration activities	Study of prior art	Application preparation
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II	KS, **MA**, JO	KS, JO, **MA**	KS, JO, **MA**	KS, JO, **MA**

MA – Margus Arak; KS – Kaarel Soots; JO – Jüri Olt.

ABBREVIATIONS AND SYMBOLS

ATV	all-terrain vehicle
CI	confidence interval
FEM	finite element method
POM-C	acetal copolymer
a	distance of a plant from the base (measuring) rope
b	length of the plant's edge that is perpendicular to the measuring line to show the blueberry bush's projection
B_m	the blueberry harvester's working width
c	length of the edge that is parallel to the measuring line to show the blueberry bush's projection
C	cross-section surface of the blueberry plant's stem
Ch, Ch_{min}, Ch_{max}	number (minimum, maximum) of chilling hours
d	distance between the plants
d_c	thickness of the copying unit runner
d_{1y}, d_{3y}	flexures at junctions 1 and 3 of cantilever beams
D	diameter of teeth
D_b	diameter of berry
D_p	diameter of picking reel
D_s	diameter of the stem.
E_m	elastic modulus of rake's tooth material
E_p	shear strength for field's soil

E_s	tensile strength of plant's stem
F	force
F_a, $F_{a,\ min}$	Connection force (minimum) between the stem and roots
F_c, $F_{c,min}$, $F_{c,aver}$, $F_{c,max}$	connection force (minimum, average, maximum) between the berry and the stem
F_f	friction force between the berry and picking rake's tooth
F_g	gravitational force being applied to the berry
F_N	elastic force of the tooth in its normal direction of travel
$F_{s,max}$	maximum tensile force applied
F_t	lifting force of the picking rake's tooth
F_{1y}, F_{2y}, F_{3y}	force at junctions 1, 2, and 3 of cantilever beam
H	height of picking reel shaft from ground
h_s	height of berry stem
h_1	height of virtual intersection of the trajectories of teeth from the ground
i	index
I	momentum of inertia
K_1, K_2	local stiffness matrixes
K	total stiffness matrix
l_t	calculated flexure of a tooth
ΔL	change in the length of the test unit or the blueberry plant's stem,
L	tooth length
L_0	initial length of the unit or the blueberry plant's stem

L_a	length of cantilever element I
L_b	length of cantilever element II
Max	upper height of picking reel's working area
Min	lower height of picking reel's working area
M_1, M_2, M_3	torques at junctions 1, 2 and 3 of cantilever beams
P0, P1, P2, P3	points on the trajectory (cycloid) of the tip of tooth
$P1_z$, $P2_z$	coordinates of points P1 and P2 on z-axis
n_b	rotational speed of the picking reel
n_f	number of fractions
n_s	rotational speed of the lathe
N	number of tests
q	machine's picking (harvesting) power
Q_b	yield
r	correlation coefficient
r_A	radius of the picking reel
r_B	radius of the end point of teeth
Re	picking reach
S_{12345}, S_{345}	area of the marked shape
Z	number of picking rakes
t	time
v	absolute speed of the end point of teeth
v_k	calculated speed of the machine's movement

v_m	working speed of the blueberry harvester
v_s	linear speed of the belt sorter belts
v_x, v_z	components of velocity of the tip of tooth
V_{fs}	Volume of the fertiliser container of the portable precision fertiliser spreader
V_w	Volume of the herbicide tank of the weed spot-control unit
w_b	With of the fractionation slot between the belt sorters belts
W	productivity
x_{54}	distance between the lowest points of the trajectories of the free tips of teeth
α	inclination angle of stem
α_i	initial angle of the rake to x-axis
β	inclination angle of blueberry harvester's tooth (beam)
β_d	average angle of deflection in durability test
β_m	measured flexure of a tooth (in degree)
β_{t1}, β_{t2}, β_{t3}	calculated flexure of a tooth (in degree)
γ	rake angle of the picking rake teeth
δ	sliding factor
δ_p	level of impurities
Δ_{Re}	unevenness of harvesting
Δ_{Vfs}	value of fertiliser dose
ε	plastic deformation
η	angle characterising the free endpoint of teeth

Θ	factor for the utilisation of the unit's width
λ	kinematics parameter
σ	tensile stress
τ	time utilisation factor
ω	angular velocity of the picking reel
μ	angle characterising the position of the picking rake

INTRODUCTION

The overall production of blueberries has increased considerably during the last twenty-five years, along with the total area being utilised for that production (Figure 1). It should be noted, however, that blueberry production capacity for various parts of the world varies greatly (Figure 2). The largest producer and consumer of blueberries is North America or, more precisely, the USA and Canada (Strik, 2005).

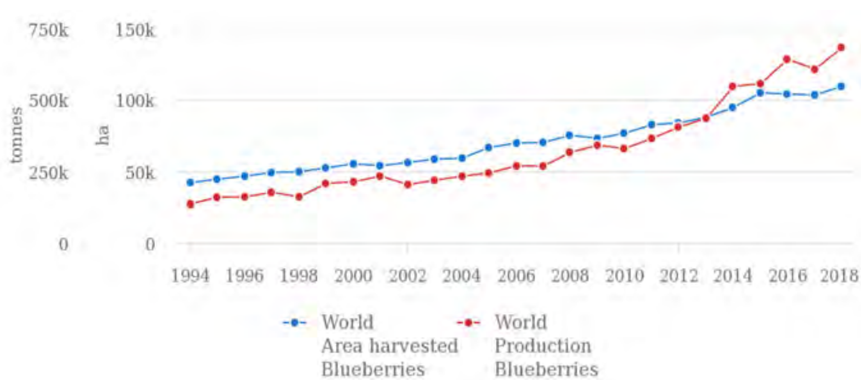


Figure 1. Production levels and yield quantities for blueberries around the world between 1994-2018 (FAOSTAT, 2020).

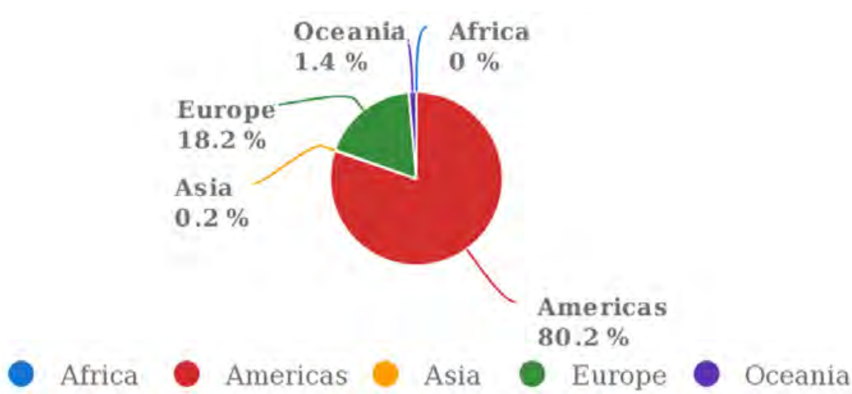


Figure 2. The production share for blueberries by region between 1994-2018 (FAOSTAT, 2020).

Figure 2 shows that in Europe, where the total population is about 1.5 times greater than it is in the Americas, the blueberry production volume is about 4.4 times smaller.

According to the "Estonian Horticulture Sector Development Plan 2015-2020", which was published by the republic of Estonia's Ministry of Rural Affairs, the total area which is cultivated for blueberry plantations in Estonia amounts to between 60-80 hectares, with the number of agriculturalists actively involved in blueberry production around forty. Therefore, it can be seen that the production volume for cultivated blueberries is somewhat small. This small level of production volume is also expressed in small consumption volumes. In comparison with other countries, Estonians eat a relatively small amount of fresh blueberries: according to the database which has been compiled by Statistics Estonia, this figure is around 0.1 kg a year (per capita). In the USA, blueberry consumption per capita was at 1.2 kg in 2017 (USHBC Export Databases, 2018; Hortifrut, 2019; Rama et al., 2018), while the respective figures for the years 2002 and 2011 were at 0.18 kg and 0.57 kg respectively (Evans & Ballen, 2014).

Several studies (Marsh, 2016; Baby et al., 2018; Kalt et al., 2020; Silva et al., 2020) have shown that blueberries contain large amounts of phytochemicals, including plenty of anthocyanin pigments, flavonoids, and antioxidants. In the phytochemical group, it is anthocyanins that have the greatest effect on the functionality of human health. Epidemiological studies have found a connection between the regular and moderate consumption of blueberries and a reduced risk of contracting cardiovascular diseases or type 2 diabetes, while also providing a better maintenance of body weight. Other important health-related aspects in terms of blueberries include their anti-inflammatory and antioxidative effect, and their beneficial effect in the treatment of cardiovascular, coronary, and neurodegenerative diseases.

Blueberries are considered to be very profitable (Starast et al., 2005; Marsh, 2016) and, therefore, many countries see good potential in increasing their consumption and production. Even Estonia has good conditions and a range of options in terms of blueberry cultivation (Starast et al., 2005).

In 1992, Toomas Jaadla's Marjasoo farm in was the first in Estonia (Tartu County, South Estonia) to establish a cultivated blueberry plantation on milled peat fields. The first plantation on mineral soil was established by Are Roosvald on Metsa Farm (Tartu County, South Estonia). Therefore, both mineral and peat soil has been (and remains) used for blueberry production in Estonia. Mineral soil is mainly used for cultivating hybrid varieties, while the more suitable solution for peat fields is lowbush blueberry which will cover the entire surface within a few years by spreading via rhizomes.

Blueberry production in Estonia is not very profitable at the moment, as the existing blueberry plantations are small and mainly depend upon manual work, which is the main problem, being a rather large obstacle when it comes to the expansion of plantations. Regardless, when keeping in mind the profitability of blueberries, their cultivation offers a promising field of perspective. As the area of land that is currently under blueberry plantations is expanded, the need increases in terms of investment into machines and equipment. Raising technological capacity will permit a lowering of the unit cost of production.

The development of blueberry cultivation is based on the mechanisation and automation of the manual work that is needed for production. On the one hand, this means the development of machines and equipment with suitable levels of productivity and, on the other hand, a reduction in the cost of using such machinery. A systematic approach is required when it comes to describing the necessary technological processes for expansion.

This doctoral thesis is largely based on six original publications and two intellectual properties that are given at the end of this thesis. The first article provides an overview of the technological peculiarities of a blueberry plantation established on exhausted and abandoned milled peat fields and the development of relevant machine cultivation technology and technological devices. The second article examines the determination of connection force between berries and stem in blueberry plants, the third article studies mechanical properties of blueberry stems. In the fourth article are pointed out methodology and explanation for the selection of the constructive and kinematics parameters of the picking reel of the motoblock-type blueberry harvester, in the fifth article, in order to design a fertilizer robot, the location of plants in the plantation was studied. The aim of the sixth article is to provide a justification of the choice of parameters for the picking reel tooth.

The first patent describes new solutions for the picking reel of blueberry harvester, the second patent describes technical solutions for belt sorter.

The novelty of this doctoral thesis lies in the determination of the mechanical properties of lowbush blueberries, the determination of the parameters of blueberry plantations which have been established on exhausted milled peat fields, the determination of the duration of the vernalisation period, a description of the relations between the various elements of blueberry cultivation system (the berry, the plant, the field, and the automation equipment), and the development of technical solutions for the cultivation of lowbush blueberries using automation equipment.

1. A REVIEW OF THE LITERATURE

1.1. Blueberry cultivation technology

The working operations that are involved in blueberry cultivation include the following: soil preparation, planting plants, fertilising plants, maintaining the plantation, weed control, plant protection, harvesting, post-harvest processing, and cutting back the plants or rejuvenation pruning (Starast et al., 2005; Zydlik et al., Olt & Arak, 2012; 2016; Retamales & Hancock, 2018; Paper **I**). The lifetime of a blueberry plantation is about 30-40 years, preceded by soil preparation and planting, both non-repetitive activities during this period.

The most important cultivated blueberry varieties can be divided into three groups (Starast et al., 2005; Retamales & Hancock, 2018):

1. lowbush blueberry (*Vaccinium angustifolium*),
2. rabbiteye blueberry (*Vaccinium virgatum*),
3. highbush blueberry (*Vaccinium corymbosum*).

Various studies have shown that, in Estonia, it is reasonable to expect to be able to grow the lowbush and rabbiteye blueberries (Starast et al., 1999; Karp et al., 2000; Starast et al., 2005). The lowbush varieties are great for milled peat fields, while the rabbiteye blueberries prefer mineral soils that have been improved with milled peat.

Peat fields have a pH level (4.5-5.5) and moisture regime that is suitable for blueberry cultivation (Noormets et al., 2003; Vahejõe et al., 2010; Paper **III**). However, the ground that is used for such blueberries has a lower load-bearing capacity (Boylan et al., 2011; Zwanenburg & Van, 2013) when compared to mineral soils and, therefore, only machinery with very low levels of ground pressure can be used here and, unfortunately, such machinery has not been the centre of attention for the larger machinery-building companies. A few of the smaller companies have produced machinery and equipment that can potentially be used in plantations that have been established on peat milling fields (Takeda et al., 2017; Paper **I**; Maine Blueberry Equipment Company, 2018; Acadian Machine, 2021).

As the number of blueberry plantations that have been established on peat fields is somewhat small, and the majority of them are located in the Baltic countries and Russia (Paal et al., 2011), no special maintenance or harvesting equipment has been developed for such plantations. The surface of peat bogs sets out specific requirements for the undercarriage of mobile machinery (such as the blueberry harvester, the fertiliser spreader, etc.). This is what makes the development and deployment of blueberry cultivation technology a truly innovative activity.

The total area of milled peat fields in Estonia amounts to 9400 ha (Ramst & Orru, 2009; Karofeld et al., 2017). About 275 ha of this area has been used during the last 45 years in the establishment of cranberry plantations (Anier 2012), and about 20 ha is used for blueberry plantations, while the total area (involving the total number of plantations on both mineral soils and milled peat fields) in terms of cultivated blueberries amounts to about 60-80 ha (Estonian Horticulture… 2015).

The main factors to be considered when choosing the blueberry variety, beside the soil's pH level, the moisture content in the soil, how well the soil is aerated, and the content of organic substances (Starast et al., 2005; Tasa et al., 2015; Retamales & Hancock, 2018), also include the prevailing weather conditions, with frost-resistance and the duration of the vernalisation period being the two most important areas of concern.

Several studies (Starast et al., 1999; Karp et al., 2000) have shown that various lowbush and half-highbush blueberry varieties have sufficient frost-resistance levels for cultivation in Estonian conditions (in terms of Northern Europe).

The lowbush blueberry requires a vernalisation period of at least a thousand hours, and is relatively frost-resistant (it is able to withstand winter temperatures of down to -30°C), while the rabbiteye varieties need a vernalisation period of at least 600 hours. However, the inflorescence of rabbiteye varieties do not withstand temperatures that fall below zero. Northern highbush cultivars, which have been bred for Nordic conditions, require a vernalisation period of between 800-1000 hours and can withstand -20°C in winter.

For any type of berry, including blueberries, the fact must be taken into account that the availability of nutrients in the soil considerably affects the productivity of the plants (Farooque et al., 2012), and larger fertilisation norms (with nitrogen levels up to 150 kg ha^{-1}) improve the growth of plants and raise productivity levels (Ehret et al., 2014); this particularly applies to poor soils (Starast et al., 2007; Paal et al., 2011). A strong positive connection has been found between the availability of nutrients and the blueberry plant's vegetative parameters, the height of the plant and the area of the leaf (Leit, 2017; Vainura, 2018).

In relation to this, fertiliser spreading depends upon the properties of the specific soil and the age of the plant. Therefore, an adjusted norm has been prescribed for each type of fertiliser. In terms of the plant's age, the fact should be taken into account that the plant's roots expand every year. Therefore, the area to be fertilised also expands. During the first year, fertiliser should be applied to a smaller area around the plant, about 20 × 20 cm, but at the age of between 6-8 years (when the bush-shaped plant has achieved its maximum measurements), fertiliser should be applied to a larger area, of about 100 × 100 cm around the plant (this also depends upon the density of the plantation: when the plants have been placed 150 cm apart then the area to be fertilised is 150 × 150 cm).

Normal working operational conditions which have the highest level of responsibility undoubtedly involve blueberry harvesting in blueberry plantations.

The main problem with manual harvesting is that the skeletal and muscular systems of workers are exposed to stress that is caused by repetitive movements, improper working positions and carrying weights. During a study (Kim et al., 2018), workers who were manually harvesting blueberries wore shoulder and waist harnesses to which buckets were fastened. Surveys conducted during the study showed that the duration of the working day for harvesters was between 6-7 hours. The weight of the box or bucket which would gradually be filled with blueberries was between 7-10 kg. Each worker harvested up to fifty buckets a day and carried those buckets to the weighing points which were located alongside the field. Each worker carried out these repetitive back-and-forth movements about ten or twenty times during a normal working day (Kim et al., 2018). Therefore, it can be claimed that harvesting blueberries manually is work that can be harmful to the health of those who undertake it.

In the case of the use of semi-mechanical pneumatic shakers, the blueberry harvesters were exposed to constant vibration, which was the cause of tiredness and which imposes several areas of health risk to the upper limbs (Kim et al., 2018). The same study concluded that working with a mechanised blueberry harvester is the best solution in terms of minimising a worker's load and tiredness levels. Furthermore, the productivity levels for manual work are low (Käis & Olt, 2010), something which serves to increase unit costs, and which therefore, directly influences manufacturing costs.

1.2. An overview of mechanical/technological blueberry cultivation

1.2.1 Harvesting technology

The most labour-intensive technologically-based working operation with the highest levels of responsibility is the harvesting of blueberries, especially those which are served fresh on the dish, as the berries must look their best with no signs of bruising. This makes the blueberry harvester the most strategic cog in the entire technological system.

Blueberry plantations which have been established in the Baltic and Nordic countries are still based on the application of manual harvesting using picking rakes (Figure 3).

Figure 3. Farm labourer harvesting in a blueberry plantation (Marjasoo Farm, 22.08.2018).

The development of industrial blueberry harvesters began in the USA in the 1950s, but the first successful units were only designed during the 1980s (Hall et al., 1982). Several types of mechanical blueberry harvesting machines have been developed since then; however, they have several technical disadvantages which can be linked to huge losses, mechanical damage caused to the plants and berries, and problem caused by uneven subsoil (Farooque et al., 2014).

Forms of harvesting technology can be divided into three different categories (Farooque et al., 2014; Yu et al., 2014; Takeda et al., 2017; Retamales & Hancock, 2018):

1. shaker-type harvesting equipment;
2. harvesting equipment with a vertical picking attachment;
3. harvesting equipment with a horizontal picking attachment.

In the case of shaker-type harvesting equipment (Takeda et al., 2017), the pneumatic shaker is used to shake the stem of the blueberry plant so that those berries which have dropped onto the catchplate can be collected. Equipment of this type is suitable for harvesting semi-high and highbush varieties of blueberries.

In the case of harvesting equipment with a vertical picking attachment (Oxbo Berry Harvesters, 2017; Littau Berry Harvester, 2020), the picking teeth which are attached to a drum are moved through or over the blueberry plant or bush, and the teeth remove the berries mechanically. Any berries which have been torn off are collected from the catchplate or are forwarded by a conveyor to collection boxes. Equipment of this type is suitable for harvesting semi-high and highbush varieties and can be used for collecting berries from blueberry bushes which are of a height of up to four metres.

In the case of harvesting equipment which has a horizontal picking attachment (Maine Blueberry Equipment Company, 2018; Acadian Machine, 2021), the picking teeth are attached to a rotary reel or drum and the teeth move through blueberry plant to remove the berries from that plant. The removed berries are gathered into a collection box or bunker, with the rotary movement of the reel moving either in same direction as the unit's forward movement or against it. Equipment of this type is suitable for harvesting lowbush blueberry varieties.

The power source for all three forms of harvesting technology can come from a variety of options, such as a tractor to which the blueberry harvester is attached. In addition to a tractor, a small motoblock-type harvesting unit can be used as an extra option.

As the load-bearing capacity of a peat field is somewhat low (Boylan et al., 2011; Zwanenburg & Van, 2013), only mobile equipment with very low pressure levels can be used here, which can be achieved only using motoblock-type harvesters.

Table 1. Relevant patents for lowbush blueberry harvesters (Espacenet, 2018)

Reference	Patent no	Patent aim
Stankavich et al., 1950	US2607180A	Cranberry harvester
Brinton, 1957	US2780905	Picker for berries and the like
Bragg & Weatherbe, 1985	CA1249727	Blueberry harvester
Robichaud, 1994	US5369944	Blueberry harvester and method of harvesting blueberries
Weatherbee & Weatherbee, 1999	US6000203	Blueberry harvester
Bouchard & Tremblay, 2000	CA2241386	Harvester for picking up berries
Emerson, Z, 2005	US6854255	Berry harvester

The patent analysis regarding the technological level of lowbush blueberry harvesting technology (Table 1) shows that the most suitable structural solution for working on milled peat fields is a blueberry harvester which contains a drive with transmission, a picking reel, a berry conveyor, a berry guide, a frame to support the unit's elements and assemblies, a copying unit, an undercarriage, and control levers with control mechanisms, with the working elements of the picking reel being the teeth which are attached to a horizontal holder and are tilted backwards in comparison to the direction of movement. The picking reel has been designed as a parallelogram reel (Paper **III**), which can be characterised by the fact that the teeth remain parallel to themselves at any angle on the reel. This form of blueberry harvester is used for harvesting lowbush blueberries which grow relatively low, preferably at a height of between 10-30 cm, and whose stems are vertical. Due to the rotation of the picking reel, the teeth first move downwards within the working area to a point between the plant stems, and then backwards relative to the unit's direction of movement by tearing the berries from the plant's stem, and then upwards by moving the berries onto the conveyor.

The greatest disadvantage of blueberry harvesters for lowbush blueberries is the presence of a danger of damaging the plants or pulling them out of the ground. The process which involves damaging the plants or pulling them out of the ground is as follows: a plant with long stems has been bent downwards in all directions around the central point of the plant due to the weight of the berries. The stems are often caught between the picking teeth as the teeth move downwards. Those blueberry stems which have been caught between the teeth are broken by the rotation of the reel - which is equipped with rigid teeth - or are pulled entirely out of the ground. This is a problem that has been widely recorded in blueberry harvesters, and it is one which needs to be resolved.

1.2.2. Fertilisation

Blueberry plants should be fertilised two or three times a season by dosing them with between 30-80 g of fertiliser per plant (less in the first few years, and more later on) (Hart et al., 2006). Therefore, the doser must be adjustable so that it can properly spread the prescribed amounts of fertiliser. Full-width fertiliser spreading cannot be used in blueberry plantations as this would cause weeds to thrive, which would increase maintenance costs somewhat unpredictably.

Regardless of the aforementioned deficiency, the blueberry plantations of the Baltic and Nordic countries utilise either full-width spreader trolleys which are pushed from the technical roads, or manual seed spreaders or backpack fertiliser spreaders.

In order to achieve the optimum results, fertiliser must be applied around the plant, under the plant's crown (Hart et al., 2006), ie. the spot-application method of fertilisation must be used. Such a method is useful in terms of several aspects: it offers a reduced cost and/or unit cost for fertilisers (while also offering greater levels of plant protection), along with reduced environmental pollution levels (Esau et al., 2018), while weed growth is reduced between the headlands (the technical roads). In terms of the plantation's age, the fact should be taken into account that the plant's roots will expand year-on-year, so the area to be fertilised will also expand. During the first year, fertiliser should be applied to a smaller area around the plant, about 20 × 20 cm, but at the age of between six to eight years (when the bush-shaped plant has achieved its maximum dimensions), fertiliser should be applied across a wider area, one with a diameter of 100 cm around the plant.

Patent analysis of the domain in the Espacenet environment shows that according to patent documents (Dillon, 2000; Seenauth, 2004; Zhang, 2007) current solutions include spot fertilisers which have added tank containers to be worn on an operative's shoulder or which can be worn as a backpack, and in which fertiliser granules leave the fertiliser container due to gravitational force, and are then directed towards the plant using a pipe-shaped fertiliser duct.

The greatest disadvantages of such a solution are that the precision of fertilisation cannot be ensured and there is no possibility of being able to adjust the dose.

1.2.3. Plant protection

Various species of weed can be found in the majority of berry plantations of all types, including blueberry plantations. The use of plant protection products is one way of inhibiting their growth or of removing them entirely.

The three main methods for delivering pesticides onto the field are broadcast, band, and targeted spraying (Hong et al., 2012; Olt, 2015).

From the environmental and economic viewpoint, the most reasonable method is targeted spraying (Esau at al., 2018), which reduces the amount of pesticide needed by up to 60% when compared to broadband spraying, while also reducing the volume of pesticides reaching the ground water by 44% (Hong et al., 2012).

The applicator method can be used for treating single plants; this means applying herbicide on selected plants using physical contact between the applicator and the plant. This method allows a specific means to be used to treat single weeds or certain types of weeds, while the surrounding plants and soil are not accidentally exposed to the chemical agent being used.

A patent search was carried out in order to develop the equipment to be used for the applicator method. According to patent documents (Moore, 1990; Stevens, 2000), contact-based weed control equipment already exists which comprise a working unit which has been moistened with herbicide and which is used to touch the weed in order to destroy it. These units are operated manually or by using a motor. The greatest disadvantages of these technical solutions include their uncomfortable use, low performance levels, and the possibility of the chemicals reaching the plants and soil where these areas were not intended to be included in the treatment programme.

1.2.4. Post-harvest (berry sorting) technology

The main physical and mechanical properties in the sorting phase for berries are the geometric dimensions; this requires the sorting of berries according to their size. There are numerous berry varieties, and berries which are served on the dish should, preferably, have a uniform diameter.

Two types of sorting are currently applied: serial and parallel. Serial sorting separates size groups from the total volume of berries according to size: first the smaller ones, then the medium-sized ones, and finally the largest. In the case of parallel sorting, the groups are separated in the opposite order, ie. descending order. Roller, net, serial, drum, and belt sorters can be distinguished according to the working unit’s structure (Grote & Feldhusen, 2007; Soots et al, 2014; Patent **II**).

Recent developments in sorting technology have included optical vision and image processing technology, which can also be used for sorting berries according to their chromatic properties or geometric dimensions (Cubero et al., 2014).

Several companies (TOMRA Food, 2019; Unitec, 2020; A&B Packing, 2021; BBC Technologies Ltd., 2021; Elifab, 2021; Lakewood Process Machinery, 2021) manufacture equipment for sorting berries (including blueberries), but these are mainly intended for large-scale industries, while they also require stationary installation and controlled working environments and, therefore, do not satisfy the post-harvest processing needs of small and medium-sized farms.

These small and medium-sized companies need a relatively simple and economic solution with productivity levels which are comparable to the berry harvesting capacity. The equipment should be easily transportable and capable of being used on the field or berry collection point for carrying out initial post-treatment work. In order to be transportable, the equipment should have a relatively low mass and small outer dimensions; it should be able to fit onto a trailer behind a passenger car or ATV, and should have low power consumption requirements.

A patent search was carried out in terms of designing the belly sorter, and relevant patents have been presented in Table 2.

Table 2. Relevant patents for sorter (Espacenet, 2018)

Reference	Patent no	Patent aim
James, 1943	US 2316159	Fruit and berry washing and grading equipment.
Percival, 1956	GB745730A	Improvements in or relating to sorting or grading apparatus
Bertz, 1960	FR1248240	Classification adjustment unit, applicable for grading machines
Bruce & Kilgour, 1984	GB2140712	Grader
Magnusson et al., 1998	W09848951	Apparatus for grading objects such as fish
Yealands, 1998	NZ314846A	Apparatus for grading mussels according to size, which includes a support frame and spacing adjustment means
Van & Johannes, 1998	NL1006272C2	A method and a unit for sorting objects, in particular fruit and bulbous plants, with regard to their cross-sectional dimensions
Valk, 2005	NL1024173	A sorting machine for bulb or tuber crops, comprising a perforated conveyor belt and beam for pressing upwards against the opening free region of the belt

Stiefvater & Willi, 2005	DE10359369	A fruit size sorter with a transporting system of multiple, diverging belts which define a number of openings of gradually and continuously increasing width
Williamson, 2006	US20060113224	Adjustable size-sorting apparatus for small produce items
Magnusson & Ragnarsson, 2006	W0200612070	Gap width adjustment mechanism for the belts of a grading system
Olt & Soots, 2013	EE05642B1	Technical solutions to make belt sorter to adjustable

The patent analysis showed that the currently-available technical solutions had the following problems: the sorting slit is not adjustable, the sorting slit can only be adjusted at certain increments, the sorting slit is adjusted manually by displacing belts, the slit between the belts can be adjusted by manually moving the pulleys one by one, the adjustable mechanisms are not rotating when they are at work, the adjustment sorting slit can only be worked with a considerable time cost or adjustments result in considerable backlash.

Feedback from the farmers and the results of the patent study show that the most suitable solution for the aforementioned task is to use technology which has been based on a belt sorter; although it is for this means of operation that the problem of adjusting fractioning slits smoothly, without any backlash and with little time cost, must be resolved.

2. THE AIM OF THE THESIS AND ITS TASKS

Nowadays most technological operations in blueberry plantations which have been established on milled peat fields are mainly carried out using hand tools.

The development of any type of agricultural production is, first and foremost, based on the mechanisation of manual work and, afterwards, the improvement of the technical and technological means that are related to these processes. On the one hand, these improvements consist of the raising of levels of efficiency in relation to the technical and technological means and machines and, on the other hand, the reduction of any cost that is involved in using them.

The aim of this doctoral thesis is to develop machine cultivation technology for lowbush blueberries which are being grown in milled peat fields in order to reduce manual production requirements.

The following tasks needed to be resolved in order to be able to achieve the ultimate stated aim:

1) To describe the relations between the elements of blueberry cultivation (berry-plant-field-machine);
2) To define the mechanical parameters of the cultivation system (berry and stem);
3) To design a novel picking element for a blueberry harvester;
4) To determine the duration of the vernalisation period in Estonia;
5) To create technical solutions so that technological work operations can be carried out using automated equipment.

3. MATERIALS AND METHODS

The simplified circular scheme regarding the technological operations that are involved in blueberry production has been presented in Figure 4.

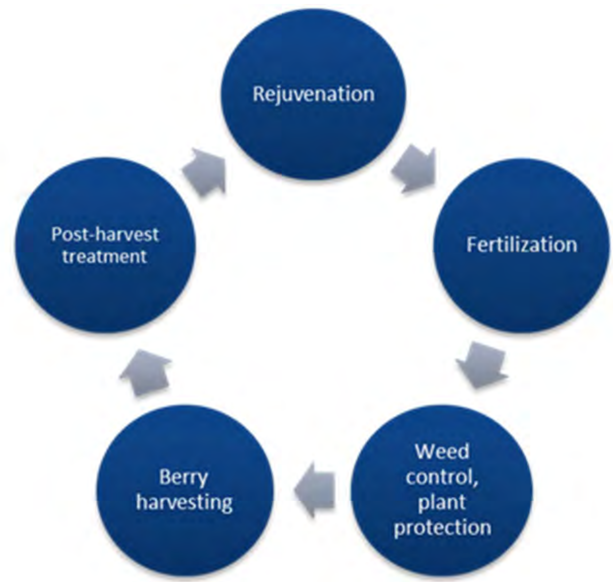


Figure 4. The technological steps involved in blueberry production.

Blueberry plantations have been established on mineral soils (Retamales & Hancock, 2018), but also on milled peat fields (Peatland Ecology Research Group, 2009).

Machinery which carries out several technological operations in terms of blueberry plantations that have been established on mineral soils have been developed and are in production. However, no machinery or equipment for peat milling fields is commercially available (Paper **I**; Paper **V**).

As blueberry plantations in milled peat fields in the Baltic and Nordic countries still mainly use manual operations when it comes to carrying out the various technological stages of the overall process, it is important to mechanise the main operations of cultivation technology, to propose technical solutions which will help to improve the efficiency of certain operations, and to improve the precision of working operations.

3.1. The basis for preparing the development work plan

The methodology involved in studying the process of blueberry production lies in a systematic approach and in the principle of optimising the working parameters of the machinery involved.

The analysis of papers that have so far been published on the topic (Starast et al., 2005; Bergs et al., 2008; Yarborough, 2012; Takeda et al., 2017; Retamales & Hancock, 2018) showed that all of the various cultivation operations have been described separately and no systematic approach has been developed in terms of technological operations. In other words, no information can be found about a description of the systematic functioning of the blueberry production process. As a result, any studies that cover blueberry plantations, plants, and machinery are treated as separate problems. There is no unifying system.

When studying any of the technological work operations that are involved in blueberry production technology, it became evident that the main object of optimisation is a technological solution or the machinery itself. Changes and optimisation can be carried out on the plantation and on the plant, but this area of improvement is very limited. When machinery or equipment is optimised, the plant as the object of processing and the plantation as the unit of processing cannot be bypassed. Previous studies have paid little attention to these elements or have completely ignored them.

The machine cultivation of blueberries is mainly carried out in terms of the interaction of between two to four components. In terms of fertilisation, weed control, plant protection, and rejuvenation, these areas all include the plant itself, the plantation, and the working machinery: three components in total. For harvesting it is reasonable to discuss the plant in terms of two groups - as the berry or berries - along with the plant stem, the plantation, and the working machinery: four components. The components involved in post-harvest processing include the harvested berries and any impurities that are related to machine-based harvesting, mainly leaves and other plant residues: two components. Harvesting, which is the most complex working operation in blueberry cultivation technology, provides a dyadic result: the harvested yield and the processed plantation. The first result is given in the cooperation between working machine and plant; the second as the interaction of the machine with the plantation. Therefore, the process which is under scrutiny has two technological aspects which differ from one another by the fact that the first one ignores the existence of the plantation as a territorial unit. These aspects can be viewed as separate processes or, on the other hand, as the inner and outer sides of the same process, providing a quantitative and qualitative aspect.

The system's components can be referred to as elements. Therefore, these elements in the overall system for the machine-based harvesting of blueberries include the blueberry plant itself - focussing specifically on its berry or berries (or yield) - the stem which supports the berries, the plantation, and the working machinery, which together fulfil the functions of the blueberry production system. Each separate element is not capable of fulfilling the overall function. Each one of them forms a function that is specific to another function. For example, the berry on a blueberry plant is an element which is connected to the plant stem; for a working item of machinery, the berries are the material that is to be harvested or processed.

The main features of the system are expressed in terms for each system, as follows:

1) they can function as a whole together with the environment and other systems;
2) they consist of a hierarchy of lower-level subsystems;
3) they form a subsystem of a higher-level system;
4) they maintain the general structure of cooperation between elements.

Figure 5 shows the forces that are applied to the blueberry plant during machine-based harvesting. One of the aims of this doctoral thesis was to determine the aforementioned forces.

It is evident from Figure 5 that, in order to avoid damaging the yield and plants during harvesting, the harvesting machine must be designed in such a way that the following condition is fulfilled:

$$\left.\begin{array}{c} F_{a,min} > F_{s,min} > F_N > F_{c,max} \\ E_m > E_s \end{array}\right\} \quad (1)$$

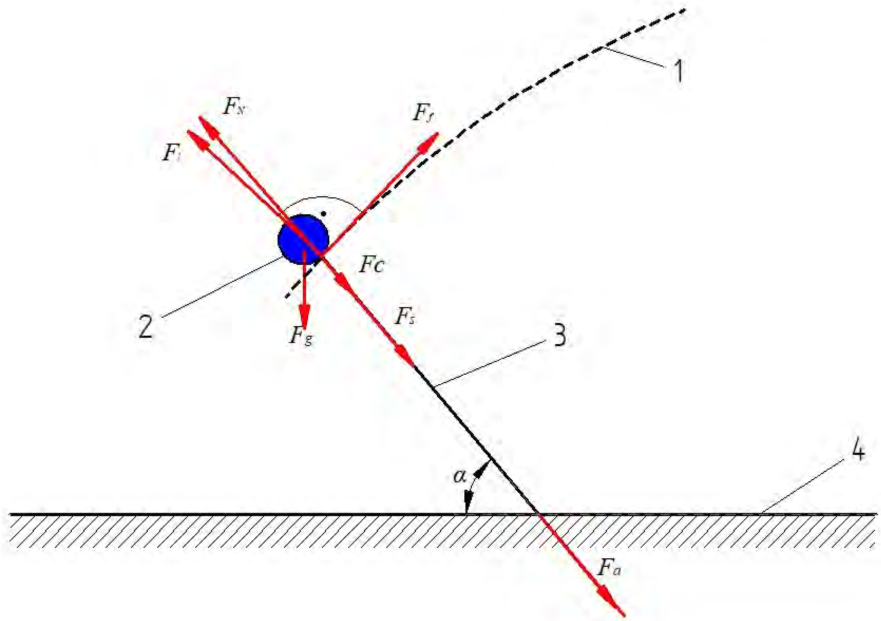


Figure 5. The forces that are applied to a blueberry plant by the harvesting machinery: 1) picking reel's tooth; 2) the berry on the blueberry plant; 3) the blueberry stem; 4) the ground of the field itself.

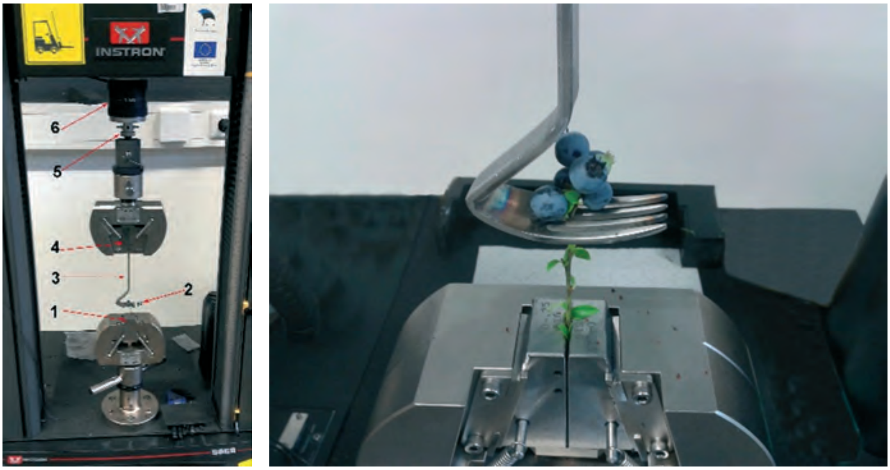
According to relation (1), one of the aims of this work was to define the blueberry plant, *i.e.* determine the connection force F_c between the berry and the stem, the tensile strength of the plant's stem F_s, and the connection force F_a between the stem and the soil. When taking these parameters into account, the material to be selected for the picking elements or the picking rake's teeth should be able to separate the berries, but should do no damage to the plant, or crush it, or tear it from the ground, and neither should it bruise the berries. Test work was carried out to determine these parameters.

3.2. The basis for preparing the test work plan to define the blueberry plant

A determination of the connection force between the berry on a blueberry plant and the plant's stem. Blueberries (1) are connected to the plant's stem (2) by means of a 'tail' (3) (Figure 6). From the mechanical point of view, the stem of the blueberry plant is attached to the ground and the berry on the blueberry plant is attached to the plant's stem. During harvesting, it is reasonable to be able to remove the berries from the stem by mechanical means. During the mechanical harvesting process, the picking element applies force to the berry on the blueberry plant and pulls it from the stem which is attached to the ground. The berries shouldn't be bruised or damaged during harvesting and, in order to avoid this and to be able to start modelling the blueberry harvester, the connection force needs to be known between the berry and the stem. Another important fact is that blueberries are harvested when fully ripe as there is no post-harvest ripening.

Figure 6. A blueberry plant with berries: 1) berries; 2) stems and the tails of the berries; 3) tails.

In order to determine the connection force F_c of the blueberry, it is reasonable to use a test scheme with operational parameters that are similar to those of the picking rake. A test unit (Figure 7a) was modelled to determine the connection force F_c between the berry on the blueberry plant and the stem. The test unit consists of a method of fastening the plant's stem (1), a jaw (3) which is equipped with rigid teeth (2) for grabbing the berry, a gripper (4), a mechanism for changing the jaw's position on the vertical plane (5), a force sensor (6) which is attached to the shaft of the jaw, and a reader for recording data.



a) b)

Figure 7. Test unit to determine the connection force for one berry (a) and a batch of berries (b) (Paper **II**).

An Instron 5969L2610 tensile force tester was used to determine the force being applied to the berry. The technical specifications of the test unit have been presented in Table 3.

Table 3. Technical specifications for the test unit

No	Part	Technical description	Parameter
1	Sensor	Loadcell 1 kN	Measuring range ±1 kN, accuracy ± 0.25% of the indicated force
2	Reader	Instron 5969L2610	
3	Gripper		Material (AISI304) thickness 2.5 mm, distance between teeth 2.6 mm
4	Jaw	Face VEE JAW S16	

The berries may be attached to the stem in the form of bunches (Figure 6). Such a position may affect the measuring results and separate tests were carried out in order to determine the connection force of bunches of berries (Figure 7b).

Test description. Plants with berries on them were cut from a point near the ground in the plantation, placed into a sealed plastic bag to avoid drying, and brought into the laboratory within the space of one hour. The plant's stem was fastened to the gripper (1) (Fig 7a) and the berry or the bunch of berries was or were placed between the jaw's (2) teeth (3). An actuator was started which was mechanically attached to the jaw. As the jaw moved vertically upwards (with a speed of 5 mm min^{-1}), the plant which was attached to the gripper started to extend, and the force between the berry and the plant's stem started to increase until the berry was removed from the plant's stem. The maximum tensile strength was used to determine the connection force $F_{c,max}$ between the berry on the blueberry plant and the plant's stem (Paper **II**).

3.3. A determination of the blueberry stem's tensile strength

The physical content involved in determining the tensile strength. It is known from the general field of mechanics (Chattopadhyay & Pandy, 1999) that the elastic modulus E can be expressed as done by

$$E_s = \frac{\sigma}{\varepsilon}. \quad (2)$$

As $\sigma = F_{s,max}/C$, $\varepsilon = \Delta L/L_0$ and $C = \pi D_s^2/4$, the relation (2) is given the form:

$$E_s = \frac{4F_{s,max}L_0}{\pi D_s^2 \Delta L}. \quad (3)$$

Therefore, we must proceed from the relation (3) in determining the elastic modulus E_s of the blueberry plant's stem.

Experimental procedure. The measuring instrument used in this thesis in order to determine the tensile test of the blueberry stem was the INSTRON 5969L2610 (Figure 8), with technical specifications that have been given in Table 4. The blueberry stems were collected and test bodies were prepared in order to obtain the required results. In order to determine the tensile strength of the blueberry plant's stems, the test units were placed between the grippers of the measuring instrument (Figure 8); tensile tests were carried out and data was recorded.

Sample preparation. The blueberry stems could not be attached to the tensile machine's grippers when the standard unit was being used. In order to avoid damaging the stems, additional softening was added or special grippers were used.

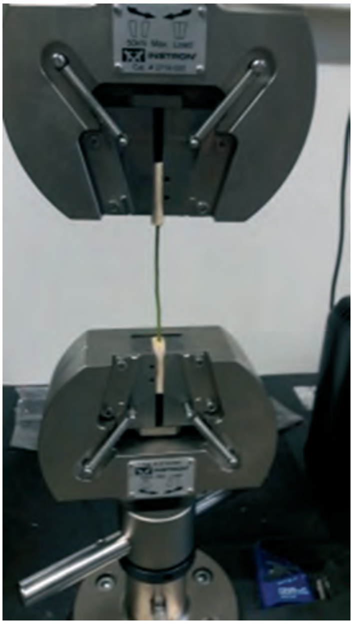


Figure 8. Measuring instrument: INSTRON 5969L2610.

The means used in this study for attaching blueberry stems to the measuring instrument were wooden clamps with dimensions of 6 × 15 × 36 mm and into which transversing holes with a diameter of 3 mm were drilled (Paper **III**). The blueberry stems were placed into these holes and attached to the wooden clamps using two-component instant adhesive Loctite 3090. As wood is a material which has higher levels of elasticity, the attaching force for the gripper is better transferred to the clamp through the wood, thereby supporting the effect of the adhesive and making wood a better material for clamping than rigid plastic would be. The blueberry stems, together with the clamps, form the test units (Figure 9).

Figure 9. The blueberry plant's stem test unit with clamps at the end of the test.

The measured data was processed with the software, BlueHill 3 (version 3.15.1343), by Illinois Tool Works Inc. This was used to calculate the tensile stress σ, plastic deformation ε, and elastic modulus E.

3.4. The connection force between the plant's stem and the ground

An original measuring system which was prepared by the author was used in determining the connection force between the plant's stem and root (Figure 10a). The force necessary for pulling the plant's stem off the root was generated by the rotational movement of a threaded rod, as the moving threaded rod increased the distance between the plant and the attachment system. Vernier Dual-Range Force Sensors were used to determine the force, and LoggerPro software was used for data processing. The plant's stem was attached via a special gripper (Figure 10b) to the measuring system; a battery-powered drill was used as the power unit.

a) b)

Figure 10. Test unit (a) to determine the connection force between the plant's stem and the ground: 1) force sensor; 2) gripper; with (b) showing in close-up: 3) threaded rod; 4) data logger; and 5) power unit.

3.5. Developing the blueberry harvester

The requirements that were set out for mechanically-driven blueberry harvesting are as follows:

1) Harvesting must be carried out on time, when the berries are fully ripe: the best time for harvesting is at the end of July and the beginning of August (Starast et al., 2009). As 90% of berries become ripe at the same time, it is reasonable to expect to carry out a single picking process for all plants at once (Paper **I**);
2) The duration of any harvesting should be as short as possible, around 15-20 days;
3) The blueberry harvester's losses during harvesting may not exceed 5%;
4) The berries may not include more than 15% of impurities (leaves and other plant residues);
5) The share of mechanically damaged (bruised) berries may not exceed 5%;

The general and individual functions of blueberry harvesting machines are as follows (Olt & Arak, 2012):

1) The berries are removed from the stem without damaging the berries and blueberry's stem;
2) Picked berries are directed onto a removal element which will transfer the berries away from the zone in which the berries are removed from the stem;
3) The berries are guided towards a replaceable collection box, container, or conveyor;
4) Due to moving on boggy soil, the requirements for any mobile machinery are as follows: the smooth movement of the machinery must be ensured, along with low rolling and rotational resistance, good traction for the undercarriage along the ground, a low surface pressure for the undercarriage, a long service life for the undercarriage, a level of simplicity in using the machine, easy maintenance and repair prospects, and machinery that can be used universally.

"The principle layout of the blueberry harvester has been presented in Fig 11. This is the so-called rough harvester, ie. the extra items which come through the blueberry harvester (such as leaves, pieces of stems, and peat, etc) and bruised berries are not separated from the berry mixture. Therefore, the technological operations of the blueberry harvester comprise the removal of the berries, harmlessly, from the stems and collecting the berries into berry boxes or containers which are intended to be handled," (Paper **IV**).

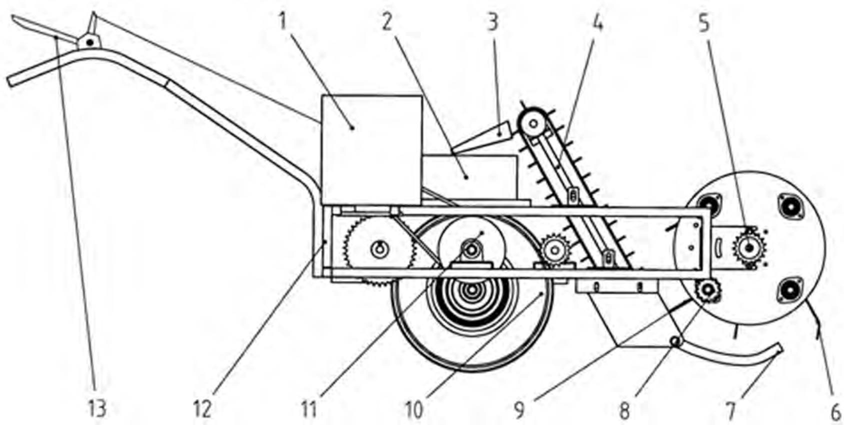
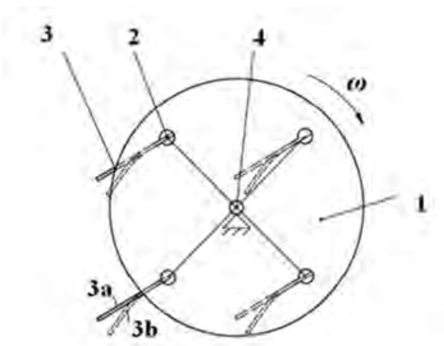


Figure 11. Main assemblies and parts of a motoblock-type harvester (Patent I): 1 – engine, 2 – berry box, 3 – chute, 4 – conveyor, 5 – picking reel, 6 – hook spring-tine, 7 – copying unit, 8 – picking rake, 9 – rake tooth, 10 – wheels, 11 – transmission, 12 – frame, 13 – steering levers.

3.5.1. Designing the blueberry harvester's picking unit

According to the description of the task in chapter 3.5, and also the patent search, it seems reasonable to design a picking machine with the picking reel as its functional working unit and a picking rake as the working element (Figure 12).

According to Figure 12, the working elements of a picking reel (1) include the horizontal picking rakes (2), which contain axes that have been attached to side discs using articulated joints, and which hold rigidly attached rake teeth (3). To avoid damaging the plant, the rake teeth (3) on the picking rake were designed of an elastic material (Patent **I**). A rake tooth (3) on the picking rake can be located in positions 3a or 3b. The berries are separated from the stems using the rake teeth (3), which are moved through the blueberry stems. In its initial position (3a) or its unloaded position, the rake tooth on the picking rake is straight and is held in the loaded position (3b), bent as depicted in Figure 12a. If an elastic rake tooth (3) on the picking rake is stuck behind the plant's stem, or a plant stem which is positioned parallel to the picking rake is stuck between the tips of the rake's teeth, the rotation of the picking reel (1) applies additional force on the rake teeth (3), and the rake tooth bends and takes up position 3b. The bending of the rake teeth (3) releases the plant stems from between the tips of the rake teeth. After releasing the plant stems, the rake tooth (3) returns to its initial shape (3a). Picking rakes (2) have been attached using the principle of the parallelogram reel. The inclination angle γ of the teeth can be adjusted.



a)

b)

Figure 12. The blueberry harvester's picking reel: a) the principal schematic (Patent **I**); and b) the prototype unit.

In order to determine the parameters of the picking reel and teeth according to the required schematic (Figure 13), equations were prepared for the movement trajectories of the tips of the teeth (fixed (A) and free (B) tips), which are rigidly attached to the reel.

The coordinate system, Oxz (Fig 13), makes it possible to describe the movement trajectory of the rake teeth tips, A and B, on the reel using the available equations (Olt & Käis, 2006; Heinloo, 2007; Paper **IV**), which are as follows for the fixed tip, A, of a tooth which is attached to the reel:

$$X_A(t) = r_A \cos(\omega t - \alpha_i) + v_m t, \tag{4}$$

$$Z_A(t) = -r_A \sin(\omega t - \alpha_i). \tag{5}$$

and the equation for the movement trajectory of free tip B is:

$$X_B(t) = X_A(t) - L sin(\gamma), \tag{6}$$

$$Z_B(t) = Z_A(t) - L\cos(\gamma), \tag{7}$$

where

$$\alpha_i = i\frac{2\pi}{Z}, \tag{8}$$

$$i = 0,1,..Z-1. \tag{9}$$

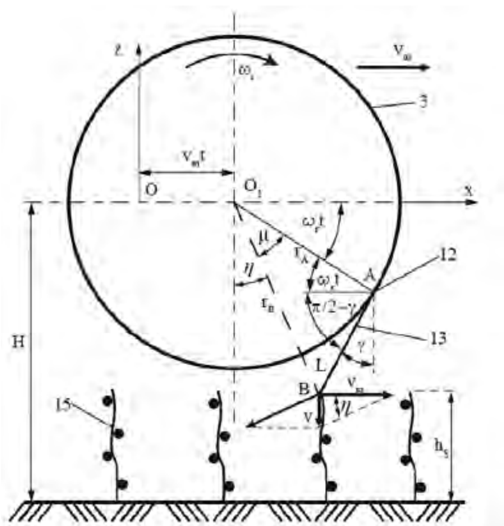


Figure 13. Calculation scheme for compiling equations regarding the trajectory of picking reel's rakes and to determine the height of the picking reel shaft from the ground: 3 – picking reel, 12 – picking rake, 13 – rake teeth, 15 – blueberry plant. (Paper **IV**).

The movement of free tip B on the tooth can be divided into four parts in the coordinate system, Oxz (Figure 14):

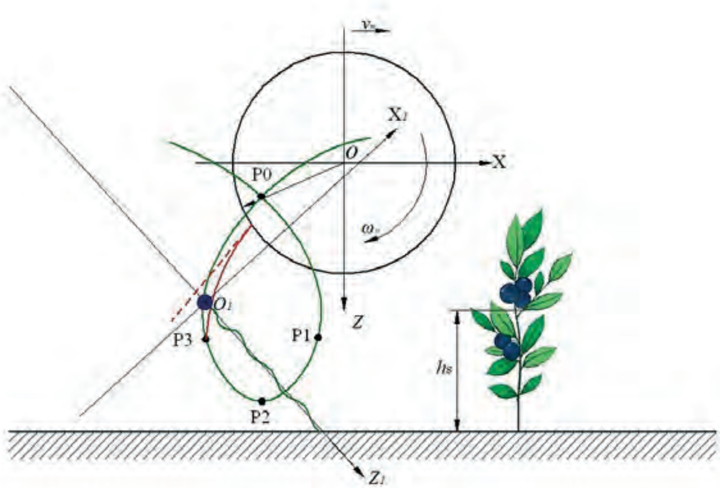


Figure 14. A diagram which characterises the different stages of work of a picking tooth.

1. Penetration (the free tip, B, of a tooth moves P1→P2), during which the tooth will move downwards, between the plants; the movement of the tip of the tooth can be described by the equations:

$$V_x = \frac{d}{dt} X_B(t) < 0 \tag{10}$$

$$V_z = \frac{d}{dt} Z_B(t) > 0 \tag{11}$$

2. Picking (the free tip, B, of a tooth moves P2→P3), during which the berry on the blueberry plant berry is torn or pulled from the stem:

$$V_x = \frac{d}{dt} X_B(t) < 0, \tag{12}$$

$$V_z = \frac{d}{dt} Z_B(t) < 0. \tag{13}$$

3. Release (the free tip, B, of a tooth moves P3→P0), during which the berry will be moved by its own gravitational force towards the transport conveyor:

$$V_x = \frac{d}{dt} X_B(t) > 0, \tag{14}$$

$$V_z = \frac{d}{dt} Z_B(t) < 0. \tag{15}$$

4. Reset (the free tip, B, of a tooth moves P0→P1), during which the tooth will move to the initial point of the working cycle:

$$V_x = \frac{d}{dt} X_B(t) > 0, \tag{16}$$

$$V_z = \frac{d}{dt} Z_B(t) > 0\ . \tag{17}$$

When we differentiate the equation (6) according to time, and when we take into account the requirement (12) which is necessary for berry picking then, following conversion, we can express the necessary relation for the picking reel's rotational velocity mode or kinematic factor:

$$\lambda > \frac{1}{\sin(\omega t)}. \tag{18}$$

According to sources (Miu, 2016) it is reasonable to choose a kinematics factor of λ for the picking reel, within the range of λ = 2–2.5.

"The task of the picking reel is to remove blueberries from the stems without any damage. In real working conditions, during the rotation of the picking reel 3, the movement direction of the rake teeth tips has to be vertical, directed top-down, when the rake teeth tips of the picking reel (point B) reach the top of the blueberry plant; in this way the picking rake teeth can penetrate between the blueberry plants 15 (Fig. 13), that is, at the moment of penetrating between the stems carrying berries the absolute speed vector of the rake teeth tips (Fig. 13) has to be directed vertically top-down." Paper **IV**.

The absolute vertical speed v of the free tip B of a tooth on the picking reel can be determined by the relation:

$$v = \sqrt{\left(\frac{d}{dt}X_B(t)\right)^2 + \left(\frac{d}{dt}Z_B(t)\right)^2}, \tag{19}$$

or

$$v = v_m\sqrt{1 + \lambda^2 - 2\lambda\sin(\omega t)}. \tag{20}$$

The angular speed ω of the picking reel can be expressed as:

$$\omega = \frac{\lambda v_m}{r_A}. \tag{21}$$

The placement height H of the picking reel's rotational axis can be determined as follows:

$$H = h_s + L\cos\gamma + r_A\sin(\omega t). \tag{22}$$

When the value of the kinematic parameter is chosen as the following condition can be set to the tooth's length L:

$$L \geq 0.5h_s. \tag{23}$$

Figure 13 can be used to express the relation for finding the virtual radius r_B:

$$r_B^2 = \frac{r_A^2 \sin^2(\omega t) + 2r_A L \sin(\omega t)\cos(\gamma) + L^2 cos^2(\gamma)}{cosx^2(\mu)}, \tag{24}$$

Taking into account the relations (22) and (23), we can find the relation for determining the radius r_A of the reel:

$$r_A \leq \frac{H - L\cos(\gamma) - d_c}{cos^2(\eta\ )}, \tag{25}$$

To be able to determine the picking depth of the reel, the z-axis coordinates for points P1 and P2 as described in Figure 14 must expressed from the conditions $P1_z$ and $P2_z$:

$$\frac{d}{dt}Z(t) = 0 \tag{26}$$

and

$$\frac{d}{dt}X(t) = 0 \tag{27}$$

The picking reach *Re* on the picking reel can be found as follows:

$$Re = P1_z - P2_z \tag{28}$$

The Mathcad 15 environment was used to model the movement of the tips of the teeth of a picking reel using equations (4)-(7) and the parameter values shown in Table 7, and to generate the movement trajectories of the tips of teeth (Figure 15).

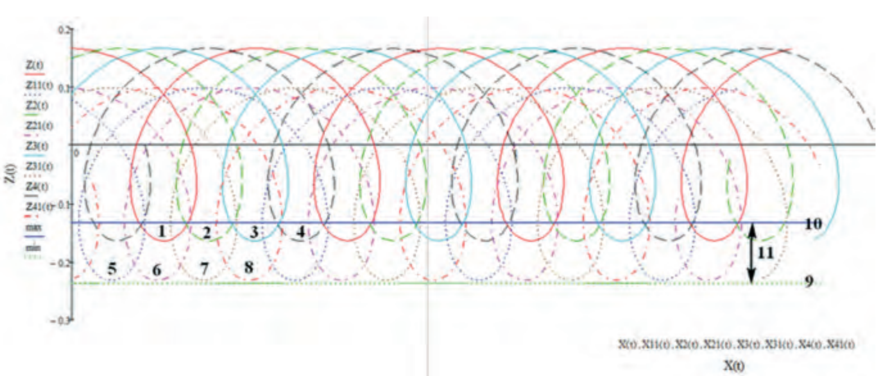


Figure 15. Trajectories of the fixed endpoints (1, 2, 3, and 4) and free endpoints (5, 6, 7, 8) of the teeth ($Z = 4$), the upper limit of the working area (10), the lower limit of the working area (9), and the picking reach 11.

3.5.2. An evaluation of the suitability of the picking reel's parameters.

Suitability tests on the picking reel's kinematics and structural parameters were carried out using the same methodology as for describing the parameters of the work of rotary tillers (Celik & Altikat, 2008; Celik et al., 2008; Belov, 2018).

Figure 16 depicts the movement trajectories of the free tips of teeth on two consecutive rakes. The picking depth or picking reach of a blueberry harvester with a picking reel which is moving in the same direction as the harvester's wheels can be described by a certain level of unevenness. According to conditions (12) and (13), berries are picked from an area with a cross-section in the direction of movement on the longitudinal vertical plane which is determined by the area of the shape, S_{1235}. The area which is left unharvested by the teeth of two consecutive rakes is S_{345} (Figure 16), which characterises the unevenness of the picking reel's work.

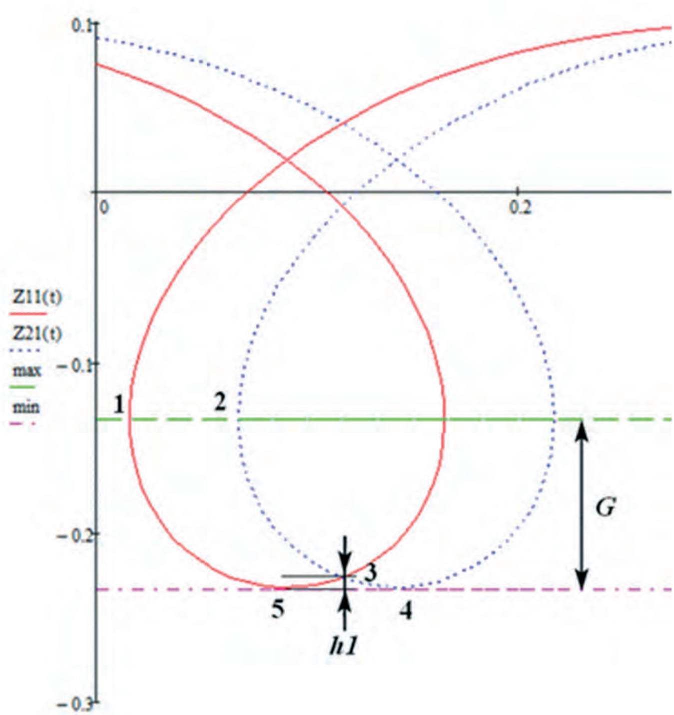


Figure 16. A scheme describing the movement of the free tips of teeth on two consecutive picking rakes when $Z = 4$.

The following relation can be used to determine the cross-sectional area S_{12345} which is harvested by the picking reel on the longitudinal vertical plane:

$$S_{12345} = \frac{2\pi r_B G}{Z\lambda} \tag{29}$$

When determining the cross-section of area S_{345} which is left unharvested, it is reasonable to offer a simplification, viewing the area of a shape which is determined by points 3-4-5 on Figure 16 as a triangle. In such a case, the area of the triangle S_{345} can be found as follows:

$$S_{345} = \frac{x_{54} h_1}{2}. \tag{30}$$

The height of triangle 345 or the height h_1 of the unharvested area can be found as follows:

$$h_1 = r_B - r_B cos\left(\frac{\pi}{Z(\lambda - 1)}\right). \tag{31}$$

The unevenness of harvesting Δ_{Re} [%] can be calculated using the formula:

$$\Delta_{Re} = \frac{S_{345}}{S_{12345}} 100. \tag{32}$$

The areal productivity levels for blueberry harvesting W can usually (Olt et al., 2019) be calculated as the product of the blueberry harvester's working width B_m and actual working speed v_k

$$W = 0.36 B_m v_k \tau \Theta. \tag{33}$$

The utilisation of the unit's width $\Theta \leq 1$ (usually $\Theta = 0.9\text{-}1.0$), $v_k = v_m(1 - \delta)$ and sliding factor $\delta \leq 1$.

On the other hand, productivity can be expressed by the machine's harvesting power q which is measured by the mass of harvested berries kg h^{-1}

$$W = \frac{q\tau}{Q_b(1 + \delta_P)}. \tag{34}$$

Taking into account the relations (33) and (34), we can calculate the blueberry harvester's picking power q as follows:

$$q = 0.36 B_m v_m \Theta Q_b \left(1 + \delta_p\right). \qquad (35)$$

3.6. Selecting the material for the reel's teeth

Any description of those forces that are applied in the blueberry harvester's picking reel should be based on the coordinate system $O_1X_1Z_1$ (Figure 14), as related to the berry that is to be removed, where the origin O_1 is located at the connection point between the berry and the stem, axis Z_1 is parallel to the blueberry plant, and the positive direction of the axis is directed towards the berry's surface and mainly forms a right angle with the non-deformed tooth.

The following forces are applied to the connection point between the berry and the tooth (Figure 5).

In order to separate the berry from the stem, the force F_x which is applied to the connecting stem must be greater than the connection force $F_{c, max}$ between the berry and the stem.

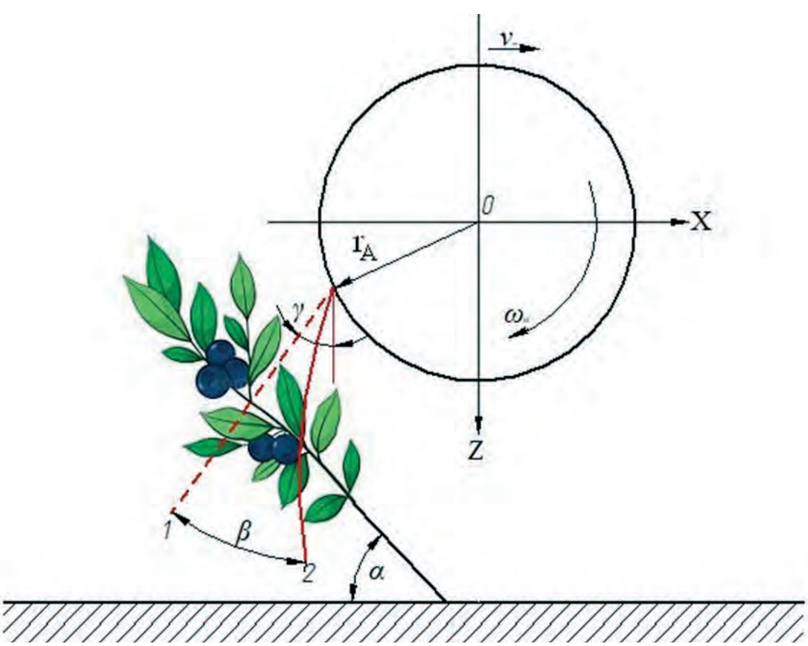


Figure 17. A diagram which characterises the work of a picking tooth.

The tooth of a picking reel is straight in the unstressed position (Figure 17, position 1). Due to force F_c, the stressed tooth attains position 2, which forms a flexure in comparison to the straight tooth, as expressed by the angle of inclination β. The angle of inclination γ of the blueberry harvester's prototype can be changed within the range of 40°-70°.

The extent of any bending is determined by the value of connection force F_c.

The berry is removed from the stem when the inequality (1) and following condition (36) is fulfilled:

$$\beta < \gamma, \tag{36}$$

where γ is the angle between the non-deformed tooth and the vertical direction.

The calculation of the force being applied to the tooth is based on the following assumptions:

1. The maximum yield of the blueberry plantation: 17,000 kg ha^{-1}, or 1.7 kg m^{-2} (Siliņa & Liepniece, 2020);
2. The mass of an individual berry: 0.14-3.4 g (Soots et al., 2017), while the average mass of the berry is 1.5 g.
3. Therefore, about a thousand berries grow over one square metre.
4. The blueberry harvester's prototype (Paper III) has teeth that are placed 21.5 mm apart, with a length of 125 mm. The maximum working area for one pair of teeth is 0.27×10^{-3} m^2.

As arising from assumptions 1-4, there are three berries for one pair of teeth during a working cycle (Figure 14, P1-P3). When we apply a reserve factor of three, a pair of teeth will pick about ten berries during one working cycle.

According to Paper **II**, the connection force of berries that are ripe for harvesting was 0.17-0.83 N and 0.89-1.93 N for unripe berries. The numerical ratio between ripe and unripe berries during harvesting season is 80% and 20% respectively. Therefore, the maximum force to be applied to one pair of teeth is 12 N.

The gravitational force that results from the tooth's mass itself is small (0.025 N for a tooth diameter of 4.3 mm and 0.038 N for a tooth diameter of 5.3 mm), and may be dismissed. Likewise, the gravitational force that results from the berry's mass may be dismissed as its maximum value is 0.034 N.

Selecting the materials for the teeth. an engineering plastic Ertacetal C (Acetal Copolymer, POM-C) was chosen as the material for the flexible teeth as it is characterised by its great mechanical strength, its impact strength, and its ability to be treated by cutting (Olt & Arak, 2012).

Selecting the diameter of the teeth. Two choices of material were selected so that the test could be carried out, with a round cross-section of the diameters of 4.3 mm and 5.3 mm.

The following tests were carried out when it came to selecting the diameter of the materials being used on the picking reel teeth, *D*:

1) Determining the plastic deformation of the teeth by systematically bending the material at various diameters (4.3 mm and 5.3 mm);
2) The resistance of the teeth to breaking-in so-called semi-aggressive and aggressive bending modes.
3) Measuring the flexure of teeth at various loads.

3.6.1. Describing teeth flexure in theoretical terms with the FEM method

To investigate the flexure of the picking reel, we consider the tooth as being a cantilevered homogeneous beam (Fig 18). This beam is characterised by the modulus of elasticity E_m and the moment of inertia *I*.

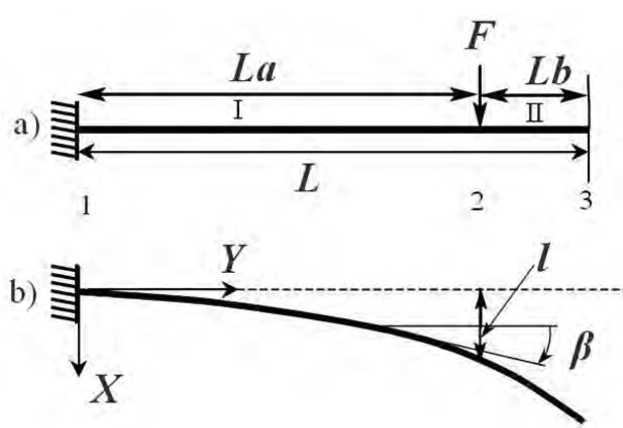


Figure 18. Cantilever beam subjected a concentrated load
a) unloaded beam,
b) loaded beam.

The finite element method, FEM, has been used to study tooth flexure (Logan, 2007). The picking reel's tooth (Fig 18) is rigidly attached at point 1 (Fig 18), and is loaded at point 2 by force *F*. The beam is now modelled using two elements, I and II, with nodes 1, 2, and 3 (Paper **VI**).

The local stiffness matrices for the elements I and II are K_1 and K_2 respectively

$$K_1 = \frac{E_m I}{La^3}\begin{bmatrix} 12 & 6La & -12 & 6La \\ 6La & 4La^2 & -6La & 2La^2 \\ -12 & -6La & 12 & -6La \\ 6La & 2La^2 & -6La & 4La^2 \end{bmatrix}, \tag{37}$$

$$K_2 = \frac{E_m I}{Lb^3}\begin{bmatrix} 12 & 6Lb & -12 & 6Lb \\ 6Lb & 4Lb^2 & -6Lb & 2Lb^2 \\ -12 & -6Lb & 12 & -6Lb \\ 6Lb & 2Lb^2 & -6Lb & 4Lb^2 \end{bmatrix}. \tag{38}$$

The total stiffness matrix *K* is the result of assembling K_1 and K_2.

$$K = K_1 + K_2 \tag{39}$$

Through direct super-positions and considering (37) and (38) the governing equations for this cantilever beam is

$$\begin{Bmatrix} F_{1y} \\ M_1 \\ F_{2y} \\ M_2 \\ F_{3y} \\ M_3 \end{Bmatrix} = K \begin{Bmatrix} d_{1y} \\ \beta_{t1} \\ l_t \\ \beta_{t2} \\ d_{3y} \\ \beta_{t3} \end{Bmatrix}. \tag{40}$$

Solving the equation (40) by boundary conditions and task settings for cantilever beam subjected a concentrated load (Paper VI), the displacement at node 2 is

$$l_t = \frac{{L_a}^3 F}{3E_m I} \tag{41}$$

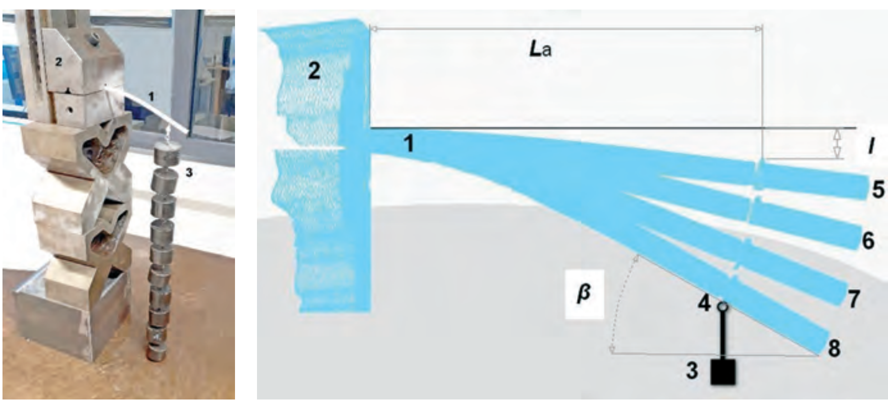
and the slope (in radians) at node 2 can be calculated

$$\beta_{t2} = \frac{2{L_a}^2 F}{E_m I}. \tag{42}$$

Equations (41) and (42) can be used to evaluate the flexure of loaded teeth of various dimensions, and to check the validity of condition (36) for the selection of the tooth's material.

3.6.2. Tests for studying teeth flexure

Tests were carried out with tooth materials of two different diameters: D_1 = 4.3 mm and D_2 = 5.3 mm. Tooth (1) was connected to the stand (2) as a cantilever (Figure 19, a). The tooth was stressed with plastic weights (3) which were connected to a point that was 20 mm from the free end. The loads were connected to the tooth (1) using a hinge (4) which ensures that the applied force is vertical. The room temperature was 22°C and relative humidity was at 26% during the tests (the value of the material's E_m was determined under the temperature and humidity conditions of 23°C and 50%).



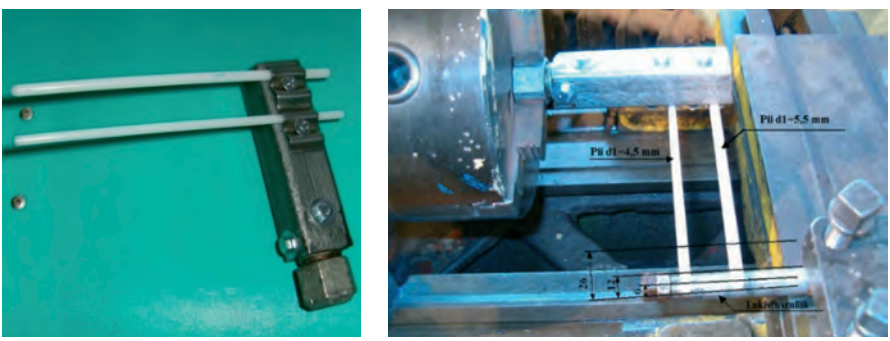
a) b)

Figure 19. Test stand for measuring the tooth's flexure (a) and a digital model of the tooth's flexure (b): three weights (position 5), six weights (position 6), nine weights (position 7), and twelve weights (position 8), where one is the deflection of the cantilever beam and L is the distance between the cantilever attachment point and the weight attachment.

The flexures of the tooth (1) under various loads were scanned using the portative laser scanner, a Nikon MCAx20/MMD50. After scanning, the resultant data was processed, a digital model was prepared, and flexure measurements were carried out using the software package, ANSYS SpaceClaim 2017.

3.6.3. Methods for determining the durability of the picking rake

In order to determine the durability of the picking rake's teeth, a durability test was organised to determine the levels of shatterproofing and plastic deformation using the multi-bending of teeth. A universal lathe, the 1K62, was used to artificially generate multi-bending (Olt & Arak, 2012). The laboratory test equipment included a fragment of a picking rake (Figure 20a) to which two teeth with diameters of 4.3 mm and 5.3 mm were fastened (*ie.* a comparative test was organised) to be able to supply a better overview. A fragment of picking rake was attached to the lathe's jaws (Figure 20b). A roller with the option of being able to rotate was fastened to the blade holder's support in order to generate an artificial obstacle to imitate rake teeth moving through the blueberry plants and the influence of the plants on the rake's teeth. The distance between the roller and the axis of rotation of the picking rake's fragment was smaller than the length of the rake teeth. During the rotational process, the rake tooth bends as it passes the obstacle.



a) b)

Figure 20. Experimental apparatus: a) a fragment of a picking rake to which rake teeth of 4mm and 5mm were attached; b) a fragment of a picking rake placed between the jaws of the lathe and roller fastened to the rest (Olt & Arak, 2012).

The rotational speed of the spindle imitated the picking reel's working mode on the assumption that the spindle's rotational speed n_s is greater than the rotational speed of the picking reel n_b, or $n_s > n_b$. The rotational speed of the lathe was chosen based on the kinematics parameter λ of the blueberry harvester's picking reel, whereby:

$$\lambda = \frac{\omega D_p}{2 v_m} , \tag{43}$$

where $D_p = 2\, r_A$.

As the picking reel's λ = 2.5, and the picking reel's angular velocity ω = $2\pi n_b$, the rotational speed of the picking reel can be expressed as follows:

$$n_b = \frac{\lambda v_m}{\pi D_p}. \tag{44}$$

If v_m = 33 m min^{-1} and D_p = 0.33 m, then n_b = 79.6 min^{-1}. Taking into account the condition $n_s > n_b$, the rotational speed of the lathe 1K62's spindle was chosen to be n_s = 100 min^{-1}.

The first stage of the durability test was used to determine the extent of plastic deformation for various diameters (4.3 mm and 5.3 mm) after repetitive bending cycles. The extent of plastic deformation can be determined using the bending angle of the rake's teeth as follows:

$$\beta_d = \arctan\frac{l_t}{L}. \tag{45}$$

Equation (45) can be used to check the condition of the material selected for the teeth (36) during the stress tests.

The rotating obstacle was placed 119 mm from the fastening clamp on the rake's tooth, *ie.* the distance from the rake tooth's free end to the central line of the obstacle or the contact point was 6 mm (Figure 20b). The diameter of the obstacle roller was 12 mm.

During the second test, the obstacle roller was moved 12 mm from the tip of the rake's teeth, which can be referred to as the semi-aggressive bending mode within the context of this thesis. During the third test, the obstacle roller was moved to a distance of 26 mm from the tip of the rake's teeth. This was done to imitate what could be referred to as the more aggressive working cycle's bending mode.

3.7. Collecting the information required for the automation of cultivation operations

The cultivation of berries, including blueberries, can be made even more effective when precision cultivation methods are used and its technological operations are automated and robotised. The introduction of precision cultivation includes increasing numbers of unmanned platforms (Dubbini et al., 2017; From et al., 2018; Grimstad & From,

2018) and agricultural robots (Hayashi et al., 2010, 2014; Yamamoto et al., 2010, 2014) for the performance of various technological operations.

Robotisation can be carried out if at least one of the following six conditions have been fulfilled (Bechar & Vigneault, 2016):

1) if the use of robots is economically more feasible than any other alternative method;
2) increased productivity and/or profitability in specific market conditions;
3) improved quality of production;
4) reduced uncertainty in the case of changing production conditions;
5) optimising production;
6) it allows production operations and/or activities to be carried out which are dangerous or which cannot be carried out manually at the required level.

Within the context of robotisation, the following claims can be made according to sources and information that has been obtained from the owners of blueberry plantations: robotisation is economically profitable in the long run (Bechar & Vigneault, 2017); the concept of using 'small' modular robots makes it possible to increase productivity and reduce the energy consumed per unit (Toledo et al., 2014); the implementation of robotisation increases the quality of fresh production (Bechar & Vigneault, 2016); the implementation of robotisation makes possible the mitigation of labour shortages in Estonian rural areas, and agricultural companies and technological operations can be carried out at agriculturally correct times (only limited by suitable weather conditions) (Estonian Organic …, 2014); the implementation of precision agriculture makes possible mitigating environmental effects (Bechar & Vigneault, 2017; Paper **V**).

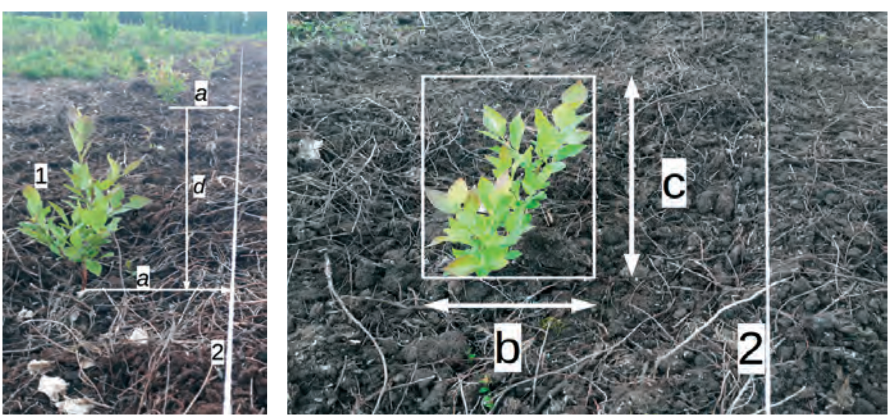
Therefore, it can be claimed that the majority of assumptions for the successful implementation of robotisation have been fulfilled.

In order to carry out automated operations in a blueberry plantation, first a blueberry plantation which has been established on a milled peat field needs to be described (including the positions of the plants and their dimensions).

Studies were carried out in June 2018 at Toomas Jaadla's Marjasoo Farm blueberry plantation, in Rannu Municipality in Tartu County (Estonia) (Fig 21).

Figure 21. A top view of the Marjasoo farm's blueberry plantation (photo: A Arula, Droon Phantom Advanced).

In order to determine the position of plants (1) (Figure 22) in each row, a straight length of rope (2) was placed a distance of 400 mm from the first and last plant in the row (to the side, next to the technical road), and a measuring tape was used to measure the parameters which describe the position of plants with an accuracy of 5 mm.



a) b)

Figure 22. Scheme to determine the parameters of a blueberry plant row, showing the parameters of the plant row (A) and the geometrical parameters of the plant (B): 1) plants; 2) base rope; a) the distance of a plant from the base (measuring) rope; b) the length of the plant's edge that is perpendicular to the measuring line to show the blueberry bush's projection; c) the length of the edge that is parallel to the measuring line to show the blueberry bush's projection; d) the distance between the plants.

3.8. Determining the vernalisation period

The duration of the vernalisation period is the sum of those positive temperature hours which are lower than 7.0°C (Sterne & Liepniece, 2010; Retamales and Hancock, 2018), or 7.2°C (Cantuarias-Avilés et al., 2014) between September and December.

This thesis treats the duration of the vernalisation period as the total of those positive temperature hours which are lower than 7.0°C.

The Estonian Weather Service has a network of observation stations which consists of a total of 96 weather stations (incorporating 57 hydrometry stations, 23 coastal stations, fifteen meteorology stations and one swamp station). The duration of the vernalisation period was calculated using data from a total of 52 weather stations (the choice of weather stations was based on as uniform a spread as possible across Estonia). Measurement data for temperatures was acquired from the Estonian Weather Service using a data request which came from the Estonian Environment Agency.

4. RESULTS

4.1. The relationships between various elements of a blueberry harvesting system

The elements of a system which is involved in the automated harvesting of blueberries include the blueberry plant itself - or, more precisely, its berries or the yield and stem which supports the berries - the general blueberry plantation, and the working equipment which together forms the overall blueberry cultivation system and subsystems. When the values for relationships between the elements are indeed known, it is possible to design a form of harvesting technology which avoids damaging the plant and berries during the process of harvesting.

Various relationships between the elements of the harvesting process have been described in Table 4.

Table 4. The functions of the system elements in the harvesting process

Element	Element			
	Berry/berries	Plant	Field	Working machinery
Berry/ berries	-	connecting element	material to be grown and harvested	material to be processed (harvested)
Plant	structure carrying the berries	-	Unit carrying the yield	element/ structure carrying the berries
Field	element containing nutrients	supporting ground for the plant	-	route used in machinery movement
Working machine	technical means mechanically influencing the berries	means of separating the berries from the stem	unit processing the plants and treading the field	-

The main characteristics of a system's elements in the harvesting process are described in Table 5.

Table 5. The main characteristics of a system's elements in the harvesting process

Element	Element			
	Berry/berries	Plant	Field	Working machinery
Berry/ berries	-	berry's connection force $F_{c,max}$ [N]	yield Q_b [kg ha^{-1}]	material to be harvested [m^3], [kg]
Plant	height of berry stem h_s [m]	-	planting scheme, a, b, c, d [mm]	tensile strength of plant's stem E_s [MPa]
Field	-	connection force of plant's stem to the roots F_a [N]	-	shear strength for field's soil E_p [kPa]
Working machine	lifting force of picking rake's teeth F_t [N]	elastic modulus of rake's tooth E_m [MPa]	productivity W [ha h^{-1}]; picking power q [kg h^{-1}]	-

4.2. A determination of the mechanical parameters of a cultivation system

4.2.1. A determination of the connection force of the berry on a blueberry plant

Test work was carried out on 3 August 2015, 10 August 2015, and 3 August 2016, all of which served to determine the connection force both for ripe and unripe berries and bunches of berries to the stem of the blueberry plant (Table 6).

Table 6. The average ($F_{C,aver}$), minimum ($F_{C,min}$) and maximum ($F_{C,max}$) connection force for ripe and unripe berries, the number of tests N, and the berry diameter D_b

	unripe berries			ripe berries		
date	03.08.15	10.08.15	03.08.16	03.08.15	10.08.15	03.08.16
N	5	6	10	7	6	7
D_b, mm	7.6-9.4	8.0-10.8	6.5-9.1	6.9-10.9	9.8-13.1	11.1-13.2
$F_{C,min}$, N	1.57	1.91	1.93	0.59	0.99	0.83
$F_{C,aver}$, N	1.42	1.45	1.15	0.41	0.51	0.66
$F_{C,max}$, N	1.27	1.00	0.89	0.17	0.29	0.53

The test results indicate that the tensile strength or connection force of individual unripe berries was within the range of 0.89-1.93 N. The test results showed that there is a positive correlation with average strength where the value of the correlation coefficient r is 0.63 (Paper **II**).

The tensile strength or connection force of ripe berries was within the range of 0.17-0.99 N, and a mean value of 0.53 N. The tests showed that there is a positive correlation with an average strength (r = 0.52) between the connection force and the berry diameter of unripe berries (Paper **II**).

The dependence of the connection force on the tension being applied to the ripe berry has been described in Figure 23.

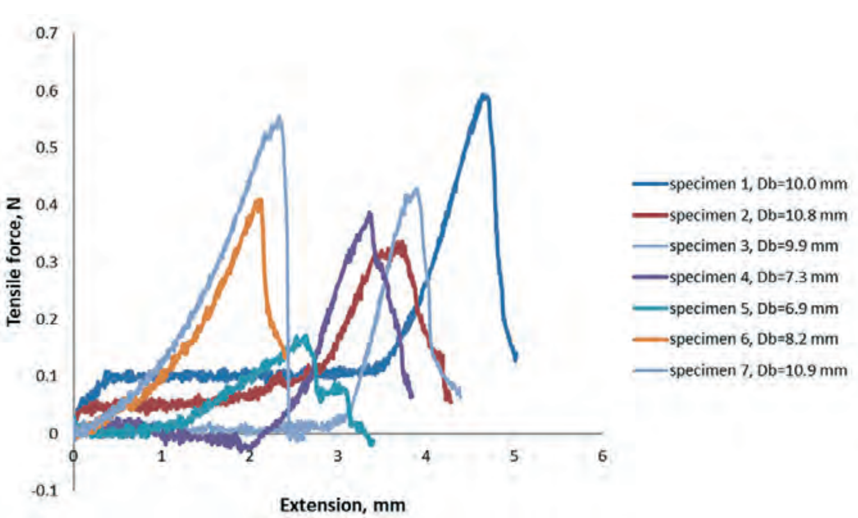


Figure 23. The connection force of ripe berries.

The force being applied to those berries which were attached to the stem in the form of bunches was within the range of 1-8.5 N. All of the berries were able to be separated individually from the stem and 90% of the berries were separated without tails (Paper **II**).

4.2.2. A determination of the tensile strength of the blueberry stem

The measured results were processed with the software, BlueHill 3 (version 3.15.1343), by Illinois Tool Works Inc. This was used to calculate the tensile stress σ [MPa], plastic deformation ε [%], and elastic modulus E_s [MPa]. The change of tensile force by the change of the length of the stem of a blueberry plant during the tensile test has been presented in Figure 20.

The test results showed that the elastic moduli E_s of the blueberry plant's stem remained within the range of 940-1605 MPa, but the average values for the elastic moduli E of three different test series differed only by 2.3% and remained within the range of 1268-1297 MPa (Paper **III**).

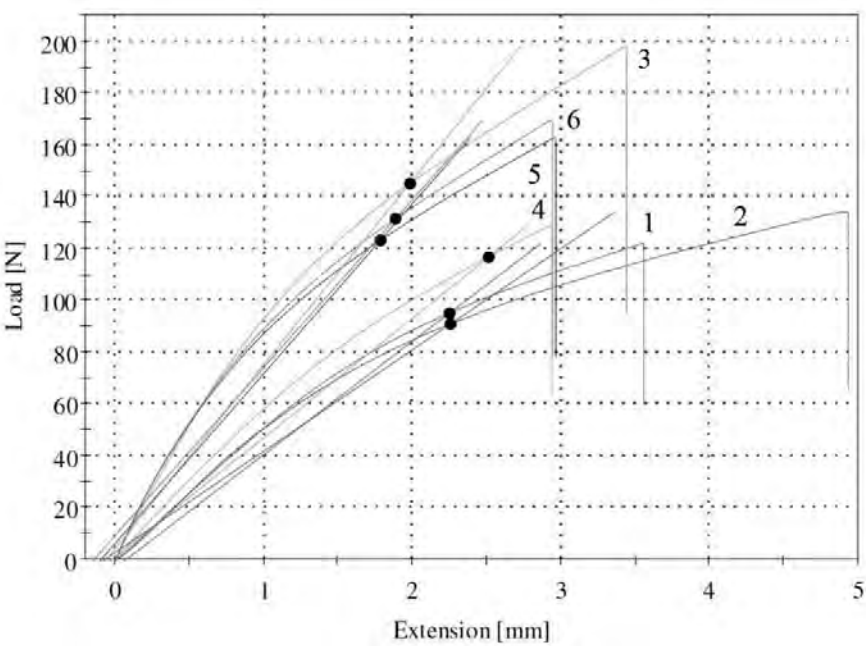


Figure 24. The relation between tensile stress and plastic deformation, with points indicating yield point and figures indicating specimen number (Paper **III**).

The correlation coefficient between E_s and D_b is -0.144, which expresses a weak correlation and, therefore, the use of stems of different diameters has no effect on the reliability of determining the value of E_s. The dependency of tensile force on any change in the length of the stem of the blueberry plant has been described in Figure 24, and this remains within the range of 100-200 N.

The properties of the blueberry plant's stem are probably influenced by its age. However, these tests did not take into account the effect of age, and such relations require further study.

4.2.3. A determination of the connection force of the blueberry stem

The measurements which were carried out on the Marjasoo farm's blueberry plantation on 22 August 2014, according to the methods that have been described in Chapter 3.4, showed that the force needed to pull the plant out of the ground according to this measuring method depends upon the duration at which the force is applied as described in Figure 25.

The plant's stem is torn out of the ground at the maximum value of the force described in the graph. The force as it is determined in this fashion describes the connection force of the plant to the ground.

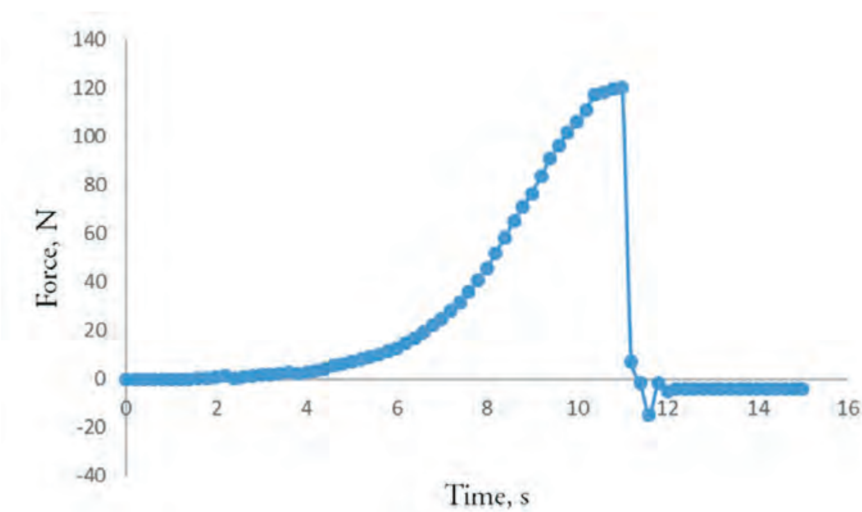


Figure 25. The determination of force required to pull the plant out of the ground in field tests.

Tests which were carried out in a six year-old plantation showed that the mean value of F_a is 96.4 N and, with 95% confidence, the mean value of the connection force remains within the range of CI (F_a) = (66.9;126.9) N.

4.3. A determination of the structural and kinematic parameters of the picking reel

The main structural and kinematic parameters of the picking reel on a lowbush blueberry harvester have been summarised in Table 7. In order to set up the blueberry harvester's picking reel even better, certain parameters on the prototype can be changed within a certain range, which is also given in Table 7.

Table 7. A technical characterisation of the picking reel

Parameter	Symbol	Unit	Calculated Value	Setting range
Radius of the picking reel	r_A	mm	165	
Length of the picking rake teeth	l_p	mm	135	
Rake angle of the picking rake teeth	γ	degree	30	40-70
Height of the axis rotation	H	mm	330	300-370
Number of picking rakes	Z		4	
Angular speed of the picking reel	ω	rad s-1	8.33	
Kinematic parameter	λ		2.5	

The inclination angle γ between the working surface of the rake's teeth and the vertical axis (Figures 13 and 17) can be determined by the condition under which, after removing the berry from the stem, the teeth of the rake should be able to transfer that berry to the next working unit, the tilted conveyor (Figure 11). Table 8 presents the results which describe the dependency of the picking range on the inclination angle γ of the teeth.

Table 8. The dependency of the picking range on the inclination angle γ of the teeth

γ, deg	*Max*, m	*Min*, m	*G*, m
30	-0.183	-0.282	0.099
45	-0.161	-0.260	0.099
60	-0.134	-0.233	0.099
70	-0.112	-0.211	0.099

The results from Table 8 show that the picking range of the prototype is around 100 mm, and that figure does not depend upon the inclination angle γ of the teeth. At the same time, choosing different values for the inclination angle γ on the teeth makes it possible to take into account the average height of specific blueberry varieties in plantations. Again at the same time, this range is sufficient as the majority of the berries are located at this height. The calculated unevenness of harvesting due to different structural parameters in the picking reel alters for the various values of Z or the number of picking rakes (Table 9).

Table 9. The dependency of uneven harvesting Δ_{Re} on the number of picking rakes and the kinematic parameter

λ \ Z	4	5	6
2	18.1	14.7	12.4
2.5	10.3	8.3	6.9
3	7.1	5.7	4.7

The information which is presented in Table 9 shows that any increase in the number of picking rakes Z and the kinematic parameter λ can reduce harvesting unevenness. However, increasing the number of picking rakes results in a more complex structure in the reel, with the result that the harvester requires more material while its mass increases and its controllability reduces. According to the equation (21), the kinematic parameters can be increased by reducing the harvester's movement speed (and thereby reducing the harvester's productivity levels), increasing the radius of the reel (and thereby increasing the reel's mass and reducing its controllability), and increasing the rotational speed (and thereby increasing the danger of damaging the plants and the berries, while also reducing controllability).

Figures 15 and 16 show that the area which the picking reel does not harvest is located near the ground and has the shape of a wave with a height of between 20-50 mm. This is an area in which practically no berries can be found anyway, so the somewhat reduced picking range and an unevenness of about 10% cannot be considered a structural flaw in the picking reel.

4.4. Selecting the materials for the blueberry harvester's teeth on a picking rake

The stressing of teeth using various weights (3 N, 6 N, 9 N, and 12 N) was intended to simulate the work of a tooth passing through the blueberry plant and removing berries from the stem.

The theoretical flexures β_t and measured flexures β_m for materials of various diameters have been given in Figure 26, where β_m. is the arithmetic means of the three series of measurements. The calculations were carried out in the Mathcad 15.0 environment.

For theoretical calculations, the value of E_m was selected to be 3000 MPa (Mitsubishi, 2020).

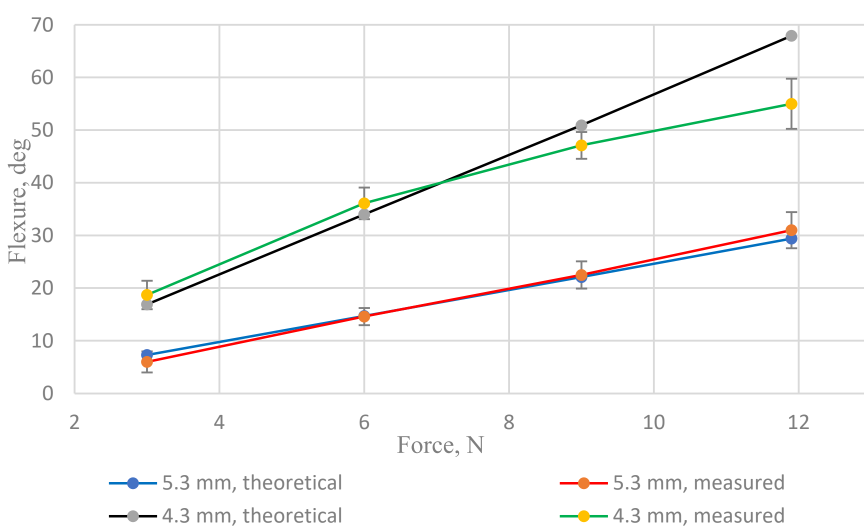


Figure 26. Calculated and measured (with standard deviation) flexure (in degree) of a tooth with a diameter of 4.3 and 5.3 mm.

Theoretical calculations (Eq 45 and 46) and test results (Fig 26) showed that the following results:

1) at maximum load (12 N), the flexure of the 5.3 mm diameter tooth test piece was at 35°;
2) the differences between the theoretical and test results for materials with diameters of 4.3 mm and 5.3 mm are 10.1% and 5.1% respectively.

The results show that both materials with both diameters are suitable as the materials for a picking reel's teeth as they both fulfil the condition that was stipulated by equation (12) under maximum load.

4.5. The results of the picking reel's durability test

The aim of the test work was to determine the plastic deformation of teeth of various diameters after multiple bending cycles. The plastic deformation of rake teeth was measured for 4.3 mm and 5.3 mm rake teeth after a total of 6,600, 10,000, 15,000, 20,000, and 23,300 bending cycles. The test results have been given in Figure 27. It became evident that plastic deformations start earlier for the thicker material, ie. the material with a diameter of 5.3 mm, and they become significantly greater than in the case of materials using the 4.3 mm diameter (Olt & Arak, 2012).

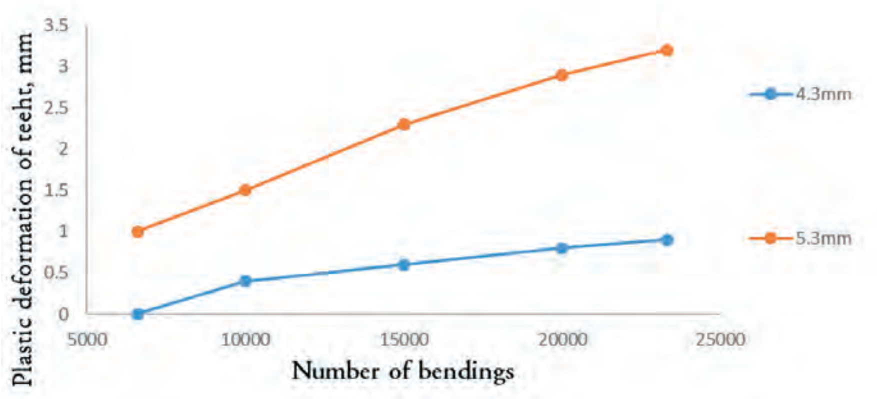


Figure 27. The permanent set of the teeth depending upon the number of bending tests.

During the next test work - what is known as the semi-aggressive bending mode - the 5.3 mm rake tooth sustained an average of 770 ± 34 bending cycles, while the rake tooth with a diameter of 4.3 mm sustained 1,330 ± 39 bending cycles.

During further testing - what is known as the aggressive bending mode - the 5.3 mm rake tooth broke on average during the fortieth bending cycle, while the 4.3 mm rake tooth broke on average during the fifty-second bending cycle. The outcome from the results that were obtained during the laboratory durability tests showed that the materials which should be selected for the picking reel's rake tooth was POM-C, with a diameter of 4.3 mm (Olt & Arak, 2012).

In order to check the results of the laboratory tests, a field test was organised to check the durability of the rake teeth on the blueberry harvester in terms of plastic deformation under actual working conditions. The blueberry harvester was put to work in the blueberry plantation on Marjasoo Farm. The area of test field that had been prepared for machine harvesting amounted to 0.416 ha from which the blueberries were to be harvested. None of the rake teeth broke during the test work, but the elastic after-effect on the rake tooth materials, POM-C, did become evident. The number of rotations that were made during the test work amounted to 19,104 rotations, and the average angle of deflection from the longitudinal axis was 1.2 ± 0.1 mm or 0.6°. This result reveals that bends with various levels of aggressiveness may occur during the harvesting process. Nonetheless, the elastic rake teeth do not tear the plant's stems and do not tear the plants from the ground. This blueberry harvester with its elastic rake teeth is protected by patent EE 05488 B1 (Patent I).

Based on the results of all three tests – the flexure, durability, and residual deformation tests – it is expedient to choose Ertacetal C with a diameter of 4.3 mm as the ideal material for the picking reel's teeth, as this diameter is more suitable for the design at hand than is the larger diameter (5.3 mm).

4.6. The positioning of blueberry plants in the plantation

The measurements were carried out on 11 June 2018 in the two-year-old blueberry plantation (a mixt of several varieties) at Marjasoo Farm

(Figure 21), and the plantation can be described in the following way according to randomly-chosen plant rows (Paper **V**):

1) The total length of the row of blueberry plants was 177 ± 5 m;
2) The distance between plant rows was 2.7 ± 0.5 m;
3) A technical road of 1.5 ± 0.4 m was located between the plant rows;
4) The number of plants in the row is 130 ± 15, out of which 10-15 plants that have dried and 2-5 planting holes hold two plants each or together.

It became evident during the positioning of the blueberry plants in a row that plants were positioned on both sides of the central axis and within the range of 600 ± 162 mm (Figure 28).

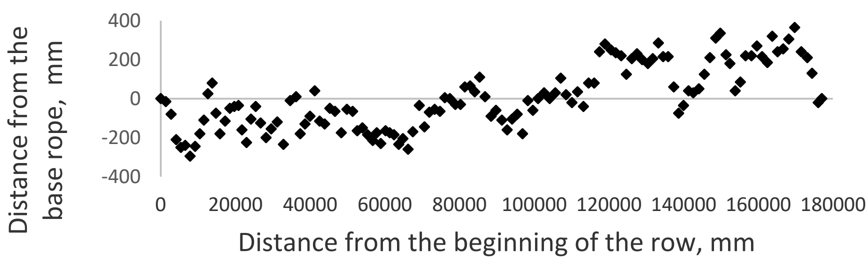


Figure 28. The position of blueberry plants in a row.

The plants are located 1372 ± 166 mm from one another on average, with the minimum and maximum distances between the plants being 915 mm and 1800 mm respectively.

In order to describe the source task for the robot, it is necessary to know the dimensions of the projection of the blueberry plant's leafage. If the shape of the projection of the plant's leafage is treated as a rectangle, then it can be claimed on the basis of this thesis that the perpendicular (b) and longitudinal (c) length of the leafage projection varies in a rather wide range between b = 50-480mm and c = 40-440 mm, and the average lengths of sides, including the standard deviation, are 180 ± 84 mm and 189 ± 87 mm.

In order to determine the clearance for robots, the height h_s of a blueberry bush must be known. Measurements gave an average result of 219.7 ± 57.9 mm, and the results of the height measuring process have been illustrated in Figure 29.

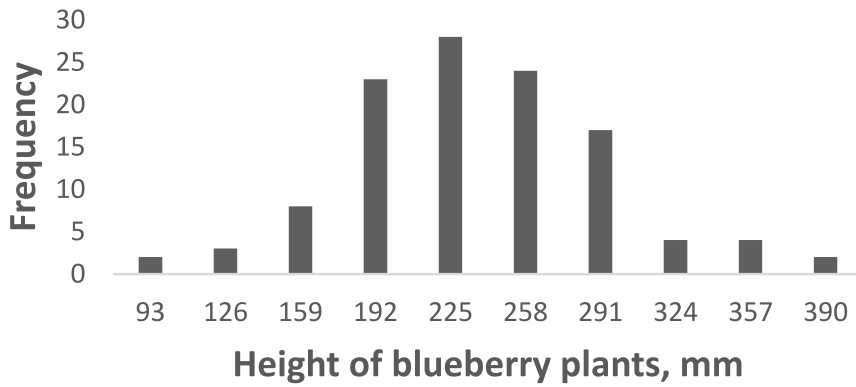


Figure 29. Histogram showing the upper limits of the height of blueberry plants.

The description of the blueberry plantation which has been obtained as the result of this study (involving the positions of the plants, their leafage projection, and the height of the plants) is used to carry out further research and development work in terms of the automation and mechanisation of blueberry plantations.

4.7. Determining the length of the vernalisation period in Estonia

The lengths of vernalisation periods which have been calculated using data from a total of 52 weather stations of the Estonian Weather Service (between 2016-2019) have been presented in Figure 30 (calculations were carried out in the MS Excel environment).

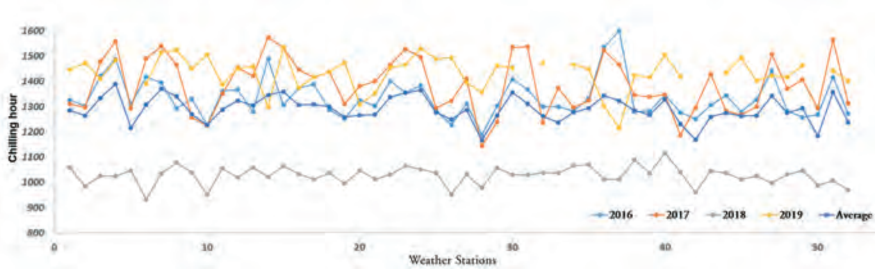


Figure 30. Vernalisation period in Estonia between 2016-2019 in data taken from 52 weather stations (raw data by the Estonian Environment Agency).

The minimum and maximum values for the observation period in Estonia remain within the range of 932-1,600 hours and have been presented in Table 11.

Table 11. Minimum and maximum values of the vernalisation period in Estonia during the years 2016-2019

Year	Ch_{min}	Ch_{max}
2016	1187	1600
2017	1144	1574
2018	932	1116
2019	1215	1535

The mean value for those years which have been studied when it comes to sub-optimal temperature periods amounts to 1,291 hours. With 95% confidence, the mean value for these sub-optimal temperature periods remains within the range of CI (*Ch*) = (1,267; 1,316) hours.

The long-term average daily temperature is measured during a climatic autumn (in which the average daily temperature falls below +13°C). The starting point for climatic autumn during the observation period (between 2016-2019) and the average daily temperatures in Estonia have been presented in Table 12.

Table 12. Starting point for a climatic autumn and average daily temperatures in Estonia during the years 2016-2019 (Estonian Weather Service, 2021)

Year	Beginning of climatic autumn			Average temperature in autumn
	Long-term average	Continental Estonia	Coastal Estonia	
2016	13.09	13.-14.09	02.10	6.1
2017	6.09	2.-15.09	27.-28.09	7.3
2018	23.09	23.09	23.09	8.5
2019	12.-16.09	12.-16.09	12.-16.09	7.7

The available data (shown in Tables 11, 12 and Figure 31) reveal the fact that, even during years which experienced a considerably warmer autumn period (such as 2018, when the observation period's average was 2.0°C higher than the climatic norm), the duration of the vernalisation period remains greater than 1,000 hours across the majority of Estonia.

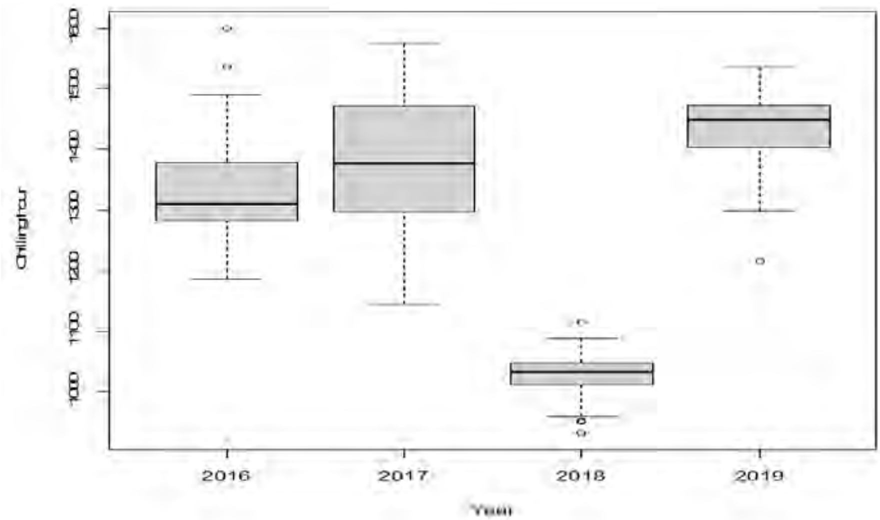


Figure 31. The duration of the vernalisation period in Estonia during the years 2016-2019.

The locations of weather stations have been given in Figure 32 (the choice of measuring stations took into account the availability of temperature data and uniform positioning across Estonia).

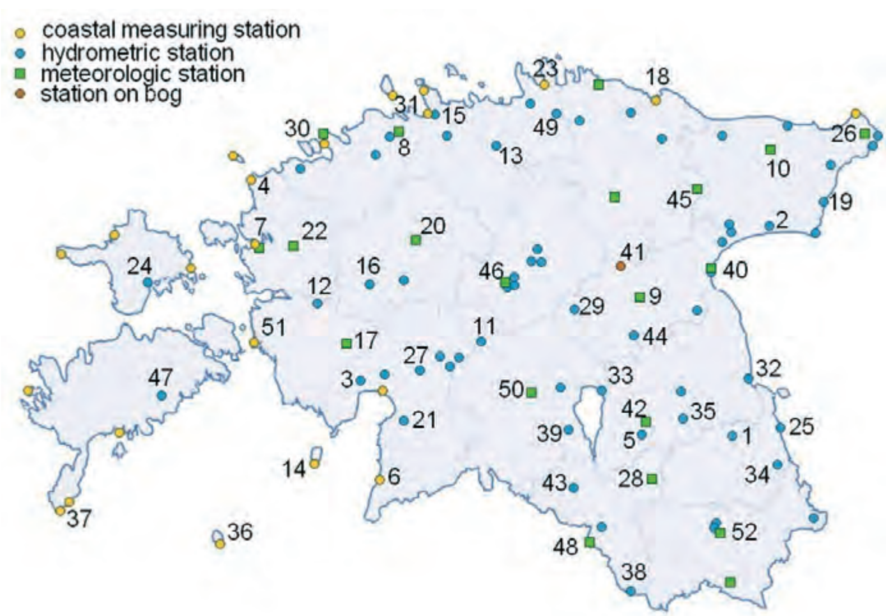


Figure 32. Locations of the weather station of the Estonian Weather Service. The 52 measuring stations being used in the calculation of the duration of the vernalisation period have been marked by numbers (numbering is based on the alphabetic order of stations).

The analysis of the durations of the vernalisation periods during the years 2016-2019 reveals that climatic conditions were suitable for establishing lowbush blueberry plantations and for growing blueberries in Estonia.

4.8. Technical solutions regarding blueberry cultivation technology

The circular scheme regarding the technological operations that are involved in blueberry production has been presented in Figure 33 (Olt & Arak, 2012), to which have been added the technical and technological equipment and means and machines that have been developed (Paper **I**; Patent **I**, Patent **II**).

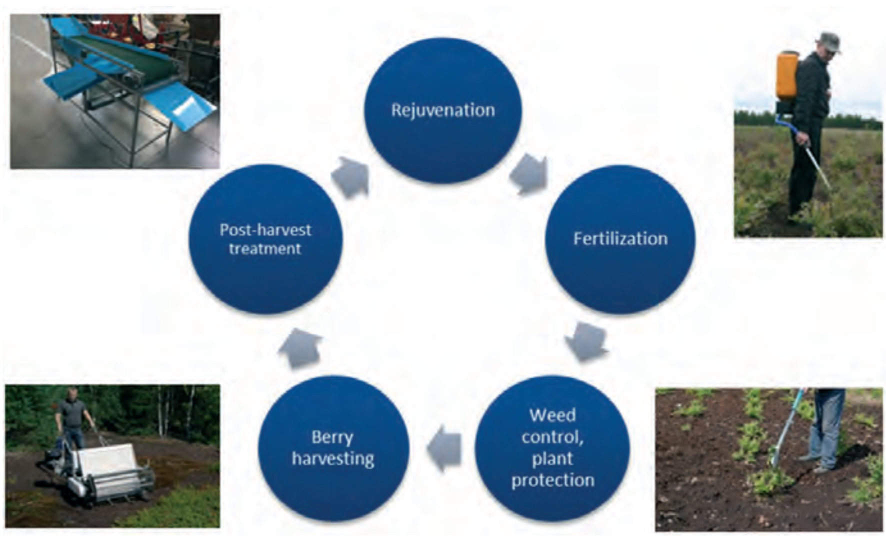
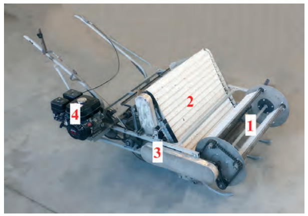


Figure 33. The technological steps with already-developed equipment which has been involved in blueberry production.

The novel solutions which have been developed within this doctoral thesis have been presented in Table 13.

Table 13. Technical solutions for blueberry cultivation technology

Unit	Design	Short description	Main characteristics	Novelty features
Blueberry harvester		Prototype motoblock-type blueberry harvester, consisting of a picking reel with elastic teeth (1), transporter (2), frame (3), and engine (4), along with transmission mechanism (Patent I).	B_m = 0.8 m, h_s = 0.1-0.3 m q = 450k g h^{-1} More characteristics are shown in Table 14	The use of elastic teeth in the picking reel is to avoid tearing the plant stems.
Portable precision fertiliser spreader		The unit consists of three main modules: the fertiliser container (1); an electronically-controlled doser with a stepping motor (2); and a pipe-shaped fertiliser duct with a handle (3) and push button.	V_{fs} = 20L Δ_{Vfs} = 2-60 g W = 0.05 ha h^{-1}	The use of a rotary volume-based doser to adjust the fertiliser amounts.

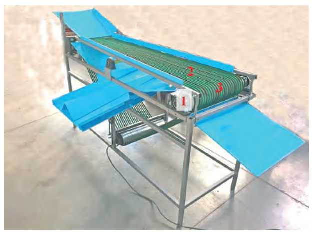
Weed spot-control applicator		The applicator consists of a bottle-shaped herbicide tank (1), a manipulator-like contact head (2), and a shallow connection pipe in between. The connection pipe is provided with a support handle which has a trigger-shaped lever (3), to serve to control the manipulator, and a holding handle with which to direct the contact head.	V_w = 1.5 L W = 0.03 ha h^{-1}	An anti-drip solution for dosing the plant with plant protection products.
Berry sorter		A belt sorter for sorting berries according to their size which has an adjustable roller (1) to smoothly change the distance between belts (2), while also containing belt pulleys (3) to carry belts, a guide shaft which is located inside the belt pulleys, a tubular sleeve with a slit which is located around the guide shaft, guide pins which connect the belt pulleys to the guide shaft, a corrugated cover, an adjusting disc, a handle, and a fixator (Patent II).	n_f = 3 w_b = 4-14 mm v_s = 0.12 m s^{-1} W=300-350 kg h^{-1}	The smooth (without increments) and quick adjustment of the distance between belts.

Table 14. Main characteristics of motoblock type harvester

Parameter	Unit	Value (optimal value)
Ground speed	ms^{-1}	0.30-0.78 (0.55)
Working width	m	0.8
Calculated picking power	kg h^{-1}	450*
Container dimensions	mm	600×400×90
Range for picking (height of the blueberry plant)	m	0.1-0.3
Rake angle on the picking rake's teeth	deg	30-70
Harvesting loss	%	<5
Impurity concentration	%	<8
Ratio of damaged berries	%	<4
Power unit		Honda GX160
Engine power	kW	4.0
Wheels size		5.00-9
Weight	kg	172
Picking teeth material		ERTACETAL C (POM-C)
Picking teeth diameter	mm	4.3
Picking teeth length	mm	135
Picking reel diameter	mm	165

*According to different works (Käis & Olt 2010; Jim, 2012), the productivity of harvesting manually depends upon the worker and their experience, and may remain within the range of 5-7 kg h^{-1}. Therefore, the theoretical picking power of a blueberry harvester is about sixty times higher than the productivity of a manual worker.

CONCLUSIONS

Due to a lack of mechanisation and specific technology, blueberry cultivation on milled peat fields is not particularly common, while also not being very profitable (both in Estonia and in the rest of the world).

The aim of this doctoral thesis was to develop the technology to permit automated harvesting for lowbush blueberries which have been grown in milled peat fields in order to reduce manual production requirements.

The following tasks were resolved so that the overall aim could be achieved:

1) the relationship between the various elements which are involved in blueberry cultivation (berry-plant-field-machine), all of which have been described;
2) the mechanical parameters of the cultivation system (berry and stem) have also been described;
3) a novel picking element was designed for the blueberry harvester;
4) the duration of the vernalisation period in Estonia was determined;
5) technical solutions were created so that automated technological operations could be successfully carried out (blueberry harvester, portable precision fertiliser spreader, portable precision fertiliser spreader, berry sorter).

The studies that have been carried out and the solutions which have been developed could help in and become a prerequisite for the development of new equipment which will serve to foster the establishment of new blueberry plantations, first and foremost on milled peat fields, but also in terms of increasing profitability levels and reducing the ecological footprint in already-established blueberry plantations.

RECERENCES

A&B Packing. 2021. https://www.abpacking.com/ (22.06.2021)

Acadian Machine. 2021. https://acadianmachine.com/ (20.06.2021)

Ammann H. 1999. FAT-Berichte Nr. 539: Maschinenkosten 2000. Kostenansätze Gebäudeteile und mechanische Ein-richtungen. Tänikon, Eidgenössische Forschungsanstalt für Agrarwirtschaft und Landtechnik.

Anier T. 2012. Methods for the restoration of extracted peatlands and their environmental analysis (in Estonian).Jääksoode korrastamise erinevad meetodid ja nende keskkonnakaitseline analüüs. Bachelor Thesis. Tartu Ülikool

Baby, B., Antony, P., Vijayan, R. 2018. Antioxidant and anticancer properties of berries. Critical Reviews in Food Science and Nutrition, 58 (15), 2491-250.

BBC TECHNOLOGIES LTD. 2021. https://www.postharvest.biz/en/company/bbc-technologies/_id:63128,seccion:productcatalog,producto:11371/ (22.06.2021)

Bechar, A., Vigneault, C. 2016. Agricultural robots for field operations: Concepts and components. Biosystems Engineering, 149, 94-111.

Bechar, A., Vigneault, C. 2017. Agricultural robots for field operations. Part 2: Operations and systems. Biosystems Engineering, 153, 110-128.

Belov, M. 2018. Kinematics of twin rotary tiller. AgricEngInt: CIGR Journal Open access at http://www.cigrjournal.org Vol. 20, No. 4 91

Bergs, J., Ivanovs, S., Melece, B. 2008. Research in the growing technology of cultivated cranberries and bush blueberries. In: Proceedings of 7th International Scientific Conference on Engineering for Rural Development, 136-140.

Bertz, G. 1960. Dispositif de réglage de grandeurs de classement applicable à des machines de classement. France patent FR1248240. https://worldwide.espacenet.com/patent/search/family/008724643/publication/FR1248240A?q=FR1248240 (19.06.2021)

Bouchard, S.; Tremblay, B. 2000. A harvester for picking berries. Canada Patent CA2241386A1. https://worldwide.espacenet.com/patent/search/family/029409518/publication/CA2241386A1?q=CA2241386 (19.06.2021)

Boylan, N., Long, M., Mathijssen, F.A.J.M. 2011. In situ strength characterisation of peat and organic soil using full-flow penetrometers. *Canadian Geotechnical Journal*, 48, 1085–1099, doi: 10.1139/T11-023.

Bragg D.; Weatherbee, l. 1985. Blueberry Harvester. Canada Patent CA1249727A. https://worldwide.espacenet.com/patent/search/family/004130955/publication/CA1249727A?q=CA1249727 (19.06.2021)

Brinton, D. T. 1957. Picker for berries and the like. US Patent US2780905A. https://worldwide.espacenet.com/patent/search/family/023404508/publication/US2780905A?q=US2780905 (19.06.2021)

Bruce, A. R.; Kilgour, J.1984. Grader. Great Britain patent GB2140712. https://worldwide.espacenet.com/patent/search/family/010543464/publication/GB2140712A?q=GB2140712 (19.06.2021)

Cantuarias-Avilés, T.; Rodrigues da Silva, S; Medina, R; Alberti, A (2014). Variety introduction of low chilling demand in the State of São Paulo. (in portuguese) Cultivo do mirtilo: atualizações e desempenho inicial de variedades de baixa exigência em frio no Estado de Säo Paulo. Revista Brasileira de Fruticultura, 36(1), 139-147.

Celik, A., Altikat, S. 2008. Geometrical analysis of the effects of rotary tiller blade path on the distribution of soil slice size. Applied Engineering in Agriculture. Vol. 24(4): 409-413

Celik, A., Ozturk, I., Way, T., R. 2008. A Theoretical Approach for Determining the Irregularity of Soil Tillage Depth Caused by Horizontal Axis Rotary Tillers. Agricultural Engineering International: the CIGR Ejournal. Manuscript PM 08 003. Vol. X.

Chattopadhyay, P.S. & Pandy, K.P. 1999. Mechanical properties of sorghum stalk in relation quasi-static deformation. *J. Agri. Res.*, 73, 199-206.

Cubero, S., Diago. M. P., Blasco, J., Tardaguila, J., Millan, B., Aleixos, N. 2014. A new method for pedicel/peduncle detection and size assessment of grapevine berries and other fruits by image analysis. Biosystems Engineering, 117(C), pp. 62-72.

Dillon, P. 2000. Backpack spreader. US Patent US6089477A. https://worldwide.espacenet.com/patent/search/family/022844109/publication/US6089477A?q=US6089477A (19.06.2021)

Dubbini, M., Pezzuolo, A., De Giglio, M., Gattelli, M., Curzio, L., Covi, D., Yezekyan, T. & Marinello, F. 2017. Last generation instrument for agriculture multispectral data collection. Agricultural Engineering International: CIGR Journal 19(1), 87 93.

Ehret D.L., Frey B., Forge T., Helmer T., Bryla D.R., Zebarth B.J. 2014. Effects of nitrogen rate and application method on early production and fruit quality in highbush blueberry. *Canadian Journal of Plant Sciences*, 94: 1165-1179.

Elifab. 2021. https://www.elifab.com/ (10.06.2021)

Emerson, Z. 2005. Berry harvester. US Patent US6854255B1. https://worldwide.espacenet.com/patent/search/family/034116801/publication/US6854255B1?q=US6854255 (19.06.2021)

Esau, T., Zaman, Q., Email Author, Groulx, D., Farooque, A., Schumann, A., Chang, Y. 2018. Machine vision smart sprayer for spot-application of agrochemical in wild blueberry fields. Precision Agriculture, 19 (4), Issue 4, 770-788.

Estonian Organic Farming Development Plan 2014-2020. (in Estonian) 2014. Annex I to ministerial decree No 95 “”Estonian Organic Farming Development Plan 2014-2020” and endorsement of its action plan”, of 27 June 2014, from the Minister of Agriculture.

Estonian Horticultural Sector Development Plan for 2015-2020 (in Estonian) 2015. Ministerial decree No 25 of 3 February 2015 from the Minister of Agriculture.

Estonian Weather Service. 2021. http://www.ilmateenistus.ee/ilmatarkus/publikatsioonid/aastaraamatud/ (15.02.2021)

Evans E.A., Ballen, F.H. 2014. An Overview of US Blueberry Production, Trade, and Consumption, with Special Reference to Florida. https://edis.ifas.ufl.edu/pdffiles/FE/FE95200.pdf, 01.05.2020.

FAOSTAT. 2020. The Food and Agriculture Organization of the United Nations. Blueberries. http://www.fao.org/faostat/en/#data/QC/visualize (15.01.2021)

Farooque A.A., Zaman Q.U., Schumann A.W., Madani A. Percival D. C. 2012. Delineating management zones for site specific fertilization in wild blueberry fields. Applied Engineering in Agriculture, 28 (1), 57-70.

Farooque, A.A., Zaman, Q.U., Groulx, D., Schumann, A.W., Yarborough, D.E., Nguyen-Quang, T. 2014. Effect of ground speed and header revolutions on the picking efficiency of a commercial wild blueberry harvester. *Applied Engineering in Agriculture*, 30 (4), 535-546.

From, P.J., Grimstad, L., Hanheide, M., Pearson, S., Cielnial, G. 2018. RASberry: Robotic and autonomous systems: For berry production. *Mechanical Engineering* **140**(6), 14-18.

Grimstad, L., From, P.J. 2018. A hardware and software modular robot for the agricultural domain. *Mechanical Engineering* 140(6), 9-13.

Grote, K.-H. & Feldhusen,J. 2007. Dubbel Taschenbuch für den Maschinenbau. Springer DE, 1798 pp.

Hall, I. V. & Aalders, L. E. 1982. Blomidon lowbush blueberry. *Canadian Journal of Plant Science*, 62, 519-521.

Hart J., Strik B., White L., Yang W. 2006. Nutrient management for blueberries in Oregon. EM8918. Oregon State University Extension Service. Corvallis, Oregon, 16 p.

Hayashi, S., Shigematsu, K., Yamamoto, S., Kobayashi, K., Kohno, Y., Kamata, J. & Kurita, M. 2010. Evaluation of a strawberry-harvesting robot in a field test. *Biorystems Engineering* **105**, 160–171. doi: 10.1016/j.biosystemseng.2009.09.011

Hayashi, S., Yamamoto, S., Tsubota, S., Ochiai, Y., Kobayashi, K., Kamata, J., Kurita, M., Inazumi, H. & Peter, R. 2014. Automation technologies for strawberry harvesting and packing operations in Japan. *Journal of Berry Research* **4**, 19–27. doi: 10.3233/JBR-140065

Heinloo, M. 2007. A Virtual Reality Technology Based Method for Study the Working Process of a Blueberry Harvester's Picking Reel. CIGR Ejournal, 9, 12 p.

Hong, S., Minzan, L., Zhang, Q. 2012. Detection system of smart sprayers: Status, challenges, and perspectives. International Journal of Agricultural and Biological Engineering, 5 (3. DOI: 10.3965/j.ijabe.20120503.00?

Hortifrut. Capital Incresae Roadshow. 2019. 32 p. Retrieved from https://www.credicorpcapital.cl/wp-content/uploads/2019/07/Hortifrut-Roadshow-Presentation-Aumento-de-Capital.pdf#page=25

James, E. R. 1943. Fruit and berry washing and grading equipment. US Patent US 2316159. https://worldwide.espacenet.com/patent/search/family/023545145/publication/US2316159A?q=US%20 2316159 (19.06.2021)

Jim, J. 2012. Mechanical Harvest of Fresh Blueberry. University of California http://cetulare.ucanr.edu/files/168378.pdf (28.07.2020)

Kalt, W., Cassidy, A., Howard, L.R., Krikorian, R., Stull, A.J., Tremblay, F., Zamora-Ros, R. 2020. Recent Research on the Health Benefits of Blueberries and Their Anthocyanins. *Advances in Nutrition*, 11 (2), pp. 224-236.

Karofeld, E., Jarašius, L., Priede, A. and Sendžikaitė, J. 2017. On the after-use and restoration of abandoned extracted peatlands in the Baltic countries. Restor Ecol, 25: 293-300. https://doi.org/10.1111/rec.12436

Karp, K., Starast, M. and Tiido, T. 2000. Frost damages of arctic bramble (Rubus arcticus) and half highbush blueberry (Vaccinium corymbosum × Vaccinium angustifolium) depend on cultivation methods. Proceedings of the International Conference: Fruit Production and Fruit Breeding. Tartu p. 244–247.

Kim, E., Freivais, A., Takeda, F., Li, C. 2018. Ergonomic evaluation of current advancements in blueberry harvesting. Agronomy 8(11), article number 266. https://doi.org/10.3390/agronomy8110266

Käis, L., Olt, J. 2010. Low-bush blueberry machine cultivation technology in plantation established on milled peat fields. 38th International Symposium on Agricultural Engineering Location: Opatija, CROATIA Date: FEB 22-26, 2010. Kosutic S. (ed.). *Actual Tasks on Agricultural Engineering*, **38**, 271-279.

Lakewood Process Machinery. 2021. https://www.lakewoodpm.com/ (22.06.2021)

Leit I. 2017. Effect of genotype and fertilization on the chemical composition of blueberries under organic farming conditions: master thesis. Eesti Maaülikool, Tartu, Estonia, (in Estonian), 46 p.

Littau Berry Harvester. 2020. The Original Littau Berry Harvester. https://littauharvester.com/or-berry-harvester/ (20.05.2021).

Logan, D.L. 2007. A First Course in the Finite Element Method. 5th Edition. Thomson, 753 pp. ISBN.13: 9780534552985

Magnusson, R. M.; Ragnarsson, E. T.; Steinsson, S. 1998. Apparatus for grading objects such as fish. Island patent WO9848951. https://worldwide.espacenet.com/patent/search/family/036699725/publication/WO9848951A1?q=WO9848951 (19.06.2021)

Magnusson, R.; Ragnarsson, E. T. 2006. Gap width adjustment mechanism for the belts for grading system. Island patent W0200612070. https://worldwide.espacenet.com/patent/search/family/036754605/publication/WO2006120706A1?q=WO2006120706 (19.06.2021)

Maine Blueberry Equipment Company. 2018. Sources of Rakes and Harvesters. https://extension.umaine.edu/blueberries/factsheets/production/sources-of-rakes-and-harvesters/ (15.01.2021).

Marsh, M. 2016. Blueberries: Harvesting methods, antioxidant properties and health effects. 116 p.

Mitsubishi Chemical Advanced Materials 2020. web page. https://media.mcam.com/fileadmin/quadrant/documents/QEPP/EU/Product_Data_Sheets_PDF/GEP/Ertacetal_C_PDS_E_01042019.pdf, 10.02.2022

Miu, P. 2016. Combine Harvesters: Theory, Modeling, and Design. CRC Press, Taylor & Francis Group- 460 p.

Moore, J. E. 1990. Manual devices and methods for selective application of chemical substances to plants. US Patent US4947580A. https://worldwide.espacenet.com/patent/search/family/027380945/publication/US4947580A?q=US4947580A (19.06.2021)

Noormets M., Karp K., Paal T. 2003. Recultivation of opencast peat pits with *Vaccinium* culture in Estonia. Iezzi E. et al. (eds). Ecosystems and sustainable development. Southampton, Boston, vol. IV (2), p. 1005-1014.

Olt, J., Käis, L. 2006. Mustikakoristi korjeorgani kinemaatika. Agraarteadus, XVII, 2: 96-100. (in Estonian)

Olt, J., Arak, M. 2012. Motoplokk-tüüpi mustikakombaini korjehaspli konstruktsioon ja arendus. *Agraarteadus*, XXIII, 2: 21-26. (in Estonian)

Olt, J., Soots, K. 2013. Belt sorter. Estonian Patent EE05642B1. https://worldwide.espacenet.com/patent/search/family/045468073/publication/EE05642B1?q=pn%3DEE05642B1 (26.09.2018)

Olt, J. 2015. Agricultural machinery I. KUMA Kirjastus (in Estonian)

Olt, J.; Küüt, K.; Ilves, R.; Küüt, A. 2019. Assessment of the harvesting costs of different combine harvester fleets. Research in Agricultural Engineering, 66 (1), 25−32. DOI: 10.17221/98/2017-RAE.

Oxbo Berry Harvesters. 2017. A complete family of solutions. Oxbo Int. Corp. 8 p. Retrieved from http://www.ammac.by/images/catalog/PLOEGER-OXBO/jagodi/OXBO930/Berry-17.pdf

Paal T., Starast M., Noormets-Šanski M., Vool E., Tasa T., Karp K. 2011. Influence of liming and fertilization on lowbush blueberry in harvested peat field condition. Scientia Horticulturae, 130 (1): 157−163.

Peatland Ecology Research Group. 2009. Production of berries in peatlands. Guide produced under the supervision of Line Rochefort and Line Lapointe. Université Laval, Quebec, Canada, 134 p.

Percival, J. P. 1956. Improvements in or relating to sorting or grading apparatus. Great Britain Patent GB745730A. https://worldwide.espacenet.com/patent/search/family/010190916/publication/GB745730A?q=pn%3DGB745730A (19.06.2021)

Rama, E., Nelson, B., Karmel, T. 2018. Blueberry Industry Outlook, MetLife. 5 p. Retrieved from https://investments.metlife.com/content/dam/metlifecom/us/investments/insights/research-topics/agricultural-finance/pdf/MetLife-Blueberry-Industry-Outlook_FINAL.pdf. ReportLinker

Ramst, R., Orru, M., 2009. Eesti mahajäetud turbatootmisalade taastaimestumine.Eesti Põlevloodusvarad ja -jäätmed. 1–2, 6–7 (in Estonian).

Retamales J. B., Hancock J. F. 2018. Blueberries (2nd ed.). Crop Production Science in Horticulture Agriculture, book 29. CABI, 424 p.

Robichaud, O. 1994. Blueberry harvester and method of harvesting blueberries. US Patent US5369944A. https://worldwide.espacenet.com/patent/search/family/022599769/publication/US5369944A?q=US5369944 (19.06.2021)

Silva, S., Costa, E.M., Veiga, M., Morais, R.M., Calhau, C., Pintado, M. 2020. Health promoting properties of blueberries: a review. Critical reviews in Food Science and Nutrition, 60 (2), 181-200.

Seenauth, H. 2004. Granular fertilizer spreader. US Patent US6729558B1. https://worldwide.espacenet.com/patent/search/family/032176353/publication/US6729558B1?q=US6729558B1 (19.06.2021)

Siliņa, D. & Liepniece, M. 2020. Variability in yield of the lowbush blueberry clones growing in modified soil. Agronomy Research 18(S4), 2770–2775.

Soots, K., Maksarov, V., Olt, J. 2014. Continuously adjustable berry sorter. Agronomy Research 12(1), 161–170.

Soots, K.; Krikmann, O.; Starast, M.; Olt, J. 2017. Determining the dimensional characteristics of blueberries. Agronomy Research, 15 (3), 886−896.

Stankavich, J. A; Stankavich, M. M.; Stankavich, M. S. 1950. Cranberry harvester. US Patent US2607180A. https://worldwide.espacenet.com/patent/search/family/026841455/publication/US2607180A?q=US2607180A (19.06.2021)

Starast, M., Karp, K., Tasa, T. 1999. Poolkõrge mustika sortide 'Northblue' ja 'Northcountry' talvekindlus. Eesti Põllumajandusülikool. Teadustööde kogumik 203: 162–163 (in Estonian).

Starast, M., Karp, K., Paal, T., Värnik, R., Vool, E. 2005. Kultuurmustikas ja selle kasvatamine. Eesti Põllumajandusülikool (in Estonian).

Starast M., Karp K., Vool E., Paal T., Albert T. 2007. Effect of NPK fertilization and elemental sulphur on growth and yield of lowbush blueberry. Agricultural and Food Science, 1: 34–45.

Starast, M.; Paal, T.; Vool, E.; Karp, K.; Albert, T.; Moor, U. 2009. The Productivity of Some Blueberry Cultivars under Estonian Conditions. IX International Vaccinium Symposium, Book Series: Acta Horticulturae Volume: 810, pp. 103-108.

Sterne, D., Liepniece, M. 2010. Preliminary observations of phenology development, yield and yield quality of some highbush blueberry cultivars in Latvia. 1. 60-64.

Stevens, A. M. 2000. Hand held motor driven applicators. US Patent US6032592A. Hand held motor driven applicators. https://worldwide.espacenet.com/patent/search/family/027157990/publication/US6032592A?q=US6032592A (19.06.2021)

Stiefvater, W.; Willi, M. 2005. Fruit size sorter has a transporting system of multiple, diverging belts which define a number of openings of gradually and continuously increasing width. Germany Patent DE10359369. https://worldwide.espacenet.com/patent/search/family/034683493/publication/DE10359369A1?q=DE10359369 (19.06.2021)

Strik, B. 2005. Blueberry: an expanding world berry crop. *Chronica Horticulturae*, 45(1): 7–12.

Takeda F., Yang W.O., Li C., Freivalds A., Sung K., Xu R., Hu B., Williamson J., Sargent S. 2017. Applying New Technologies to Transform Blueberry Harvesting. *Agronomy*, 7, 33. doi:10.3390/agronomy7020033.

Tasa, T., Starast, M., Jõgar, K., Paal, T., Kruus, M., Williams, I.H. 2015. Lowbush blueberry plantation age influences natural biodiversity on an abandoned extracted peatland. *Ecological Engineering*, 84, 336−345.

Toledo, O. M., Steward, B. L., Gai, J., Tang, L. 2014. Techno-economic analysis of future precision field robots. In: *Proceedings of American Society of Agricultural and Biological Engineerings Annual International Meeting 2014*, ASABE 2014, 5, 3151-3157.

TOMRA Food. 2019. https://www.tomra.com/en/sorting/food/your-produce/fruit/blueberries (10.06.2019)

Unitec. 2020. https://en.unitec-group.com/fruit-vegetables-technology/blueberry-processing-sorting-grading-machines/ (10.06.2021)

USHBC Export Databases. Fresh + Frozen Blueberry Sales: 2013 - 2017 Executive Summary April 2018. http://ushbc.org/wp- content/uploads/2018/10/IRI-Fresh-Look-USHBC-Spring-2018_FINAL.pdf 11.05.2020

Vahejõe, K., Albert, T., Noormets, M., Karp, K., Paal, T., Starast, M. & Värnik, R. 2010. Berry cultivation in cutover peatlands in Estonia: Agricultural and economical aspects. *Baltic Forestry*, 16 (2), 264−272.

Vainura K. 2018. The influence of Monterra Malt fertilizers on the productivity and fruit chemical composition of blueberry's selections (*Vaccinium*): master thesis, Eesti Maaülikool, Tartu, Estonia, 63 p. (in Estonian).

Valk, J. 2005. Sorting machine for bulb or tuber crops, comprises perforated conveyor belt and beam for pressing upwards against opening free region of belt. Netherland patent NL1024173C2. https://worldwide.espacenet.com/patent/search/family/034464847/publication/NL1024173C2?q=NL1024173 (19.06.2021)

Van, D. P.; Johannes, G. 1998. Method and device for sorting objects, in particular fruit and bulbous plants, with regard to their cross-sectional dimensioon. Netherland patent NL1006272C2. https://worldwide.espacenet.com/patent/search/family/019765130/publication/EP0884113A1?q=EP0884113 (19.06.2021)

Weatherbee, B.; Weatherbee, l. H. 1999. Blueberry harvester. US Patent US6000203A. https://worldwide.espacenet.com/patent/search/family/027170310/publication/US6000203A?q=US6000203 (19.06.2021)

Williamson, R. 2006. Adjustable size sorting apparatus for small produce. US Patent US20060113224. https://worldwide.espacenet.com/patent/search/family/036566386/publication/US2006113224A1?q=US20060113224 (19.06.2021)

Zhang, H. 2007. Back carried hand fertilizer spreader. China Patent CN2872822Y. https://worldwide.espacenet.com/patent/search/family/037779411/publication/CN2872822Y?q=CN2872822Y (19.06.2021)

Zwanenburg C., Van M.A. 2013. Full scale field tests for strength assessment of peat. In: Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris, 3329-3332.

Zydlik Z., Pacholak E., Rutkowski K., Styła K. 2016. The influence of a mycorrhizal vaccine on a biochemical properties of soil in the plantation of blueberry. Zemdirbyste-Agriculture, 103 (1): 61–66 DOI 10.13080/z-a.2016.103.008

Yamamoto, S., Hayashi, S., Saito, S., Ochiai, Y., Yamashita, T. & Sugano, S. 2010. Development of robotic strawberry harvester to approach target fruit from hanging bench side. *IFAC Proceedings Volumes* **43**(26), 95–100. doi: 10.3182/20101206-3-JP-3009.00016

Yamamoto, S., Hayashi, S., Yoshida, H. & Kobayashi, K. 2014. Development of a stationary robotic strawberry harvester with a picking mechanism that approaches target fruit from below. *Japan Agricultural Research Quarterly* **48**(3), 261–269. doi: 10.6090/jarq.48.261

Yarborough, D.E. 2012. Establishment and Management of the Cultivated Lowbush Blueberry (Vaccinium angustifolium), International Journal of Fruit Science, 12:1-3, 14-22, doi: 10.1080/15538362.2011.619130.

Yealands, S. W. 1998. Apparatus for grading mussels according to size, includes a support frame and spacing adjustment means. New Zealand patent NZ314846A. https://worldwide.espacenet.com/patent/search/family/019926251/publication/NZ314846A?q=NZ314846A (19.06.2021)

Yu, P., Li, C., Takeda, F., Krewer, G., Rains, G., Hamrita, T. 2014. Measurement of mechanical impacts created by rotary, slapper, and sway blueberry mechanical harvesters. *Computers and Electronics in Agriculture*, 101, 84–92.

KOKKUVÕTE

Kultuurmustikate kasvupind ja kogutoodang on maailmas viimaste aastatega oluliselt suurenenud. ÜRO Toidu- ja Põllumajandusorganisatsiooni andmetel kasvatati 2018. aastal kultuurmustikaid 113,000 hektaril ja kogutoodang ulatus 666,000 tonnini. Eestis on mustikate hinnanguline kasvupind kuni 80 hektarit.

Mustikakasvatus Eestis ei ole praegu eriti tulus, kuna mustikaistandused on väikesed ja töö põhineb suurel määral käsitsitööl.

Mustikaviljeluse arengu aluseks on tootmise mehhaniseerimine ja automatiseerimine. See seisneb ühelt poolt sobiva tootlikkusega masinate ja tehniliste vahendite arendamises ja ning teiselt poolt masinate kasutuskulude vähenemises.

Käesoleva doktoritöö eesmärgiks oli ammendunud freesturbaväljadel kasvatatava ahtalehise kultuurmustika masinviljelustehnoloogia väljatöötamine käsitööndusliku tootmise vähendamiseks.

Püstitatud eesmärgi täitmiseks lahendati järgmised ülesanded:

1) kirjeldati mustikaviljelussüsteemi erinevate elementide (mari-taim-põld-masin) vahelisi seoseid;
2) määrati viljelussüsteemi elementide (mari, vars) mehaanikalised parameetrid;
3) kavandati mustikakombaini uudse lahendusega korjeorgan;
4) määrati vernalisatsiooniperioodi pikkus Eestis;
5) loodi tehnilised lahenused tehnoloogiliste masinaliste tööoperatsioonide läbiviimiseks.

Teostatud uuringud ja välja töötatud lahendused võiksid olla abiks ja eelduseks uute tehnoloogiliste seadmete loomisel, mis aitavad kaasa uute mustikaistanduste loomisele eelkõige ammendunud freesturbaväljadele ning kasumlikkuse suurendamiseks ja ökoloogilise jalajälje vähendamiseks juba rajatud mustikaistandustes.

I

ORIGINAL PUBLICATIONS

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DEVELOPMENT OF MECHANICAL TECHNOLOGY FOR LOW-BUSH BLUEBERRY CULTIVATING IN THE PLANTATION ESTABLISHED ON MILLED PEAT FIELDS

MECHANINĖS TECHNOLOGIJOS IŠVYSTYMAS APLEISTŲ DURPIŲ LAUKUOSE ĮKURTOSE ŽEMAŪGIŲ MĖLYNIŲ KRŪMŲ AUGINIMO PLANTACIJOSE

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This article provides an overview of the technological peculiarities of a blueberry plantation established on exhausted and abandoned milled peat fields and the development of relevant machine cultivation technology and technological devices. The soil properties of exhausted and abandoned milled peat fields are specific to establishing blueberry plantations. This article outlines the problems that need to be resolved, tasks, generated technical ideas and methods of fulfilling these. In the framework of product development the following technological devices have been developed: a portable spot-fertilizing device; a portable contact-type weed control device; a motoblock-type blueberry harvester; and a blueberry sorting device. It also discusses the peculiarities of implementing these devices.

Low-bush blueberry, mechanical cultivation technology, engineering design and development, fertilization, weed control, berry harvesting.

Introduction

Growing commercial blueberries is a developing arm of the global berry-growing industry (Strik, 2005). In most countries commercial blueberries are consumed freshly as delicious berries. They boost health and provide essential nutrients needed by the human body. Blueberry cultivation is rather new in Estonian conditions, yet it is a continuously widening and developing plant growing industry. Thereby the biggest blueberry plantations in Estonia have been established on exhausted milled peat fields. Unfortunately, development of this field of activity is limited as there is no machine cultivation technology available for this. The machines currently used in blueberry cultivation cannot be used on abandoned milled peat fields. One of the reasons is that the machines are meant for harvesting high-bush blueberry species and are thus big, sturdy and heavy and cannot be used on turf soil in bog conditions.

In Estonia, commercial blueberries can be grown on exhausted and abandoned milled peat fields, where the layer of residual turf is sufficiently thick. Blueberries are not demanding plants and prefer acidic soils, the optimal pH level is between 4.5 and 5.5 (Hall et al., 1964; Holmes, 1960; Starast et al., 2009). The area of exhausted and abandoned milled peat fields in Estonia is approximately 8000 ha, of which over 2000 ha is suitable for blueberry cultivation (Ilomets, 1996; Paal et al., 1998). 73 ha is already in use, but this represents an insignificant proportion of production capacity.

At present, blueberry cultivation on exhausted and abandoned milled peat fields is done manually in Estonia. This has been the major obstacle in the development of blueberry plantations on exhausted and abandoned milled peat fields.

Blueberry cultivation consists of the following work phases: soil preparation; planting; plant fertilization; plantation maintenance; weed control; plant protection; and crop harvesting, which is followed by post-harvesting processing of the crop. The lifetime of a blueberry plantation is approximately 30-40 years.

The wider objective of this study is to assist in developing mechanical cultivation technology for low-bush blueberries on exhausted and abandoned milled peat fields in Estonia. Although the aim is to offer advanced solutions for a new and economically efficient arm of berry cultivation, it also has a significant positive impact on the environment. Because of turf production there are thousands of hectares of abandoned milled peat fields in Estonia. On bare and plant-free milled peat fields turf is constantly mineralising, in the process of which carbon dioxide is emitted. As there is no vegetation locally, huge quantities of CO_2 are intensively emitted directly into the atmosphere. Thus it is considered very important to find solutions to introduce new vegetation to exhausted milled turf areas. Establishing a low-bush blueberry plantation on abandoned turf areas would help significantly in restoring balanced carbon circulation in exhausted peat fields. Developing special machine technology for blueberry cultivation that have significantly reduced production costs would facilitate even wider use of peat fields. Technological solutions developed could also be implemented more widely. Also, other countries leading in turf production are facing a need to solve similar environmental problems. Like Estonia, blueberry cultivation with the aim of reducing environmental risks has started in Finland, Latvia, Lithuania, Belarus, Canada and elsewhere.

In a narrower meaning this article focuses on mechanical or machine-based blueberry harvesting and maintenance during growth, since these are major cost sources of crop-giving plantations – manual work is not economically profitable and there is insufficient labour for manual harvesting.

Description of technology

Plantation preparation includes minimal cultivation work, which in any production strategy involves the cleaning of draining ditches, the excavation of water furrows, the removal of stubs from the surface layer and shaping of the soil. For soil preparation, machines and technological solutions well known in soil improvement can be used.

Plants are planted in a row with a plant step of 0.9-1.0 m and a distance between rows of 0.9-1.0 m. The plants are planted manually or with the help of a planting machine.

Fertilizing a blueberry plantation. The fertilizer level of an abandoned milled peat field is close to zero. Broadcast fertilization of a blueberry field with a centrifugal-type disc spreader is not feasible, since it would also encourage weed growth on the field. Nevertheless, the plants must be fertilized. According to the data of Noormets et. al. (2002) and Paal et al. (2011) the fertilization of young low-bush blueberry plants resulted in a crop yield of 2190-2930 kg ha^{-1}, whereas the crop yield of unfertilized plants was just 173 kg ha^{-1}. These data speak for themselves. Use of a compound fertilizer (N19, P24 or K48) resulted in bigger berries and higher crop yield.

Blueberry plants must be fertilized twice a year:

1) in spring (April) – granulated fertilizer as top dressing; and
2) during formation of the berries (June) – liquid fertilizer as leaf dressing.

Maintenance of plantation – weed control. A small planation of no more than a couple of hectares can be maintained manually. If the plantation is bigger, manual maintenance is unreasonable since it is very labour-intensive. Where weeds are concerned, Tussoc cotton-grass and birch prevail. Plantation maintenance includes weeding and, if necessary, trimming. So far, plantation maintenance on Estonian low-bush blueberry plantations has been done manually.

Plant protection. At the outset, plantations established on exhausted milled peat fields are free from plant diseases and plant pests. At present, plant protection products sprayed from sprayers carried on the back during spraying and/or contact plant protection products are used on Estonian blueberry plantations.

To date, blueberries have been harvested manually in turf moss.

The maturing signs of a blueberry bush are the splitting of the branch bark and its darkening and drying. The number of new growth branches is reduced. Also, lighting conditions within old bushes are reduced, which in turn reduces the intensity of photosynthesis. In order to prevent this, it is recommended to cut back the older branches of semi-high and low-bush blueberry species. In production plantations, cutting back single branches is very labour-intensive.

Considering the fact that berries grow on young branches, their growth must be promoted by means of cutting. In the case of free thinning, old branches are removed from the bushes. Approximately 4-6 strong one-year branches and 3-6 copiously branched several-year-old branches should be left in place. In a bush with a thin crown, all berries grow in good lighting conditions. Free thinning is labour-intensive and thus on bigger plantations rejuvenation cutting may be done. In this case all branches are cut to the ground in early spring, leaving stubs with a length of a couple of centimetres. It is important to leave stubs, since new shoots start growing from sleeping buds on the stubs.

Materials and methods

In the development of machine cultivation technology the well-known TRIZ method was used, which in this case consisted of the following basic steps (Pahl et al., 2007):

1) determination and formulation of the problem;
2) setting of the objective;
3) searching for typical problems similar to the objective set;
4) analysis of known technical and technological solutions;
5) generating and selecting ideas; and
6) choosing the most suitable solution for the problem needing to be solved.

The problems to be resolved and the development tasks were derived from the following:

1) in fertilizing blueberry plants – dosing of the fertilizer from both the quantity and precision of positioning perspectives and productivity of operations;
2) in maintenance – some weed species are also plants with two embryonic seed leaves like blueberry plants and thus well-known chemical weed control devices cannot be used;
3) in harvesting – jamming of a picking reel with metal tines of a motoblock-type harvester, which tears blueberry plants to pieces and pulls them out of the ground; and
4) the problem of post-harvesting processing – it is complicated to adjust well-known sorting devices to sort blueberry species of different sizes.

Determination of innovative objectives: Blueberry cultivation can be modernised by means of implementing machines. Use of machines in blueberry cultivation sets specific requirements (preconditions) on the plants:

1) mechanical harvesting is possible on constantly maintained and rejuvenated plantations;
2) to allow normal functioning of maintenance and harvesting machines the soil surface on plantations should be land-levelled and kept thus during usage;
3) to operate machines, service tracks (technological tracks) should be established; and
4) for successful machine harvesting, old branches should be cut back regularly – first rejuvenation cutting is done in the 4^{th} or 5^{th} year, afterwards every 2-3 years.

Plants should be planted in beds which are separated with service tracks for technological machines. As the distance of the centre lines of the draining ditches dug between the fields established for excavating milled peat is 20 m and the width of the ditches is 1 m, the width of the fields is 19 m. If you leave a 0.5 m wide protection zone along the ditch, the useful width of the field is 18 m. On this field it is reasonable to make a 6 m wide bed in the middle and 3 m wide bed on the sides. The beds are separated with technological tracks (Käis & Olt, 2009).

Requirements of structure of spot-fertilizing device:

1) it must be possible to carry the equipment on your back and it must be ergonomic, comfortable and light;
2) dosing with sufficient precision – deviation from the stipulated value shall not exceed ± 3%;
3) stepless adjustment of bulk fertilizer quantity;
4) possibility to apply fertilizer to one plant at a time (precision fertilization); and
5) the device shall be portable.

Besides increasing crop yield, fertilization also influences the development of the plants – more precisely the length of the plant stems, whereas higher plants droop in every direction.

Requirements of structure of weed control device:

1) the device should allow contact treatment of weeds;
2) the device should be drip-free; and
3) the device should be portable.

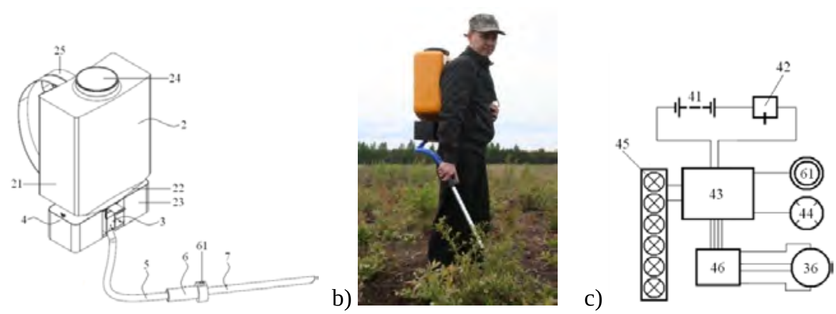
Requirements of blueberry harvesting:

1) blueberries should be harvested in due time, when the berries are fully ripe – the most suitable time is considered to be August (in Estonian conditions berries ripen by the beginning or middle of August) and as approximately 90% of berries become ripe at the same time, harvesting should take place in one operation;
2) the duration of harvesting should be as short as possible – approximately 15-20 days;
3) under normal load conditions the harvesting loss of a blueberry harvester should not exceed 5%;
4) the ratio of impurities (leaves and other plant remnants) in the berries should not exceed 15%; and
5) the ratio of mechanically damaged (crushed) berries should not exceed 12%.

Innovative solutions for devices: During product development the following devices were developed:

1) a portable spot-fertilizing device (precise dosing);
2) a weed spot-control device;
3) a blueberry harvester equipped with a reel with flexible picking tines and interim tines; and
4) a stepless adjustment roller for a blueberry sorting device.

An innovative portable spot-fertilizing device consists of three main components (Fig 1): a fertilizer tank 2; a batcher unit including a drive 23; and a pipe-shaped fertilizer duct and handle with a button switch. A portable spot-fertilizing device (Fig 1, a) is provided with two cushioned straps for carrying the device over the shoulders. The straps are fastened to the fertilizer tank 2 of the spot-fertilizing device. The fertilizer tank 2 is equipped with a tank cap and is designed for storing granulated fertilizer. There is a batcher unit fastened to the bottom of the fertilizer tank of the spot-fertilizing device whose function is to measure the required quantity of granulated fertilizer and to forward it to the fertilizer duct. The batcher drive consists of a step motor together with control units and a power source. The step motor is activated by pressing a button 61 on the handle. Each time the button is pressed the fluted roller of the batcher rotates by the stipulated rotation angle and as a result the adjusted quantity of granulated fertilizer is sprayed each time. The size of the rotation angle of the shaft of the step motor is controlled via a control unit. The granulated fertilizer released from the batcher moves via a flexible section of a pipe-shaped fertilizer duct to the handle, which is equipped with a button switch provided with a signal sensor and further on through a fertilizer duct to the pipe-shaped rigid section of the fertilizer duct, via which the required quantity of granulated fertilizer finally reaches the fertilizing spot – the shoot of the plant.



a) b) c)

Figure 1. Portable spot-fertilizing device: a – model; b – spot-fertilizing device in operation, c – principle control scheme: 2 – fertilizer tank, 3 – batcher, 4 – drive, 5 – upper part of fertilizer duct, 6 – handle, 7 – lower part of fertilizer duct, 21 – housing of fertilizer tank, 22 – bottom of fertilizer tank, 23 – cover, 24 – cap, 36 – step motor, 41 – power source, 42 – control switch, 43 – micro controller, 44 – signal diodes of power source, 45 – signal diode set of position of fluted roller, 46 – main controller, 61 – button-switch.

1 pav. Nešiojamas lokalinio tręšimo įrenginys: a – modelis; b – veikiantis lokalinio tręšimo įrenginys; c – principinė valdymo schema: 2 – trąšų bakas, 3 – dozatorius, 4 – pavara, 5 – trąšų vamzdžio viršutinė dalis, 6 – rankena, 7 – trąšų vamzdžio apatinė dalis, 21 – trąšų bakas, 22 – trąšų bako apatinė dalis, 23 – dangtis, 24 – bako dangtelis, 36 – variklis, 41 – maitinimo šaltinis, 42 – valdymo jungiklis, 43 – mikro valdiklis, 44 – maitinimo šaltinio signalų diodai, 45 – signalo diodų komplekto padėtis rifliuotame volelyje, 46 – pagrindinis valdiklis, 61 – mygtukas-jungiklis.

Data regarding productivity and costs of fertilizing technologies are shown in table 1.

Table 1. Comparison of the characteristics of fertilizing technologies
1 lentelė. Tręšimo technologijų charakteristikų palyginimas

Parameter	Manual technology	Mechanical technology (using portable spot-fertilizing device)
Productivity ha h^{-1}	0.008	0.06
Unit cost €	20.00	530.00
Labour cost € ha^{-1}	504.00	80.85
Specific cost € ha^{-1}	506.50	169.18

The portable weed spot-control device (Fig. 2) is designed for applying herbicides to weeds. It consists of a bottle-shaped herbicide tank, a manipulator-like contact head and a shallow connection pipe in between. The connection pipe is provided with a support handle with a trigger-shaped lever controlling the manipulator and a holding handle for directing the contact head.

a) b) c)

Figure 2. Portable weed spot-control device: a – device model; b – device in operation; c – working element of device.

2 pav. Nešiojamas kontaktinio tipo piktžolių kontrolės įrenginys: a – įrenginio modelis, b – veikiantis įrenginys; c – įrenginio darbinis elementas.

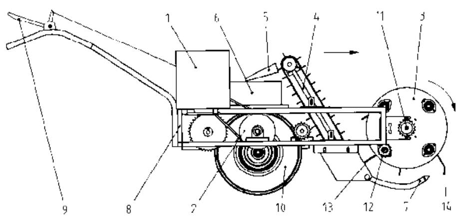
The device helps to apply the minimum quantity of pesticides to achieve maximum results. Minimum and contact use ensures that the plant protection product does not reach the ground, on the blueberry plants. This helps avoid pesticides getting into the soil and from there into ground water.

The device ensures minimum air pollution when working in strong wind conditions. The health of the operator is optimally protected. Data regarding productivity and costs of weed control are shown in table 2.

Table 2. Comparison of the characteristics of weed control technologies
2 lentelė. Piktžolių kontrolės technologijų charakteristikų palyginimas

Parameter	Manual technology	Mechanical technology (using portable weed spot-control device)
Productivity ha h^{-1}	0.006	0.031
Unit cost €	-	60
Labour cost € ha^{-1}	1075.2	129.8
Specific cost € ha^{-1}	1075.2	135.9

A blueberry harvester is a small self-propelled machine (Fig. 3) consisting of a drive 1 with power transmission elements 2, a parallelogram picking reel 3, a berry conveyor 4, a chute 5, a berry tank 6, a copying unit 7, a frame 8 supporting the machine elements and assembly units, steering levers 9 and wheels 10. An important advantage of the machine is the simplicity of the structural design of the picking reel 3 as well as its stem-saving workflow, user-friendliness and reliability.



a)

b)

Figure 3. Blueberry harvester: a – principle scheme; b – blueberry harvester in operation: 1 – drive, 2 – power transmission elements, 3 – picking reel, 4 – berry conveyor, 5 – chute, 6 – berry tank, 7 – copying unit, 8 – frame, 9 – steering levers, 10 – wheels, 11 – reel shaft, 12 – picking rake, 13 – rake tooth, 14 – hook spring-tine.

3 pav. Mėlynių kombainas: a – principinė schema, b – veikiantis mėlynių kombainas:1 – pavara, 2 – energijos perdavimo elementai, 3 – skynimo ritės, 4 – uogų konvejeris, 5 – latakas, 6 – uogų bunkeris, 7 – kopijavimo įrenginys, 8 – rėmas, 9 – vairavimo rankenėlės, 10 – ratai, 11 – ritės velenas, 12 – skynimo grėblys, 13 – grėblio dantis, 14 – spyruoklinis kablys.

To avoid the working elements of the blueberry harvester becoming jammed and to prevent damage to the blueberry plants, the picking reel 3 is equipped with elements 14 to direct blueberry branches into the path of the picking rake 12, where the rake teeth 13 of the picking rake 12 are designed to be flexible in order to avoid damaging the plants. Elements 14 for directing the blueberry branches into the path of the picking rake 12 are designed as hook spring-tines. These elements are rigidly fastened to the holder of the picking rake 12, where the function of each element is to direct the blueberry branches into the path of the next picking rake 12 during rotation of the picking reel 3.

For the harvesting of the blueberry crop, the blueberry harvester is moved in a shuttle pattern starting from the edge of the blueberry field or technological track. A parallelogram picking reel 3 gets its rotation from the power transmission 2 of the drive 1; the picking reel 3 is rotated in the same direction as the wheels of the machine. During rotation of the picking reel 3 the elements designed as hook spring-tines 14 direct the blueberry branches that otherwise point in different directions into the path in which the machine is travelling and the rake teeth 13 moving behind the spring tines are directed between the blueberry stems. This operation minimizes the risk of the stems getting between the rake teeth 13. After this the rake teeth 13 start tearing the blueberries off the blueberry branch. The rake teeth 13 forward the released berries to the berry conveyor 4 which transports them from the harvesting zone through a chute to the berry tank 6. When the berry tank is full, the operator of the blueberry harvester replaces the full tank with an empty one and the operation continues.

If the flexible rake tooth 13 of the picking rake gets stuck on a plant stem or a plant stem in the way of the picking rake 12 gets stuck in the tip of the rake teeth, additional load is applied to the rake teeth 13 when the picking reel is rotating and the rake tooth bends and assumes position 13b (Fig. 4). When the rake teeth 13 are bent, the plant stems are released from the tips of the rake teeth. When the plant stems are released, the rake tooth 13 resumes its initial position 13a.

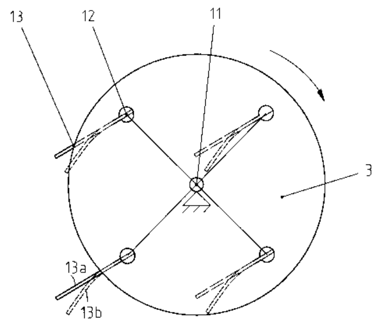


Figure 4. The principal scheme of the picking reel of blueberry harvester
4 pav. Mėlynių kombaino rinkimo būgno principinė schema

ERTACETAL C with the chemical structure of POM-C, $(CH_2O)_n$ was chosen for the material of the teeth of picking rake 12. Technical specification of the material ERTACETAL C chosen for the tooth of picking rake is shown in table 3.

Table 3. ERTACETAL C Technical Specification (Quadrant EPP…)
3 lentelė. ERTACETAL C Techninė specifikacija (Quadrant EPP…)

Property	ISO Methods	Units	ERTACETA L C
Colour	-	-	White
Density	1183	g cm^3	1,41
Trensile strength	527	N mm^2	68
Trensile modulus of elasticity	527	N mm^2	3100
Elongation at break	527	%	35
Hardness	Rockwell M	-	84
Melting point	-	ºC	165

ERTACETAL C is an elastic material. Its product range includes a choice of material of circular cross-section of 4 mm and 5 mm in diameter (Table 4). In order to determine the suitability of these choices, a laboratory experiment was conducted.

Table 4. Characteristics of the specimens of rake tooth
4 lentelė. Grėblio dantų charakteristikos

Parameter	Units	Parameter	
Material	-	POM-C	
Working length	mm	125	
Diameter	mm	4.0	5.0
Price*	€ m^{-1}	0,22	0.33
Relative price per volume unit	%	100	96

Note: *materials' prices per meter are given without VAT

The height of the picking reel 3 of the blueberry harvester from the ground can be adjusted by regulating the position of the copying unit so that the picking reel can also pick the berries closest to the ground. The pins of the copying unit 7 slide between the plants when the blueberry harvester moves on the field and help to lift plant stems which have fallen down. Data regarding productivity and costs of berry harvesting are shown in table 5.

Table 5. Comparison of the characteristics berry harvesting technologies
5 lentelė. Uogų derliaus nuėmimo technologijų charakteristikų palyginimas

Parameter	Manual technology	Mechanical technology (using blueberry harvester and ATV)
Productivity kg h^{-1}	4	414
Unit cost €	12	13700
Labour cost € kg^{-1}	1.35	0.04
Specific cost € ha^{-1}	1.353	0.088

Conclusion

This article describes the development methodology of blueberry machine cultivation technology and the results thereof. During product development a portable spot-fertilization device, a portable contact-type weed control device, a motoblock-type blueberry harvester and a blueberry sorting device were developed. An important advantage of the novel picking reel of blueberry harvester is the simplicity of constructive solution, stem-saving workflow, user-friendliness and reliability. Saving the stems was achieved through introducing elastic rake teeth produced of Polyoxymethylene (POM-C). Elastic rake teeth do not tear the plant stems into shreds nor pull the plants out of the ground, but bend when a barrier occurs and return to their original shape after overcoming barrier resistance. The conclusion is that implementation of this equipment has a positive impact. Also, the logistical issues of the technology have been solved.

References

1. Albert, T.; Starast, M.; Karp, K.; Kaldmäe, H.; Vool, E.; Paal, T. 2009. The influence of propagation method on growth of the half-highbush blueberry 'Northblue'. *Acta Horticulturae*, vol. 812, pp.141-146.

2. Hall, I.V.; Aalders, L.E.; Townsend, L.R. 1964. The effects of soil pH on the mineral composition and growth of the lowbush blueberry. *Can. J. Plant Sci*. 44, 433-438.

3. Holmes, R.S. 1960. Effect of phosphorus and pH on iron chlorosis of the blueberry in water culture. *Soil Sci*. 90, 374-379.

4. Ilomets, M. 1996. Temporal changes of Estonian peatlands and carbon balance. In: *Punning, J.-M. (Ed.). Estonia in the System of Global Climate Change*. Institute of Ecology, Tallinn, Estonia, pp. 65-75.

5. Käis, L.; Olt, J. 2009. Bilberry cultivating technology in plantations established on milled peat fields. *Int. conf. proceedings* "*Energy Efficiency and Agricultural Engineering"*. Rousse, pp. 616-624.

6. Käis, L.; Olt, J. 2010. Low-bush blueberry machine cultivation technology in plantations established on milled peat fields. Proceedings of the 38th Int. *Symposium on Agricultural Engineering* "*Actual Tasks on Agricultural Engineering*". Opatija, pp. 148-159.

7. Noormtes, M.; Karp, K.; Starast, M.; Paal, T. 2002. The influence of fertilization on the production of lowbush blueberry (*Vaccinium angustifolium* Ait.) seedlings on opencast peat pits. *J. Agric. Sci*. 5, 293-303.

8. Paal, T.; Ilomets, M.; Fremstad, E.; Moen, A.; Børset, E.; Kuusemets, V.; Truus, L.; Leibak, E. 1998. Estonian Wetland Inventory 1997. *Publication of the Project "Estonian Wetlands Conservation and Management" Eesti Loodusfoto*, Tartu.

9. Paal, T.; Starast, M.; Noormets-Šanski, M.; Vool, E.; Tasa, T.; Karp, K. 2011. Influence of liming and fertilization on lowbush blueberry in harvested peat field condition. *Scientia Horticulturae*, 130, 157-163.

10. Pahl, G.; Bitz, W.; Feldhusen, J.; Grote, K. H. 2007. Engineering Design. A System Approach. Third Edition. Springer, Germany. 617 p.

11. Quadrant EPP Product Data Sheet. Available: [http://www.gcip.co.uk/pdf/ertacetalc.pdf].

12. Starast, M.; Paal, T.; Vool, E.; Karp, K.; Albert, T.; Moor, U. 2009. The Productivity of Some Blueberry Cultivars under Estonian Conditions. IX International Vaccinium Symposium, Book Series*: Acta Horticulturae Volume*: 810, pp. 103-108.

13. Strik, B. 2005. Blueberry: An Expanding World Berry Crop. *Chronica Horticulturae*, 45 (1), 7-12.

Jüri Olt, Margus Arak, Algirdas Jasinskas

MECHANINĖS TECHNOLOGIJOS IŠVYSTYMAS APLEISTŲ DURPIŲ LAUKUOSE ĮKURTOSE ŽEMAŪGIŲ MĖLYNIŲ KRŪMŲ AUGINIMO PLANTACIJOSE

Santrauka

Šiame straipsnyje apžvelgti nualintų ir apleistų durpių laukuose įveistų mėlynių plantacijų technologiniai ypatumai ir pateiktas atitinkamų auginimo technologijų ir technologinių įrenginių išvystymas. Dirvožemio savybės nualintų ir apleistų durpių laukuose yra specifinės, dėl to jas būtina įvertinti įveisiant mėlynių plantacijas. Šis straipsnis išryškina problemas, kurias reikia išspręsti auginant mėlynių krūmus apleistuose durpynuose, užduotis bei gautas technines idėjas ir metodus. Siekiant tobulinti auginamų produktų gamybą buvo sukurti šie technologiniai įrenginiai: nešiojamas lokalinio tręšimo įrenginys; nešiojamas kontaktinio tipo piktžolių kontrolės įrenginys; motobloko tipo mėlynių kombainas ir mėlynių rūšiavimo įrenginys. Taip pat buvo aptarti šių įrenginių įdiegimo ypatumai.

Žemaūgiai mėlynių krūmai, mechaninio auginimo technologija, inžinerinis projektavimas ir kūrimas, tręšimas, piktžolių kontrolė, uogų derliaus nuėmimas.

Юри Ольт, Маргус Арак, Алгирдас Ясинскас

РАЗРАБОТКА ТЕХНИЧЕСКИХ СРЕДСТВ МЕХАНИЗАЦИИ ДЛЯ ВЫРАЩИВАНИЯ ЧЕРНИКИ В ПИТОМНИКАХ НА ЗАБРОШЕННЫХ ТОРФЯНЫХ ПОЛЯХ

Резюме

В данной статье проведен обзор технологических особенностей плантаций черники, посаженых в деградированных или заброшенных торфяных полях и представлено развитие соответствующих технологий выращивания и технологического оборудования. Свойства почв деградированных и заброшенных торфяных полей являются специфичными, потому это необходимо оценить перед посадкой плантаций черники. В этой статье освещаются проблемы, которые требуются решить при выращивании кустов черники в заброшенных торфяниках, а также задачи и полученые технические идеи и методы. В целях повышения производства выращиваемых продуктов были разработаны эти технологические устройства: портативный удобритель, портативное контактное противосорняковое устройство, черникоуборочная машина и устройство для сортировки черники. Кроме того были обсуждены особенности внедрения этого оборудования.

Карликовые кусты черники, технология механического выращивания, инженерное проектирование и разработка, внесение удобрений, борьба с сорняками, уборка урожая фруктов.

II

Arak, M., Olt, J. 2017. Determination of the connection force between berries and stem in blueberry plants. Proceedings of the 45th International Symposium on Agricultural Engineering: Actual Tasks on Agricultural Engineering, Opatija, Croatia, 21-24.02.2017. Ed. Igor Kovacev. University of Zagreb, 589−595**.**

45. SIMPOZIJ AKTUALNI ZADACI MEHANIZACIJE POLJOPRIVREDE

UDC 634.7:634.73
Prethodno priopćenje
Preliminary communication

DETERMINATION OF THE CONNECTION FORCE BETWEEN BERRIES AND STEM IN BLUEBERRY PLANTS

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SUMMARY

The berries of a blueberry plant are connected one-by-one to the stem with stalks. A blueberry harvester equipped with a rotary picking reel is used for harvesting blueberries mechanically. During mechanical harvesting, the berry is removed from the plant stem by pulling. The berries separate from the stem when the pulling force of the teeth of the picking reel is greater than the connection force of the berries. However, it must be taken into account that blueberry berries are fragile, even elastic to some extent, but certain mechanical forces may cause plastic deformations to the berries, which may damage them. Damaged blueberries have no commercial value for serving on dish. This must be taken into account while modelling the picking unit of a blueberry harvester and the constructional and cinematic parameters of the machine must be selected in a way that the teeth of the picking rake exert soft forces to the berry during contact and pulling the berry off. Therefore, the purpose of this study is to determine experimentally the connection force between berries and stem in blueberry plants.

Key words: agricultural engineering, blueberry harvesting, picking rake teeth, connection force, experiment.

INTRODUCTION

The increasing cultivation area of commercially cultivated blueberries and increasing costs of manual harvesting has resulted in increased interest in mechanical harvesting (van Dalfsen & Gaye, 1999). The mechanical harvesting of blueberries requires that the berries are pulled off from the stem using some working element or picking device. The picking device of the harvester of lowbush blueberries (*Vaccinium angustifolium* Ait.) consists of a drum or a picking reel with horizontal rotary axis which removes the berries from the stems (Käis & Olt, 2010; Arak & Olt, 2014). The working elements of the picking reel (Figure 1) are its hinged horizontal picking rakes which contain picking teeth rigidly attached to the shafts. In order to remove the berries, the drum and its teeth are rotated clockwise, the plants remain between the teeth and as the drum rotates, the teeth pull the berries away from the stem.

The most important quality indicator of a blueberry's berry is its texture, which is mostly described by its hardness, viscosity, elasticity and adhesiveness (Giese, 1995; Li et al., 2011). The fact that blueberries are sensitive to crushing may become a problem for mechanical harvesting (Yu et al., 2012). As nearly a half of the blueberries are usually harvested to be served fresh on dish (Strick & Yarborough, 2005), then these berries must be of high quality and look perfect and, therefore, avoiding crushing is of utmost importance in harvesting these berries mechanically. In order to avoid the mechanical damaging of the berries, the picking teeth must have elastic design (Olt & Arak, 2012).

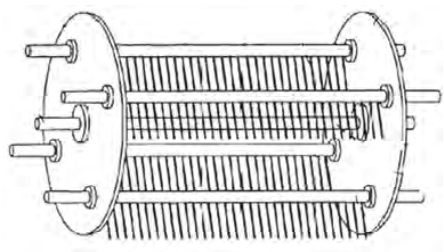


Figure 1: The principle of blueberry harvester's picking reel.

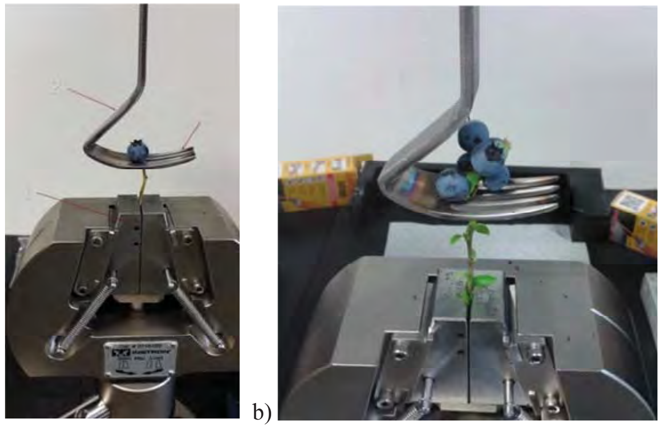
The purpose of this study was to determine the connection force between berries and stem in order to acquire source data for choosing the material for preparing the picking reel's elastic teeth with suitable mechanical properties.

METHODS

The fieldworks were performed in the Marjasoo Farm whose blueberry plantation has been established on depleted peat milling fields. The object of study was the lowbush blueberry (*Vaccinium angustifolium* Ait.), which is the most common variety in blueberry plantations established on depleted peat milling fields in Estonia.

In order to determine the connection force of the blueberry, it is reasonable to use a scheme whose operation is similar to the picking rake. From the mechanical point of view the stem of the blueberry plant is attached to the ground and the blueberry's berry to the plant's stem. During the mechanical harvesting process the blueberry's berry is lifted up by the teeth of the picking rake and pulled off from the stem, which is attached to the ground.

Arising from the abovementioned, the physically modelled test device for determining experimentally the connection force between blueberry's berries and stem (Figure 2) consists of a device for fastening the plant's stem, a jaw equipped with rigid teeth for grabbing the berry, a gripper, a mechanism for changing the jaw's position on the vertical plane, a force sensor attached to the shaft of the jaw and a reader for recording data. The plant has been attached to the gripper as follows. Tensile Force Tester Instron 5969L2610 is used to determine the force applied to the berry. The technical specifications of the test device have been presented in Table 1.



a) b)

Figure 2: Test device for determining the connection force of one berry (a) and a bunch of berries (b).

The berries may be attached to the stem as bunches. Such a position may affect the measuring results and separate tests were performed to determine the connection force of bunches of berries (Figure 2b).

Table 1 Technical specifications of the test device

No.	Part	Technical description	Parameter
1	Sensor	Loadcell 1kN	Measuring range ±1 kN, accuracy ±0.25% of the indicated force
2	Reader	Instron 5969L2610	
3	Gripper		Material (AISI304) thickness 2.5 mm, distance between teeth 2.6 mm
4	Jaw	Face VEE JAW S16	

The test device's operation is the following. Plants with berries are cut from near the ground in the plantation, put in a sealed plastic bag to avoid drying and brought to the laboratory within one hour. The plant's stem is fastened to the gripper (Figure 2a, 1) and the berry or the bunch of berries is placed between the jaw's (Figure 2a, 2) teeth (Figure 2a, 3). Subsequently, an actuator mechanically attached to the jaw is started. As the jaw moves vertically upwards (with the speed 5 mm/min) the plant attached to the gripper starts to extend and the tension between the berry and the plant's stem starts to increase until the berry is removed from the plant's stem. The maximum tensile strength allows determining the connection force between the blueberry's berry and plant's stem.

RESULTS AND DISCUSSION

The tests were performed on 3rd and 10th of August 2015 and 3rd of August 2016 and they included the measurement of the connection force between the stem and both ripe and unripe berries and bunches of berries.

The test results of the measurement (3rd of August 2015) of the connection force of ripe berries (7 specimens, diameter 6.9 mm to 10.9 mm) has been illustrated in Figure 3.

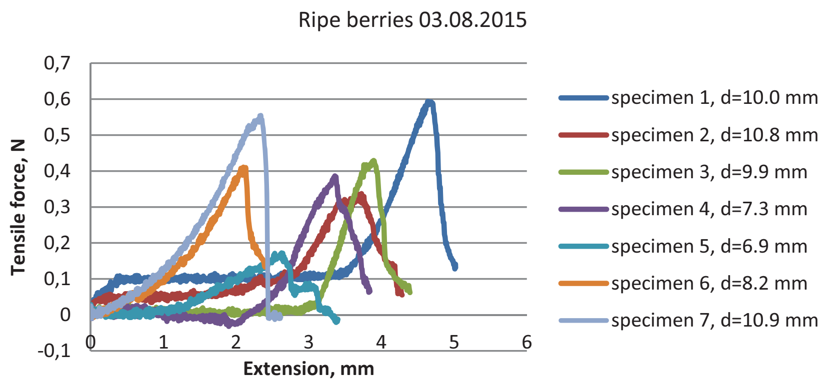


Figure 3: Connection force of ripe berries.

The values of the connection force of unripe and ripe berries measured according to the abovementioned method have been presented in Table 2.

Table 2: The average (F_{aver}), minimum (F_{min}) and maximum (F_{max}) connection force of unripe and ripe berries, number of tests n and berry diameter d.

	Unripe berries			Ripe berries		
Date	3.08.2015	10.08.2015	3.08.2016	3.08.2015	10.08.2015	3.08.2016
n	5	6	10	7	6	7
d	7.6–9.4	8.0–10.8	6.5–9.1	6.9–10.9	9.8–13.1	11.1–13.2
F_{min}, N	1.57	1.91	1.93	0.59	0.99	0.83
F_{aver}, N	1.42	1.45	1.15	0.41	0.51	0.66
F_{max}, N	1.27	1.00	0.89	0.17	0.29	0.53

The test results indicate that the tensile strength or connection force of individual unripe berries was in the range of 0.89–1.93 N. The test results showed that there is a positive correlation with average strength between the connection force and berry diameter of unripe berries where the value of correlation coefficient r is 0.63.

To these results the type B expanded uncertainty U_B evaluation can be applied using the following formula

$$U_B(F) = t_{\infty,95\%}\frac{e_p}{3}, \quad (1)$$

where F stands for the value of measured strength, $t_{\infty,95\%}$ stands for Student's coefficient at 95% confidence level and e_p expresses the maximum tolerance limit.

The type B expanded uncertainty values for the determination of minimum and maximum connection force of unripe berries was 0.0015 N and 0.0032 N respectively.

The tensile strength or connection force of ripe berries was in the range from 0.17 to 0.99 N and mean value 0.53 N. The tests showed that there is a positive correlation with average strength (r = 0.52) between the connection force and berry diameter of ripe berries. The type B expanded uncertainty values for the minimum and maximum values are 0.0003 N and 0.0016 N. The mean value's confidence limits at 95% confidence level are determined using the following formula

$$\left(F_{aver} - t_{n-1,95\%}\frac{s}{\sqrt{n}};\ F_{aver} + t_{n-1,95\%}\frac{s}{\sqrt{n}};\right), \quad (2)$$

where s stands for standard deviation. The upper and lower limits of standard deviation at 95% confidence level is 0.39 N and 0.65 N respectively, whereby the upper limit may be regarded as the minimum force required to harvest the majority of the berries.

The connection force of berries which are attached to the stem as bunches is larger than that of single berries. The connection force of berries in bunches was also measured in the test of 3rd of August 2015, where the bunch consisted of 30 berries, 18 (60%) of which were ripe (diameters 8.6–13.6 mm), 3 were semi-ripe (6.7–8.5 mm) and 9 were unripe (2.9–8.9 mm). The force that was needed to remove the berries from the stem was within the range of 1–8.5 N. All of the berries were removed from the stem individually, which can be seen in Figure 5, whereat 90% of the berries were removed without a tail.

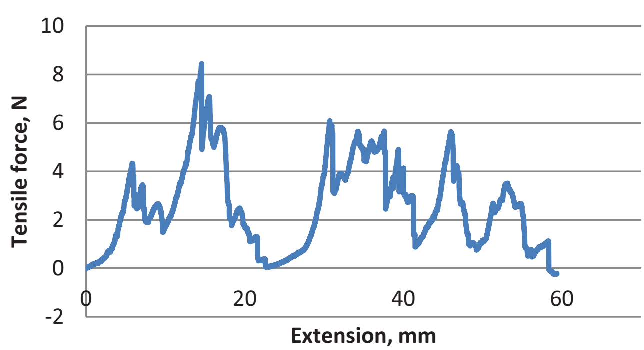


Figure 5: The connection force of blueberry's berries in bunches on 3rd of August 2015.

In the test performed a week later, on the 10th of August 2015, where the bunch consisted of 39 berries, 31 (79.5%) of which were ripe (diameters 8.1–11.7 mm), 2 were semi-ripe (8.3–8.4 mm) and 6 were unripe (5.3–7.7 mm). The force that was needed to remove the berries from the stem was within the range of 0.8–5.8 N (Figure 6). All of the berries were removed from the stem individually, whereat 95% of the berries were removed without a tail.

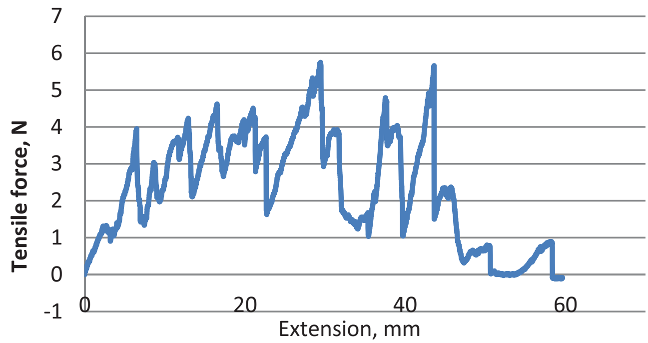


Figure 6 The connection force of blueberry's berries in bunches on 10th of August 2015.

CONCLUSIONS

This experimental study allowed determining the connection force between the blueberry's berry and stem for single berries and bunches of berries. The connection forces of single unripe berries were in the range of 1–2 N, for ripe berries the force was up to 1 N. Berries attached as bunches are removed from the plant's stem individually, however, their connection force is up to 9 N. The results obtained are used as source data for choosing the material for preparing the picking reel's elastic teeth with suitable mechanical properties.

REFERENCES

1. Arak, M., Olt, J. (2014). Constructive and kinematics parameters of the picking device of blueberry harvester, Agronomy Research, 12 (1), 25-32.
2. Giese, J. (1995). Measuring physical properties of foods, Food Technology, 49, 54-56.
3. Käis, L., Olt, J. (2010). Low-bush blueberry machine cultivation technology in plantation established on milled peat fields, 38th International Symposium on Agricultural Engineering Location: Opatija, CROATIA Date: FEB 22-26, 2010 Actual Tasks on Agricultural Engineering, 38, 271-279.
4. Li, C., Luo, J., MacLean, D. (2011). A novel instrument to delineate varietal and harvest effects on blueberry frukt texture during storage, Journal of the Science of Food and Agriculture, 91 (9), 1653-1658.
5. Laaneots, R., Mathiesen, O. (2011). An Introduction to Metrology. The second, thoroughly completed edition. TUT press, Tallinn., pp. 283.
6. Olt, J., Arak, M., Jasinskas, A. (2013). Development of mechanical technology for low-bush blueberry cultivating in the plantation established on milled peat fields, Agricultural Engineering. Research Papers, Vol. 45 (2), 120-131.
7. Olt, J., Arak, M. (2012). Design and development of the picking reel of motoblock-type harvester, Journal of Agricultural Science, Vol. 23 (2), 21-26.

8. Strik, B., Yarborough, D. (2005). Blueberry production trends in North America, 1922-3003, and predictions for growth, Horticultural Technology, 18, 130-138.
9. van Dalfsen, K.B., Gaye, M.M. (1999). Yield from hand and mechanical harvesting of highbush blueberries in British Columbia, Applied Engineering in Agriculture, 15 (2), 393-398.
10. Yu, P., Li, C., Takeda, F., Krewer, G., Rains, G., Hamrita. (2012). Quantitative evaluation of a rotary mechanical harvester using a miniature instrumented sphere, Computers and Electronics in Agriculture, 88, 25-31.

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III

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Mechanical properties of blueberry stems

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Abstract

Arak M., Soots K., Starast M., Olt J. (2018): Mechanical properties of blueberry stems. Res. Agr. Eng., 64: 202–208.

In order to model and optimise the structural parameters of the working parts of agricultural machines, including harvesting machines, the mechanical properties of the culture harvested must be known. The purpose of this article is to determine the mechanical properties of the blueberry plant's stem; more precisely the tensile strength and consequent elastic modulus *E*. In order to achieve this goal, the measuring instrument Instron 5969L2610 was used and accompanying software BlueHill 3 was used for analysing the test results. The tested blueberry plant's stems were collected from the blueberry plantation of the Farm Marjasoo. The diameters of the stems were measured, test units were prepared, tensile tests were performed, tensile strength was determined and the elastic modulus was obtained. Average value of the elastic modulus of the blueberry (Northblue) plant's stem remained in the range of 1268.27–1297.73 MPa.

Keywords: agricultural engineering; blueberry; harvesting; mechanical properties; elastic modulus

Lowbush blueberry (*Vaccinium angustifolium* Ait.) is a native naturally occurring plant in North America. This species is managed as a wild crop and it has a remarkable position in berry production in US and Canada (Strik 2005). The bushes of the blueberry are quite small (up to 60 cm tall) long-lived woody perennial (Vander Kloet 1988). The plant grows stems which then produce branches and the floral buds and later berries are located on the upper part of the stem. These berries are characterized by a high nutritional value (Gibson et al. 2013) and therefore interest of lowbush blueberry cultivation is expanded to other countries as well. For example in Europe *V. angustifolium* plantations are established in Estonia (Starast et al. 2002), Finland (Hiirsalmi, Hietaranta 1989), Sweden (Hjalmarsson 2006), Poland (Ochmian 2013), Belarus (Yakovlev et al. 2016), and Lithuania (Stackeviciene 2003). Several studies have shown cultivation of lowbush blueberry is successful and economically profitable on heavily drained abandoned peat fields because of soils with high organic matter content and low pH (Yakovlev et al. 2016; Tasa et al. 2015; Vahejõe et al. 2010; Starast et al. 2007).

Harvesting of lowbush blueberry has largely been done by handpicking but increasingly, cultivated blueberries are harvested using different types of mechanical harvesters (Yu, et al., 2014; Sibleye 1993; Yarborouph 1992; Marra et al. 1989). The best choice for harvesting blueberries from depleted peat milling fields is the Darlington harvester or walk behind blueberry harvester due to its relatively low special pressure applied to surface. Despite the lower operating speed and, therefore, lower productivity of the Darlington harvester (walk behind, single-head unit) compared to the Bragg harvester (the harvester is mounted on two- or four-wheel-drive tractors), its advantage is that it splits considerably fewer berries (Marra et al. 1989). One of the real reasons for mechanical harvesting is the high demand for manual labour in the agricultural

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domain which has led to the shortage of berry pickers during the harvesting season.

The mechanical properties of the lowbush blueberry plant must be known for modelling the walk behind blueberry harvester, also named motoblock-type blueberry harvester (Arak, Olt 2014; Käis, Olt 2010), more precisely for choosing the optimal structural parameters of its picking reel. These properties include the connection force between the berry and the stem (Arak, Olt 2017) and the tensile strength of the blueberry plant's stem. The first approach to the blueberry plant's stem treats it as an isotropic and homogeneous body. The isotropic and elastic body is characterised by two parameters: the elastic modulus E and Poisson's modulus (or shear modulus).

There are several methods for determining the tensile strength of plant stems. According to literature (Yu 2004; Amer Eissa et al. 2008; Kowalik et al. 2013) tests have been performed to determine the tensile strength of reed-mace, millet, cotton, corn and sugarcane. In most cases the tensile strength measuring instruments or tensile machines were used.

There may arise problems with attaching the plant stems to the tensile machine's grippers when the standard device is used. The plants with strong stems can be attached directly between the grippers of the tensile machine without any additional clamps. However, in order to perform tensile tests on plant stems prone to damages, including blueberry plant's stems, additional softening must be added or special grippers must be used to avoid damaging. According to literature (Bakeer et al. 2013; Kronbergs et al. 2011; Hassan-Beygi et al. 2010; Kromer 2009) the following attachment methods are used:

(1) using a special gripper and adhesive;
(2) using a special gripper and materials increasing friction (for example, emery paper, etc.);
(3) attaching to the standard gripper by using epoxy paste around the plant's stem.

These attachment methods have been used for performing tensile tests on the stems of sorghum, flax, hemp, thistle and saffron.

The purpose of this article was to determine the mechanical properties of the lowbush blueberry plant stem in order to model and optimise the structural parameters of the walk behind blueberry harvester working parts.

Theoretical consideration. It is known from mechanics that the elastic modulus E is expressed by Chattopadhyay and Pandy (1999):

$$E = \frac{\sigma}{\varepsilon}$$

where: σ – mechanical stress, tensile stress in our case; ε – elastic deformation

As $\sigma = F_{max}/A$, $\varepsilon = \Delta L/L_0$ and $A = \pi d^2/4$, the relation (1) is given the form:

$$E = \frac{4 \times F_{max} \times L_0}{\pi \times d^2 \times \Delta L}$$

where: A – surface to which the stress is applied, the cross-section surface of the blueberry plant's stem in our case; $F_{\max}$ – max. tensile force applied; L_0 – initial length of the unit or blueberry plant's stem; ΔL – change of the length of the test unit or blueberry plant's stem; d – diameter of stem

Therefore, we must proceed from the relation (2) in determining the elastic modulus E of the blueberry plant's stem.

MATERIALS AND METHODS

Experimental procedure. In our case the measuring instrument INSTRON 5969 L (INSTRON, USA) with the technical specifications given in Table 1 was used. The blueberry plant stems for the tensile tests were collected during the harvesting period, *i.e.*, on August 3, 2015, August 10, 2015 and August 3, 2016. The blueberry plant stems were collected from Farm Marjasoo whose blueberry plantation has been established on depleted peat milling fields in Rannu municipality in Tartu County (Estonia).

Samples preparation. The methods used in this study were based on the methods described in literature (Kronbergs et al. 2011; Shahbazi 2012) to attach blueberry plant's stems to the measuring instrument. Unlike the descriptions in the literature, instead of plastic clamps the test included wooden clamps with dimensions 6 × 15 × 36 mm and to which traversing holes with the diameter of 3 mm were drilled. The blueberry stems were placed to these holes and attached to the wooden clamps using two-component instant adhesive Loctite 3090. The minimum curing time of the adhesive was 90 minutes. As wood is a material with higher elasticity, the attaching force of the gripper is transferred better to the clamp through wood,

https://doi.org/10.17221/90/2017-RAE

Table 1. Technical specifications of the test device.

No.	Part	Technical description	Parameter
1	Sensor	Loadcell 1 kN	Measuring range ±1 kN, accuracy ±0.25% of the indicated force
2	Reader	Instron 5969L2610	
3	Jaw	Face VEE JAW S16	

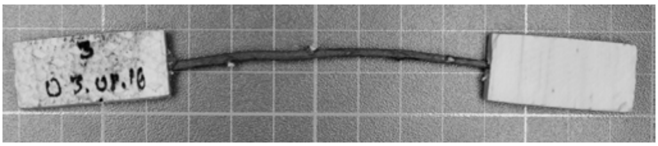

Fig.1. The blueberry plant's stem test unit with clamps

thereby supporting the effect of the adhesive and making wood a better material for clamping than rigid plastic. The blueberry (Northblue) stems together with the clamps form the test units (Fig. 1).

Statistical evaluation. Equation (2) can be viewed as a function of four variables:

$$E = F\,(x_1, x_2, x_3, x_4) \qquad (3)$$

where: $x_1 = F_{max}$, $x_2 = L_0$, $x_3 = d$, $x_4 = \Delta L$.

Electrical measuring instruments were used for finding the values of x_i (Table 2) and it is reasonable to use type B uncertainty for estimating their uncertainty (Laaneots, Mathiesen 2011):

$$U(x_i) = UB(x_i) \qquad (4)$$

$$U_B\left(x_i\right) = t_{\infty,\beta}\frac{e_p}{3} \qquad (5)$$

where: $t_{\infty,\beta}$ – Student's coefficient on level of confidence β, the value of which is $t_{\infty,95\%}$ = 1.96 according to Laaneots and Mathiesen (2011) and e_p is the tolerable deviation of measurements (Table 2).

As the arguments x_i of Equation (3) can be treated as independent values, then uncertainly *U(E)* of the value *E* can be calculated as follows according to sources (Kirkup, Frenkel, 2006; Laaneots, Mathiesen, 2011)

$$U\left(E\right) = \sqrt{\left[\frac{\partial f\left(x_1,\ldots,x_4\right)}{\partial x_1}U\left(x_1\right)\right]^2 + \ldots + \left[\frac{\partial f\left(x_1,\ldots,x_4\right)}{\partial x_4}U\left(x_4\right)\right]^2} \qquad (6)$$

When applying formula (6) to equation (2), it results in:

$$U\left(E\right) = 4\sqrt{\frac{L_o^{\,2}}{\pi^2\times d^4\times\Delta L^2}U^2\left(F_{max}\right) + \frac{F_{max}^{\,2}}{\pi^2\times d^4\times\Delta L^2}U^2\left(L_o\right) + \frac{4F_{max}^{\,2}\times L_o^2}{\pi^2\times d^6\times\Delta L^2}U^2\left(d\right) + \frac{F_{max}^{\,2}\times L_o^2}{\pi^2\times d^4\times L^4}U^2(\Delta L)} \qquad (7)$$

where:

$$U\left(F_{max}\right) = 1.96\frac{0.0025\times F_{max}}{3} \qquad (8)$$

$$U\left(L_o\right) = U\left(d\right) = 1.96\frac{0.03}{3} \qquad (9)$$

$$U\left(\Delta L\right) = 1.96\frac{0.01}{3} \qquad (10)$$

The measured results were processed with the software BlueHill 3 (version 3.15.1343) by Illinois Tool Works Inc. It was used to calculate the tensile stress (σ, N·mm^{-2}), elastic deformation (ε, %) and elastic modulus (*E*, N·mm^{-2}).

Table 2. Tolerance of the used measurement instruments

Variable	Symbol	Measuring instrument	Type	Measurement accuracy (e_p)
Diameter of stem	d	digital caliper	Mahr 16 EX	0.03 mm
Lenght of stem	L_0	Digital caliper	Mahr 16 EX	0.03 mm
Maximum load	F_{max}	tensile force tester	Instron 5969L2610	0.25% RDG
Change of the length	ΔL	tensile force tester	Instron 5969L2610	0.01 mm

https://doi.org/10.17221/90/2017-RAE

Table 3. Results of the tensile tests (10.08.2015)

Specimen	Diameter (*d*, mm)	Maximum load (F_{max}, N)	Tensile stress at maximum load (σ, MPa)	Tensile strain at yield (ε, %)	Elastic modulus (*E*, MPa)
1	2.3	122.10	29.91	1.95	1,233.6
2	2.3	134.18	31.20	2.01	1,017.4
3	2.8	198.32	33.15	1.71	1,378.1
4	2.4	129.08	28.53	2.11	1,210.0
5	2.5	163.11	34.04	1.56	1,558.6
6	2.7	169.53	30.51	1.73	1,271.0
Max.	2.8	198.32	34.04	2.11	1,558.6
Mean	2.5	152.72	31.22	1.84	1,278.1
Min.	2.3	107.92	20.64	1.43	1,017.4

Table 4. Assembled test data

Date	Aug 3, 2015	Aug. 10,2015	Aug 3, 2016
Number of specimens (*n*)	4	6	5
Diameter of specimen (*d*, mm)	1.98–2.78	2.30–2.80	1.67–2.25
Length of specimen (L_0, mm)	102.4–127.0	109.8–119.7	47.9–86.7
Minimum value of elastic modulus (E_{min}, MPa)	1,029.80	1,017.40	939.85
Average value of elastic modulus (E_{aver}, MPa)	1,268.27	1,278.10	1,297.73
Maximum value of elastic modulus (E_{max}, MPa)	1,604.45	1,558.60	1,571.48

RESULTS AND DISCUSSION

The diameters of the stems collected for testing were measured (Table 2), test units were prepared and numbered. In order to determine the tensile strength of blueberry plant's stems, the test units were placed between the grippers of the measuring instrument (Fig. 2); the time of applying stress on the test unit, or the tensile time, was decided; tensile tests were performed and data was recorded.

The data collected during testing has been presented in Table 3. The change of tensile force by the change of blueberry plant's stem's length during the tensile test has been presented in Fig. 3 and the relation between tensile stress and elastic deformation has been given in.

The elastic modulus *E* results of three test series (August 3,2015; August 10, 2015; and August 3, 2016) have been drawn together to Table 4.

It can be concluded from the test data (Table 3) that the elasticity modulus of lowbush blueberry's (Northblue) first year's shoots after pruning is 1,278 ± 28 MPa and it was determined with 2.2% precision.

Fig. 2. Measuring instrument INSTRON 5969L2610.

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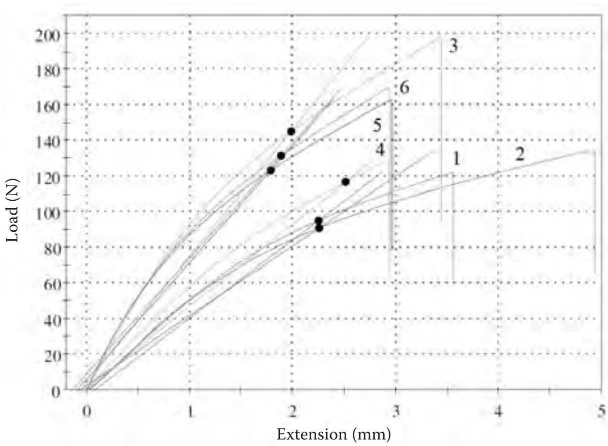

Fig. 3. Relation between tensile force and elongation of blueberry plant's stem

points indicate yield point and numbers are indicating specimen number,

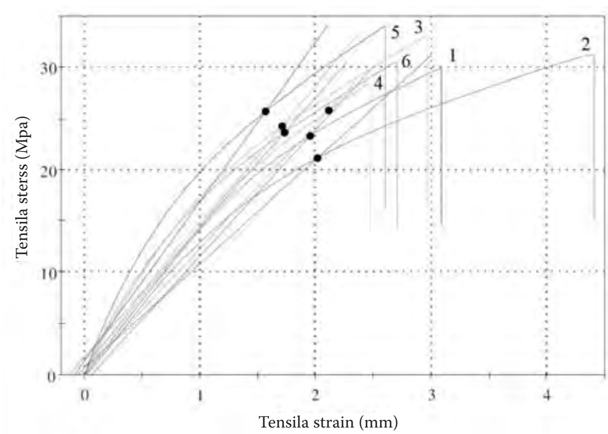

Fig. 4. Relation between tensile stress and elastic deformation

points indicate yield point and numbers are indicate specimen number, test series 10.08.2015

This value of the elasticity modulus differs from the value stated in the article Guo Yanling et al. (2012) about 2.5 times. At this point it must be specified that the article Guo Yanling et al. (2012) determines the elasticity modulus for the variety Blomidon, which is the first lowbush blueberry variety bred for industrial production in Canada (Hall, Aalders 1982). Therefore, the difference between the elasticity modulus of this article and the referred article may be caused by the different mechanical properties of the stems of the varieties (diameter, tensile strength). Furthermore, Guo Yanling et al. (2012) have not described the method for determining the elasticity modulus.

CONCLUSION

The test results showed that the elastic modulus E of the blueberry (Northblue) plant's stem remained in the range of 940–1605 MPa, but the average values of the elastic moduli E of three different test series were in the range of 1,268.27–1,297.73 MPa. The difference is only 2.2%.

https://doi.org/10.17221/90/2017-RAE

The correlation coefficient between E and d is –0.144 which expresses weak correlation and, therefore, the use of stems with different diameters has no effect on the reliability of determining the value of E. Depending on its diameter the tensile strength of blueberry plant's stem remains in the range of 100–200 N. The obtained results can be used for modelling the working parts of blueberry harvesters, more precisely the picking reel.

The properties of blueberry plant's stem are probably influenced by its age, however, this first approach to the topic did not include this effect.

References

Amer Eissa A.H., Gomaa A.H., Baiomy M.H., Ibrahim A.A. (2008): Physical and mechanical characteristics for some agricultural residues. Misr Journal of Agricultural Engineering, 25: 121–146.

Arak M., Olt J. (2014): Constructive and kinematics parameters of the picking device of blueberry harvester. Agronomy Research, 12: 25–32.

Arak M., Olt J. (2017): Determination of the connection force between berries and stem in blueberry plants. In: Proceedings of the 45th International Symposium Actual Tasks on Agricultural Engineering, Opatija, Croatia, Feb 21–24, 2017: 589–595.

Bakeer B., Taha I., El-Mously H., Shehata S.A. (2013): On the characterisation of structure and properties of sorghum stalks. Ain Shams Engineering Journal, 4: 265–271.

Chattopadhyay P.S., Pandy K.P. (1999): Mechanical properties of sorghum stalk in relation quasi-static deformation. Journal of Agricultural Research, 73: 199–206.

Guo Y., Bao Y., He P., Wang H. (2012): Design and experiment analysis of hand-push lowbush blueberry picking machine. Transactions of the Chinese Society of Agricultural Engineering, 28: 40–45.

Gibson L., Vasantha Rupasinghe H.P., Forney C.F., Eaton L. (2013): Characterization of changes in polyphenols, antioxidant capacity and physico-chemical parameters during lowbush blueberry fruit ripening. Antioxidants, 2: 216–229.

Hall I.V., Aalders L.E. (1982): Blomidon lowbush blueberry. Canadian Journal of Plant Science, 62: 519–521.

Hassan-Beygi S.R., Ghozhdi H.V., Khazaei J. (2010): Picking force of saffron flower and shear strength of saffron stalk. Electronic Journal of Polish Agricultural Universities, 13(1): 1–11.

Hiirsalmi H.M., Hietaranta T.P. (1989): Winter injuries to highbush and lowbush blueberries in Finland. Acta Horticulturae, 241: 221–226.

Hjalmarsson I. (2006): Introduction of lowbush blueberry and hybrids in Sweden. Acta Horticulturae (ISHS), 715: 143–146.

Kirkup L., Frenkel B. (2006): An Introduction to Uncertainty in Measurement. Cambridge, Cambridge University Press.

Kowalik W., Pachuta K., Jeznach J. (2013): The stabilization and protection of shorelines using the broadleaf cattail and reed sweet grass. Annals of Warsaw University of Life Sciences – SGGW, Land Reclamation, 45: 61–70.

Kromer K.-H. (2009): Physical properties of flax fibre for non-textile-use. Research in Agricultural Engineering, 55: 52–61.

Kronbergs A., Širaks E., Adamovičs A., Kronberg, Ē. (2011): Mechanical properties of hemp (*Cannabis sativa*) biomass. In: Proceedings of the 8th International Scientific and Practical Conference, Environment, Technology. Resources, Rezekne, Latvia, Jun 20–22: 184–190.

Käis L., Olt J. (2010): Low-bush blueberry machine cultivation technology in plantation established on milled peat fields. In: Proceedings of the 38th International Symposium Actual Tasks on Agricultural Engineering, Opatija, Croatia, Feb 22–26, 2010: 271–279.

Laaneots R., Mathiesen O. (2011): An Introduction to Metrology. 2nd Ed. Tallinn, TUT press.

Marra M.C., Woods T.A., Parker R., San N.N., Teisl M. (1989): A comparison of lowbush blueberry harvesting technologies: Experimental and economic results from the 1988 field tests in Washington County, Maine. Maine Agricultural Experiment Station Bulletin 825.

Ochmian I. (2013): Growth, yield and fruit quality two cultivars lowbush blueberry. Acta Scientiarum Polonorum Hortorum Cultus, 12: 87–96.

Shahbazi F. (2012): Tensile strength of safflower stalk as affected by moisture content, stalk region and loading rate. Agricultural Engineering International: CIGR Journal, 14: 203–208.

Sibleye K.J. (1993): Effect of head-speed-ground-speed ratio on the picking effectiveness of a lowbush blueberry harvester. Canadian Agricultural Engineering, 35: 33–39.

Stackeviciene E. (2003): Analysis of introductional adaptivity of blueberries (Vaccinium). Botanica Lithuanica, 5: 97–107.

Starast M., Karp K., Noormets M. (2002): The effect of foliar fertilisation on the growth and yield of lowbush blueberry in Estonia. Acta Horticulturae (ISHS), 594: 679–684.

Starast M., Karp K., Vool E., Paal T., Albert T. (2007): Effect of NPK fertilization and elemental sulphur on growth and yield of lowbush blueberry. Agricultural and Food Science, 1: 34–45.

Strik B. (2005): Blueberry: an expanding world berry crop. Chronica Horticulturae, 45: 7–12.

Tasa T., Starast M., Jõgar K., Paal T., Kruus M., Williams I.H. (2015): Lowbush blueberry plantation age influences natural biodiversity on an abandoned extracted peatland. Ecological Engineering, 84: 336–345.

Vahejõe K., Albert T., Noormets M., Karp K., Paal T., Starast M., Värnik R. (2010): Berry cultivation in cutover peatlands

https://doi.org/10.17221/90/2017-RAE

in Estonia: Agricultural and economical aspects. Baltic Forestry, 16: 264–272.

Vander Kloet S.P. (1988): The genus *Vaccinium* in North America. Ottawa, Canada Goverment Publishing Centre.

Yakovlev A.P., Rupasova Zh.A., Bulavko G.I., Titok V.V., Reshetnikov V.N., Vasilevskaya T.I., Krinitskaya N.B., Tishkovskaya E.V. (2016): Development vegetative and generative sphere of *Vaccinium angustifolium* Ait. Introduced under conditions of Belarus. American Journal of Engineering Research, 5: 233–235.

Yarborouph D.E. (1992): A comparison of three mechanical harvesters and handraking for wild blueberries. HortScience, 27: 600.

Yu M. (2004): Ultimate Strength Characteristics of Switchgrass Stem Cross-Sections at Representative Processing Conditions. [Master´s Theses.] University of Tennessee.

Yu P., Li C., Takeda F., Krewer G., Rains G., Hamrita T. (2014): Measurement of mechanical impacts created by rotary, slapper, and sway blueberry mechanical harvesters. Computers and Electronics in Agriculture, 101: 84–92.

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IV

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Agronomy Research **12**(1), 25–32, 2014

Constructive and kinematics parameters of the picking device of blueberry harvester

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Abstract. The article focuses on the selection of constructive and kinematics parameters of the picking device intended for picking lowbush blueberry, cultivated on milled peat fields. The constructive parameters of the picking device are reel radius, the height of the picking device's axis of rotation from the ground, the number of picking rakes (or the displacement angle of neighbouring rakes) and the angle of inclination of rake teeth in relation to the upward direction. The kinematics parameters include the angular speed of the picking reel, the machine velocity and the kinematics number.

Key words: agricultural engineering, blueberry harvester, picking reel, constructive and kinematics parameters.

INTRODUCTION

Lowbush blueberries, the height of which is between 10…60 cm depending on the variety and the berries of which ripen more or less at the same time (Starast et. al, 2005; Strik, 2009), could be harvested most reasonably with a machine, where the functional working unit is a drum or a picking reel (Olt & Käis, 2006). Picking rake contains teeth attached to the axis of rotation (Olt & Arak, 2012). Blueberries do not ripen after harvesting and therefore the berries have to be picked at their full maturity (Albert et al., 2009). Ripened blueberries do not defoliate easily and could thus stay on the bush ca 10 days when ripened (Starast et. al, 2009).

The principle layout of the blueberry harvester has been presented in Fig. 1. It is the so-called rough harvester, i.e. the additives of the blueberry harvester (leaves, pieces of stems and peat, etc) and bruised berries are not separated from the berry mixture. Thus, the technological operations of the blueberry harvester comprise removing the berries harmlessly from the stems and collecting the berries into berry boxes or containers, meant for handling.

Picking reel 3 contains picking rakes 12 that have been attached to the axes between side discs; rake teeth 13 have been rigidly attached to the picking rakes. Berries are separated from the stems with the help of rake teeth 13 that are put into motion through the blueberry stems. The diameter of the rake teeth 13 is 5 mm and their interval from each other on the picking rake 6 is 8 mm.

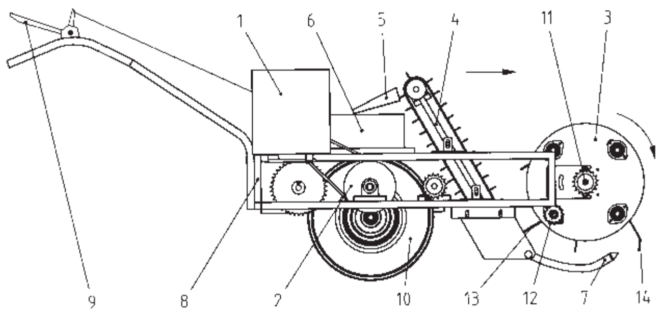

Figure 1. Main assemblies and parts of a motoblock-type harvester (Patent EE05488 B1): 1 – engine, 2 – power transmission elements, 3 – picking reel, 4 – conveyor, 5 – chute, 6 – berry box, 7 – copying unit, 8 – frame, 9 – steering levers, 10 – wheels, 11 – reel shaft, 12 – picking rake, 13 – rake tooth, 14 – hook spring-tine.

MATERIALS AND METHODS

The article studies the constructive parameters of the picking reel of the blueberry harvester: radius r_A, the height of the picking reel shaft from the ground H, (Fig. 2) the number of picking rakes z (or the angle of displacement of neighbouring rakes) and the angle of inclination of the rake teeth of the picking rake γ in relation to the vertical direction, as well as the angular speed of the kinematic parameters' picking reel ω_r, velocity of the machine v_m, and the selection principles of the kinematic indication number λ.

The picking reel 3 is a parallelogram reel, which is characterised by the fact that the rake tooth 13 of the picking rake 12 is located with a permanent (constant) rake angle toward the ground, and, thus, the following condition has to be followed

$$|\omega_r| = |\omega_p|, \tag{1}$$

where: ω_r – the angular speed of the picking reel 3; ω_p – the angular speed of the picking rake 12.

The rake angle γ of the rake teeth 13 of the picking rake 12 can be changed according to need.

The picking rake 12 participates in unitary movement: linear moving with the machine and rotary relative movement around the horizontal axis. According to the scheme presented in Fig. 2, the coordinates of point B, the free tip of the rake teeth of the picking reel are expressed as follows:

$$x(t) = v_m \cdot t + r_A \cdot \cos\varphi - l_p \sin\gamma; \tag{2}$$

$$y(t) = 0; \tag{3}$$

$$z(t) = -r_A \cdot \sin\varphi - l_p \cos\gamma; \quad (4)$$

where: v_m – speed of the blueberry harvester; r_A – radius of the picking reel 3 (the distance of the centre-axle A of the picking rake from the axis of rotation O of the picking reel); $\varphi = \omega_r t$ – angle of rotation of the picking reel; ω_r – angular speed of the picking reel; γ – rake angle of the picking rake teeth; γ = const; β – the angle characterising the position of the picking rake; $\beta \neq$ const; l_p – length of the picking rake teeth; t – time.

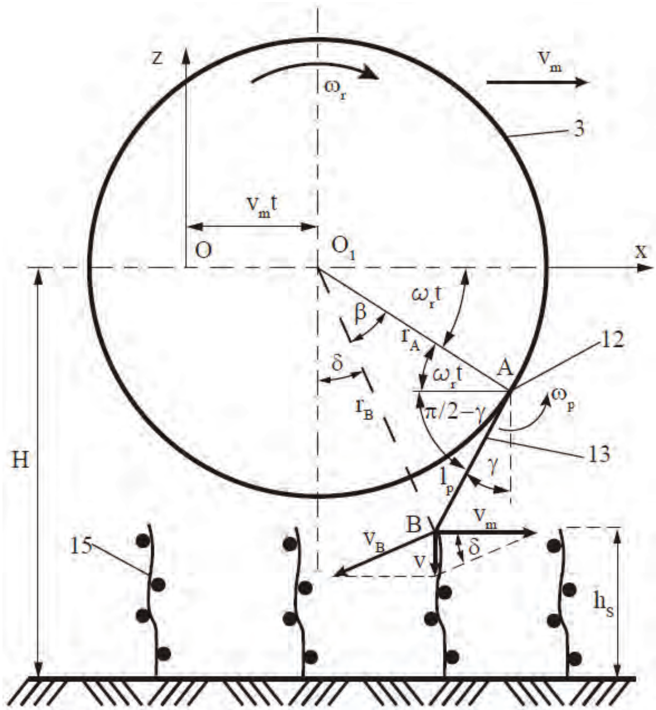

Figure 2. Calculation scheme for compiling equations of the trajectory of picking reel's rakes and for determining the height of the picking reel shaft from the ground: 3 – picking reel, 12 – picking rake, 13 – rake teeth, 15 – blueberry plant.

The trajectory of the picking reel has been studied by Heinloo (2007), but in this case we are not interested in the trajectory of the picking reel and the picking rake. Nevertheless, some important analytical relations for the technological calculation of the picking reel can be indicated with the trajectory equations (2, 3, 4). Firstly, this includes a relation for the selection of the rotational speed of the picking reel. So that the picking of berries could at all occur, the following condition has to be met:

$$v_x = \frac{dx}{dt} < 0,$$

Thus, after differentiation of the first equation (2) according to time *t,* the result is

$$v_m - \omega_r r_A \sin \omega_r t < 0. \qquad (5)$$

Dividing the inequality (5) with the machine velocity v_m and marking $\lambda = \omega_r r_A / v_m$, which indicates the kinematic indication number of the picking reel, the result is

$$\lambda > \frac{1}{\sin \omega_r t}.$$

That is, calculating that the maximum value of sine is 1, then $\lambda > 1$, whereas the value of λ changes practically in the limit of $\lambda \approx 2 \ldots 2.5$, and the absolute velocity of the picking reel is expressed as follows:

$$v = v_m \sqrt{1 + \lambda^2 - 2\lambda \sin \omega_r t}, \qquad (6)$$

and the angular velocity of the picking reel ω_r is expressed thus:

$$\omega_r = \frac{\lambda \cdot v_m}{r_A}. \qquad (7)$$

As this is a motoblock-type machine, the machine velocity v_m is limited with the operator's velocity, that is, $v_m < 1$ m s^{-1}. The velocity of the machine prototype is changeable in the interval of $v_m = 0.30 \ldots 0.78$ m s^{-1}. During tests, most suitable working velocity is $v_{m,opt} = 0.55$ m s^{-1}.

The task of the picking reel 3 is to remove blueberries from the stems without any damage. In real working conditions, during the rotation of the picking reel 3, the movement direction of the rake teeth tips has to be vertical, directed top-down, when the rake teeth 13 tips of the picking reel (point B) reach the top of the blueberry plant; in this way the picking rake teeth can penetrate between the blueberry plants 15, that is, at the moment of penetrating between the stems carrying berries the absolute speed vector of the rake teeth tips (Fig. 2) has to be directed vertically top-down. In this case, the height H of the picking reel 3 shaft from the ground is expressed as follows:

$$H = h_s + l_p \cdot \cos\gamma + r_A \cdot \sin\omega_r t \qquad (8)$$

where: h_s – the average height of the blueberry plant from the ground to the top, as $\lambda = 2.5$, then it is reasonable to implement the condition $l_p \geq 0.5 h_s$.

RESULTS AND DISCUSSION

Analysing equation (8), it is evident that except for the angle $\omega_r t$ all other parameters can be determined. Thus, for the purpose of being able to use the equation (8), an unknown angle has to be expressed $\omega_r t$. This is possible if we express the fictive radius r_B from the triangle O_1AB (Fig. 2), using a cosine sentence as follows:

$$r_B^2 = r_A^2 + l_p^2 - 2r_A l_p \cos\left[\frac{\pi}{2} + (\omega_r t - \gamma)\right]. \tag{9}$$

Considering that

$$\cos\left[\frac{\pi}{2} + (\omega_r t - \gamma)\right] = -\sin(\omega_r t - \gamma) = -\sin\omega_r t \cdot \cos\gamma + \cos\omega_r t \cdot \sin\gamma,$$

the relation (9) can be expressed as follows

$$r_B^2 = r_A^2 + l_p^2 + 2r_A l_p[\sin\omega_r t \cdot \cos\gamma - \cos\omega_r t \cdot \sin\gamma]. \tag{10}$$

Also, the following relation can be drawn from the Fig. 2

$$r_B \cdot \cos\delta = r_A \cdot \sin\omega_r t + l_p \cdot \cos\gamma. \tag{11}$$

by squaring both sides of the relation (11) and formulating from this fictive radius r_B

$$r_B^2 = \frac{r_A^2 \cdot \sin^2\omega_r t + 2r_A l_p \sin\omega_r t \cdot \cos\gamma + l_p^2\cos^2\gamma}{\cos^2\delta}, \tag{12}$$

where δ – positional angle of the rake tooth tip B.

If we apply a sine low for the triangle formed from velocity vectors (Fig. 2):

$$\frac{\sin\delta}{v} = \frac{\sin\left(\frac{\pi}{2} - \delta\right)}{v_m} \tag{13}$$

and considering relation (6) as well as the fact that $\sin\left(\frac{\pi}{2} - \delta\right) = \cos(\delta)$, then we can express it after the conversions as this

$$\frac{1}{\cos^2\delta} = \lambda^2 - 2\lambda\sin\omega_r t + 2. \tag{14}$$

When solving together relations (10), (12) and (14), grouping the units and after squaring and converting of both sides, we can formulate the following equation for the angle $\omega_r t$:

$$\begin{aligned} 4\lambda^2 r_A^4 \sin^6\omega_r t + r_A^2\left(\lambda^2 r_A - 4\lambda l_p + 2r_A\right)^2 \sin^4\omega_r t + \\ + 4l_p^2[\cos^2\gamma(r_A - \lambda^2 r_A + \lambda - 2r_A)^2 + \\ + r_A\sin^2\gamma]\sin^2\omega_r t - l_p^4[(\lambda^2+2)^2\cos^2\gamma - 1] + r_A^4 = 0. \end{aligned} \tag{15}$$

If we mark
$\sin^6\omega_r t = z^3$

$\sin^4 \omega_r t = z^2$
$\sin^2 \omega_r t = z$
and $4\lambda^2 r_A^4 = a$
$r_A^2\left(\lambda^2 r_A - 4\lambda l_p + 2r_A\right)^2 = b$
$4l_p^2[\cos^2\gamma(r_A - \lambda^2 r_A + \lambda - 2r_A)^2 + r_A \sin^2\gamma] = c$
$l_p^4[(\lambda^2+2)^2\cos^2\gamma - 1] + r_A^4 = d,$

We can write the relation (15) in this form

$$az^3 + bz^2 + cz - d = 0$$

that is,

$$z^3 + \frac{b}{a}z^2 + \frac{c}{a}z - \frac{d}{a} = 0. \tag{16}$$

If we mark $A = b/a$; $B = c/a$ and $C = -d/a$, then the satisfactory result of the equation (16) is expressed in the following form:

$$\sin \omega_r t_1 = \sqrt{z} = \sqrt{K_1 - \frac{K_2}{K_1} - K_3}, \tag{17}$$

where

$$K_1 = \left(\sqrt{\frac{B^3}{27} - \frac{C^2}{4} + \frac{A^3C}{27} - \frac{A^2B^2}{108} - \frac{ABC}{6}} - \frac{A^3}{27} + \frac{AB}{6} - \frac{C}{2}\right)^{\frac{1}{3}},$$

$$K_2 = \frac{1}{3}\left(B - \frac{A^2}{3}\right),$$

$$K_3 = \frac{A}{3}.$$

Because in different plantations the height of the blueberry plant h_s (the length of the stems) (Starast et. al, 2005) can differ, then the position of the axis of rotation of the picking device shall be changeable, so as to ensure harvesting without any loss.

Considering the fact that the average height of the blueberry plant from ground to top is $h_s = 0.2$ m and the technical parameters of the picking reel correspond to the ones indicated in Table 1, then the angle of rotation of the picking rake is $\omega_r t = 8°$, and we get the minimum height of the picking reel shaft according to relation (8) as $H_{\min} = 330$ mm.

Table 1. Technical characterisation of the picking reel

Parameter	Symbol	Unit	Value
Radius of the picking reel	r_A	mm	165
Length of the picking rake teeth	l_p	mm	135
Rake angle of the picking rake teeth	γ	degree	30

If we consider that the working speed of the machine is $v_{m,opt} = 0.55$ m s^{-1}, then according to the relation (7),the angular speed of the picking reel is $\omega_r = 8.33$ rad s^{-1}.

Rake teeth tips B of the picking rake have to reach the ground in their lower position. Deducing from this, we can check the distance of the picking rake axis from the shaft centre r_A with the following relation:

$$r_A \leq \frac{H - l_p \cdot \cos\gamma - d_c}{\cos\beta}, \tag{18}$$

where: d_c is the thickness of the copying unit runner, β – the angle characterising the position of the picking rake; $\beta \neq$ const; $\beta = 0\ldots360°$.

Thus, if $H = 330$ mm, the rake angle of the picking rake teeth is $\gamma = 30°$, the thickness of the runner $d_c = 30$ mm of the copying unit 7 (Fig. 1), the angle characterising the position of the picking rake $\beta = 20°$ if $\omega_r t = \pi/2$ and considering also the fact that the berries may be located close to the ground, then the maximum radius of the picking unit according to relation (19) has to be $r_A \leq 173$ mm. The radius of the picking reel of the blueberry harvester prototype (Fig. 3) is 165 mm, which prevents clutching peat pieces and other litter from the ground during the harvesting process.

Figure 3. Prototype of the blueberry harvester.

The number of rakes depends both on the kinematics of the picking reel as well as the positioning of its shaft. During design, it would be most reasonable to choose the number of the reel rakes in the limit of $z = 4\ldots6$ (Landtechnik, 1999). Following from these recommendations, the number of rakes has been chosen $z = 4$ when designing the prototype of this machine.

CONCLUSIONS

The article has pointed out methodology and explanation for the selection of the most important part of the motoblock-type blueberry harvester - the constructive and kinematics parameters of the picking reel. The constructive parameters of the prototype of the blueberry harvester (Fig. 3) are the following:

1) the diameter of the picking reel $2r_A = 330$ mm,
2) the height of the axis of rotation of the picking reel from the ground $H = 330$ mm,
3) the number of picking rakes $z = 4$.

Kinematics parameters are the following:

1) angular speed of the picking reel $\omega_r = 8.33$ rad s^{-1},
2) machine movement speed $v_m = 0.55$ m s^{-1},
3) kinematic indication number $\lambda = 2.5$.

REFERENCES

Albert, T., Starast, M., Karp, K., Kaldmäe, H., Vool, E. & Paal, T. 2009. The influence of propagation method on growth of the half-highbush blueberry 'Northblue'. *Acta Horticulturae*, vol. 812, pp.141–146.

Heinloo, M. 2007. A virtual reality technology-based method for the study of the working process of blueberry harvester´s picking reel. *Agricultural Engineering International: the CIGR Ejournal*, 12 pp.

Landtechnik / Herausgegeben von H. Eichhorn. 7. Aufgabe.– Hohenheim, Verlag Eugen Ulmer GmbH & Co, 1999, 688 S.

Olt, J. & Arak. M. 2012. Moto block-type structure and development of the blueberry harvester reel. *Journal of Agricultural Science* **XXIII** (2), 21–26.

Olt, J. & Käis, L. 2006. Kinematics of the working unit of the blueberry harvester. *Journal of Agricultural Science* **XVII**(2), 101–105.

Starast, M., Karp, K., Paal, T. & Värnik, R. 2005. Kultuurmustikas ja selle kasvatamine Eestis. Eesti Põllumajandusülikool, 65 pp. (in Estonian).

Starast, M., Paal, T., Vool, E., Karp, K., Albert, T. & Moor, U. 2009. The Productivity of Some Blueberry Cultivars under Estonian Conditions. *Acta Horticulturae*, 810, p. 103–108.

Strik, B. 2005. Blueberry: An Expanding World Berry Crop. *Chronica Horticulturae* **45**(1), 7–12.

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Arak, M., Olt, J. 2020. Technological description for automating the cultivation of blueberries in blueberry plantations established on depleted peat milling fields. In: Proceedings of the 7th International Scientific Conference Rural Development 2019, 98–103. Kaunas, Lithuania: Vytautas Magnus University, doi: 10.15544/RD.2019.024

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TECHNOLOGICAL DESCRIPTION FOR AUTOMATING THE CULTIVATION OF BLUEBERRIES IN BLUEBERRY PLANTATIONS ESTABLISHED ON DEPLETED PEAT MILLING FIELDS

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In order to increase the cost-effectiveness of blueberry (*Vaccinium*) cultivation in blueberry plantations, all of its technological operations should be automatized. It is reasonable to start the automation of blueberry cultivation from the technological operation of fertilising the blueberries as the main purpose of this operation is to dose a prescribed amount of fertiliser under the plant's crown. When a new blueberry plantation is established on depleted peat milling fields, then the plants are set at pre-determined steps into parallel rows. Fertilisation of the plants in the first years of growth must be performed individually, i.e. each plant is fertilised separately. This is called precision fertilisation. In order to design the technological devices for blueberry cultivation, including the fertiliser robot, it is important to know the location of plants on the field or, more precisely, their position in the row. The goal of this study is to determine the position of blueberry plants in the plantation. In order to meet the goal, measurements were performed in the blueberry plantation and the position of plants in randomly chosen row was measured. It became clear from the study that plants are not positioned regularly at equal intervals in a straight line; therefore, the fertiliser robot to be designed must include the functions of plant identification and control of fertiliser jet to ensure individual or precision fertilisation of plants.

Keywords: *blueberry plantation, plant identification, position of plants, precision cultivation, robotization*

INTRODUCTION

According to sources (Olt et al., 2013; Starast et al., 2002; Retamales, Hancock, 2018; Zydlik et al., 2016), the blueberry (*Vaccinium*) cultivation system contains the following technological operations: 1) soil preparation, 2) planting of the plants, 3) maintenance of the plantation, 4) fertilisation of plants, 5) plant protection, 6) improvement of soil properties with vaccines 7) harvesting, 8) post-harvesting processing and 9) cutting back the plants or rejuvenation pruning. These technological operations can be performed either manually or using a machine (Olt et al., 2013; Scherm et al., 2010), whereat the latter method of cultivating the blueberries is more productive and efficient than the former (Käis, Olt, 2010; Takeda et al., 2017). Blueberry plantations have been established on mineral soils, but also on depleted peat milling fields (Peatland Ecology…, 2009). Machines have been developed for performing all of the technological operations in blueberry plantations established on mineral soils.

Peat milling fields have a pH level and moisture regime that is suitable for blueberry cultivation (Noormets et al., 2003; Smagula et al., 2003; Arak et al., 2018); however, their ground has a low load bearing capacity and, therefore, machines with very low special pressure can be used here and, unfortunately, these have not been in the centre of attention of larger machine-building companies. A few smaller companies have produced machines and devices that can potentially be used in plantations established on peat milling fields (Olt et al., 2013).

One of the possibilities of reducing the unit cost of blueberry cultivation is by implementing machines. The use of machines in blueberry cultivation sets specific requirements to the plantation, namely the following: 1) the use of machines is possible in continuously maintenanced and pruned plantations; 2) in order to ensure the normal operation of servicing and harvesting machines, the ground of the plantation must be level and it should remain level during exploitation; 3) service or technical roads must be established; 40 machine harvesting requires the periodic pruning of old branches; the first rejuvenation pruning is performed from the 8th to 10th year, thereafter every 3–4 years.

The efficiency of machine cultivation of berries, including blueberries, can be further increased by using the methods of precision cultivation (Chang et al., 2012) and by robotizing the performance of its technological operations. It is reasonable to start the robotization of blueberry cultivation from the fertilisation of the plantation by modelling a fertiliser robot. It must be taken into account that the availability of nutrients in the soil affects significantly the productivity of the plants (Farooque et al., 2012); greater fertilisation norms (nitrogen up to 150 kg ha^{-1}) improve significantly the growth of the plants and improve yield (Ehret at al., 2014), especially on soils low in nutrients (Starast et al., 2007; Paal et al., 2011). A strong positive relation has been found between the availability of nutrients and the vegetative parameters of the blueberry plant: the plant's height and area of the leaves (Leit, 2017; Vainura, 2018).

However, fertilisation depends on the properties of a specific soil and the plant's age, which results in a specific norm for each fertiliser. From the point of view of the plant's age, it should be kept in mind that the root grows each year and this results in a larger area to be fertilised. In the first year, the fertiliser should be spread to a smaller area of about 20 × 20 cm around the plant; at the age of 6–8 years, the area of plant's roots has achieved maximum dimensions (about 100 × 100 cm); this also depends on the density of plantation: if the distance between plants in a row is 150 cm, then the area to be fertilised is 150 × 150 cm).

The following main and specific functions need to be defined to design a fertiliser robot for blueberry plants: 1) the blueberry plants in the plantation have been placed at certain intervals (1, 1.5 and 2.0 m) in a row and, therefore, the fertiliser robot must move in a straight line on the field along the plant row; 2) fertiliser must be spread around the plant under its crown (Hart et al., 2006); 3) blueberry plants must be fertilised 2–3 times per season by dosing 30–80 g plant^{-1} (less in the first years, more in the later years (Hart et al., 2006), which means that the dosing unit of the fertiliser robot must be adjustable for dosing predetermined amounts of fertiliser. It is not possible to use overall fertilisation in a blueberry plantation as this will result in the thriving of weeds and this would raise the maintenance costs unexpectedly.

If the blueberry plants would be located in one row and at fixed intervals, then the designing of the fertiliser robot would be relatively easy. However, the plant rows are usually not straight, because the plants are not located in distinct rows and the distance between them varies; therefore, the fertiliser robot must be equipped with the functions of identifying the blueberry plant and controlling the fertiliser jet. Thus, the goal of this study is to define the position of blueberry plants in plant rows in established blueberry plantations.

MATERIALS AND METHODS

Studies were carried out in June 2018 in the in Toomas Jaadla's Marjasoo farm blueberry plantation in Rannu municipality in Tartu County (Estonia) (Fig. 1).

Figure 1. Top view of the Marjasoo farm's blueberry plantation (photo A. Arula, Droon Phantom Advanced)

A random plant row with plants 1 (Fig. 2) of two years of age was chosen in a young blueberry (*Vaccinium angustifolium Ait.*) plantation for determining the position of blueberry plants.

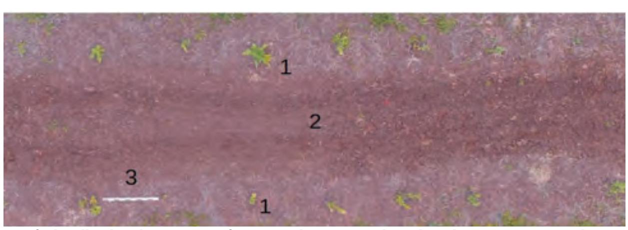
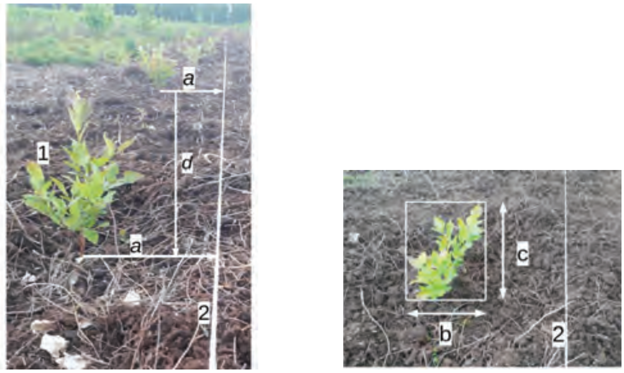


Figure 2. Fragment of a headland in the Marjasoo farm: 1 – plants, 2 – technical road, 3 – measuring rod (1 m) (photo A. Arula, Droon Phantom Advanced)

In order to determine the position of plants 1 (Fig. 3) in rows, rope 2 was placed 400 mm from the first and last plant of the row (on the side next to the technical road) and measuring tape was used to measure using the accuracy of 5 mm.



A B

Figure 3. Scheme for determining the parameters of a blueberry plant row: parameters of the plant row (A) and geometrical parameters of the plant (B): 1 – plants, 2 – base rope, a – distance of a plant from the base (measuring) rope, b – length of the edge perpendicular to the measuring line of the blueberry bush's projection, c – length of the edge parallel to the measuring line of the blueberry bush's projection, d – distance between the plants, h – height of the plant

A crater for planting had been formed around the plant using hand tools and the plant is located in the centre of this crater (Fig. 4) with the following parameters: outer diameter of the planting crater D_v = 935 mm, inner diameter of the planting crater D_s = 340 mm and height of the planting crater h_k = 93 mm.

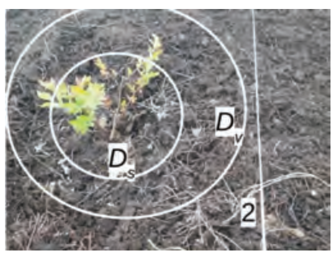


Figure 4**.** Parameters of the crater around the blueberry plant: D_v is the outer diameter of the crater, D_s – its inner diameter, 2 – base rope.

RESULTS AND DISCUSSION

One plant row planted in 2016 in Toomas Jaadla's Marjasoo farm's blueberry plantation was chosen for measuring. The characteristic technological parameters of this row were the following: 1) total length of the row of blueberry plants is 177 m; 2) distance between plant rows is 2.7 m; 3) a technical road of 1.5 m was located between the rows; 4) the number of plants in the row is 130, including 15 plants that have dried and 2 planting craters hold 2 plants each.

It became evident during the positioning of blueberry plants in the row (Fig. 5) that the deviation of plants from the central axis remained in the range of −295 mm to 365 mm.

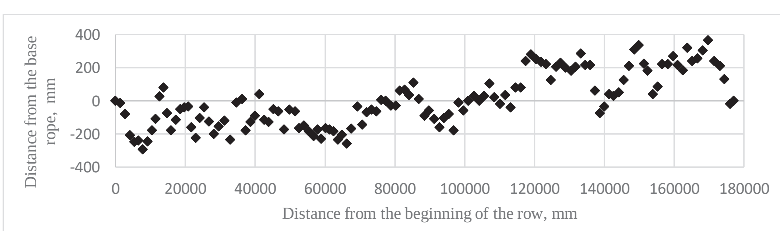


Figure 5. Position of blueberry plants in a row

It became evident from data analysis (*MS Excel*) that the average distance of plants from the central axis of the plant row is relatively small (only 1.8 mm); however, as the plants are located on both sides of the central axis and they have a wide range (660 mm), then the standard deviation is a high ±162 mm. The asymmetry multiplier (skewness) and excess (kurtosis) of the position of the plants are 0.35 and −0.86, respectively. It can be claimed using this information that the majority of the plants are positioned to the left of the plant row and distances have concentrated away from the mean value towards the negative values. The distribution of plant positions is described in Figure 6.

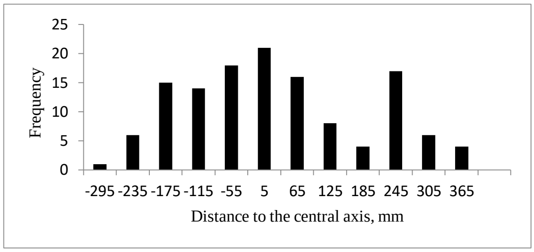


Figure 6. Histogram of the upper limits of the distance of blueberry plants to the central axis of the plant row

The mean distance of blueberry plants in the row described in Figure 2 including standard deviation, is 1372 ± 166 mm, with the minimum and maximum distance between the plants being 915 and 1800 mm, respectively. The asymmetry multiplier (skewness) and excess (kurtosis) of the distance between the plants are −0.17 and 0.26, respectively; this can used to claim that the majority of the distances are greater than the mean value. The distance between the plants in a plant row has been described in Figure 7.

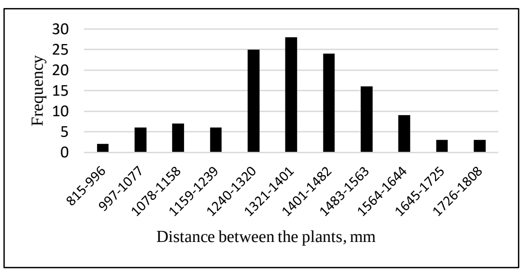


Figure 7. Histogram of the upper limits of the distance between the plants

From the point of view of modelling the fertiliser robot, it is necessary to know the dimensions of the projection of the blueberry plant's leaves. This study treats the shape of a blueberry plant as a rectangle with side's mean length, including standard deviation, being 180 ± 84 mm and 189 ± 87 mm. The perpendicular (b) and longitudinal (c) length of the projection of leafage varies greatly: b = 50...480 mm and c = 40...440 mm. The measurement results have been given in Table 1 and illustrated in Figures 8 and 9.

Table 1. Parameters of blueberry plant's leafage and height

Parameter	b, mm	c, mm	d, mm
Mean	179.8	188.7	219.7
Standard deviation	83.7	86.9	57.9
Kurtosis	1.2	–0.1	0.6
Skewness	1.1	0.7	0.3
Range	430	400	330
Minimum	50	40	60
Maximum	480	440	390

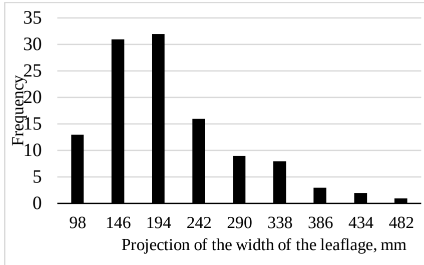


Figure 8. Histogram of the upper limits of the projection of the width of the leafage of blueberry plants

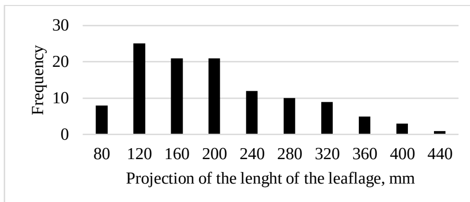


Figure 9. Histogram of the upper limits of the projection of the length of the leafage of blueberry plants

The height of the blueberry bush must be known to determine the machine's clearance. The measurement results of the heights of blueberry bushes have been illustrated in Figure 10 and statistical data has been presented Table 1.

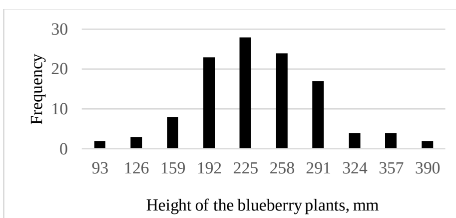


Figure 10. Histogram of the upper limits of the height of blueberry plants

Table 1 shows that the height of plants varies greatly (330 mm), which also gives an input for modelling the parameters of the fertiliser robot.

This study is one of the first steps in defining the technology of blueberry plantations established on depleted peat milling fields. The obtained results can be used for modelling technological machines and continuing research. Results show that manually planted plants may not be located in a straight line; the deviations from the central axis of the plant row in this study were −295 up to 365 mm. At the same time, the distance between the plants or their interval was not homogenous and remained in the range of 915 to 1800 mm. The values of the perpendicular and longitudinal projections of leafage vary greatly, 50...480 and 40...440 mm, respectively. The mean height of two-year-old plants was 220 mm, but this value also varies greatly in the range of 60 to 390 mm.

The numerical values obtained in this study can be used to determine the overall machine-building dimensions (like the working range of the fertiliser unit, clearance of the machine) of the prototype of the fertiliser robot to be designed. The functions of an autonomous fertiliser robot must include the identification of a blueberry plant and control over the fertiliser jet in addition to the precise dosing of the fertiliser.

CONCLUSION

This study is one of the first studies to define a blueberry plantation on depleted peatland fields. The results are the basis for further research. The results shows that the manually planted plants do not lie in one narrow row, but the plants are located on both sides of the central axis in a wide range (660 mm). Also, the distance between plants in a row varies greatly (915…1800 mm).

Consequently, the fertilizer robot to be designed must be equipped with a blueberry crop detection device and a fertilizer application control.

REFERENCES

1. Arak M., Soots K., Starast M., Olt J. 2018. Mechanical properties of blueberry stems. *Research in Agricultural Engineering*, Vol. 64, pp. 202–208. https://doi.org/10.17221/90/2017-RAE
2. Chang Y. K., Zaman Q., Farooque A. A., Schumann A. W., Percival D. C. 2012. An automated yield monitoring system II for commercial wild blueberry double-head harvester. *Computers and Electronics in Agriculture*, Vol. 81, pp. 97–103. https://doi.org/10.1016/j.compag.2011.11.012
3. Ehret D. L., Frey B., Forge T., Helmer T., Bryla D. R., Zebarth B. J. 2014. Effects of nitrogen rate and application method on early production and fruit quality in highbush blueberry. *Canadian Journal of Plant Sciences*, Vol. 94, pp. 1165–1179. https://doi.org/10.4141/cjps2013-401
4. Farooque A. A., Zaman Q. U., Schumann A. W., Madani A. Percival D. C. 2012. Delineating management zones for site specific fertilization in wild blueberry fields. *Applied Engineering in Agriculture*, Vol. 28, Iss. 1, pp. 57–70. https://doi.org/10.13031/2013.41286
5. Hart J., Strik B., White L., Yang W. 2006. Nutrient management for blueberries in Oregon. EM8918. Oregon State University Extension Service. Corvallis, Oregon, 16 p.
6. Käis L., Olt J. 2010. Low-bush blueberry machine cultivation technology in plantations established on milled peat fields. Kosutic S. (ed.). *Actual tasks on agricultural engineering. HINUS*, Vol. 38, pp. 271−279.
7. Leit I. 2017. Effect of genotype and fertilization on the chemical composition of blueberries under organic farming conditions: master thesis. Eesti Maaülikool, Tartu, Estonia, (in Estonian), 46 p.
8. Noormets M., Karp K., Paal T. 2003. Recultivation of opencast peat pits with *Vaccinium* culture in Estonia. Iezzi E. et al. (eds). Ecosystems and sustainable development. *Southampton, Boston*, Vol. IV (2), pp. 1005–1014.
9. Olt J., Arak M., Jasinskas A. 2013. Development of mechanical technology for low-bush blueberry cultivating in the plantation established on milled peat fields. *Agricultural Engineering*, Vol. 45, Iss. 2, pp. 120–131.
10. Paal T., Starast M., Noormets-Šanski M., Vool E., Tasa T., Karp K. 2011. Influence of liming and fertilization on lowbush blueberry in harvested peat field condition. *Scientia Horticulturae*, Vol. 130, Iss. 1, pp. 157−163. https://doi.org/10.1016/j.scienta.2011.06.031
11. Peatland Ecology Research Group. 2009. Production of berries in peatlands. Guide produced under the supervision of Line Rochefort and Line Lapointe. Université Laval, Quebec, Canada, 134 p.
12. Retamales J. B., Hancock J. F. 2018. Blueberries (2nd ed.). Crop Production Science in Horticulture Agriculture, book 29. CABI, 424 p. https://doi.org/10.1079/9781780647265.0000
13. Scherm H., Krewer G., Cline W. O., Harmon P., Morgan K., Takeda F. 2010. Advancing blueberry production efficiency by enabling mechanical harvest, improving fruit quality and safety, and managing emerging disease. *HortScience*, Vol. 45, Iss. 8, pp. 199–200.
14. Smagula J., Litten W. 2003. Can lowbush blueberry soil pH be too low? Acta Horticulturae, 626: 309-314. doi: 10.17660/ActaHortic.2003.626.43 https://doi.org/10.17660/ActaHortic.2003.626.43
15. Starast M., Karp K. Noormets M. 2002. The effect of foliar fertilisation on the growth and yield of lowbush blueberry in Estonia. *Acta Horticulturae*, Vol. 594, pp. 679–684. https://doi.org/10.17660/ActaHortic.2002.594.92
16. Starast M., Karp K., Vool E., Paal T., Albert T. 2007. Effect of NPK fertilization and elemental sulphur on growth and yield of lowbush blueberry. *Agricultural and Food Science*, Vol. 1, pp. 34–45. https://doi.org/10.2137/145960607781635859
17. Takeda F., Yang W.O., Li C., Freivalds A., Sung K., Xu R., Hu B., Williamson J., Sargent S. 2017. Applying New Technologies to Transform Blueberry Harvesting. *Agronomy*, Vol. 7, Iss. 33. https://doi.org/10.3390/agronomy7020033
18. Vainura K. 2018. The influence of Monterra Malt fertilizers on the productivity and fruit chemical composition of blueberry's selections (*Vaccinium*): master thesis, Eesti Maaülikool, Tartu, Estonia, 63 p. (in Estonian).
19. Zydlik Z., Pacholak E., Rutkowski K., Styła K. 2016. The influence of a mycorrhizal vaccine on a biochemical properties of soil in the plantation of blueberry. *Zemdirbyste-Agriculture*, Vol. 103, Iss. 1, pp. 61–66 https://doi.org/10.13080/z-a.2016.103.008

VI

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A justification of the choice of parameters for the picking reel tooth on a lowbush blueberry harvester

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Abstract. The functional working tool on the blueberry harvester is its rotating picking reel. Its working element is the picking rake which is attached to the picking reel. A total of four rakes are attached to the picking reel. A picking rake includes an axis which is attached in an articulated manner between the reel's end discs, and pin-shaped teeth which are rigidly attached to it. The picking rake's tooth must be made of a fully flexible material to prevent damage to the blueberry plant. The aim of this research was to determine the flexure of test specimens (plastic rods) which have been constructed from a fully flexible material of different conditions, along with the suitability for use of such flexible material as the teeth on the picking rake. As a result of this study, it became clear that, based on the results from flexure, durability, and residual deformation tests, it is more expedient to choose Ertacetal C (POM-C) as the material for the picking reel's tooth, with a diameter of 4.3 mm.

Key words: blueberry harvester, elastic modulus, flexible tooth, picking reel.

INTRODUCTION

Blueberry plantations have been established on mineral lands, but also on exhausted milled peat fields (Peatland Ecology Research Group, 2009). Machinery has been created to take care of all technologically-involved operations, including harvesting, where medium and tall blueberry varieties are concerned which have been planted on mineral lands.

According to the available literature (Starast et al., 2007; Olt et al 2013; Ali, 2016; Retamales & Hancock, 2018), blueberry cultivation consists of a series of technologically-involved operations, of which harvesting is one of the most labour-intensive-, and logistically-demanding operation. Harvesting can be done by machine or hand harvest, with machine harvesting optimizing harvest efficiency (Käis & Olt, 2010; Olt et al., 2013; Takeda et al., 2017).

With lowbush blueberries (*Vaccinium angustifolium* Ait.), which have a plant height of 10–20 cm and whose berries ripen more or less simultaneously (Noormets et al., 2003), it is common practise on mineral lands to harvest them commertcially using automated equipment (Fig. 1) and a horizontally-located rotating picking reel (Fig. 2, a, b), with its working element being a picking rake (Heinloo, 2007; Arak & Olt, 2014). The picking rake is of the parallelogram type, which means that a picking rake remains parallel to its initial position at any angle of rotation. The picking rake contains an axis which is attached in an articulated manner between the end discs, to which teeth are rigidly attached in parallel with each other. The teeth are attached to the axis of the picking rake with spacing that allows them to move between blueberry plants without damaging them, while separating the berries from the stalks. This format is also known as a coarse harvester, which means that any impurities (such as leaves, twigs, peat particles, etc) and crushed berries are not separated by the harvester. Therefore the harvester's technologically-involved operations involve separating the berries from the stalks without any damage and to direct them to the exchangeable berry boxes or containers during the operation by means of a chute.

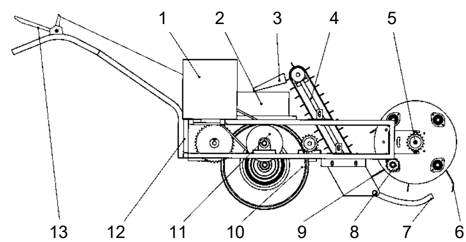

Figure 1. The main assemblies and parts of a motoblock-type harvester: 1 – engine; 2 – berry box; 3 – chute; 4 – conveyor; 5 – picking reel; 6 – hook spring-tine; 7 – copying unit; 8 – picking rake; 9 – rake tooth; 10 – wheels; 11 – transmission; 12 – frame; and 13 – steering levers.

The main disadvantage of the motoblock harvester for use with lowbush blueberries is the risk of damaging the plants, such as pulling them out of the ground. The process of damaging and tearing the plants occurs as follows: on a plant with long stems, where the stems are low to the ground in all directions around the centre of the plant due to the weight of the berries, those stems which mainly face in the same direction as the picking rake often get stuck between the picking rake's teeth as the picking rake moves downwards. The stems of a blueberry plant which are caught between three or more teeth are torn to shreds or are pulled out of the ground by the rotating picking reel when the wheel is equipped with rigid teeth (usually made from stainless steel). There is no problem with plants which have low stems of up to 15 cm long, as they mainly remain upright, but it is a serious problem for plants with stems which are longer than 20 cm. The problem comes from poor compatibility between variations in plant growth and the picking reel teeth in currently-available blueberry harvesters.

The simplest technical solution to the problem would be to replace the rigid picking rate teeth with flexible teeth. To accomplish this, a material with suitable properties must be selected for the production of the teeth.

According to Fig. 2, a, the operating elements of the picking reel 1 are horizontal picking rakes, which comprise picking rake teeth, 3, which are rigidly affixed to the axes, 2, which in turn are attached in an articulated manner between the side discs. The picking rake teeth, 3, are designed to be produced from a flexible material in order to prevent damage being inflicted on the blueberry plants. The picking rake teeth, 3, can be located positions 3a and 3b. The berries are separated from the stalks by means of the teeth, 3, which are moved through the blueberry stalks. In the initial position, 3a, with this being the unloaded position, the picking rake is straight; in the loaded position, 3b, the picking rake is bent (Fig. 2, a). If a picking rake's elastic tooth, 3, gets stuck behind a plant stem or if a plant stem located on the picking rake's path gets stuck between the ends of the teeth, the rotation of the picking reel, 1, places an additional load on the teeth, 3, with the tooth bending and assuming position 3b. When the teeth, 3, bend this means the plant stems are released from between the ends of the teeth and tooth moves past the plant without damaging the stem. After being released from the plant stems, the teeth, 3, reassume their initial shape, as in position 3a. The picking rakes are connected according to the parallelogram principle and the angle γ of the tooth, 3, is adjustable.

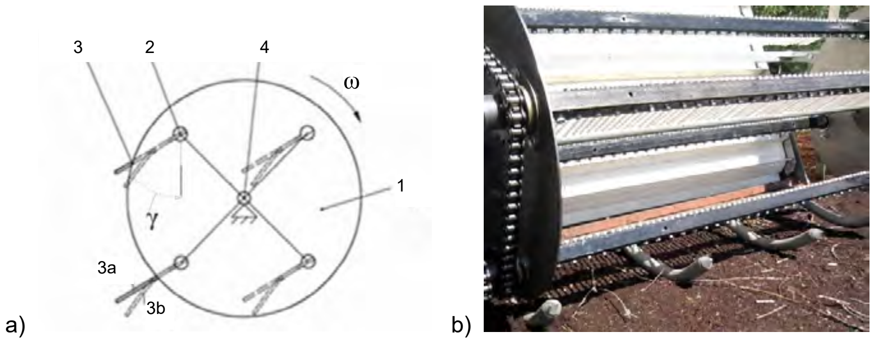

Figure 2. The blueberry harvester's picking reel: a) the principal schematic; b) prototype, with 1 – picking reel, 2 – picking rake, 3 – rake tooth, 3a – straight tooth, 3b – bent tooth, and 4 – spindle.

The aim of this work was to determine the flexure and durability of test specimens (plastic rods) which have been produced from elastic material which have differing general parameters, ie. observing and testing their suitability for use as picking rake teeth. The modified harvester with the flexible picking teeth may improve harvest efficiency and reduce plant damage, but requires testing to determine the feasibility of using this new harvester technology. Additionally, picking teeth conditions need to be studied to optimize harvest.

MATERIALS AND METHODS

In the case of lowbush blueberry harvesting, the system's elements are the blueberry plant, namely its berries, ie. the crop, along with the plant stalk which supports the berries, and the plantation and working harvester, which together form the blueberry cultivation system and subsystems. When the values of the relationships between the elements are known, it is possible to design harvesting technology in such a way that the requirement of preventing plant and berry damage during harvesting is ultimately fulfilled.

The Fig. 3 describes the forces exerted by the tooth on the berry and the plant during berry picking, where F_c is the connection force between the berry and the stem, F_s is the tensile strength of the plant's stem, and the connection force F_a between the stem and the soil, F_l is the lifting force, F_g is the gravitational force, E_m is elastic modulus of rake´s tooth material and E_s is tensile strength of plant's stem. It is evident from Fig. 3 that, in order to avoid damaging the crop or blueberry plants during harvesting, the harvesting machine must be designed in such a way that the following condition are fulfilled:

$$\left.\begin{matrix} F_{a,min} > F_{s,min} > F_l > F_{c,max} \\ E_m > E_s \end{matrix}\right\} \quad (1)$$

When taking these variables (Arak & Olt, 2017; Arak et al., 2018) into account, the material to be selected for the picking elements or the picking rake's teeth should be able to separate the berries, but should do no damage to the plant, or crush it, or tear it from the ground, and neither should it bruise the berries. Test work was carried out to select suitable material for rake tooth.

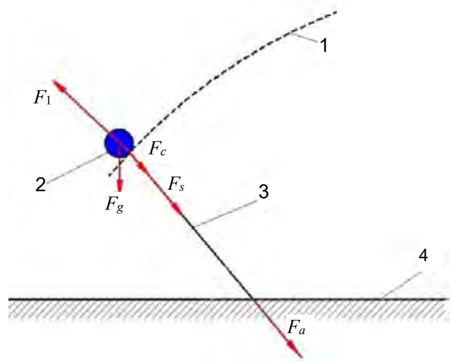

Figure 3. Those forces which are applied to a blueberry plant by the harvesting machinery flexible picking teeth: 1 – the picking reel's teeth; 2 – the berry on the blueberry plant; 3 – the blueberry stem; 4 – the field surface.

Any description of those forces which are applied in the blueberry harvester's picking reel should be based on the coordinate system $O_1X_1Z_1$ (Fig. 4, a), as related to the berry that is to be removed, where the origin O_1 is located at the connection point between the berry and the stem, axis Z_1 is parallel to the blueberry plant, and the positive direction of the axis is directed towards the berry's surface and mainly forms a right angle with the non-deformed tooth.

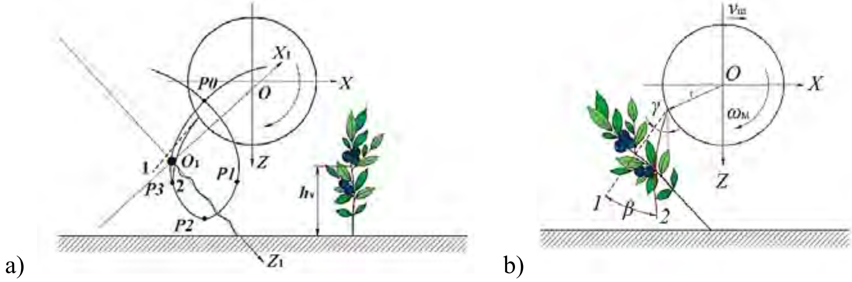

Figure 4. A diagram which characterises the work of a picking tooth: a) stages (*P1-P4*) of work of picking tooth; b) angles characterizing the work process for an elastic tooth.

The following forces are applied to the connection point between the berry and the tooth (Fig. 4, a).

In order to separate the berry from the stem, the force F_x which is applied to the connecting stem must be greater than the connection force $F_{c,\ max}$ between the berry and the stem.

The tooth of a picking reel is straight in the unstressed position (Fig. 4, position 1). Due to force $F_{c,}$ the stressed tooth attains position 2, which forms a flexure in comparison to the straight tooth, as expressed by the angle of inclination β. The angle of inclination γ of the blueberry harvester's prototype can be changed within the range of 40°–70°.

The extent of any bending is determined by the value of connection force F_c.

The berry is removed from the stem when the inequality (1) and following condition (2) is fulfilled:

$$\beta < \gamma, \quad (2)$$

where γ is the angle between the non-deformed tooth and the vertical direction.

The calculation of the force being applied to the tooth is based on the following assumptions:

1. The maximum yield of the blueberry plantation: 17,000 kg ha^{-1}, or 1.7 kg m^{-2} (Siliņa & Liepniece, 2020);
2. The mass of an individual berry: 0.14–3.40 g (Soots et al., 2017);
3. Therefore, about a thousand berries grow over one square metre;
4. The blueberry harvester's prototype (Arak et al., 2018) has teeth that are placed 21.5 mm apart, with a length of 125.0 mm. The maximum working area for one pair of teeth is 0.27×10^{-3} m^2.

As arising from assumptions 1-4, there are three berries for one pair of teeth during a working cycle (Fig. 4, a, *P1-P3*). When we apply a reserve factor of three, a pair of teeth will pick about ten berries during one working cycle.

According to Arak & Olt (2017), the connection force of berries that are ripe for harvesting was 0.17–0.83 N and 0.89–1.93 N for unripe berries. The numerical ratio between ripe and unripe berries during harvesting season is 80% and 20% respectively. Therefore, the maximum force to be applied to one pair of teeth is 12 N.

The gravitational force which results from the tooth's mass itself is small (0.025 N for a tooth diameter of 4.3 mm and 0.038 N for a tooth diameter of 5.3 mm), and may be dismissed. Likewise, the gravitational force which results from the berry's mass may be dismissed as its maximum value is 0.034 N.

Selecting the materials for the teeth: an engineering plastic Ertacetal C (Acetal Copolymer, POM-C) was chosen as the material for the flexible teeth as it is characterised by its great mechanical strength, its impact strength, and its ability to be treated by cutting in manufacturing process of tooth (Olt & Arak, 2012).

Selecting the diameter of the teeth: two choices of material were selected so that the test could be carried out, with a round cross-section of the diameters of 4.3 mm and 5.3 mm.

The following tests were carried out when it came to selecting the diameter of the materials being used on the picking reel teeth, *D*:

1) Determining the plastic deformation of the teeth by systematically bending the material at various diameters (4.3 mm and 5.3 mm);

2) The resistance of the teeth to breaking-in so-called semi-aggressive and aggressive bending modes.

3) Measuring the flexure of teeth at various loads.

Describing teeth flexure theoretically

To investigate the flexure of the picking reel, we consider the tooth as being a cantilevered homogeneous beam (Fig. 5). This beam is characterised by the modulus of elasticity E_m and the moment of inertia I.

The finite element method, FEM, has been used to study tooth flexure (Logan, 2007). The picking reel's tooth (Fig. 5) is rigidly attached at point 1 (Fig. 5), and is loaded at point 2 by force F. The beam is now modelled using two elements, I and II, with nodes 1, 2, and 3.

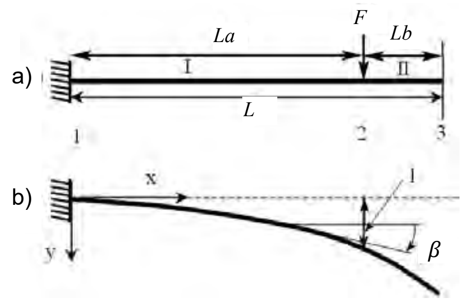

Figure 5. Cantilever beam being subjected a concentrated load: a) unloaded beam; b) loaded beam.

The local stiffness matrices for the elements I and II are K_1 and K_2 respectively.

$$K_1 = \frac{E_m I}{La^3}\begin{bmatrix} 12 & 6La & -12 & 6La \\ 6La & 4La^2 & -6La & 2La^2 \\ -12 & -6La & 12 & -6La \\ 6La & 2La^2 & -6La & 4La^2 \end{bmatrix}, \quad (3)$$

$$K_2 = \frac{E_m I}{Lb^3}\begin{bmatrix} 12 & 6Lb & -12 & 6Lb \\ 6Lb & 4Lb^2 & -6Lb & 2Lb^2 \\ -12 & -6Lb & 12 & -6Lb \\ 6Lb & 2Lb^2 & -6Lb & 4Lb^2 \end{bmatrix}. \quad (4)$$

The total stiffness matrix K is the result of assembling K_1 and K_2.

$$K = K_1 + K_2 \quad (5)$$

Through direct superposition and considering (3) and (4), the governing equation for this cantilever beam is:

$$\begin{Bmatrix} F_{1y} \\ M_1 \\ F_{2y} \\ M_2 \\ F_{3y} \\ M_3 \end{Bmatrix} = K \begin{Bmatrix} d_{1y} \\ \beta_{t1} \\ l_t \\ \beta_{t2} \\ d_{3y} \\ \beta_{t3} \end{Bmatrix}. \quad (6)$$

Considering the boundary conditions at node 1, we have:

$$\beta_{t1} = 0 \quad (7)$$

and:

$$d_{1y} = 0. \quad (8)$$

The momentum of inertia I for the beam with a circular cross-section can be described (Mäkelä et al., 2011):

$$I = \frac{\pi D^4}{64}. \quad (9)$$

Due to the initial task (Fig. 5), we get:

$$F_{2y} = F. \quad (10)$$

Solving the equation (6) by conditions (7), (8), and (10), the displacement at node 2 is:

$$l_t = \frac{{L_a}^3 F}{3 E_m I} \tag{11}$$

where L_a – distance of the attachment point from the point at which the force F was applied and the slope (in radians) at node 2 can be calculated as:

$$\beta_{t2} = \frac{2{L_a}^2 F}{E_m I}. \tag{12}$$

Experiments for studying the flexure of the teeth

Tests were carried out with tooth materials of two different diameters: D_1 = 4.3 mm and D_2 = 5.3 mm (these values have been chosen based on theoretical calculations and material availability). Tooth (1) was connected to the stand (2) as a cantilever (Fig. 6, a). The tooth was stressed with plastic weights (3) which were connected to a point that was 20 mm from the free end. The loads were connected to the tooth (1) using a hinge (4) which ensured that the applied force was vertical. The room temperature was 22 °C and relative humidity was at 26% during the tests (the value of the material's modulus of elasticity E_m was determined under the temperature and humidity conditions of 23 °C and 50%).

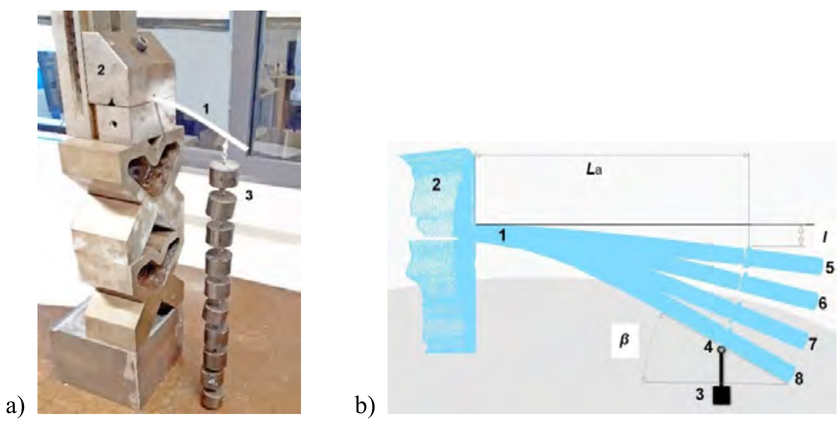

Figure 6. Test stand for measuring the tooth's flexure, a): and a digital model of the tooth's flexure b): with three weights (position 5), six weights (position 6), nine weights (position 7), and twelve weights (position 8), where l is the flexure of the cantilever beam and L is the distance between the cantilever attachment point and the weight attachment.

The flexures of the tooth (1) under various loads were scanned using a Nikon MCAx20/MMD50 portative laser scanner. After scanning, the resultant data was processed, a digital model was prepared, and flexure measurements were carried out using the software package, ANSYS SpaceClaim 2017.

A universal lathe was used to carry out the durability test on the tooth test specimens. The test equipment contained a fragment of a picking rake to which two tooth specimens were rigidly attached, one with a diameter of 4.3 mm and the other with a diameter of 5.3 mm. The fragment of the picking rake was installed on the lathe's jaws. A roller acting as an artificial obstacle was attached to the lathe's blade holder to simulate the passage of teeth between blueberry plants and their effect on the teeth in the test. Its distance from the axis of rotation of the picking rake fragment was less than the length of the tooth, while the tooth flexed upon its passing the artificial obstacle. The rotation of the lathe mimicked the work of the teeth upon blueberries being harvested, creating repeated bending cycles. The total number of revolutions for the test piece and therefore also the number of flexings in the teeth was 23,300.

During a field test, a blueberry crop (a mixt of several varieties) was harvested from a 0.1 hectare test plot. The test was carried out on Marjasoo Farm in Tartu County, South Estonia. The aim of the test was to check the durability of the flexing teeth in a commercial setting. The picking reel of used harvester has four rakes (Fig. 2, a), every rake has 66 tooth. The length and diameter of the tooth was controlled with the digitaal caliper ((Mitutoyo 200 mm) during of the installation of them, rotational speed of picking reel was controlled with rotational speed measuring device (ТЧ 10-P). The flexure of teeth (5 randomly selected teeth on each rake) was measured before and after harvest of test plot with digital angle meter (ADA 20).

RESULTS AND DISCUSSION

The theoretical flexures l_t and β_t and the measured flexures l_m and β_m for materials of various diameters are given in Table 1 and Fig. 7, where l_m and β_m. are the arithmetic means of the three series of measurements. The calculations were carried out in the Mathcad 15.0 environment. For the theoretical calculations, the value of E_m was selected to be 3,000 MPa (Mitsubishi, 2020).

The teeth's work in passing through a blueberry plant and in removing the berries from the stem was simulated by loading the teeth with weights.

Table 1. Calculated and measured flexures of a tooth with diameters of 5.3 mm and 4.3 mm

F, *N*	*D* = 5.3 mm		*D* = 4.3 mm	
	l_t, mm	l_m, mm	l_t, mm	l_m, mm
3.0	8.5	8.8	19.7	23.1
6.0	17.2	17.8	39.6	44.5
9.0	25.7	27.7	59.3	59.3
11.9	34.3	36.7	79.1	69.0

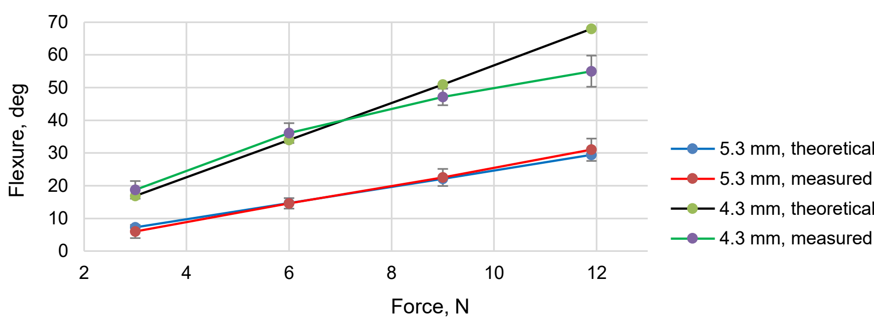

Figure 7. Calculated and measured (with standard deviation) flexures (in degrees) of a tooth with diameters of 4.3 mm and 5.3 mm.

Theoretical calculations (Eq. 11 and 12) and test results (Table 1 and Fig. 7) showed that the following results:

1) at maximum load (12 N), the flexure of the 4.3 mm diameter tooth test piece was at 70°;

2) at maximum load (12 N), the flexure of the 5.3 mm diameter tooth test piece was at 35°;

3) the differences between the theoretical and test results for materials with diameters of 4.3 mm and 5.3 mm are 10.1% and 5.1% respectively.

The results show that selected material with both diameters are suitable as materials for a picking reel's teeth as they both fulfil the condition under maximum load which was stipulated by Eq. (2).

The durability tests for the teeth revealed that, upon the long-term loading (23,300 flexings cycles) of the teeth, the residual deformation of a tooth with a diameter of 5.3 mm is up to three times higher than is the residual deformation of a tooth with a diameter of 4.3 mm (Olt & Arak, 2012).

No teeth were broken during the field test, but a flexing effect was observed in the tooth material (in the form of spring-back). The number of revolutions of the teeth during this test was 2,300. The average deviation of the free ends of the teeth from the longitudinal axis was 1.2 mm. After being left at a standstill for three days at a temperature of $T = 20–22$ °C, a new set of measurements were carried out with the following results: the permanent deformation in the 4.3 mm diameter teeth had disappeared and they had resumed their original position.

CONCLUSIONS

As a result of the flexure as the material for the picking reel's teeth, both 4.3 mm and 5.3 mm diameter test specimens were found to be suitable for the production of teeth, with the difference between theoretical and test results for 4.3 mm and 5.3 mm diameter materials being 10.1% and 5.1% respectively.

The flexing teeth do not tear the stem apart and neither do they pull the plants out of the ground, instead bending when an obstacle is encountered and regaining their original shape after clearing the obstacle.

Based on the results of all three tests - the flexure, durability, and residual deformation tests – the Ertacetal C with a diameter of 4.3 mm was shown to be a suitable replacement for standard teeth made from (stainless) steel, that led to reduced plant damage. This diameter was preferred over the 5.3 mm diameter because it has less residual deformation and the initial position recovers faster.

Further research should be done, such as larger field testing that evaluates long-term durability, harvest efficiency, economics of the proposed system, and impacts on berry quality. Also the length of tooth of picking rake and kinematic parameters (rotation speed of picking reel and working speed of the blueberry harvester) are also affect blueberry harvesting and should be additionally studied.

REFERENCES

Ali, S. 2016. *Effect of Harvesting Time on Berry Losses During Mechanical Harvesting of Wild Blueberries*. Dalhousie University, Halifax, Nova Scotia, 146 pp.

Arak, M. & Olt, J. 2014. Constructive and kinematics parameters of the picking device of blueberry harvester. *Agronomy Research* **12**(1), 25−32.

Arak, M. & Olt, J. 2017. Determination of the connection force between berries and stem in blueberry plants. *Proceedings of the 45th International Symposium on Agricultural Engineering: Actual Tasks on Agricultural Engineering, Opatija, Croatia, 21-24.02.2017.* Ed. Igor Kovacev. University of Zagreb, 589−595.

Arak, M., Soots, K., Starast, M. & Olt, J. 2018. Mechanical properties of blueberry stems. *Research in Agricultural Engineering* (RAE) **64**(4), 202−208, doi: 10.17221/90/2017-RAE

Heinloo, M. 2007. A Virtual Reality Technology Based Method for Study the Working Process of a Blueberry Harvester's Picking Reel. Agricultural Engineering International: the CIGR Ejournal. Manuscript IT 07 001. Vol. **IX**, 12 p.

Käis, L. & Olt, J. 2010. Low-bush blueberry machine cultivation technology in plantations established on milled peat fields. Kosutic S. (ed.). *Actual tasks on agricultural engineering*. HINUS, **38**, 271−279.

Logan, D.L. 2007. *A First Course in the Finite Element Method*. 5th Edition. Thomson, 753 pp. ISBN.13: 9780534552985

Mitsubishi Chemical Advanced Materials. 2020. Web page. https://media.mcam.com/fileadmin/quadrant/documents/QEPP/EU/Product_Data_Sheets_PDF/GEP/Ertacetal_C_PDS_E_01042019.pdf.

Mäkelä, M., Soininen, L., Tuomola, S. & Öistämö, J. 2011. *Technical Formulas - Basic Formulas of Mathematics, Physics, Chemistry and Strength of Materials, and SI Systems of Units*. 3rd Revised Edition. Tammertekniikka, 203 pp.

Noormets, M., Karp, K. & Paal, T. 2003. Recultivation of opencast peat pits with *Vaccinium* culture in Estonia. Iezzi E. et al. (eds). Ecosystems and sustainable development. Southampton, Boston, vol. **IV**(2), 1005−1014.

Olt, J. & Arak, M. 2012. Design and development of the picking reel of motoblock-type harvester. *Agraarteadus/Journal of Agricultural Science* **23**(2), 21−26.

Olt, J., Arak, M. & Jasinskas, A. 2013. Development of mechanical technology for low-bush blueberry cultivating in the plantation established on milled peat fields. *Agricultural Engineering* **45**(2), 120−131.

Peatland Ecology Research Group. 2009. Production of berries in peatlands. Guide produced under the supervision of Line Rochefort and Line Lapointe. Université Laval, Quebec, Canada, 134 pp.

Retamales, J.B. & Hancock, J.F. 2018. *Blueberries* (2nd ed.). Crop Production Science in Horticulture Agriculture, book 29. CABI, 424 pp.

Siliņa, D. & Liepniece, M. 2020. Variability in yield of the lowbush blueberry clones growing in modified soil. *Agronomy Research* **18**(S4), 2770–2775.

Soots, K., Krikmann, O., Starast, M. & Olt, J. 2017. Determining the dimensional characteristics of blueberries. *Agronomy Research* **15**(3), 886−896.

Starast, M., Karp, K., Paal, T., Värnik, R. & Vool, E. 2005. *Blueberry and its cultivation in Estonia*. Estonian University of Life Sciences, 65 pp. (in Estonian).

Takeda, F., Yang, W.O., Li, C., Freivalds, A., Sung, K., Xu, R., Hu, B., Williamson, J. & Sargent, S. 2017. Applying New Technologies to Transform Blueberry Harvesting. *Agronomy* **7**(33). doi:10.3390/agronomy7020033

I

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Olt, J., **Arak, M.** 2011.
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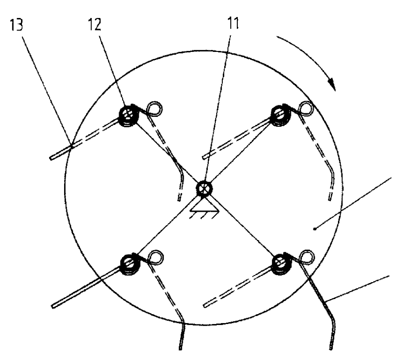
(54) Mustikakoristi

(57) Käesolev leiutis kuulub põllumajandusliku koristustehnika valdkonda, täpsemalt marjakogumis- ja -koristusmasinate hulka ning on kasutatav mustikate koristamiseks istandikes, kaasa arvatud ammendunud freesturbaväljadele rajatud istandikes. Mustikakoristi on väikeliikurmasin, mis sisaldab peamiselt ajamit koos ülekandega, korjehasplit, marjasegukonveierit, marjasuunurit, marjamahutit, kopeerseadist, raami masinaelementide ja koostude toetamiseks, juhthoobasid ja veermikku. Mustikakoristi tööseadis ummistuste ja mustikataimede vigastuste vältimiseks on korjehaspel (3) varustatud elementidega (14) mustikavarte orienteerimiseks korjekammi ette, kusjuures korjekammi varbpiid (13) on taimevigastuste vältimiseks kujundatud elastsetena.

(57) The present invention relates to the field of agricultural harvesting apparatus and machinery, particularly to berry harvesters for use to harvest blueberries in plantations, including plantations established on depleted cutaway peatlands. Blueberry harvester is a small-scale easily maneuverable machine, that comprises mainly of motor drive, rake head, berry conveyor, chute, berry collection box, copying device, frame to support mechanical elements and assemblies, principal levers and wheel Rake head (3) is equipped with elements (14) to direct blueberry stalks in front of harvesting frame to avoid stoppages of working organs of blueberry harvester and injuries to blueberry plants, whereby rake teeth (13) of a rake bar are designed elastic to avoid plant injuries



MUSTIKAKORISTI

TEHNIKAVALDKOND

Käesolev leiutis kuulub põllumajandusliku koristustehnika valdkonda, täpsemalt marjade kogumis- ja koristusmasinate hulka ning on kasutatav mustikate mehhaniseeritud koristamiseks istandikes, kaasa arvatud ammendunud freesturbaväljadele rajatud istandikes.

TEHNIKA TASE

Ahtalehelist mustikat, mille taime kõrgus on vahemikus 10 kuni 60 cm ja mille marjad valmivad enam-vähem üheaegselt, on otstarbekas koristada masinaga. Mustikad ei järelvalmi pärast koristust ja seepärast on vajalik marjad korjata täisküpsuses. Valminud mustikad ei varise kergelt ja võivad valminult olla põõsal umbes 10 päeva. Käesolevale leiutisele sarnased mustikakoristite tehnilised lahendused on enamasti väikeliikurmasinad ja varustatud käitatava korjeorganiga. Mustikakoristi ülesandeks on marjade vigastusteta eraldamine varte küljest ja eraldatud marjade kogumine vahetatavasse ja teisaldavasse mahutisse, kotti, kasti või konteinerisse.

Mustikaistandikke on hakatud üha enam rajama ammendatud freesturbaväljadele. Freesturbaväljade turvas on mustikataimedele sobiva pH-ga ja hea õhustatusega. Sobiva niiskuse loomiseks varustatakse freesturbaväli kuivenduskraavidega. Madalakasvulised mustikad kasvavad esimestel aastatel põõsana, mis hiljem laieneb ning risoomidega levides katab lõpuks üsna suure ala. Sel põhjusel on mustikat otstarbekam viljelda eelkõige freesturbaväljadel, kus mõne aastaga taimed katavad kogu pinna.

Vastavalt patendidokumendile US 2780905 on tuntud marjakoristi, mis sobib kasutamiseks madalakasvuliste taimedega istandikes. Tuntud masin on väikeliikurmasin, sisaldades jõuallikana väikest ühesilindrilist sisepõlemismootorit. Veoratastele, marjakonveierile ja korjeorganitele kantakse pöördemoment üle painduva veoelemendi, täpsemalt kett- ja rihmülekannete abil. Korjeorganiks on korjehaspel, mis sisaldab kuut kindlat trajektoori mööda liikuvat sirgete piidega kammi. Tuntud masina korjehaspel kujutab endast kopeerhasplit. Korjehasplile antakse pärisuunaline liikumine. Pärisuunalise liikumise all mõeldakse siinkohal, et korjehaspel pannakse pöörlema masina veermiku elemendi – ratta või roomiku – liikumisega samas suunas. Marjad rebitakse varte küljest jäikadest piidest koostatud kammide abil lahti ja paisatakse konveierile, mis teisaldab need kogumiskotti või kasti. Tuntud masina puuduseks on piidega varustatud korjekammide kopeerseadise keerukus ja väike töökindlus masina kasutamisel.

Vastavalt patendidokumendile CA 2241386 A1 on tuntud marjakoristi, mis sisaldab juhtpiisid, hasplit, marjade teisaldusosa ja kogumisosa. Juhtpiide ülesanne on takistada taimejuurte lõhkumist marjade eraldamise ajal. Haspel kujutab endast radiaalhasplit ja koosneb pöörlevale võllile kinnitatud peenikestest eralduspiidest kujundatud neljast kammist. Kuna haspel meenutab oma konstruktsioonilt varbbiitrit, siis marjad eraldatakse rehitsemise teel peente eralduspiide abil. Eraldunud marjad paisatakse vastu põlle, kust need põrkuvad tagasi, langevad põikkonveierile, mille abil teisaldatakse need edasi kaldkonveierile ja sealt edasi kogumiskastidesse. Marjad saavad rehitsemise käigus mitmeid lööke, mis halvendavad marjade kvaliteeti. Masin haagitakse põllumajandustraktori külge ning see saab ajami traktori käitusvõllilt kardaanülekande kaudu. Kuna marjakoristi haagitakse traktori taha, peab traktor marjade koristamisel liikuma tagurpidi. Tuntud masina puuduseks on suur materjalimahukus ja väike töökindlus.

Vastavalt patendile US 5369944 on tuntud marjakoristi, mis sisaldab trumlit, mille külge on kinnitatud painutatud otstega piidest koostatud kammid, vastuvõturenni ja marjamahutit. Trumlile antakse vastusuunaline liikumine hüdroajami abil. Kuna kammide piide vahe on väiksem kui marjade läbimõõt, siis marjad eraldatakse taimevarte küljest rehitsemise teel. Taimedelt eraldatud marjad kukuvad pöörlevalt trumlilt raskusjõu mõjul spetsiaalsesse vastuvõturenni, mida mööda veerevad marjakasti. Tänu marjade ümarale kujule ja headele veeremisomadustele saavutatakse kogutud saagi hea puhtus, kuna vastuvõturenni kukuvad enamasti ainult marjad. Lehed ja muud lisandid jäävad oma väiksema massi ja veeremisomaduste puudumise tõttu trumli ja piide vahele ning eralduvad hiljem. Seadme tööd jälgib ja korrigeerib platvormil töötav tööline, kes reguleerib vajadusel trumli pöörlemissagedust ja asetuskõrgust maapinnast. Tööline jälgib marjakastide täitumist ja vahetab neid, tõstes täitunud kastid trumli peal asuvale platvormile.

Pärast marja lahtirebimist marjakoristiga vastavalt patendile US 5369944, liigub mari pii otsa poolt trumli tsentri suunas kuni kokkupõrkeni trumliga. Trumli pöörlemisel kuni marja veeremistingimuste tekkimiseni hakkavad marjad veerema mööda trumlit vastupidises suunas, seega trumli pinnalt piide otste suunas kuni eraldumiseni piidest. Samal ajal veereva marja kiirus suureneb ja piidelt lahkunud marja liikumise peatamisel saab mari täiendavaid lööke. Peale selle, tuntud marjakoristi trumli vastassuunalise liikumise tõttu tekib täiendav koormus masina veermiku ajamile, mis omakorda suurendab koristamise kütusekulu ja seoses sellega marjasaagi omahinda.

Patendidokumendist US 6000203 on tuntud marjakoristi, mis on monteeritav tavalise põllumajandustraktori külge ja sobilik madalakasvuliste mustikasortide koristamiseks. Mustikate korjeorgan koos edastuskonveieriga on kinnitatud vastavate sildade abil traktori külge. Marjade kogumisplatvorm koos marjakastidega paikneb traktori tagaosas. Liigendatud kinnitussillad võimaldavad kogu marjakoristi pöörata traktori taha teisaldusasendisse. Marjade korjeorgan kujutab endast kammkonveierit, kusjuures nimetatud kammkonveierile antakse traktori liikumisega vastassuunaline liikumine. Marjad eraldatakse kammi piide abil, mille pealt langevad marjad põikkonveierile. Kuna tuntud marjakoristi paikneb traktori ühel küljel, siis masina liikumist istandikus arvestades on sellel kaks olulist puudust. Esiteks, traktor tallab kraaviäärsetes piirkondades ehk ee servas marjad rataste alla, mida tuleb käsitleda koristuskaona. Teiseks, kui jätta kraaviäärsed piirkonnad mustikataimedest vabaks, siis seda tuleb käsitleda maa ebaotstarbeka kasutamisena. Kultuurtaimedest vaba maa kattub lühikese ajaga umbrohuga, mida tuleb tõrjuda kas mehaaniliselt või keemiliselt, mis omakorda põhjustab täiendavat kulu. Agregaati, mis koosneb traktorist ja koristusmasinast, teenindab kaks inimest – traktorist, kes juhib traktorit, ja operaator, kes teenindab koristusmasinat ja opereerib marjakastidega.

Kõige lähemaks konstruktiivseks lahenduseks on mustikakoristi vastavalt patendile US 6854255 B1, mis sisaldab ajamit koos ülekandega, parallelogrammkorjehasplit, marjasegu konveierit, marjasuunurit, raami masinaelementide ja koostude toetamiseks, kopeerseadist, veermikku ja juhthoobasid koos juhtmehhanismidega, kusjuures korjehaspli tööelementideks on korjekammid, mis sisaldavad rõhtse hoidiku külge kinnitatud ja liikumissihi suhtes tahapoole kallutatud piisid. Korjehaspel on kujundatud parallelogrammhasplina, mida iseloomustab asjaolu, et nimetatud piid jäävad haspli mistahes pöördenurga juures iseendaga paralleelseks. See mustikakoristi on ettenähtud ahtalehise mustika, mille taime kõrgus on väike, eelistatult 10 kuni 20 cm ja varred püstsed, koristamiseks. Korjehaspli pöörleva liikumise korral liiguvad piid tööpiirkonnas esialgu suunaga alla taimevarte vahele, seejärel masina liikumissuuna suhtes tahapoole, rebides marjad taimevarre küljest lahti ning seejärel üles, teisaldades marjad konveierile.

Tuntud mustikakoristi puuduseks on see, et pikema taime korral, mille varred on 30 kuni 60 cm pikad ja marjade raskuse mõjul vajunud looka igas suunas taime keskpunkti ümber, jäävad põikisuunas lookas olevad taime varred, mis paiknevad korjekammi sihiliselt, kammi alla liikudes tihti piide vahele kinni. Kolme või enama pii vahele kinni jäänud mustikataime varred rebitakse jäikade piidega varustatud haspli pööreldes puruks või tõmmatakse maa seest välja. See on tuntud mustikakoristi peamine puudus.

LEIUTISE OLEMUS

Käesoleva leiutise olemus seisneb selles, et luuakse senituntud lahendusest erinev mustikakoristi, mis oleks ühtlasi vaba eespool mainitud puudustest. Selline masin on väikeliikurmasin, mis sisaldab peamiselt ajamit koos ülekandega, parallelogrammkorjehasplit, marjasegu konveierit, marjasuunurit, marjamahutit, kopeerseadist, raami masinaelementide ja koostude toetamiseks, juhthoobasid ja veermikku. Leiutisele vastava masina oluliseks eeliseks on korjehaspli konstruktiivse lahenduse lihtsus, taimevarte säästmine tööprotsessis, kasutajasõbralikkus ja töökindlus.

Mustikakoristi tööorganite ummistuste ja mustikataimede vigastuste vältimiseks on korjehaspel varustatud elementidega mustikavarte orienteerimiseks korjekammi ette, kusjuures korjekammi varbpiid on taimevigastuste vältimiseks kujundatud elastsetena. Elemendid mustikavarte orienteerimiseks korjekammi ette on kujundatud konksjate vedrupiidena. Konksjate vedrupiidena kujundatud elemendid on kinnitatud korjekammi hoidiku külge jäigalt, kusjuures iga korjekammi hoidiku külge jäigalt kinnitatud konksja vedrupiina kujundatud element on ettenähtud mustikavarte orienteerimiseks haspli pöörlemisel järgneva korjekammi ette.

Konksja vedrupiina kujundatud element mustikavarte orienteerimiseks korjekammi ette on kinnitatud korjekammi külge peamiselt püstselt nii, et vedrupii jäik kinnitus paikneb ülal ja vedrupii vetruv ots all. Taimevarte paremaks haaramiseks ja kergitamiseks on vedrupii alumine konksjas osa painutatud tahapoole, kusjuures painutusnurk, mis moodustub vedrupii ülemise osa ja alumise osa vahel, on eelistatult kuni 30°. Korjekammi külge kinnitatud varbpiide ja vedrupiide vahele moodustub teravnurk ($\alpha + \beta$), mis on eelistatult 30° kuni 60°.

Mustikakoristi konstruktsiooni materjalimahukuse vähendamiseks on konksja verdupiidena kujundatud elemendid mustikavarte orienteerimiseks korjekammi ette dimensioneeritud nende paiknemise asukohas tekkivatele jõududele.

JOONISTE LOETELU

Käesolevat leiutise konstruktsiooni kirjeldavad detailsemalt joonised FIG 1, FIG 2, FIG 3 ja FIG 4, mis on lisatud teostusnäidete juurde.

Joonisel FIG 1 on kujutatud ühte leiutise konstruktsiooni külgvaadet,

joonisel FIG 2 on kujutatud mustikakoristi korjehaspli konstruktiivne skeem,

joonisel FIG 3 on kujutatud korjehaspel koos vedrupiidega,

joonisel FIG 4 on näidatud korjekammi ja verdupii paigutusskeem korjekammi hoidiku küljes.

TEOSTUSNÄIDE

Järgnevalt kirjeldatakse leiutist täielikumalt, koos viidetega lisatud joonistele, millel on kujutatud leiutise eelistatud teostus.

Joonisel FIG 1 on kujutatud mustikakoristi, mis sisaldab ajamit 1 koos ülekandega 2, parallelogrammkorjehasplit 3, marjasegu konveierit 4, marjasuunurit 5, marjamahutit 6, kopeerseadist 7, raami 8 masinaelementide ja koostude toetamiseks, juhthoobasid 9 ja veermikku 10. Mustikakoristi kopeerseadis 7 sisaldab sõrmi, mis on liigendiliselt kinnitatud koristi raami 8 külge ja mille vabad otsad on ette nähtud toetuma maapinnale mustikakoristi töötamisel. Kopeerseadise 7 ülesandeks on korjehaspli asetuskõrguse tagamine. Kopeerseadise 7 täiendavaks ülesandeks on veel taimede maa-aluse osa toetamine põllupinnalt, sel ajal ja kohas, kus koristuse käigus eraldatakse taimevarte küljest korjehaspli 3 abil marju. Sellega välditakse taimejuurte lõhkumist. Kopeerseadise 7 sõrmede taha võib olla paigutatud kopeerrull (joonisel pole näidatud).

Korjehasplile 3 antakse pöördemoment võlli 11 kaudu, mis on laagerdatud raami 8 külge. Korjehaspli 3 tööelementideks on rõhtsed korjekammid, mis sisaldavad võllide 12 külge jäigalt kinnitatud korjekammi varbpiisid 13. Korjekammi varbpiid 13 on taimevigastuste vältimiseks kujundatud elastsetena. Korjekammi varbpii 13 võib olla asendites 13a ja 13b. Algasendis 13a ehk koormamata asendis on korjekammi varbpii sirge ja koormatud asendis 13b painutatud, nagu kujutatud joonisel FIG 2.

Mustikakoristi tööorganite ummistuste ja mustikataimede vigastuste vältimiseks on korjehaspel 3 varustatud konksja vedrupiina kujundatud elementidega 14 mustikavarte orienteerimiseks korjekammi ette, täpsemalt vedrupiidega. Vedrupiid on kinnitatud korjekammi hoidiku 12 külge jäigalt, kusjuures iga korjekammi hoidiku külge jäigalt kinnitatud konksja vedrupiina kujundatud element 14 on ette nähtud mustikavarte orienteerimiseks korjehaspli 3 pöörlemisel järgneva korjekammi ette, nagu näidatud joonisel FIG 3.

Konksja vedrupiina kujundatud element 14 mustikavarte orienteerimiseks on kinnitatud korjekammi külge peamiselt püstselt nii, et vedrupii jäik kinnitus paikneb ülal ja vedrupii vetruv ots all. Taimevarte paremaks haaramiseks ja kergitamiseks on konksja vedrupiina kujundatud element 14 pikkusega l alumine osa 14b painutatud tahapoole, kusjuures painutusnurk φ, mis moodustub vedrupii ülemise osa 14a sihi ja alumine osa 14b sihi vahel, on eelistatult kuni 30°. Korjekammi külge kinnitatud varbpiide 13 ja konksja vedrupiina kujundatud elemendi 14 vahele moodustub teravnurk $\alpha + \beta$ (joonis FIG 4), mis on eelistatult 30° kuni 60°. Tehnoloogiliselt paiknevad korjekammi varbpiid 13 ja konksja vedrupiina kujundatud elemendid 14 korjehaspli 3 küljes vaheldumisi. Konksja vedrupiina kujundatud elemendi 14 konksjat kuju iseloomustab nurk γ (joonis FIG 4) konksja vedrupiina kujundatud elemendi 14 otste vahelise mõttelise ühendussirge ja vedrupii ülemise osa 14a vahel, mis on eelistatult teravnurk.

Mustikakoristi konstruktsiooni materjalimahukuse vähendamiseks on korjekammi piid ja konksja vedrupiina kujundatud elemendid mustikavarte orienteerimiseks dimensioneeritud nende paiknemise asukohas tekkivatele jõududele.

Mustikakoristi raami 8 külge on kinnitud marjakasti alus, mis on ette nähtud marjamahuti 6, eelistatult marjakasti toetamiseks. Mustikakoristi raami 8 küljes võib täiendavalt olla kas jäigalt või liigendiliselt kinnitatud marjasaagi koristusel vajaminevate tühjade marjakastide hoidik (joonistel pole näidatud).

Mustikakoristi töötab järgmiselt. Mustikasaagi koristamisel liigutakse mustikakoristiga süstikuliselt, alustades mustikapõllu või tehnoraja äärest. Parallelogrammtüüpi korjehaspel 3 saab pöörlemise ajamilt 1 ülekande 2 kaudu, kusjuures korjehaspel 3 pannakse pöörlema masina ratastega samas suunas. Korjehaspli 3 pööreldes orienteerivad konksja vedrupiina kujundatud elemendid 14 erinevates suundades paiknevad mustikavarred masina liikumissuunda ning vedrupiide järel liikuvad varbpiid 13 suunatakse mustikavarte vahele. Selle toiminguga viiakse miinimumini mustikavarte sattumine varbpiide 13 vahele. Seejärel hakkavad varbpiid 13 marju mustikavarre küljest lahti rebima. Lahtirebitud marjad teisaldatakse varbpiide 13 poolt marjasegu konveierile 4. Konveieri 4 abil teisaldatakse marjad koristustsoonist üle marjasuunuri 5 marjamahutisse 6. Marjamahuti 6 täitumise korral asendatakse täis mahuti mustikakoristi operaatori poolt tühja mahutiga ja mustikakoristi töö saab jätkuda.

Juhul kui korjekammi elastne varbpii 13 jääb taimevarre taha kinni või kui korjekammi sihis paiknev taimevars jääb varbpiide otse vahele kinni, siis korjehaspli 3 pööreldes tekib varbpiidele 13 täiendav koormus ja varbpii paindub läbi ja võtab asendi 13b (joonis FIG 2). Varbpiide 13 paindumisel vabanevad taimevarred varbpiide otste vahelt. Pärast taimevartest vabanemist võtab varbpii 13 tagasi algasendi 13a kuju.

Mustikakoristi korjehaspli 3 asetuskõrgust maapinnast seatakse tööeel kopeerseadise 7 asendi muutmisega nii, et ka kõige madalamal asetsevad marjad saaksid korjehaspli poolt kokku kogutud. Kopeerseadise 7 sõrmed libisevad mustikakoristi liikudes põllu pinnal taimede vahel ja aitavad kergitada mahalangenud taimevarsi.

PATENDINÕUDLUS

1. Mustikakoristi, mis on kujundatud väikeliikurmasinana ning sisaldab ajamit (1) koos ülekandega (2), tööorganeid, milleks on parallelogrammkorjehaspel (3), marjasegu konveier (4), marjasuunur (5), marjamahuti (6) ja kopeerseadis (7) ning raami (8) masinaelementide ja koostude toetamiseks, juhthoobasid (9) koos juhtimismehhanismidega ja veermikku (10), kusjuures korjehaspli (3) tööelementideks on korjekammid, mis sisaldavad rõhtse hoidiku (12) külge kinnitatud ja liikumissihi suhtes tahapoole kallutatud varbpiisid (13), **erineb selle poolest**, et tööorganite ummistuste ja mustikataimede vigastuste vältimiseks on korjehaspel (3) varustatud elementidega (14) mustikavarte orienteerimiseks korjekammi ette, kusjuures elemendid (14) mustikavarte orienteerimiseks on kujundatud konksjate vedrupiidena ning korjekammi varbpiid (13) on taimevigastuste vältimiseks kujundatud elastsetena.

2. Mustikakoristi, vastavalt nõudluspunktile 1, **erineb selle poolest**, et konksjate vedrupiidena kujundatud elemendid (14) mustikavarte orienteerimiseks korjekammi ette on kinnitatud korjekammi hoidiku (12) külge.

3. Mustikakoristi, vastavalt nõudluspunktidele 1 ja 2, **erineb selle poolest**, konksjate vedrupiidena kujundatud elemendid (14) mustikavarte orienteerimiseks korjekammi ette on kinnitatud korjekammi hoidiku (12) külge jäigalt, kusjuures iga korjekammi hoidiku külge jäigalt kinnitatud konksja vedrupiina kujundatud element (14) on ette nähtud mustikavarte orienteerimiseks korjehaspli (3) pöörlemisel järgneva korjekammi ette.

4. Mustikakoristi, vastavalt nõudluspunktidele 1 kuni 3, **erineb selle poolest**, et iga konksja vedrupiina kujundatud element (14) mustikavarte orienteerimiseks korjekammi ette on kinnitatud korjekammi külge peamiselt püstselt nii, et vedrupii jäik kinnitus paikneb ülal ja vedrupii vetruv ots all.

5. Mustikakoristi, vastavalt nõudluspunktidele 1 kuni 4, **erineb selle poolest**, et konksja vedrupiina kujundatud element (14) mustikavarte orienteerimiseks korjekammi ette on kujundatud nii, et taimevarte paremaks haaramiseks ja kergitamiseks on vedrupii alumine konksjas osa (14b) painutatud tahapoole, kusjuures painutusnurk φ, mis moodustub

vedrupii ülemise osa (14a) sihi ja alumise konksja osa (14b) sihi vahel, on eelistatult kuni 30°.

6. Mustikakoristi, vastavalt punktidele 1 kuni 5, **erineb selle poolest**, et korjekammi külge kinnitatud varbpiide (13) ja konksja vedrupiina kujundatud elemendi (14) vahele moodustub teravnurk ($\alpha + \beta$), mis on eelistatult 30° kuni 60°.

7. Mustikakoristi, vastavalt punktidele 1 ja 2, **erineb selle poolest**, et konstruktsiooni materjalimahukuse vähendamiseks on konksja vedrupiina kujundatud elemendid (14) mustikavarte orienteerimiseks korjekammi ette dimensioneeritud nende paiknemise asukohas tekkivatele jõududele.

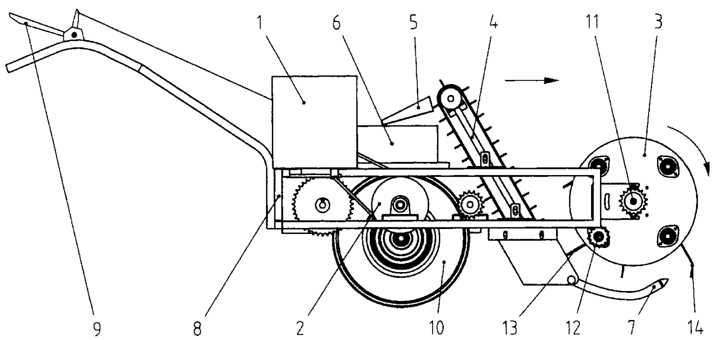


FIG 1

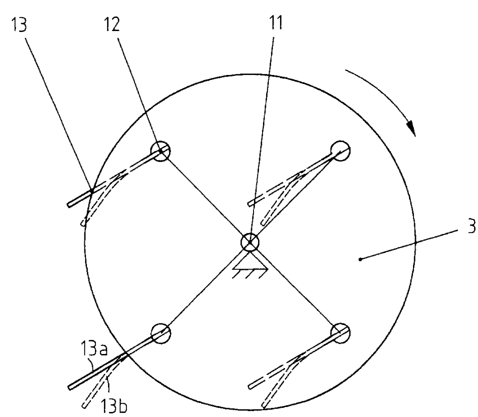


FIG 2

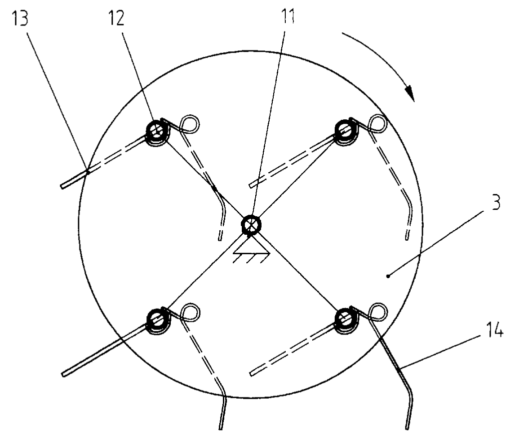


FIG 3

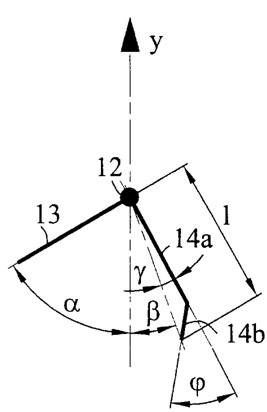


FIG 4

II

Soots, K., **Arak, M.**, Olt, J. 2017. Belt sorter.
Patent no EE 05798 B1

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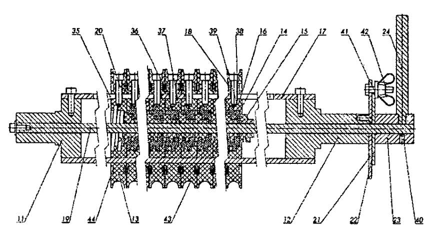
(54) **Rihmsorteer**

(57) Marjade rihmsorteer, mida kasutatakse marjade sorteerimiseks suuruse järgi, sisaldab reguleeritavat rihmatrumlit, mis on ette nähtud rihmade vahekauguse sujuvaks muutmiseks ning mis sisaldab rihmasid kandvaid rihmarattaid, rihmarataste sees paiknevat juhtvõlli ning selle ümber paiknevat torukujulist lõhikuga varustatud hülssi, rihmarattaid ja juhtvõlli ühendavaid juhtvardaid, gofreeritud katet, jaotusketast, käepidet ja fiksaatorit. Reguleeritava rihmatrumli juhtvõll sisaldab muhvi ja muhvi südamikku, mis on omavahel ühendatud keerme abil. Juhtvõlli ümber paiknev torukujuline hülss on varustatud vähemalt kolme lõhikuga. Kuuekandilise ristlõikega reguleervõll, mis on paigutatud muhvi südamike sisse, on ühendatud käepidemega ja muhvide südamikega, et pöörata muhvide südamikke ümber oma telje ning nihutada rihmarataste juhtvõlli ümber paikneva torukujulise hülsi suhtes.

(57) Belt sorter for sorting berries according to their size that has an adjustable roller to smoothly change distance between belts contains belt pulleys to carry belts, a guide shaft located inside of belt pulleys, a tubular sleeve with a slit located around the guide shaft, guide pins that connect belt pulleys to the guide shaft, a corrugated cover, an adjusting disc, a handle and a fixator. Adjustable roller guide shaft includes sleeves and sleeve cores which are connected to each other by threads. Tubular sleeve that is located around guide shaft has at least three slits. A hexagonal-shape guide shaft located inside the sleeve cores is connected by a handle and sleeve cores to turn sleeve cores around their axis and to move belt pulleys on tubular sleeve that is located around the guide shaft.



RIHMSORTEER

TEHNIKAVALDKOND

Käesolev leiutis kuulub põllumajandus- ja aiandustehnika valdkonda, täpsemalt marjade koristusjärgse esmatöötlusmasinate hulka, ning on kasutatav marjade mehhaniseeritud sorteerimiseks suuruse järgi.

TEHNIKA TASE

Marjade peamisteks füüsikalis-mehaanikalisteks omadusteks sorteerimisel on geomeetrilised mõõtmed, mis eeldab marjade sorteerimist suuruse järgi. Marju ja marjasorte on palju ning erinevate sortide lauamarjad peavad olema eelistatult ühesuguse läbimõõduga. Näiteks mustika lauamarja minimaalne läbimõõt on 8mm.

Tuntud on kaks sorteerimisviisi – järjestikune ja rööpne. Järjestikkuse sorteerimisviisi puhul eraldatakse suurusrühmad kogu mugulakogusest suuruse järjekorras, algul väiksed, seejärel keskmised ja lõpuks suured. Rööpse sorteerimisviisi puhul toimub rühmitamine vastupidiselt, seega vähenevas järjekorras. Tööorgani ehituse järgi eritatakse rull-, võrk-, sari-, trummel- ja rihmsorteere.

Käesoleva leiutise puhul on tegemist rihmsorteeri reguleeritava trumliga, mis on ettenähtud järjestikkuse sorteerimisviisi põhimõttel töötavale rihmsorteerile tema kasutusvõimaluse suurendamiseks.

Vastavalt patendidokumendile NL1024173 on tuntud sorteer, mis sisaldab aukudega konveierlinti, milledest väiksema läbimõõduga marjad saavad läbi kukkuda ja mis sisaldab vähemalt ühte sorteerimisavadeta pikiriba. Sorteeritud saagi kogumisseadis on paigaldatud osaliselt konveierlindi alla.

Vastavalt patendidokumendile US 2316159 on tuntud marjade pesemise ja sorteerimise seade. Tuntud põldmarja, mustika ja teiste sarnaste marjade sorteer kujutab endast rihmkonveierit, mis sisaldab kahte trumlit koos rihmadega, kusjuures rihmade vaheline pilu on kujundatud suurenevana materjali liikumise suunas konveieri peal moodustunud sorteerimispinnal. Konveieri sorteerimispinnal edastatavad marjad kukuvad rihmade vahelt alla kogunemisseadmele rihmapilu piisava laiuse korral.

Kui rihmade vaheline pilu on ühelaiune, siis sellise sorteeriga on marjasegust võimalik eraldada ainult üks fraktsioon konveieri sorteerimispinnal, mille geomeetrilised mõõtmed võimaldavad rihmade vahelt läbi vajuda. Kui rihmade vaheline pilu on muutuva suurusega, nagu kirjeldatud patendidokumendis US2316159, siis on marjasegust võimalik konveieri sorteerimispinnal eraldada rohkem kui üks fraktsioon.

Vastavalt patendidokumendile GB745730-A on tuntud kartulite sorteerimise seade, mis kujutab endast rihmkonveierit. Rihmadel on lame ristlõige, rihmade alumisse poolde on kujundatud soon ning rihmade peale on kinnitatud rombi kujulised kõrgendused kartulite separeerimiseks üksteisest sorteerimise ajal. Pilu rihmade ja juhtäärikute vahel on reguleeritav juhtsõrmedega, mille ots paigutub rihma alumises soones. Juhtsõrmede asendit sorteeriva pinna laiuse suhtes on võimalik muuta juhtvõlli, mis sisaldab erineva käe ja erineva sammuga keermeid, pööramisega. Juhtvõll paikneb sorteerimispinna lõpus, vahetult enne sorteerimispinna lõpus asetsevat teist siledat rihmatrumlit. Tuntud kartulite sorteerimise seadmes ei kasutata reguleeritavat trumlit, reguleerimise mehhanism ei pöörle tööolukorras.

Vastavalt patendidokumendile WO9848951 on tuntud sorteerimise seade, mis on sobilik kaladele. Tuntud sorteerimise seade kujutab endast rihmkonveierit, mis sisaldab kahte trumlit koos rihmadega, kusjuures rihmade vaheline pilu on kujundatud suurenevana materjali liikumise suunas konveieri peal moodustunud sorteerimispinnal. Rihmade suunamiseks kasutatakse kolme juhtvõlli ning neil asuvaid juhtsõrmi. Tuntud sorteerimisseadmes ei kasutata reguleeritavat trumlit, reguleerimise mehhanism ei pöörle tööolukorras. Juhtvõllidel on 4 reguleerimise astet.

Vastavalt patendidokumendile US20060113224 on tuntud reguleeritav sorteerimise seade mõõtmetelt väiksematele esemetele. Tuntud sorteerimise seade kujutab endast rihmkonveierit, mis sisaldab 4 trumlit. Elastsete rihmade vaheline pilu on muudetav. Mehhanism paikneb sorteerimisala lõpus, vahetult enne sorteerimisala teist rihmatrumlit. Rihmade vaheline pilu on muudetav rihmade tõstmise ja langetamisega üle ühe.

Vastavalt patendidokumendile DE10359369 on tuntud sorteerimise seade. Tuntud sorteerimise seade kujutab endast rihmkonveierit. Rihmade vaheline pilu on muudetav käsitsi nihutades rihmade juhtsõrmi ühe kaupa.

Vastavalt patendidokumendile GB2140712 on tuntud sorteerimise seade. Tuntud sorteerimise seade kujutab endast rihmkonveierit. Rihmade vaheline pilu on muudetav käsitsi nihutades rihmarattaid ühe kaupa sorteerimisala alguses ja lõpus. Rihmarattad ei asetse ühisel teljel, igal rihmarattal on eraldi olev kinnituskonsool.

Vastavalt patendidokumendile FR1248240 on tuntud sorteerimise seade. Tuntud sorteerimise seade kujutab endast rihmkonveierit. Rihmade vaheline pilu on muudetav käsitsi. Rihmarattad paiknevad ühisel võllil. Igal rihmaratta kohta on juhtsõrm, mille ots paikneb rihmaratta rihmasoones. Reguleerimine toimub nihutades juhtsõrmi ühe kaupa.

Vastavalt patendidokumendile WO2006120706 on tuntud sorteerimise seade. Tuntud sorteerimise seade kujutab endast rihmkonveierit. Rihmade vaheline pilu on muudetav juhtsõrmede liigutamisega. Reguleerimismehhanism on lahendatud kiilu põhimõttel, kus juhtsõrmede vahele on paigutatud ümarad kiilud, mille püörates muutub juhtsõrmede vahekaugus. Reguleerimismehhanismis kasutatakse survevedrusid, mis suruvad vaheldumisi paiknevaid ümaraid kiile ja juhtsõrmi üksteise vastu. Tuntud sorteerimisseadmes ei kasutata reguleeritavat trumlit, reguleerimise mehhanism ei pöörle tööolukorras.

Vastavalt patendidokumendile NZ314846A on tuntud rannakarpide sorteerimise seade. Sorteeritava ala moodustavad varvad, mis on allapoole kaldu sorteerimisala lõpu suunas. Varvaste alumised otsad toetuvad ümarale juhtvõllile, millele on kujundatud keskel asetsev rõngas vagu ning vasaku käe ja parema käe keermed kusjuures keermete sammud suurenevad eemaldudes keskmisest rõngas vaost. Varbade otsad toetuvad juhtvõllil paiknevatesse vagudesse ning juhtvõlli pöörates on võimalik muuta varbade vahelise pilu laiust.

Vastavalt patendidokumendile EP0884113 on tuntud sorteerimise seade. Tuntud sorteerimise seade kujutab endast rihmkonveierit. Rihmade vaheline pilu on muudetav rihmarataste liigutamisega. Reguleerimismehhanism on lahendatud käärmehhanismiga, mis ühendab omavahel rihmarataste kinnituskronsteine. Käärmehhanismi liigutamiseks ja fikseerimiseks kasutatakse juhtvõlli, millele on ühele poole kujundatud vasaku ja teisele poole parema käe keere. Tuntud sorteerimise seadmes ei kasutata reguleeritavat trumlit, reguleerimise mehhanism on passiivne ja see ei pöörle tööolukorras.

Kõige lähimaks tehniliseks lahenduseks on vastavalt patendidokumendile EE05642 B1 tuntud rihmsorteer marjade sorteerimiseks, kus sorteerimispinda moodustavate rihmade vahelised pilud on seadistavad tagumise reguleeritava trumliga, mis sisaldab rihmarattaid, juhtvõlli ning selle ümber paiknevat torukujulist hülssi koos lõhikuga, juhtvardaid, jaotusketast, käepidet ja fiksaatorit. Tuntud rihmsorteeri puuduseks on reguleeritavat trumlit moodustavate rihmaseibide lõtk pikki reguleeritava trumli telge ja piiratud reguleeritava trumli pikkus. Lõtk on üheltpoolt tingitud rihmaseibide lõtkuga istust torukujulise juhtvõlli hülsil ning teiselt poolt rihmaseibide fikseerimisest ühe juhtvarda kaudu juhtvõlli juhtsoonega. Reguleeritava trumli pikkus on piiratud juhtvõlli juhtsoonte keermesammuga, mis muutub pikema reguleeritava trumli puhul liiga suureks.

LEIUTISE OLEMUS

Käesoleva leiutise olemus seisneb selles, et luua senituntud lahendustest erinev rihmsorteeri reguleeritav rihmatrummel, mis oleks ühtlasi vaba eelpool mainitud puudustest. Rihmsorteer sisaldab vähemalt ühte reguleeritavat rihmatrumlit rihmarataste vahekauguste astmevabaks muutmiseks. Selline seade on kasutatav marjasorteeril, mille sorteerimispinna moodustavad vähemalt kaks rihmatrumlit nendele paigaldatud rihmadega. Vaadates sorteerimispinda marjade liikumise suunas, siis esimene rihmatrummel on kujundatud püsiva vahekaugusega süvenditega varustatud trumlist rihmade hoidmiseks ja võllist. Sorteerimispinna tagumine reguleeritav rihmatrummel sisaldab rihmarattaid, juhtvõlli, juhtvardaid, torukujulist juhtvõlli hülssi, distantspukse, juhtvõlli gofreeritud katet, käepideme kinnituspuksi koos käepidemega, jaotusketast ning fikseerketast koos fiksaatoriga.

Rihmsorteeri reguleeritava tagumise rihmatrumli juhtvõll koosneb vaheldumisi paiknevatest muhvidest ja muhvi südamikest. Muhvi sisse on kujundatud mitteläbiv ava paremkeermega, muhvist eenduva osa peale on kujundatud vasaku käre keere, muhvi külgpinnas on vähemalt kolm keermestatud ava ja pikki muhvi eenduvat osa on kujundatud ümara ristlõikega ava. Muhvi südamiku sisse on kujundatud vasaku käe keermega mitteläbiv ava nii, et moodustub äärik, mille sisse on kujundatud kuusnurkse ristlõikega ava ning muhvi südamiku peale on kujundatud parema käe keere. Muhvi sees olev parema käe keermega ava sügavus on võrdne muhvi südamiku kõrgusega ning muhvi eenduva osa kõrgus on võrdne muhvi südamiku sees oleva vasaku käe keermega ava sügavusega. Torukujuline hülss on varustatud hülsi pikisihiliste lõhikutega, mis on ettenähtud juhtvarraste liikumise suunamiseks pikki reguleeritava rihmatrumli telge. Hülsi lõhikute arv on võrdne muhvi külgpinnas olevate keermestatud avade arvuga. Muhvi südamikud on ühendatud läbi kuusnurksete avade paigutatud kuuekandilise ristlõikega reguleervõlliga. Muhvi ja muhvi südamiku keermed on kujundatud nii, et juhtvardad, mis on paigutatud läbi rihmarataste, distantspukside ja hülsi lõhikute ning mis on jäigalt kinnitatud keermeliitega muhvi külge, kindlustavad reguleervõlli mistahes pöördenurga või asendi puhul ühesuguse rihmarataste vahekauguse. Torukujulise hülsiga on jäigalt ühendatud jaotusketas. Reguleervõlliga on jäigalt ühendatud fikseerketas koos fiksaatoriga. Jaotusketas, fikseerketas ja fiksaator tagavad reguleervõlli asendi ja rihmaseibide vahekauguse fikseerimise astmevabalt. Rihmarataste vahele on kinnitatud gofreeritud kate, mis takistab prahi sattumist läbi torukujulise hülsi lõhikute muhvi ning muhvi südamiku keermetesse.

JOONISTE LOETELU

Käesolevat leiutise konstruktsiooni kirjeldavad detailsemalt joonised FIG 1, FIG 2, FIG 3 ja FIG 4, mis on lisatud teostusnäidete juurde. Leiutis ei ole piiratud nende näidetega, vaid ainult kaasnevate nõudluspunktidega.

Joonisel FIG 1 on näidatud rihmsorteeri külgvaade ühe võimaliku konstruktiivse teostusvariandi korral,
joonisel FIG 2 on toodud reguleeritava tagumise rihmatrumli koostisosad rihmatrumli ühe võimaliku konstruktiivse teostusvariandi korral,
joonisel FIG 3 on toodud reguleeritava tagumise rihmatrumli juhtvõlli muhvi ristlõige,
joonisel FIG 4 on toodud reguleeritava tagumise rihmatrumli juhtvõlli muhvi südamiku ristlõige.

TEOSTUSNÄIDE

Järgnevalt kirjeldatakse leiutist täielikumalt koos viidetega lisatud joonistele, millel on kujutatud leiutise eelistatud teostus. Sellele vaatamata võib käesoleval leiutisel olla eri variante mistõttu illustratsioonidel kujutatut ei peaks tõlgendama kui ainsat võimalikku teostust. Pigem on antud teostus kujutatud selleks, et anda vastava eriala asjatundjale täielikku ja terviklikku ülevaadet leiutisest ja selle rakendusalast.

Joonisel FIG 1 kujutatud seade on paikne, kuid selle võib kujundada ka teisaldatavana. Teisaldatav seade on varustatud tugiratastega (joonisel ei ole näidatud). Rihmsorteer sisaldab raami 1, mille külge on kinnitatud kolm rihmatrumlit: eesmist 2, tagumist 3 ja alumist 4 koos nendele paigutatud rihmadega 5 ning ajamit. Rihmad 5 on kujundatud lõputute rihmadena ja moodustavad üle eesmise 2, tagumise 3 ja alumise 4 rihmatrumlite paigutatult kinnise kontuuri. Rihmad 5 moodustavad eesmise 2 ja tagumise 3 rihmatrumli vahelisel alal marjade sorteerimispinna. Alumine rihmatrummel 4 on paigutatud nimetatud sorteerimispinna alla arvestusega, et sorteerimispinna all rihmadest moodustunud kinnise kontuuri sisse paigutuksid seadised marjasegust väljasorditud fraktsioonide kõrvalejuhtimiseks. Antud teostusnäites on nendeks seadisteks prügirenn 6, väikeste marjade renn 7 ja nihutatav põll 8. Prügirenni 6 ja väikeste marjade renni 7 ülesannet võivad täita ka põikkonveierid (joonistel pole näidatud). Raam 1 kujutab endast eelistatult keeviskonstruktsiooni. Prügirenn 6 ja väikeste marjade renn 7 on kinnitatud raami 1 külge. Suurte marjade renn 9 on samuti kinnitatud raami 1 külge, kuid paigutatud sorteerimispinna otsa.

Eesmise rihmatrumli 2 lähedalt antakse väikestest ja suurtest marjadest ning lisanditest koosnev marjamass sorteerimispinnale. Üle tagumise rihmatrumli 3 liikuvad marjad lahkuvad sorteerimispinnalt ja suunduvad järgmisele koristusjärgse töötlemisliini tehnoloogilisele seadmele. Alumise rihmatrumli 4 ülesandeks on ruumi tekitamine abiseadiste, rennide 6 ja 7 ning nihutatava põlle 8 paigutamiseks sorteerimispinna alla, rihmade 5 harude vahele. Rihmsorteer käitatakse mootori 10 abil.

Esimesele rihmatrumlile 2 on kujundatud ühesuguse vahekaugusega rihmasooned rihmade 5 hoidmiseks. Tagumine rihmatrummel 3 on otstele 11 ja 12 istatud laagrite ning laagreid hoidvate laagripukkide vahendusel kinnitatud rihmsorteeri raamile. Mõlemast otsast laagritele istatud reguleeritaval tagumisel rihmatrumlil 3 on valmisolek pöörelda ümber oma pikitelje. Joonisel FIG 2 kujutatud reguleeritav tagumine rihmatrummel 3 on koostatud reast ühesugustest paaritust arvust rihmaratastest 13. Reguleeritava tagumine rihmatrumli 3 rihmarataste 13 vahekaugused on sujuvalt muudetavad. Reguleeritav tagumine rihmatrummel 3 sisaldab täiendavalt juhtvõlli 14, mis on koostatud muhvides 15, muhvide südamikest 16, torukujulist hülssi 17, distantspukse 18, reguleervõlli 19, mis on kandilise, täpsemalt kuuekandilise ristlõikega, juhtvardaid 20, jaotusketast 21, fikseerketast 22, käepideme kinnituspuksi 23 ja käepidet 24. Reguleervõlli 19 ülesandeks on pöördemomendi üleandmine muhvi südamikule ja seetõttu võib see olla kandilise (kolme-, nelja- või kuuekandilise) ristlõikega või liistuga varustatud ümarvõll. Antud teostusnäites on tegemist kuuekandilise ristlõikega reguleervõlliga.

Rihmarataste vahekauguse reguleerimiseks on juhtvõll koostatud muhvidest 15 ja muhvi südamikest 16. Joonisel FIG 3 kujutatud muhvi 15 sisse on kujundatud mitteläbiv ava 25 parema käe sisekeermega 26 ja muhvist eenduva osa 27 peale on kujundatud vasaku käe väliskeere 28, kusjuures nii sise- kui ka väliskeere on ühesuguse keermesammuga. Muhvi 15 külgpinnas on vähemalt kolm keermestatud ava 29 juhtvarraste 20 fikseerimiseks ja pikki muhvi eenduvat osa 27 on kujundatud ümara ristlõikega ava 30, mille läbimõõt on suurem kui kuuekandilise ristlõikega reguleervõlli 19 läbimõõt. Muhvi südamiku 16 (joonis FIG 4) sisse on kujundatud vasaku käe sisekeermega mitteläbiv ava 31 nii, et moodustub äärik 32, mille sisse on lõigatud kuusnurkse ristlõikega ava 33 ning muhvi südamiku 16 peale on kujundatud parema käe väliskeere 34, kusjuures sise- ja väliskeermed on sama keermesammuga. Muhvi 15 sees olev parema käe sisekeermega 26 varustatud mitteläbiva ava 25 sügavus on võrdne muhvi südamiku 16 kõrgusega ning muhvi 15 eenduva osa 27 kõrgus on võrdne muhvi südamiku 16 sees oleva vasaku käe sisekeermega ava 31 sügavusega. Muhvi 15 parema käe sisekeere 26 on sobitatud kokku muhvi südamiku 16 parema käe väliskeermega 34 ning muhvi 15 vasaku käe väliskeere 28 sobib kokku muhvi südamik 16 vasaku käe sisekeermega avaga 31. Juhtvõll 14 on koostatud vaheldumisi muhvidest 15 ja muhvi südamikest 16.

Torukujuline hülss 17 on varustatud lõhikutega 35, mis on ettenähtud juhtvarraste 20 liikumise suunamiseks piki reguleeritava tagumise rihmatrumli 3 telge. Torukujulise hülsi

17 keskele on kujundatud avad 36 keskmise muhvi 37 jäigaks fikseerimiseks. Lõhikud 35 asuvad mõlemal pool torukujulist hülssi 17 avasid 36. Juhtvardad 20 on paigutatud läbi rihmarataste 13 olevate avade 38, distantspukside 18 ja torukujulise hülsi 17 lõhikute 35 või avade 36 ning juhtvarraste otsad 39 kinnituvad jäigalt keermeliite abil keermestatud avade 29 kaudu muhvi 15 külge.

Rihmsorteeri reguleeritav tagumine rihmatrummel (3) toimib järgmiselt. Kuuekandilise ristlõikega reguleervõll 19 on paigutatud kõikide muhvide 15 ja muhvi südamike 16 sisse. Pöörates kuuekandilise ristlõikega reguleervõlli 19, kandub pöördemoment läbi muhvi südamike 16 sees olevate kuusnurkse ristlõikega avade 33 üle muhvi südamikele 16. Kuna muhvide 15 liikumisvabadus on piiratud torukujulise hülsi 17 lõhikuid 35 läbivate juhtvarrastega 20, siis muhvid 15 saavad keermete 26, 28, 31 ja 34 kaudu muhvi südamikelt 16 sirgjoonelise liikumise pikki reguleeritavat rihmatrumlit 3. Keskmine muhv 37 on jäigalt fikseeritud reguleeritava tagumise rihmatrumli 3 keskpunktis asuvate torukujulise hülsi avade 38 kaudu ning see tagab selle, et reguleeritava tagumise rihmatrumli 3 seadistamisel liiguvad rihmarattad 13 võrdselt ühesugusele kaugusele reguleeritava tagumise rihmatrumli 3 keskpunkti suhtes.

Reguleerasendi fikseerimiseks on fikseerketta 22 külge jäigalt ühendatud käepideme 24 kinnituspuks 23, mis on paigutatud kuuekandilise ristlõikega reguleervõllile 19 ja moodustatud sellega liikumatu liide pingutuskruvi 40 abil. Fikseerketas 22 on seega koos käepideme 24 kinnituspuksiga 23 jäigalt ühendatud kuuekandilise ristlõikega reguleervõlliga 19. Jaotusketas 21 on varustatud keermestatud fiksaatoriga 41, mis paikneb jaotusketta 21 teljest sellisel kaugusel nagu on fikseerketta 22 läbimõõt. Selline konstruktiivne lahendus annab võimaluse jaotusketta 21 keermestatud fiksaatori 41 ja liblikmutri 42 abil fikseerida fikseerketta 22 ja jaotusketta 21 omavaheline asend ning sellest tulenevalt annab võimaluse muhvi südamikku 16 pöörata muhvi 15 sees ning sobiva seadistuse korral muhvi südamiku 16, muhvi 15 ja torukujulise hülsi 17 omavaheline asendi jäigalt fikseerida. Käepide 24 on kinnituspuksi 23 külge kinnitatav keermeliitega ning peale reguleeritava tagumise rihmatrumli 3 seadistamist rihmsorteeri kasutaja ohutuse tagamiseks eemaldatav.

Rihmarataste 13 vahele on paigutatud gofreeritud kate 43, mis takistab prahi sattumist torukujulise hülsi 17 sees paiknevate muhvi 15 ja muhvi südamiku 16 keermetesse 26, 28, 31 ja 34. Gofreeritud katete 43 jaoks on rihmarataste 13 külgpindadesse sisse lõigatud gofreeritud katete sooned 44, mis tagab võimaluse kasutada sellist reguleeritava rihmatrumli 3 reguleerimise astet, mille korral on rihmarattad 13 üksteise vastu surutud ning gofreeritud katted 43 on paigutunud täielikult gofreeritud katete soonte 44 sisse.

PATENDINÕUDLUS

1. Rihmsorteer, mis sisaldab kolme rihmatrumlit, kusjuures üks rihmatrumlitest, reguleeritav tagumine rihmatrummel (3), on ette nähtud sorteerimispinda moodustavate rihmade (5) vahekauguse sujuvaks muutmiseks ning mis sisaldab rihmasid (5) kandvaid rihmarattaid (13), rihmarataste (13) sees paiknevat juhtvõlli (14) ning selle ümber paiknevat torukujulist lõhikuga varustatud hülssi (17), rihmarattaid (13) ja juhtvõlli (14) ühendavaid juhtvardaid (20), jaotusketast (21), käepidet (24), fikseerketast (22) ja fiksaatorit (41), **erineb selles poolest,** et tagumise reguleeritava tagumise rihmatrumli (3) juhtvõll (14) sisaldab muhvi (15) ja muhvi südamikku (16), mis on omavahel ühendatud keerme abil, juhtvõlli (14) ümber paiknevat torukujulist hülssi (17), mis on varustatud vähemalt kolme lõhikuga (35), reguleervõlli (19), mis on ühendatud käepidemega (24) ja muhvide südamikega (16), muhvide südamike pööramiseks ümber oma telje ning rihmarataste (13) nihutamiseks juhtvõlli (14) ümber paikneva torukujulise hülsi (17) suhtes, ja gofreeritud katet (43).

2. Rihmsorteer vastavalt nõudluspunktile 1, **erineb selle poolest,** et reguleeritava tagumise rihmatrumli (3) juhtvõlli (14) moodustavad komponendid, muhv (15) on varustatud parema käe sisekeermega (26) ning vasaku käe väliskeermega (28) ja muhvi südamik (16) on varustatud parema käe väliskeermega (34) ning vasaku käe sisekeermega (31), kusjuures rihmarataste (13) omavaheline kaugus on seadistatav muhvide (15) ja muhvi südamikke (16) omavahelise asendiga ja selle muutmisega torukujulise hülsi (17) sees.

3. Rihmsorteer vastavalt nõudluspunktile 1, **erineb selle poolest,** et reguleeritava tagumise rihmatrumli (3) reguleervõll (19) on kandilise ristlõikega.

4. Rihmsorteer vastavalt nõudluspunktile 1 ja 3, **erineb selle poolest,** et reguleeritava tagumise rihmatrumli (3) reguleervõll (19) on kuuekandilise ristlõikega.

5. Rihmsorteer vastavalt nõudluspunktidele 1 kuni 4, **erineb selle poolest**, et reguleeritava tagumise rihmatrumli (3) käepide (24) on ühendatud reguleervõlli (19) kaudu muhvi südamikega (16) läbi muhvi südamike (16) sees olevate kuusnurkse ristlõikega avade (33).

6. Rihmsorteer vastavalt nõudluspunktidele 1 kuni 5, **erineb selle poolest**, et reguleeritava tagumise rihmatrumli (3) rihmarattad (13) ja muhvid (15) on ühendatud omavahel läbi torukujulise hülsi (17) sees olevate vähemalt kolme lõhiku (35) paigutatud juhtvarraste (20) kaudu.

7. Rihmsorteer vastavalt nõudluspunktidele 1 kuni 6, **erineb selle poolest**, et reguleeritava tagumise rihmatrumli (3) keskmine muhv (37) on reguleeritava rihmatrumli (3) suhtes pikisihis liikumatult fikseeritud reguleeritava rihmatrumli (3) keskpunktis asuvate torukujulise hülsi avade (38) kaudu.

8. Rihmsorteer vastavalt nõudluspunktidele 1 kuni 7, **erineb selle poolest**, et reguleeritava tagumise rihmatrumli (3) muhvide (15) ja muhvi südamike (16) omavaheline asend ning rihmarataste (13) omavaheline kaugus on fikseeritud läbi muhvide (15) ja muhvi südamike (16) paigutatud reguleervõlli (19) külge ühendatud jaotusketta (21) ja torukujulise hülsi (17) külge ühendatud fikseerketta (22) omavahelise asendi fikseerimisega.

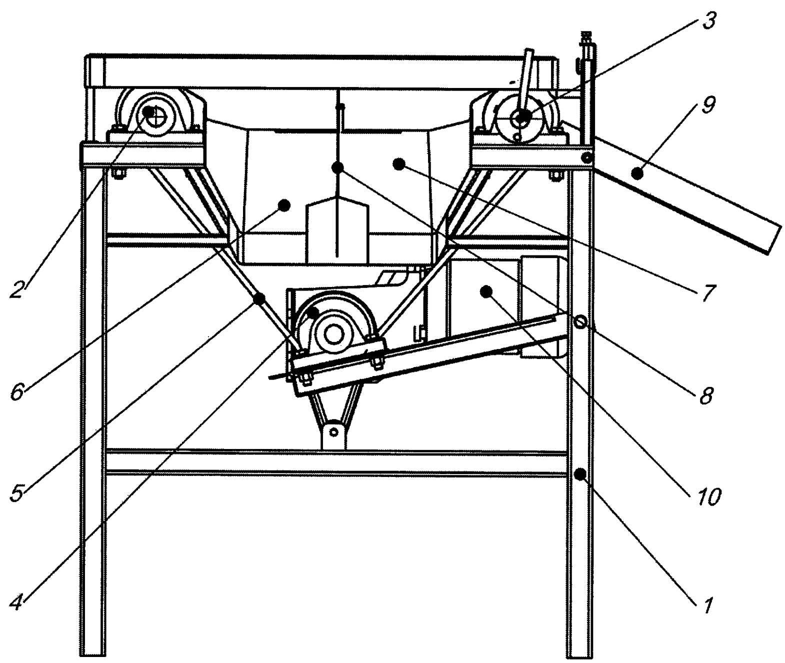


FIG 1

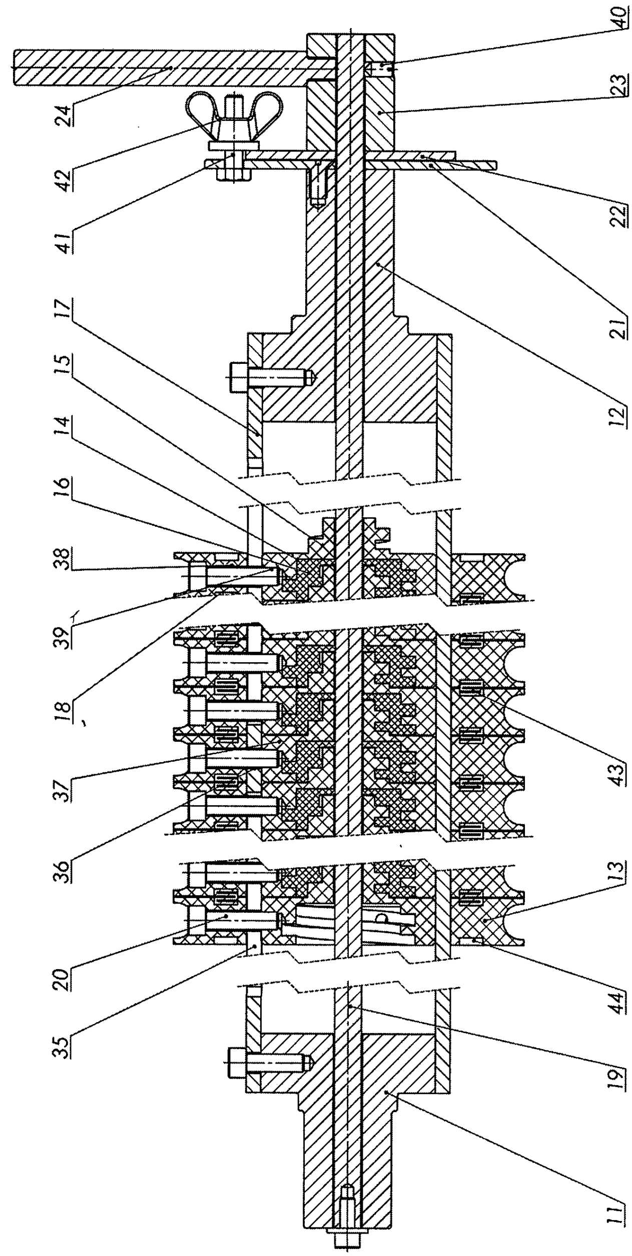


FIG 2

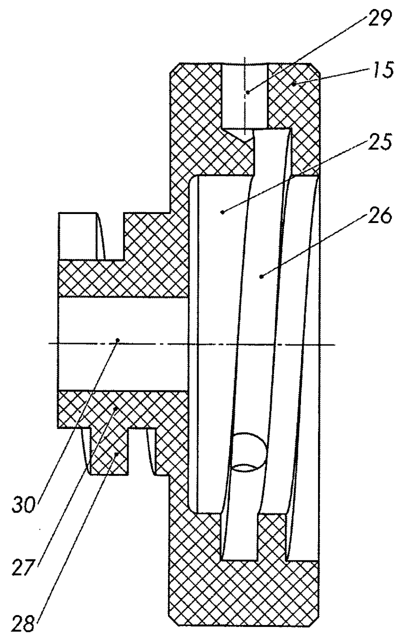


FIG 3

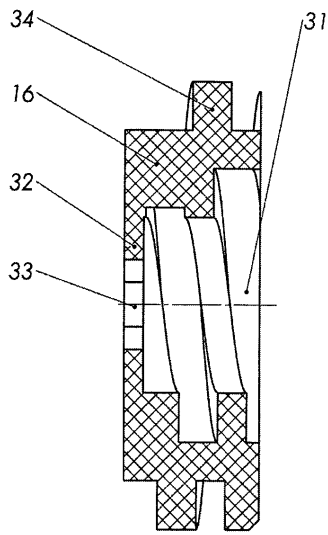


FIG 4

CURRICULUM VITAE

Contact information

Name:	Margus Arak
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Education

2017-2021	PhD studies, Estonian University of Life Sciences
1991-1995	Master of Sciences in Environmental Physics, University of Tartu
1984-1991	Diploma degree in Physics, University of Tartu
1982-1984	Nõo Secondary School

Career

2018-	Estonian University of Life Sciences, lecturer of environmental physics and agrometeorology
1995-2018	Estonian University of Life Sciences, lecturer of physics
1995-1999	Estonian Energy Ltd, vocational training specialist
1994-1995	G-Therm Ltd, sales engineer

Managerial and administrative work

2008 - …	Director of Institute of Technology, Estonian University of Life Sciences
2008 - …	Director of Tartu College of Technology, Estonian University of Life Sciences
2010 - …	Head of Organizing Committee of Scientific Conference Biosystems Engineering, Estonia

Software skills

Planning:	Aspire, AutoCad
Statistics:	R, Mathcad
Office:	MS Office

Languages

Estonian	Native speaker
English	Good in spoken and written
Russian	Good in spoken and written

Participation in professional societies

2008 - …	Member of Board of Estonian Association of Engineers

Teaching

2016 - …	Agrometeorology
2002 - …	Environmental Physics
1991- 2005	General Physics

Training and courses

July 2010	English Language Course, EAC Language Centre, London
July 2011	Managing People and Organizations, Clarus Advisory Service, Athen
July 2011	Public presentation, University of Tartu, Estonia
August 2014	ICT for Collaborative, Project-Based, Teaching and Learning, Smart Solutions Ltd, Malta
August 2016	Efficient & Effective Project Management for EU Funded Projects, Shipcon Limassol Ltd, Palermo, Italy
November 2017	Practical Temperature Measurement, AS Metrosert, Tallinn, Estonia
March 2018	Measurement Uncertainty, AS Metrosert, Tallinn, Estonia

August 2018	Frontiers of Environmental Principles and Research, Tomas Bata University in Zlin, Czech Republic
January 2020	Self-analysis by DISC method, Estonian Training
December 2020	Introduction to non-destructive plant leaf spectroscopy, e-course, AVANTES B.V.

ELULOOKIRJELDUS

Kontaktandmed

Nimi:	Margus Arak
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Aadress:	Eesti Maaülikool Fr.R. Kreutzwaldi 56/1, Tartu, 51006
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Haridustee

2017–2021	Doktoriõpe, Eesti Maaülikool
1991–1995	Magistriõpe, keskkonnafüüsika, Tartu Ülikool
1984–1991	Diplomiõpe, füüsika, Tartu Ülikool
1982-–1984	Nõo Keskkool

Töökogemus

2018–	Eesti Maaülikool, keskkonnafüüsika ja agrometeoroloogia lektor
1995–2018	Eesti Maaülikool, füüsika lektor
1995–1999	Eesti Energia AS, ametikoolituse peaspetsialist
1994–1995	G-Therm AS, müügiinsener

Teadusorganisatsiooniline ja administratiivne tegevus

2008– …	Eesti Maaülikooli Tehnikainstituudi direktor
2008– …	Eesti Maaülikooli Tartu Tehnikakolledži direktor
2010– …	Rahvusvahelise teaduskonverentsi „Biosystems Engineering" (Eesti) korralduskomitee esimees

Arvutioskused

Projekteerimine:	Aspire, AutoCad
Statistika:	R, MathCAD
Kontoritarkvara	MS Office

Keeled

Eesti keel	Emakeel
Inglise keel	Hea nii kõnes kui kirjas
Vene keel	Hea nii kõnes kui kirjas

Organisatsiooniline tegevus

2008– …	Eesti Inseneride Liidu juhatuse liige

Õppetöö

1991–2005	Üldfüüsika
2002– …	Keskkonnafüüsika
2016– …	Agrometeoroloogia

Koolitused ja kursused

Juuli 2010	Inglise keele kursus, EAC Language Centre, London, Inglismaa
Juuli 2011	Inimeste ja organisatsiooni juhtimine, Clarus Advisory Service, Ateena, Kreeka
Juuli 2011	Avalik esinemine, University of Tartu, Estonia
August 2014	ICT for Collaborative, Project-Based, Teaching and Learning, Smart Solutions Ltd, Malta
August 2016	Efficient & Effective Project Management for EU Funded Projects, Shiocon Limassol Ltd, Palermo, Italy
November 2017	Praktiline temperatuuri mõõtmine, AS Metrosert, Tallinn, Estonia
Märts 2018	Põhjalikumalt mõõtemääramatusest, AS Metrosert, Tallinn, Estonia
August 2018	Frontiers of Environmental Pronciples and Research, Tomas Bata University in Zlin, Chech Republic
Jaanuar 2020	Eneseanalüüs DISC meetodil, Estonian Training
Detsember 2020	Introduction to non-destructive plant leaf spectroscopy, e-kursus, AVANTES B.V.

LIST OF ORIGINAL PUBLICATIONS

Classification	1		3	5
Subclassifier	1.1	1.2	3.1	5.2
Number of publications	21	5	5	2

1.1 Scholarly articles indexed by Web of Science Science Citation Index Expanded, Social Sciences Citation Index, Arts & Humanities Citation Index, Emerging Sources Citation Index and/or indexed by Scopus (excluding chapters in books)

Arak, M., Liivapuu, O., Maksarov, V., Olt, J. 2021. A justification of the choice of parameters for the picking reel tooth on a lowbush blueberry harvester. Agronomy Research 19(X), xxx–ccc, 2021, (in press), doi.org/10.15159/AR.21.133

Virro, I.; **Arak, M.**; Maksarov, V.; Olt, J. 2020. Precision fertilisation technologies for berry plantation. Agronomy Research, 18 (S4), 2797−2810. DOI: 10.15159/AR.20.207.

Bulgakov, V.; Holovach, I.; Kiurchev, S.; Pascuzzi, S.; **Arak, M.**; Santoro, F.; Anifantis, A. S.; Olt, J. 2020. The theory of vibrational wave movement in drying grain mixture. Agronomy Research, 18 (2), 360−375.10.15159/AR.20.051.

Bulgakov, V.; Pascuzzi, S.; **Arak, M.**; Santoro, F.; Anifantis, A. S.; Ihnatiev, Y.; Olt, J. 2019. An experimental investigation of performance levels in a new root crown cleaner. Agronomy Research, 17 (2), 358−370.10.15159/AR.19.132.

Bulgakov, V.; Ivanovs, S.; **Arak, M.**; Olt, J. 2019. Theoretical research of force interaction of a flexible cleaning blade with a beet root head. Agronomy Research, 17 (4), 1547−1559.10.15159/AR.19.193.

Bulgakov, V.; **Arak, M.**; Boris, A.; Boris, M.; Bandura, V.; Olt, J. 2019. Experimental study of the distribution of the heights of sugar beet root crowns above the soil surface. Agronomy Research, 17 (6), 2211−2219.10.15159/AR.19.207.

Arak, Margus; Soots, Kaarel; Starast, Marge; Olt, Jüri 2018. Mechanical properties of blueberry stems. Research in Agricultural Engineering, 64 (4), 202−208.10.17221/90/2017-RAE.

Bulgakov, V.; Bandura; V.; **Arak, M.**; Olt, J. 2018. Intensification of rape seed drying process through the use of infrared emitters. Agronomy Research, 16 (2), 349−356.10.15159/AR.18.054.

Bulgakov, V.; Nikolaenko, S.; **Arak, M.**; Holovach, I.; Ruzhylo Z.; Olt, J. 2018. Mathematical model of cleaning potatoes on surface of spiral separator. Agronomy Research, 16 (4), 1590−1606.10.15159/AR.18.173.

Bulgakov, V.; Adamchuk, V.; Arak, M.; Olt, J. 2018. The theory of cleaning the crowns of standing beet roots with the use of elastic blades. Agronomy Research, 16 (5), 1931−1949.10.15159/AR.18.213.

Bulgakov, V.; Ivanovs, S.; **Arak, Margus**; Kuvachov, V.; Shymko, L.; Bandura, V. 2018. Experimental investigation of the work of a ploughing aggregate, operating according to the system ‘push- pull’. Agronomy Research, 16 (5), 1950−1959.10.15159/ar.18.174.

Bulgakov, V.; Adamchuk, V.; **Arak, M.**; Olt, J. 2017. A theoretical study of haulm loss resulting from rotor topper oscillation. Chemical Engineering Transactions, 58, 223−228.10.3303/CET1758038.

Bulgakov, V.; Adamchuk, V.; **Arak, M.**; Petrychenko, I.; Olt, J. 2017. Theoretical research into the motion of combined fertilising and sowing tractor-implement unit. Agronomy Research, 15 (4), 1498−1516.10.15159/AR.17.059.

Bulgakov, V.; Adamchuk, V.; Kuvachov, V.; **Arak, M**; Olt, J. 2017. Study into movement of wide span tractors (vehicles) used in controlled traffic farming. Proceedings of the 28th DAAAM International Symposium: 28th DAAAM International Symposium on Intelligent Manufacturing and Automation, 08 – 11th November 2017, Zadar, Croatia, EU. Ed. B. Katalinic. Vienna, Austria: DAAAM International Vienna, 0199−0208.10.2507/28th.daaam.proceedings.027.

Bulgakov, V.; Adamchuk, V.; **Arak, M.**; Nadykto, V.; Kyurchev, V.; Olt, J. 2016. Theory of vertical oscillations and dynamic stability of combined tractor-implement unit. Agronomy Research, 14 (3), 689−710.

Streikus D.; Jasinskas A.; **Arak, M.**; Jotautienė E.; Mieldažys R.; Čekanauskas S.; Jankauskienė Z. 2016. Investigations of fibre plants preparation and utilization of solid biofuels. Agronomy Research, 14 (1), 259−268.

Bulgakov, V.; Adamchuk, V.; **Arak, M.**; Olt, J. 2015. Theory of vibration-assisted sugar beet root lifting. Agronomy Research, 13 (5), 1165−1192.

Nadykto, V.; **Arak, M.**; Olt, J. 2015. Theoretical research into the frictional slipping of wheel-type undercarriage taking into account the limitation of their impact on the soil. Agronomy Research, 13 (1), 148−157.

Bulgakov, V.; Adamchuk, V.; Kaletnik, G.; **Arak, M.**; Olt, J. 2014. Mathematical model of vibration digging up of root crops from soil. Agronomy Research, 12 (1), 41−58.

Arak, M.; Olt, J. 2014. Constructive and kinematics parameters of the picking device of blueberry harvester. Agronomy Research, 12 (1), 25−32.

Jasinskas, A.; Simonaviciute, R.; Siaudinis, G.; Liaudanskiene, I.; Antanaitis, S.; **Arak, M.**; Olt, J. 2014. The assessment of common mugwort (Artemisia vulgaris L.) and cup plant (Silphium perfoliatum L.) productivity and technological preparation for solid biofuel. Zemdirbyste-Agriculture, 101 (1), 19−26.

1.2. Peer-reviewed articles in other international research journals with an ISSN code and international editorial board, which are circulated internationally and open to international contributions

Bulgakov, V.; **Arak, M.**; Olt, J.; Holovach, I.; Kuvachov, V. 2018. Study of special aspects of hitching to wide span tractors (vehicles). Mechanization in Agriculture, 4, 111−113.

Bulgakov, V.; Olt, J.; Adamchuk, V.; **Arak, M.** 2015. Theory of asymmetric impact interaction between vibrating digging tool and body of sugar beet root. Mechanization in Agriculture, 7, 23−25.

Olt, J.; **Arak, M.**; Jasinskas, A. 2013. Development of mechanical technology for low-bush blueberry cultivating in the plantation established on milled peat fields. Agricultural Engineering, 2 (45), 120−131.

Olt, J.; **Arak, M.** 2012. Motoplokk-tüüpi mustikakombaini korjehaspli konstruktsioon ja arendus. Agraarteadus, XXIII (2), 21−26.

Heikinheimo, M.; Ohvril, H.; Venälainen, A.; Skartveit, A.; Olseth, J. A.; Laine, V.; Teral, H.; **Arak, M.**; Teral, K. 1996. Recent variations of atmospheric turbidity at selected sites in Finland, Estonia and Norway as revealed by surface solar radiation measurements. Geophysica, 32, 195−216.

3.1. Articles/chapters in books published by the publishers listed in Annex (including collections indexed by the Web of Science Book Citation Index, Web of Science Conference Proceedings Citation Index, Scopus)

Arak, Margus; Olt, Jüri 2020. Technological description for automating the cultivation of blueberries in blueberry plantations established on depleted peat milling fields. Proceedings of the 9th International Scientific Conference Rural Development 2019: 9th International Scientific Conference Rural Development 2019. Research and Innovation for Bioeconomy. Ed. Asta Raupeliene. Kaunas: Vytautas Magnus University, 98−103.10.15544/RD.2019.024.

Arak, M.; Olt, J. 2017. Determination of the connection force between berries and stem in blueberry plants. Proceedings of the 45th International Symposium on Agricultural Engineering: Actual Tasks on Agricultural Engineering, Opatija, Croatia, 21-24.02.2017. Editors Abbr Igor Kovacev. University of Zagreb, 589−595.

Bulgakov, V.; Adamchuk, V.; **Arak, M.**; Olt, J. 2015. Mathematical modelling of the process of renewal of the fleet of combine harvesters. Agriculture and Agricultural Science Procedia, 7, 35−39.

Jasinskas, A.; Kucinskas, V.; **Arak, M.**; Olt, J. 2013. Research of Physical-Mechanical Properties of Sawdust Fuel Briquettes with the Additives. Rural development, 6 (3), 55−59.

Olt, Jüri; Traat, Ülo; **Arak, Margus**; Ilves, Risto 2011. Changes in Agricultural Tractor Park Maintenance Costs Depending on Tractor's Age. 2011 INTERNATIONAL CONFERENCE ON APPLIED SOCIAL SCIENCE (ICASS 2011), 1: 2011 International Conference on Applied Social Science (ICASS 2011), Changsha, China, 19-20 March, 2011. 263−267.

5.2. Conference abstracts that do not indexed by Thomson Reuters Web of Science

Arak, M.; Olt, J. 2019. An alternative way for re-cultivating of depleted peat fields. In: Book of Abstracts. VI Synergy International Conferences Engineering, Agriculture and Green Industry Innovation. Szent István University, Faculty of Mechanical Engineering, Gödöllö, Hungary.

Bulgakov, V.; **Arak, M.**; Boris, A.; Boris M.; Olt, J. 2018. Experimental study of the distribution of the heights of sugar beet root crown protrusion above the field surface level. Program & Abstracts' Book: XIX World Congress of CIGR. Sustainable Life for Children, Antalya, Turkey, 22-25 April 2018. CIGR Journal, 229.

LIST OF INTELLECTUAL PROTERTIES

Olt, Jüri; **Arak, Margus** .2011. Blueberry harvester. Patent EE 05488 B1. A01D46/00.

Soots, Kaarel; **Arak, Margus**; Olt, Jüri. 2017. Belt sorter. Patent EE 05798 B1. B07B13/065.

Olt, Jüri; **Arak, Margus**; Bulgakov, Volodymyr; Adamchuk, Valerii. 2019. Device for topping unlifted coot crops. Patent EE 05815 B1. A01D23/02; A01D27/92; A01D33/02.

Olt, Jüri; **Arak, Margus**; Bulgakov, Volodymyr; Adamchuk, Valerii. 2019. A method and device for conveying and separating tubers and root crops. Patent EE 05817 B1. A01D33/00; A01D33/08.

Olt, Jüri; **Arak, Margus**; Bulgakov, Volodymyr; Adamchuk, Valerii. 2020. Device for conveying and separating tubers and root crops. Patent EE 05820 B1. A01D33/00.

Arak, Margus; Virro, Indrek; Olt, Jüri. 2021. Fertilizing robot. Patent application EE 202000002 A. A01C15/14; G05D1/00.

LIST OF CONFERENCE PRESENTATIONS

Oral presentations

Arak, Margus; Olt, Jüri; Jasinskas, Algirdas. 2013. Justification of the Materials Selection for Manufacturing Rake Teeth of Blueberry Harvester. Engineering of Agricultural Technologies – 2013, Kaunas, Lithuania, 19.09.2013

Arak, Margus; Olt, Jüri. 2014. Constructive and kinematics parameters of the picking device of blueberry harvester. Biosystems Engineering, Tartu, Estonia, 8.05.2014

Arak, Margus; Olt, Jüri. 2017. Determination of the connection force between berries and stem in blueberry plants. Actual Tasks on Agricultural Engineering, 2017, Opatia, Croatia, 22.02 2017

Arak, Margus; Olt, Jüri. 2018. Automatisation in blueberry plantations. The third millennium sustainable development goals: challenges for Life Sciences Universities. Kiev, Ukraine, 23-25.05.2018

Arak, Margus; Olt, Jüri. 2019. An Alternative Way for Re-cultivation of Depleted Peat Fields. Synergy 2019 VI International Conferences of Engineering, Agriculture, Waste Management and Green Industry Innovations, Gödöllö, Hungary, 04.11.2019

Arak, Margus. 2021. Cultivation Technology for Lowbush Blueberry Cultivation in Milled Peat Field Plantations. Biosystems Engineering 2021, Tartu, Estonia, 5.05.2021

Poster presentations

Bulgakov, Valodimir; Adamchuk, V; **Arak, Margus**; Olt, Jüri. 2017. A Theoretical Study of Halum Loss Resulting from Rotor Topper Oscillation. XXXVII CIOSTA & CIGR Section V Conference: Research and Innovation for the Sustainable and Safe Management of Agricultural and Forestry Systems, Palermo, Italy, 15.06.2017

Arak, Margus; Virro, Indrek; Olt, Jüri. 2019. Technological description for automating the cultivation of blueberries in blueberry plantations established on depleted peat milling fields, Rural Development 2019: Challenges for Sustainable Bioeconomy and Climate Change, Kaunas, Lithuania, 26-28.98.2019

VIIS VIIMAST KAITSMIST

NASIME JANATIAN GHADIKOLAEI
HÜDROMETEOROLOOGILISTE JA KLIIMATEGURITE MÕJU JÄRVEDE FÜTOPLANKTONILE: AJASKAALADE OLULISUS
HYDROMETEOROLOGICAL AND CLIMATIC CONTROL OVER LAKE PHYTOPLANKTON: THE IMPORTANCE OF TIME SCALES
Juhtivteadur **Peeter Nõges**, **Biel Obrador**, vanemteadur **Fabien Cremona**, vanemteadur **Alo Laas**
27. august 2021

KRISTIINA AUN
RAIETE LÜHIAJALINE MÕJU SÜSINIKU VOOGUDELE JA VARUDELE ERINEVATES EESTI METSAÖKOSÜSTEEMIDES
SHORT-TERM EFFECT OF FELLING ON CARBON FLUXES AND STORAGES IN DIFFERENT ESTONIAN FOREST ECOSYSTEMS
Professor **Veiko Uri**
27. august 2021

PRIIT KARIS
TOITUMUSE, LIPOMOBILISATISOONI JA INSULIINIRESISTENTSUSE SEOSED PIIMALEHMADEL
RELATIONSHIPS BETWEEN BODY CONDITION, LIPOMOBILIZATION AND INSULIIN RESISTANCE IN DAIRY COWS
Doktor **Hanno Jaakson**, doktor **Katri Ling**, doktor **Meelis Ots**
31. august 2021

HARES KHAN
KALTSIIDI AVAVEELINE SADENEMINE: PÕHJUSED JA TAGAJÄRJED GLOBAALSES JA KOHALIKUS VAATES
PELAGIC CALCITE PRECIPITATION IN LAKES: FROM A GLOBAL TO A LOCAL PERSPECTIVE ON ITS DRIVERS AND IMPLICATIONS
Doktor **Biel Obrador** (University of Barcelona, Hispaania), doktor **Alo Laas**
16. september 2021

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