LIFE Environment and Resource Efficiency project

"Nutrient recycling circular economy model for large cities – water treatment sludge and ashes to biomass to bio-energy "

Project Acronym: NutriBiomass4LIFE
Project Number: LIFE17 ENV/LT/000310

Biomass yield improvement assessment report in NutriBiomass4LIFE circular economy model

WEB Report prepared by

UAB "Pageldynių plantacija"

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Preface

The purpose of this document is to provide results on the development of biomass yield assessment model and assessment of biomass yield improvement due to fertilization with dried municipal waste-water treatment sludge digestate during the project NutriBiomass4LIFE. It is expected that yield improvement may provide solid background for business continuation of nutrient rich waste recycling in biomass plantations, though clear policies are needed to implement Circular Economy directive.

For the implementation of the NutriBiomass4LIFE project, a subsidy is awarded from the EU LIFE program, the EU's funding instrument for environment and climate action. The funding of the project also come from the Swedish Energy Agency and Ministry of Environment of the Republic of Lithuania.

I. Table of Contents

II. List of Tables and Figures

III. About the NutriBiomass4LIFE Project

The Nutribiomass4LIFE project was launched on 1 July 2018 and will be running until the end of September 2023. Within the framework of this project, 6 beneficiaries from Lithuania and Sweden aim to create and demonstrate the first of its kind on the EU level full scale self-sustainable closed loop circular economy model for large cities' nutrient rich waste - municipal wastewater treatment sludge and biomass ashes – recycling into renewable energy for city's needs via environment friendly biomass plantation phytoremediation filter. The circular economy model is based upon Vilnius city, the capital of Lithuania (550 thousand population).

The specific objectives of the project included:

- promoting resource efficiency through reuse of nutrients (less usage of mineral fertilizer) and decrease in transportation distances and flows;
- promoting waste management pyramid priorities via changing path from landfilling and incineration of nutrient rich waste towards reuse in biomass growth improvement;
- mitigation of food chain contamination risks via changing path of nutrient rich waste from uncontrolled usage in food crop growing towards 100% legally compliant and monitored non-food biomass yield improvement;
- creating new best practices for dried MWTS digestate usage for non-food biomass;
- developing new business models to make biomass growing / forestry on marginal and less suitable to agriculture soils economically attractive via substantial biomass yield improvement;
- promoting soil organic content improvement via bio-solids applications;
- promoting renewable energy production;
- promoting afforestation of less suitable for agriculture / marginal lands;
- contributing significantly to climate change impact reduction by sequestrating significant volume of CO_2 in the whole circular economy model value chain, promoting renewable energy production, soil carbon content improvement;
- promoting of EU and national legislation and policies and contributing to their development by promoting safe and environment friendly reuse of nutrients from wastes.

The Coordinating beneficiary:

1. UAB "Pageldynių plantacija" (Lithuania)

Associated beneficiaries:

2. Forest and Landowners Association of Lithuania (Lithuania)
3. Lithuanian Research Centre for Agriculture and Forestry (Lithuania)
4. UAB "Kirtimu katiline" (Lithuania)
5. UAB "Vilniaus vandenys" (Lithuania)
6. Swedish University of Agricultural Sciences (Sweden)

For more information, please visit the project's website: www.nutribiomass.eu.

IV. List of Abbreviations and Partner Acronyms

NutriBiomass4LIFE	EU LIFE project "Nutrient recycling circular economy model for large cities – water treatment sludge and ashes to biomass to bio-energy ", No. LIFE17 ENV/LT/000310
AV	UAB "Aukštaitijos vandenys", Panevė-ys city municipal water supply and sewage water treatment company
AB	Albeluvisols (soil type)
AGB	Above ground biomass (stem, branches and leaves biomass)
AGROLAB	Lithuanian Research Centre for Agriculture and Forestry
AR	Arenosols (soil type)
BGB	Below ground biomass (stump, coarse root, medium root and fine root biomass)
CE	Circular economy
CM	Cambisols (soil type)
CO2	Carbon dioxide
CR	Coarse roots (above 10 mm in diameter)
d	diameter
dbh	diameter breast height in cm
Dq	average tree diameter in cm
dmt	Dry matter ton (t)
DMWTSD	Dried granulated municipal waste-water treatment sludge digestate
EU	European Union
FR	Fine roots (bellow 2 mm in diameter)
FTE	Full time employed
g	gram, 1 kg = 1000 g
GL	Glaysols (soil type)
h	height
Hq	average tree height in m
HS	Histosols (soil type)
kg	kilogram, 1 t = 1000 kg
ha	hectare, 1 ha = 1000 square meteres
km	kilometre, 1 km = 1000 m
LMSA	Forest and landowner's association of Lithuania
LV	Luvisols (soil type)
MR	Medium roots (from 2 mm to 10 mm in diameter)
PP	UAB "Pageldyniu plantacija"
PE	UAB "Kirtimu katiline", biomass boiler in Visaginas
PL	Planosols (soil type)
PZ	Podzols (soil type)
r. or reg.	administrative district
R2	coefficient of determination
sen.	regional units of administrative district
t	metric ton, 1 t = 1000 kg
VV	UAB "Vilniaus vandenys", Vilnius city municipal water supply and sewage water treatment company

Introduction

Purpose and Aim

The purpose of this document is:

(1) to present the results of developed biomass models based on empirical degree functions that could be applied in practice
(2) to reveal results of biomass yield improvement while using DMWTS, which were estimated using developed biomass model and destructive measurement data

Structure

The document is divided into four main chapters:

- Chapter 1 “Development of biomass yield assessment model” provides analysis of biomass estimations at researched hybrid poplar and hybrid aspen plantations and defines key developed coefficients for biomass assessment models to be used in Nutribiomass4LIFE model for biomass yield estimations and CO2 sequestration in biomass plantations.
- Chapter 2 “Assessment of biomass yield improvement due to fertilization with municipal waste-water treatment sludge” discloses measurement results and developed models for estimation of above ground biomass and bellow grass biomass improvement due to fertilization.
- Chapter 3 “Carbon footprint” discloses CO2 footprint of assessment oof biomass yield improvement due to fertilization with municipal waste-water treatment sludge during NutriBiomass4LIFE project.
- Chapter 4 “Continuation” discusses post project continuation activities for improvement of biomass yield assessment model and biomass yield improvement due to fertilization with municipal waste-water treatment sludge assessment.

1 Development of biomass yield assessment model

1.1 Introduction

Back in 2014, the European Council agreed on the long-term commitment of the European Union and set the goal that the share of renewable energy in the EU member states would be at least 27%[1]. Later these targets were significantly adjusted and new ambitious targets to move towards full carbon neutrality were set. The growing renewable energy sector occupies an increasing share of the energy market, thereby reducing the amount of energy obtained from non-renewable sources, thus effectively reducing CO_2 emissions, while green biomass remains the most important renewable energy source and occupies the largest share of renewable energy in twenty-eight European Union countries.[2].

Lithuania became a full member of the European Union in 2004. and adopted the bioenergy directives of the European Union[1]. Since then, significant changes have taken place in the Lithuanian energy sector, mainly in order to reduce energy dependence on Russia, which was manifested in unreasonably high prices of energy resources[3] and in using energy as political instrument. In the national energy independence strategy of Lithuania, the greatest attention is paid to increasing the diversity of energy sources. According to its guidelines, by 2030 the share of renewable energy resources in the total balance of final energy consumption should reach 93%[4].

This is an ambitious but realistic goal, as Lithuania has sufficient bioenergy potential, taking into account available natural resources, including unused forest biofuel resources, as well as competence or organization abilities[5].

However, increasing the use of biomass from native forests is quite limited due to existing conservation requirements that do not apply to short-rotation plantations. Therefore, the development of these plantations and the cultivation of biomass in them is much simpler and more attractive. Excellent conditions are also created for the utilization of abandoned areas and low productivity areas for agriculture.

However, growing productive short-rotation crops is not so simple. It is well known that biomass yield in short-rotation plantations depends greatly on the cultivated tree species and its genotypes[6], cultivation technologies, rotation length and soil conditions[7].

Research carried out by scientists from Latvia [8] shows that Populus hybrids are suitable for breeding bioenergy plantations. The authors indicate that hybrids of poplars can yield 4.2-9.8 tons of annual increase in dry biomass. Even more impressive results of Populus cultivation were obtained in the Czech Republic. Authors [9] indicates that the analysed clones achieved annual yield of 14 tons of dry biomass. Based on research by Jasinskas et al[10], the annual dry biomass increase of Populus nigra L. in Lithuania was 4.2 tons per hectare.

In Lithuania, the studies carried out on hybrids of the genus Populus were more fundamental, for example to study the ecogenetic plasticity or adaptation of different clones of the genus Populus in the natural conditions of Lithuania[11],[12]. Meanwhile, applied research, which is crucial for plantation managers, is sorely lacking.

As the areas of commercial plantations of trees of the genus *Populus* increase in Lithuania, the need for practically applicable measures, which could be used to easily assess the accumulated amounts of dry biomass or annual yield in managed plantations, also increases. After all, it is very important for the plantation manager to know how much biomass is growing, what is the productivity of the available plantations.

In the literature, one can find a number of non-destructive biomass estimation methods that are more or less user-friendly and reliable. Several such methods are worth a closer look. Prodan [13] found that the sum of cross section areas of tree stems is related to their biomass. Therefore, the average diameter method was developed. By having the average diameter of the trees and the biomass of the average tree, and multiplying it by the number of trees per hectare, it is possible to find out the amount of biomass per hectare. Hauk et al.[14] further improved this method and achieved more accurate results by using not the biomass of a single tree with a diameter at breast height equal to the average tree diameter, but the biomass averages of three such trees. According to Hauk et al.[14] results, this method worked quite accurately in poplar plantations, its error reached-6.15%. Meanwhile, Zabek and Prescott [15] obtained even up to -30% errors using this method in hybrid aspen plantations.

It is also worth discussing in more detail the "Yield Estimation" method developed in Germany at the Dresden University of Technology[16]. This method is slightly more complex compared to the average diameter method because it is necessary to first develop models of soil biomass productivity from the average tree height. Further, it is also necessary to have the average diameter of the trees and the number of trees per hectare. Hartman [16]found that the error of this method was only 4% in poplar plantations. It is also necessary to note that on the basis of this method, in Germany, a program was created and placed on the Internet for the state of Saxony, using which local farmers could easily estimate the amount of biomass grown in their plantations. Also, based on this method, Ali[17] produced maps of biomass productivity across the German state of Saxony.

The next method worth discussing in more detail is the method based on empirical power functions. This method is quite common and very often used in scientific studies[18],[19],[17]. Based on this method, it is possible to create both individual plots and general functions, for example, for each clone. However, the application of this method in practice is more complicated, because far from every farmer knows how to use empirical degree functions. This problem is easily solved by creating and placing various spreadsheets on the Internet. Also, this method is considered to be the most accurate of all other methods developed and is used as a benchmark for all other methods to be developed[20].

1.2 Methodology

1.2.1 Research objects

In order to assess the condition, growth, and biomass accumulation patterns of biomass plantations of Populus trees, six research objects located in the municipalities of Anykščiai, Šilutė, Kelmė, Marijampole and Kaišiadorių districts were selected (Table 1-1). Plantations were planted in 2011-2015, so their age at the time of measurements varied from 4 to 9 years. Measurements were made in November-December 2019. Measurements were made in Anykščiai experimental field in January 2019.

Table 1-1.Characteristics of research objects

Field	Detailed location	Age	Establish ment year	Clones	Soil producti-vity score	Soil type	Soil texture	Soil moistu -re	Planting density	Seedling types	Soil prepa-ration
Anykščiai	Anykščiai distr., Kurkliai reg., Vanagai village,	9	2011	8, 9	31-35	AB	ps/p1	S	1250	KS	V
Šilutė	Silutė distr., Usėnai reg., Veržinkai village,	9	2011	8, 9	31-34	PZ	ps/s	S	1500	KS	V
Kelmė	Kelmė distr., Šaukėnai reg., Užvarmis village,	6	2014	8, 9	46-53	CM	dp1/dm	M	1250	KS	V
Marijam-pole	Marijampolė distr., Sasnava reg., Brasta vill.	4	2016	AF7	30-32	GL/PZ	ps/s	M	1650	AT	N
Kašiado-rys	Kaišiadorių distr., Žiežmariai reg., Bačkonys	6	2014	AF7, AF34, OP42	37-45	LV	ps/sp	S	1650	AT	IS
Anykščiai experime nt	Anykščiai distr., Kurkliai reg., Sargūnai village	5	2014	AF7, AF6, AF34, OP42, Max1, Max3, Max 4	41.8	LV/ GL	sp/sp2	M	1650	AT / TA	IS

Soil group: Luvisols (LV), Gleysols (GL), Podzols (PZ), Cambisols (CM), Arenosols (AR), Albeluvisols (AB), Planosols (PL), Histosols (HS)
Soil texture: z – gravel; s – loose sand; s1 – cohesive sand; ps – sand; sp- sandy light loam; sp2 - sandy heavy loam; p – light loam; p1 – medium loam; p2 – heavy loam; m - light clay; m1 – medium clay; m2 - heavy clay; pv - peavan; d - peat. dp1 – dusty medium loam; dm - dusty clay
Soil moisture: D - dry; S - slightly humid; M – moist; W - wet.
Seedling types: KS - containerized plants, AT - 1.5-1.8m long poles, TA - 30 cm cuttings.
Soil preparation– V-soil prepared with furrows, IS-soil completely plowed, N-soil not prepared, planted in a meadow.

The plantations were established in relatively low-fertility, low-moist/moist soils (Albeluvisols, Podzols, Gelysosl), whose productivity score varied from 30 to 35 (Anykščiai, Šilutė, Marijampole). Also in moderately fertile, low-moist soil (Luvisols) with a productivity score of 37-45 (Kaishiadorys), and in fertile, moist soils (Cambisols) with a productivity score of 46-53 (Kelmė).

In Anykščiai, Šilutė, Kelmė fields Lithuanian hybrid aspen clones 8 and 9 were planted in the fields. Meanwhile, in Marijampolė field only one AF7 poplar clone was planted. In Kaišiadorys field three poplar clones AF7, AF34 and OP42 were analysed. Meanwhile, a total of seven clones AF7, AF34, OP42, AF6, Max1, Max3 and Max 4 were analysed in the Anykščiai experimental field.

When establishing plantations, the planting density varied from 1250 to 1650 plants per hectare (Table 1-1). Plantations are planted using containerized plantings or 1.5-1.8 m long poles. In the Anykščiai experimental field, additionally 30 cm long cuttings were used. In most plantations, the soil is prepared in furrows or completely ploughed before planting. It should be noted that, during the establishment Marijampolė plantation, the soil was not prepared at all, and the seedlings were planted directly in the meadow.

It is necessary to emphasize that the Experimental field located in Anykščiai was fertilized with sewage sludge. Fertilization was carried out in 2016. June 27-30 The test plantations were fertilized using 19.5 dmt/ha of UAB "Vilniaus vandenys" DMWTSD and 26.3 dmt/ha of UAB "Kauno vandenys" DMWTSD. After fertilization, DMWTSD was inserted into the soil by disking.

1.2.2 Data collection methods

Biomass assessment of plantation plantations of *Populus* trees was carried out using the biomass assessment methodology prepared by scientists of the Dresden University of Technology (Germany, Saxony)[21],[22],[23],[16]and[14].

According to the German methodology, during field work, temporary research sampling plots are first established, which are used to assess the variability of tree diameters in the field.

The temporary sampling plots method was applied in all fields except Kaišiadorys and Anykščiai experimental field, where continuous measurement of trees of selected clones was carried out, due to the specific principles of clone establishing applied in that field (planted only after a few dozen trees in a row or established several clones in one row every several dozen trees).

The total area of all sampling plots covers about 5% of the entire plantation. In order to place the accounting sampling plots as evenly as possible, thereby eliminating the systematic errors of the researchers, the accounting sampling plot was linked to the established row, without including the rows located on the edges of the fields. Knowing the total number of rows and multiplying it by 0.05, the number of accounting rows is obtained. In the field, accounting rows are arranged evenly. Depending on the size of the field, accounting rows are drawn every 10-20 rows. After marking the beginning and end of each row, the length and width of the accounting row at the beginning and end of the row is measured. This is done so that when the biomass amounts in the rows are measured later, everything can be recalculated per hectare or for the entire plantation. The characteristics of accounting rows are presented in Table 1.2.

Table 1-2.Characteristics of accounting rows

Field	Total number of rows in the field	Number of accounting rows	The average width of accounting rows at the beginning, in	The average width of accounting rows at the end,	Average length of accounting rows, m	Total length of accounting rows, m	The total area of accounting rows m2	Field area by rows, ha
Anykščiai	190	12	3.9	3.91	344.44	4133.30	16120.9	27.8
Šilutė	186	9	3.03	2.93	547.79	4930.10	14733.1	34.3
Kelmė	161	8	4.25	4.35	730.51	5844.05	25187.9	57.9
Marijampole	78	7	3.21	3.24	275.35	1927.45	6246.7	8.1
Kašiadorys	38	12	3.01	3.03		1452.75	4568.5	2.4
Anykščiai experiment	35	21	3.00	3.00	61	1280	0.384	0.64

Next, the following measurements are performed in each accounting row. First, the clone to which the tree belongs is determined. The diameter of each tree at breast height (dbh) is also measured (exactly 1.3 m, a 1.3 m stick is used to determine the measurement location) while holding the legs of the caliper perpendicular to the direction of the row. After measuring the diameters in all rows, the diameter dispersion limits are estimated - the largest and smallest diameters of the measured trees are determined. This information is needed to select 15 model trees in each field, which will be used to estimate tree height and biomass. Thus, knowing the limits of variation in tree diameters, 15 model trees per clone are selected and cut in the entire field, with diameters evenly spaced from the largest to the smallest measured diameter. Before cutting the trees, the diameter of the model tree is measured using the same principle and the breast height is marked with a marker. After cutting a tree, its height is measured first. Measurements are made with a measuring tape, accurate to one centimetre. When measuring the height of the tree, it is necessary to match the breast height 1.3 m marked on the tree with the 1.3 m of the tape. This is done to include the height of the stump in the total height of the tree.

Finally, each tree is weighed and its weight or wet biomass is known. In all fields, except the Anykščiai experiment, tree stems and tree branches without leaves were weighed separately, with hanging scales with a measurement accuracy of 100g.

After weighing the stems and branches of the trees, a sample from them is prepared for determination of dry biomass in the laboratory. For this purpose, evenly (depending on the height of the tree, every 1-2 m) from different parts of the stem, starting from the stump, samples are cut. Samples are also taken from the crown of the trees, proportional to the weight of the tree trunks and branches. The total fresh mass of each sample weighs 3-4 kg. For very small trees, 2 cm or less in diameter, the whole tree is sampled.

In Kaišiadorys field branch and stem samples were formed separately. Each of them weighed about 1.5-2 kg. The samples were weighed with a hanging scale with a measurement accuracy of 10g.

The prepared samples were handed over to the Agrobiology laboratory belonging to "Nemunas slėnai", Lithuanian agricultural university, Kaunas district. The tree samples were dried in drying chammbers at a temperature of 105 C^0 until their weight no longer changed. Then, the bone dry samples were weighed to obtain the dry weight of the samples.

1.2.3 Data analysis methods

1.2.3.1 Assessment of the general condition of the plantations

Several criteria were used to assess the general condition of plantations. The most important criterion is the annual increment of accumulated biomass per hectare. How to calculate the accumulated biomass per hectare is described in more detail in section 1.2.3.4. Having this data and dividing it by the age of the plantations gives the annual biomass increments for each field hectare.

The second criterion for assessing the general condition of plantations is the number of surviving trees compared to the number of planting sites. When measuring the rows in each field, it was first assessed whether every two meters, such was the initial density of the planting in the rows, there is a growing tree. If the tree is growing, the growing tree is recorded, if not, only the planting location is recorded.

Another criterion for the evaluation of the plantation was the average diameter and average height of the trees according to the clones in each field depending on the age. Their calculation methods are specified in section 1.2.3.4.

In order to visualize the state of the plantations, plans were made for the arrangement of the trees in each field. Knowing that the trees were planted every 3 or 4 meters between the rows and about 2 meters in the rows, knowing how many rows there are in total and recording the row numbers from the edge of the selected field, as well as recording the growing and fallen trees in each row, it is possible to give a coordinate for each tree. Having the coordinates of the trees on the plan, having the diameters of all trees or fixed planting places in the rows, it is possible to represent the distribution of trees by diameters in the entire plantation on the plans. To reveal plantation areas where the trees have completely fallen, in which areas the trees are growing intensively and in which areas the trees are growing weakly. Also to show the distribution of trees by clones.

1.2.3.2 Modelling tree height and biomass in each field by clone

It should be noted that in each field, 6 biomass models from tree diameter and 6 biomass models from tree height were made for each clone separately. This is because biomass models of freshly cut branches, freshly cut stems, total fresh weight of trees, dry branches, dry stems, total dry weight of trees were made based on tree height and diameter.

To assess the dependence of tree canopy and freshly cut or dry biomass, most authors Hytönen et al.[18], Verwijst and Nordh[24]and Röhle et al.[22]uses the allometric power formula (Equation 1):

$$bm = a_1 \cdot d^{a_2} \tag{1}$$

Where, bm- dry or wet tree biomass in kg,
d- tree diameter in cm,
a1 and a2 are coefficients of the equation.

Therefore, in this report as well, it was Equation (1) that was used to model the biomass of model trees from diameter in each field separately, according to clones. Next, the biomass in each field depending on the clones was also modelled by the height of the model trees using the following formula (Equation (2):

$$bm = a_1 \cdot h^{a_2} \tag{2}$$

Where, bm- dry or wet tree biomass in kg
h- tree height in m,
a1 and a2 equation coefficients.

Also, the height of the model trees from their diameter was modelled according to the clones in each field. Korsun used for this purpose [25] derived formula (Equation (3)):

$$h = e^{\left(a_1 + a_2 \cdot \ln d + a_3 \cdot \ln^2 d\right)} \tag{3}$$

Where, h – tree heights in m,
d – tree diameter in cm,
a1, a2 and a3 – equation coefficients.

1.2.3.3 Comparison of biomass curves of experiments planted in Kaišiadorys and Anykščiai

The same poplar clones were established in the experimental fields of Kaišiadorys and Anykščiai experimental field. Anykščiai experimental field was fertilized with sludge. Therefore, it became possible to assess whether fertilization with sludge changes the allometric relationships of trees between tree diameter at breast height and biomass, and tree height and their biomass. Since the biomass study was carried out only for AF7, AF34 and OP42 clones in the Kaišiadorys field, the biomass curves of these clones from the Anykščiai experimental field and Kaišiadorys field were put together in common graphs and compared with each other.

1.2.3.4 General patterns of biomass and tree height by clone

Freshly general models of biomass depending on diameter or height of branches, freshly stems, fresh total weight of trees, dry branches, dry stems and dry total weight were developed using all data from the same clone from different fields. In this way, models of No. 8 and No. 9 of hybrid aspen clones were created using information from Anykščiai, Šilutė and Kelmė fields. The general model for poplar AF7 clone was compiled using Marijampolė, Kaišiadorys and Anykščiai experiment field data.

Accordingly, poplar AF34 and OP4Kelmė Šilutė, AnykščiaiVinč2 general biomass models of biomass were compiled using the Kaišiadorys district. weekly and Anykščiai experiment field data.

The same Equation (1) was used for modelling fresh-cut and dry biomass from diameter, while Equation (2) was used for modelling fresh-cut and dry biomass from height.

General models of height versus tree diameter by clone were constructed using data sequences prepared using the same principles as building general models of biomass by clone, using all data from the same clone from different fields. Next, using the same Korsun [25] formula (Equation (3)), coefficients a1, a2 and a3 are estimated.

1.2.3.5 Calculation of average plantation indicators

The most important average indicators of plantations are the following: average diameter of trees, average height of trees, number of growing trees per hectare, freshly cut or dry biomass weight of branches, stem or total weight per hectare. The ratio of dry and freshly cut biomass is also important. It should be noted that only in Kaišiadorys field case, the ratio of dry and freshly cut biomass was calculated separately for tree branches and tree stem.

Average diameter of trees (Dq) is calculated as the root mean square of tree diameters using the following formula (Equation (4)):

$$D_q = \sqrt{\frac{\sum_{i=1}^{K} d^2}{K}} \quad (4)$$

Where Dq is the average diameter of the trees in cm,
d- the diameter of the trees in cm,
K- the number of trees for which d was measured.

Average height of trees (Hq) is calculated using the same formula describing the ratio of tree diameters and heights, but with Dq instead of individual tree diameters (Equation (5)). It should be noted that when applying this formula, the equation coefficients a1, a2 and a3 are obtained by analyzing the dependences of diameters and heights of trees of the same clone in the same field.

$$H_q = e^{\left(a_1 + a_2 \cdot \ln D_q + a_3 \cdot \ln^2 Dq\right)} \quad (5)$$

Where Hq is the average tree height in m,
Dq is the average tree diameter in cm,
a1, a2 and a3 – coefficients of the 4th Equation.

Average number of trees per hectare (N) is calculated by dividing the number of trees for which the diameter was measured in all rows by the area occupied by the rows in square meters and multiplying by 10,000 square meters.

Calculation of freshly cut or dry biomass branches, stem or total weight in kg per hectare. Since the height and biomass of only 15 model trees were measured and weighed per sampling plot, the biomass of the remaining trees in the study sampling plots, and in this case rows, was calculated using regression methods. With the interdependence of tree diameter and biomass (Equation (1)), it is possible to model the biomass of freshly cut or dry biomass branches, stem or total weight of trees from the diameter of the trees, and by applying the Equation (2) from their height. But before that, the heights of all the trees need to be modelled using Equation (3).

Knowing the amount of biomass of all the trees in the rows, dividing them by the total area of the rows in m2 and multiplying by 10,000 m2, the amount of biomass per hectare is obtained.

1.2.3.6 Biomass patterns from average plantation rates

Amounts of freshly felled or dry biomass branches, stem or total weight per kg hectare depending on the clones are modeled from average tree diameter (Dq) and average tree height (Hq). Models are built using all averaged data from different fields. In this way, models of 8 and 9 hybrid aspen clones were created using information from Anykščiai, Šilutė and Kelmė districts. old existing fields. Meanwhile, the average models of poplar clone AF7 were compiled using Marijampolė district. week, Kaišiadorys district weekly and and the data of the Anykščiai experiment fields. Accordingly, the general biomass models of AF34 and OP42 poplars were compiled using the Kaišiadorys district. weekly and Anykščiai experiment field data. Equations 6 and 7 were used for modeling:

$$BM = a_1 \cdot D_q^{a_2} \tag{6}$$

Where, BM- Fresh or dry quantities of branches, stem or total weight of biomass in kg/ha,
Dq – average tree diameter in cm,
a1 and a2 equation coefficients.

$$BM = a_1 \cdot H_q^{a_2} \tag{7}$$

Where, BM- Amounts of freshly cut or dry biomass branches, stem or total weight in kg/ha,
Hq – average height of trees in m,
a1 and a2 equation coefficients.

1.2.3.7 Methods of calculating regression coefficients

The regression coefficients of the presented equations were calculated using the MS Excell 2010 program and its Solver add-on. Regression coefficients can also be easily calculated using any other statistical package such as SPSS, SAS, STATISTCA, R STUDIO or others.

The main statistical criterion used to evaluate all models was the coefficient of determination (R2). The value of this coefficient, more than 0.9, when modelling biomass, shows that the chosen model is suitable for modelling the dependent variable from the independent variable. A coefficient of determination value of 0.9 means that 90% of the variation in the dependent variable is explained by the variation in the values of the independent variable in the model [26].

When modelling tree heights, the value of R2 should be at least 0.8.

1.3 Results

1.3.1 Assessment of plantation status in each field by clone

The most important criteria for assessing the state of plantations is the amount of accumulated biomass (total biomass or annual biomass increase) in the fields, and the main indicators that determine it are the number of growing trees per unit area and the size of those trees.

1.3.1.1 Amount of accumulated biomass

The amounts of accumulated biomass in the fields were calculated by modelling the biomass of trees from the diameter of the trees, as well as by modelling the biomass of the trees from their height. Table 1-3 presents the amounts of plantation biomass (Freshly cut branches, freshly cut stems, fresh total weight of trees, dry branches, dry stems, dry total weight) in kilograms per hectare, modelling biomass from their diameter. In order to compare the amounts of biomass accumulated in plantations, it is appropriate to discuss in more detail the annual increases in total weight of dry biomass per hectare.

Comparing hybrid aspen located in Anykščiai, Šilutė and Kelmė fields it was determined that the highest annual increase in the total weight of dry biomass was in Šilutė field and reached 2600 kg/ha per year. Meanwhile, the lowest annual increase in total weight of dry biomass was in Kelmė field and reached 128 kg/ha.

Analyzing poplar clones, it was found that in Kaišiadorys field, the AF7 clone gave the best results, the total dry biomass gain reached 3467.8 kg/ha. However, the results of this clone in Marijampolė field were significantly worse, where the increase of total weight of dry biomass reached 1394.1 kg/ha per year.

In the Anykščiai experimental field, clone AF34 had the highest annual increase in dry biomass at 7912.6 kg/ha per year, and OP42 had the lowest at 3957.2 kg/ha per year.

Table 1-3. Plantation productivity indicators calculated using biomass models from tree diameter

Field	Soil productivity score	Age	Clones	Freshly cut biomass kg/ha			Dry biomass kg/ha			Mean annual total biomass increment kg/ha	
				Branches	Stem	total weight	Branches	Stem	tootal weight	Fresh	Dry
Šilutė	31-35	9	8	3431.2	11412.8	14843.8	1563.4	5190.7	6757.2	1649.3	750.8
	31-35	9	9	4587.2	8973.1	13534.7	2179.9	4234.3	6403.2	1503.9	711.5
Totally common				**8018.4**	**20385.9**	**28378.5**	**3743.3**	**9425.0**	**13160.4**	**3153.2**	**1462.3**
Anykščiai	31-34	9	8	4206.4	13496.4	17730.1	1954.0	6302.1	8269.7	1970.0	918.9
	31-34	9	9	11811.9	19331,2	31140.2	5772.8	9372.6	15130.7	3460.0	1681.2
General warmth				**16018,3**	**32827.6**	**48870.3**	**7726.8**	**15674.7**	**23400.4**	**5430.0**	**2600.0**
Kelmė	46-53	6	8	80.5	326.2	398.9	35.7	146.4	179.5	66.5	29.9
	46-53	6	9	511.8	765.6	1273.7	237.1	355.0	590.4	212.3	98.4
Stump common				**592.3**	**1091.8**	**1672.6**	**272.9**	**501.4**	**769.8**	**278.8**	**128.3**
Marijampole	30-32	4	AF7	**3002.3**	**9911.6**	**12813.6**	**1299.0**	**4340.9**	**5576.4**	**3203.4**	**1394.1**
Kašiadorys	37-45	6	AF7	**17454.3**	**52179.6**	**69653.2**	**8346,3**	**22853.7**	**31210.0**	**11608.9**	**5201.7**
	37-45	6	AF34	**12007.45**	**45227.9**	**57229.1**	**5942.6**	**19389.3**	**25317,1**	**9538.2**	**4219.5**
	37-45	6	OP42	**9929.6**	**28391.7**	**38393.2**	**5121.8**	**14466.2**	**19639.7**	**6398.9**	**3273.3**
Anykščiai experiment	41.8	5	AF7			**60948.6**			**29073.3**	**12189.7**	**5814.7**
	41.8	5	AF34			**89137.4**			**39562.8**	**17827.5**	**7912.6**
	41.8	5	OP42			**42732.9**			**19786.1**	**8546.6**	**3957.2**
	41.8	5	AF6			**62146.7**			**28845.4**	**12429.3**	**5769.1**
	41.8	5	Max1			**77238.6**			**35707.5**	**15447.7**	**7141.5**
	41.8	5	Max3			**77170.1**			**36638.6**	**15434.0**	**7327.7**
	41.8	5	Max4			**74813.0**			**34770.3**	**14962.6**	**6954.1**

Table 1-4 presents the amounts of plantation biomass (fresh branches, fresh stem, fresh total weight of trees, dry branches, dry stems, dry total weight) in kilograms per hectare, modelling biomass from the height of model trees.

Comparing these two methods (when modelling based on tree diameter and tree height), the increase in total weight of dry biomass in Anykščiai field was calculated to be 174.3 kg/ha higher using biomass models from the height of the model trees. Even greater positives were received in Šilutė field. By simulating the increase of the total weight of dry biomass from the height of the model trees, an additional 396.7 kg/ha of biomass per year was obtained. Meanwhile, in Kelmė field the differences in the annual increase of the total weight of dry biomass was not significant. When applying the second (height) method, only 4 kg/ha less biomass was obtained compared to the first (diameter) method.

Simulating the growth of total weight dry biomass of poplar clone AF7 from the height of model trees in Marijampole and Kaišiadorys fields, less biomass is obtained than when applying the diameter method in the same fields, 52 and 169.5 kg/ha, respectively. For the other clones AF34 and OP42, applying the method of modelling the increase in total weight of dry biomass from height, 82.9 and 294.8 kg higher mean annual increment were obtained comparing to modelling from tree diameter.

In the Anykščiai experimental field, especially significant differences in modelling the annual dry biomass growth from diameter and height were obtained for Max clones. For Max 1 clone, modelling from height resulted in an additional 909.6 kg/ha of dry biomass per year. However, in this field for AF34, OP42 and AF6 clones, the increase in dry biomass was about 200 kg/ha per year lower than in height simulations.

Table 1-4. Plantation productivity indicators calculated using biomass models from tree height

Field	Soil productivity score	Age	Clones	Freshly cut biomass kg/ha			Dry biomass kg/ha			Mean annual total biomass increment kg/ha	
				Branches	Stem	total weight	Branches	Stem	tootal weight	Fresh	Dry
Šilutė	31-35	9	8	3943.2	12796.8	16742.7	1816.0	5871.7	7689.0	1860.3	854.3
	31-35	9	9	5268.0	9517.0	14764.4	2531.8	4514.2	7040.2	1640.5	782.2
Total Šilutė				**8018.4**	**20385.9**	**28378.5**	**9211.3**	**22313.8**	**31507,2**	**4347.8**	**10385.9**
Anykščiai	31-34	9	8	4900.3	14389.4	19296.7	2277.0	6706.5	8991.8	2144.1	999.1
	31-34	9	9	13625.5	22752.9	37106.0	6611.9	11009.2	17978.5	4122.9	1997.6
Total Anykščiai				**16018,3**	**32827.6**	**48870.3**	**18525.8**	**37142,3**	**56402.6**	**8888.9**	**17715.7**
Kelmė	46-53	6	8	88.9	365.0	448.9	31.8	139.5	182.2	74.8	30.4
	46-53	6	9	479.5	741.0	1215.5	222.3	343.9	563.8	202.6	94.0
Total Kelmė				**592.3**	**1091.8**	**1672.6**	**568.4**	**1106.0**	**1664.4**	**254.1**	**483.3**
Marijampole	30-32	4	AF7	**3613.7**	**9229.9**	**12213.1**	**1699.8**	**4228.1**	**5364.9**	**3053.3**	**1341.2**
Kašiadorys	37-45	6	AF7	**18010.2**	**52697.0**	**70700.9**	**8633.0**	**23206,4**	**29684.6**	**11783.5**	**4947.4**
	37-45	6	AF34	**13276.5**	**41549.1**	**55600.1**	**7077.5**	**18294.9**	**26063.6**	**9266.7**	**4344.0**
	37-45	6	OP42	**12128.5**	**30906.4**	**43037,1**	**6369.1**	**15966.9**	**22292.7**	**7172.9**	**3715.4**
Anykščiai experiment	41.8	5	AF7			**62873.9**			**30099.9**	**12574.8**	**6020.0**
	41.8	5	AF34			**86604.9**			**38398.7**	**17321.0**	**7679.7**
	41.8	5	OP42			**41708.1**			**19293.5**	**8341.6**	**3858.7**
	41.8	5	AF6			**60801.0**			**28184.9**	**12160.2**	**5637.0**
	41.8	5	Max1			**87213.5**			**40255.4**	**17442.7**	**8051.1**
	41.8	5	Max3			**79611.8**			**37799.5**	**15922.4**	**7559.9**
	41.8	5	Max4			**79774.1**			**37317.3**	**15954.8**	**7463.5**

Therefore, after summarizing the results, it can be stated that when modelling the increase of total weight of dry biomass from the height of the model trees, slightly more biomass is obtained than when modelling from the diameter of the trees, but these differences are not very significant.

Table 1-5 presents the results regarding the ratio of dry to freshly biomass. In Anykščiai, Anykščiai experimental field, Šilutė, Kelmė and Marijampole fields the ratio of dry and freshly cut biomass was calculated by taking stem and branches together, while in Kaišiadorys field, this ratio was calculated separately for stem and branches.

Table 1-5. Ratio of dry to freshly cut biomass

Field	Performance score	A	Q	Dq, cm	Hq, m	No, ha	Ratio of dry to fresh biomass		
							Stem and Branches	Stem	Branches
Šiutė	31-35	9	8	6.8	8.6	811	0.46		
	31-35	9	9	12.1	10.8	183	0.47		
Anykščiai	31-34	9	8	7.2	8.3	874	0.47		
	31-34	9	9	15.7	14.0	212	0.49		
Kelmė	46-53	6	8	1.8	3.3	227	0.45		
	46-53	6	9	3.1	4.3	211	0.46		
Marijampole	30-32	4	AF7	5.7	6.6	1063	0.44		
Kašiadorys	37-45	6	AF7	11.3	10.3	1319	0.45	0.43	0.47
	37-45	6	AF34	9.9	9.9	1515	0.44	0.43	0.49
	37-45	6	OP42	8.8	9.6	1249	0.51	0.51	0.54
Anykščiai experiment	41.8	5	AF7	10.0	9.5	1532	0.48		
	41.8	5	AF34	11.6	10.8	1631	0.44		
	41.8	5	OP42	11.2	11.0	806	0.46		
	41.8	5	AF6	11.0	11.0	1158	0.46		
	41.8	5	Max1	10.5	10.5	1631	0.46		
	41.8	5	Max3	10.3	10.6	1631	0.47		
	41.8	5	Max4	11.1	10.3	1344	0.46		

Analysis showed that the ratio of dry and fresh biomass of hybrid aspen trees located in Anykščiai, Šilutė and Kelmė fields reached 0.45-0.49. It was observed that this ratio for clone 8 was on average 0.01 points lower compared to clone 9.

Meanwhile, the ratio of dry and fresh biomass of poplars in the Kaišiadorys field, of AF7 and AF34 clones, taking stem and branches together, was about 0.44-0.45. Taking stems and branches separately for these clones, the ratio of dry and fresh biomass of branches was 0.04-0.06 points higher compared to the ratio of dry and fresh stem biomass. In poplars, OP42 clone stood out with a relatively high ratio of fresh cut biomass both for stem 0.51 and for branches 0.54 and taking the stem and branches together 0.51.

In Anykščiai experimental field, the ratio of dry and fresh biomass of AF7, AF34, OP42, AF6, Max1, Max3 and Max4 clones varied from 0.44 (AF34) to 0.48 (AF7).

1.3.1.2 Analysis of key indicators determining the amount of biomass

The amount of biomass in *Pupulus* plantations is mainly determined by the number of growing trees per area and the size of those trees. The number of growing trees is understood as the number of surviving trees compared to the number of planting sites (or how many trees were planted when the plantation was established), so the percentage of surviving trees is much more informative.

The simplest way to describe the size of trees is based on the average tree diameters Dq and average heights Hq, and the distribution of trees by diameters by visualizing tree layout plans, where the size of the circle is associated with the size of the diameter of the trees. In this way, the distribution of trees in plantations according to diameters is expressed.

The highest percentage of tree survival was observed in the Kaišiadori plantation for AF34 clone - 92.4% and Anykščiai experimental field for AF34, Max1 and Max 3 clones - 97.8%. Meanwhile, the lowest survival was in Kelmė field, where the survival for hybrid aspen was only 64.1% and in Anykščiai experimental field for OP42 clone - 48.4% (Table 1-6). A slightly better survival rate was in Marijampolė field - 67.5%. The percentage of survival in Anykščiai and Šilutė fields were 77.3 and 74.9%, respectively.

Analyzing the number of trees per hectare (N) in plantations by clone, it was found that hybrid aspen clone No.8 in Anykščiai and Šilutė fields was four times higher than in clone No.9, i.e about 800 and 200 trees per ha, respectively. Meanwhile, in Kelmė fields the number of both hybrid aspen clones was similar and reached about 400 units ha.

In Anykščiai experimental field, the largest number of survived trees, 1631 per ha, was for AF34, Max1 and Max 3 clones, and the lowest for OP42 clone - 806 trees.

Table 1-6. Assessment of plantation status in each field by clone

Field	Productivity score	Age	Q	Dq, cm	Hq, m	No, ha	Total N, ha	Planting density	Survival rate
Šilutė	31-35	9	8	6.8	8.6	811	994	1285.9	77.3
	31-35	9	9	12.1	10.8	183			
Anykščiai	31-34	9	8	7.2	8.3	874	1086	1450.0	74.9
	31-34	9	9	15.7	14.0	212			
Kelmė	46-53	6	8	1.8	3.7	360	694	1082.7	64.1
	46-53	6	9	3.1	4.3	334			
Marijampole	30-32	4	AF7	5.7	6.6	1063	1063	1573.6	67.5
Kašiadory	37-45	6	AF7	11.3	10.3	575	1319	1673	78.8
	37-45	6	AF34	9.9	9.9	607	1515	1639	92.4
	37-45	6	OP42	8.8	9.6	204	1249	1651	75.6
Anykščiai experiment	41.8	5	AF7	10.0	9.5	1532		1667	91.9
	41.8	5	AF34	11.6	10.8	1631		1667	97.8
	41.8	5	OP42	11.2	11.0	806		1667	48.4
	41.8	5	AF6	11.0	11.0	1158		1667	69.5
	41.8	5	Max1	10.5	10.5	1631		1667	97.8
	41.8	5	Max3	10.3	10.6	1631		1667	97.8
	41.8	5	Max4	11.1	10.3	1344		1667	80.6

Comparing the average diameters Dq and average heights Hq of hybrid aspen clones No. 8 and No.9, it was found that the trees of clone No.9 in all plantations are characterized by significantly higher Dq, which in Anykščiai, Kelmė and Šilutė fields is almost twice the Dq of clone No. 8 (Table 1-6). For example, in Anykščiai r field, Dq of hybrid aspen clones No.8 and No.9 had was 6.8 and 12.1 cm respectively.

Accordingly, the Hq of clone hubrid aspen No. 9 was also higher in all fields, and exceeded the Hq of clone No.8 by about 1.3 times. In the same Anykščiai field, the Hq of clones No.8 and No.9 were 8.6 and 10.8 m. respectively.

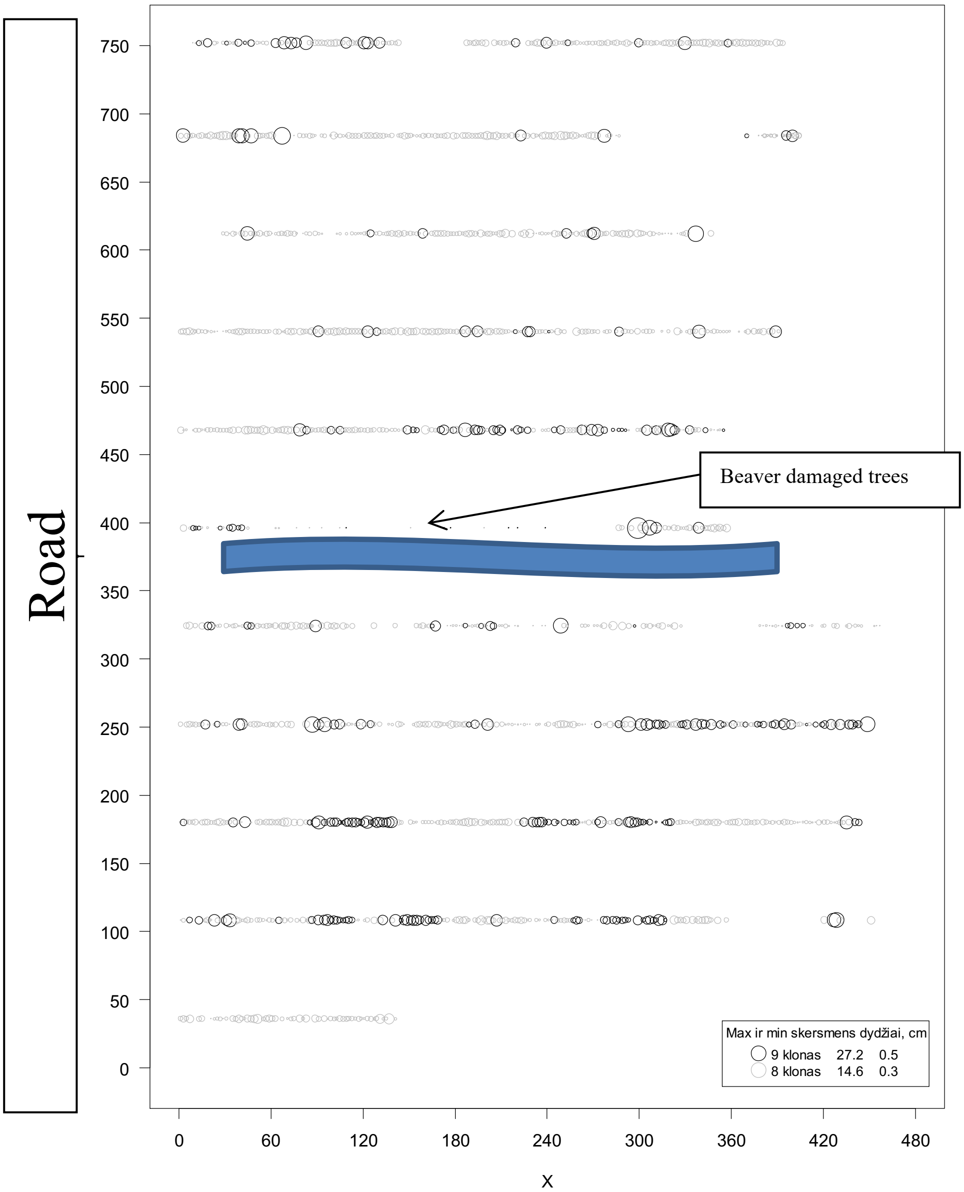
Comparing poplar clones of the same age in Kaišiadorys fild, AF7 clone had the highest Dq and Hq (11.3 cm and 10.3 m), while the OP42 clone had the lowest Dq and Hq - 8.8 cm and 9.6 m, respectively.

In the Anykščiai experimental field, clone AF6 had the highest Dq at 11.6 cm, and clone AF7 had the lowest at 10.0 cm. Accordingly, OP42 and AF6 clones had the highest mean height and reached 11.0 m.

This hybrid aspen plantation was characterized by several aspects: firstly, the pronounced hilly terrain and secondly, the drainage ditch running along the strips through the middle of the plantation. It is clear that clone No.9 showed significantly better growth results in this plantation compared to clone No.8, which reached a maximum diameter of 27.2 cm in this plantation. Meanwhile, the maximum diameter of clone No. 8 was only 14.6 cm. The black circles in the Picture 1-1 representing the position and diameters of clone No.9 were significantly larger than the grey circles representing the position and diameters of clone No.8.

However, higher amounts of clone No.9 were planted in only one third of the plantation area (in rows with Y values up to 250 m). Meanwhile, in other rows, this clone was planted quite episodically, focusing only on clone No.8. It is also necessary to note that the trees growing in a row near the drainage ditch (a row whose Y coordinate is 400m) were severely damaged by beavers.

Picture 1-1. ***Distribution of hybrid aspen clones No.8 and No.9 according to diameters in Anykščiai.***

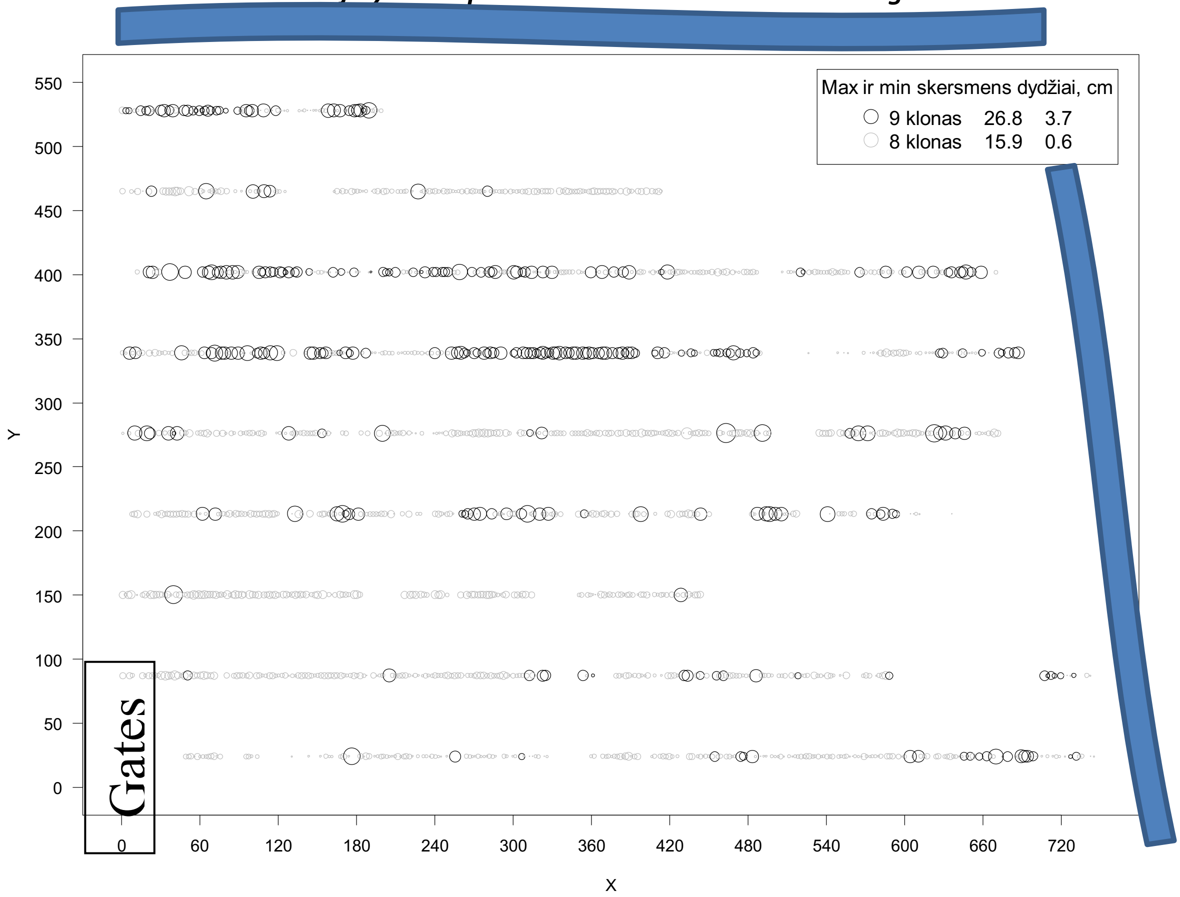


Distribution of trees according to diameters and clones in Šilutė field shown in Picture 1-2. It can be said that this plantation was established on a flat terrain with micro depressions where water stagnates. However, the drainage system installed under the plantation prevented the plantation from getting wet. Also, drainage ditches installed around the plantation led excess water away from it, and it was a place where beavers bred. Therefore, significant damage by beavers was recorded in the rows of trees planted close to the ditches.

It is clear that in this plantation as well, clone No.9 showed significantly better growth results compared to clone No.8. Clone No.9 had a maximum diameter of 26.8 cm, while clone No.8 was 15.9 cm. The black circles in the Picture 1-2 representing the position and diameters of clone No.9 show a relatively even distribution of overstory trees with a diameter of about 20 cm throughout the plantation.

In the same figure, the grey circles representing the positions of clone No. 8 and the sizes of tree diameters show that the diameters of most trees in clone No.8 ranged from about 6-8 cm, and only a few trees reached the maximum limit of 15.9 cm.

Picture 1-2. *Distribution of hybrid aspen clones No.8 and No.9 according to diameters in Šilutė*

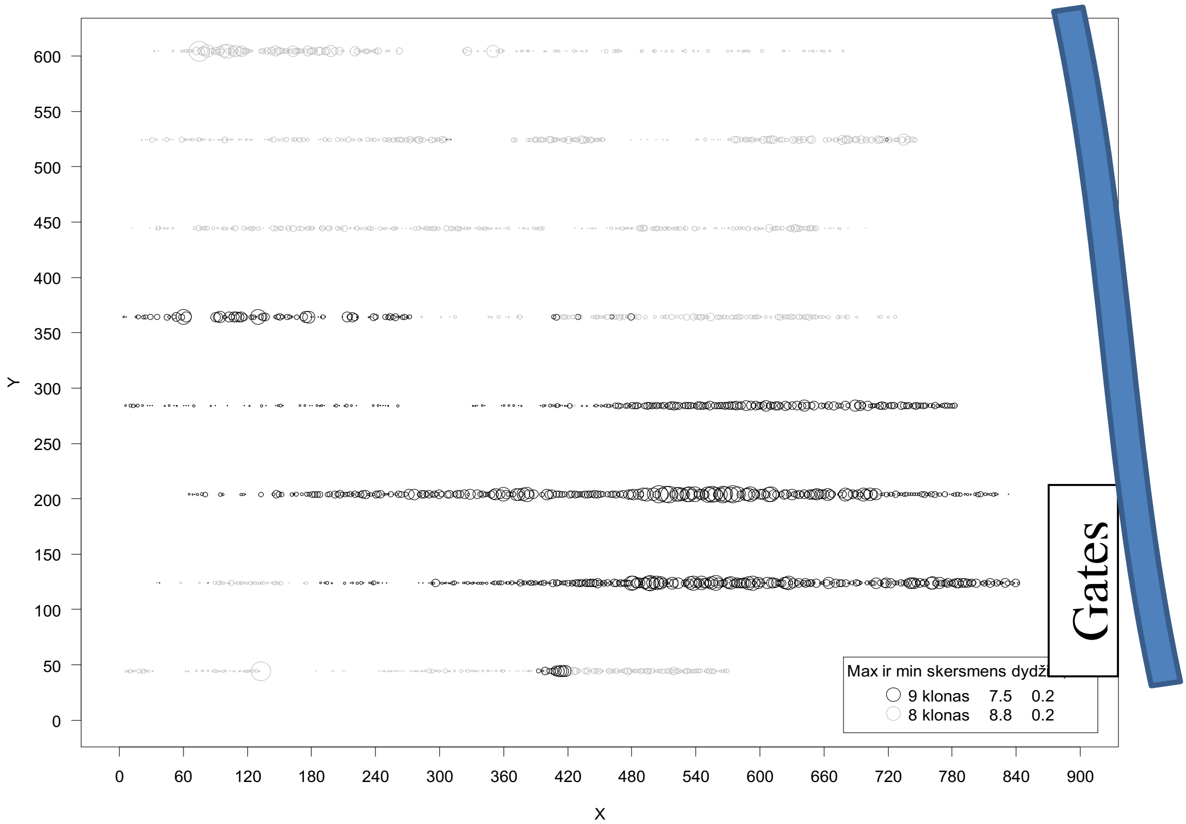


In Kelme, none part of the field was planted with clone 8 (Y-coordinate of rows > than 350) and another part with clone 9 (Y-coordinate of rows < than 350), maintaining a relatively similar amount of planting trees per hectare. Although this Kelme field was established on the soil with the highest productivity score (Table 1-2) belonging to the very fertile Retisol soil group, the tree growth performance was the worst after 6 growing seasons. This was due to the low survival rate and youngest age among analysed hybrid aspen plantations. Picture 1-3 shows high mortality rate (empty gaps) in all rows, regardless of clone.

In Picture 1-3, the black circles representing the position and diameters of clone No.9 are significantly larger than those of clone No.8. However, this clone also featured many trees that were only a few centimetres or less in diameter. No.9 clone trees stood out for their growth rate, whose X coordinate was greater than 360 m, and Y coordinate was less than 300 m. The maximum tree diameter for clone 9 in this field was 7.5 cm.

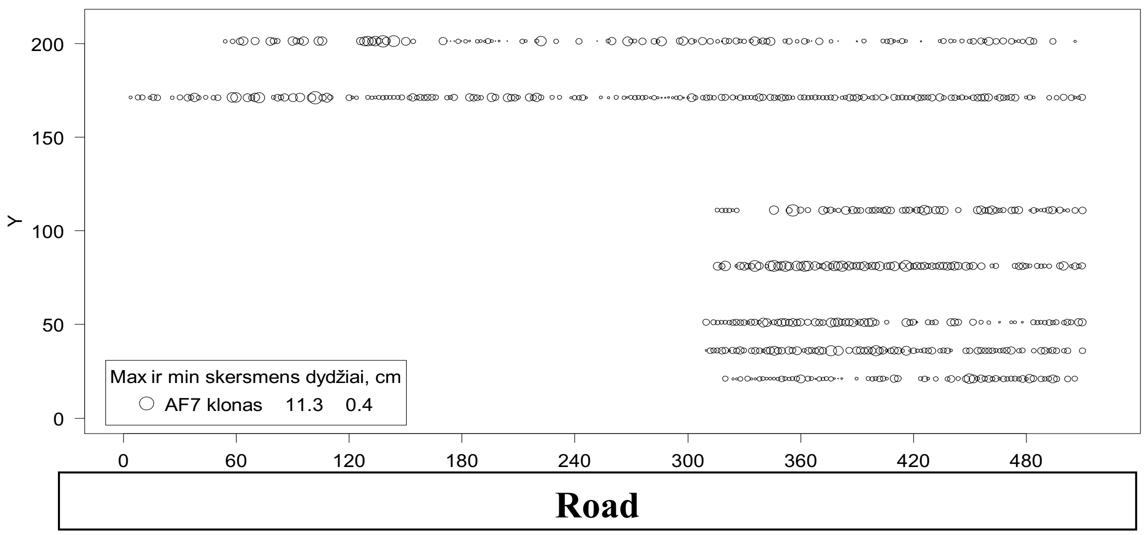
In Picture 1-3, the grey circles represent the positions of the No.8 clones and the sizes of the diameters of the trees. A large number of No.8 clone trees with a diameter of only 1-2 cm can be observed evenly distributed throughout the field. However, two trees with a maximum diameter larger than clone 9 trees were also measured at 8.8 cm.

Picture 1-3. ***Distribution of hybrid aspen clones No.8 and No.9 according to diameters in Kelmė***



Distribution of poplar clone AF7 according to diameters and clones in Marijampolė field shown in Picture 1-4. Only one AF 7 poplar clone was planted in this plantation, as indicated by the black circles only in the figure. In this plantation, 5 short rows with a length of up to 250 meters and two long rows with a length of about 500 meters were measured.

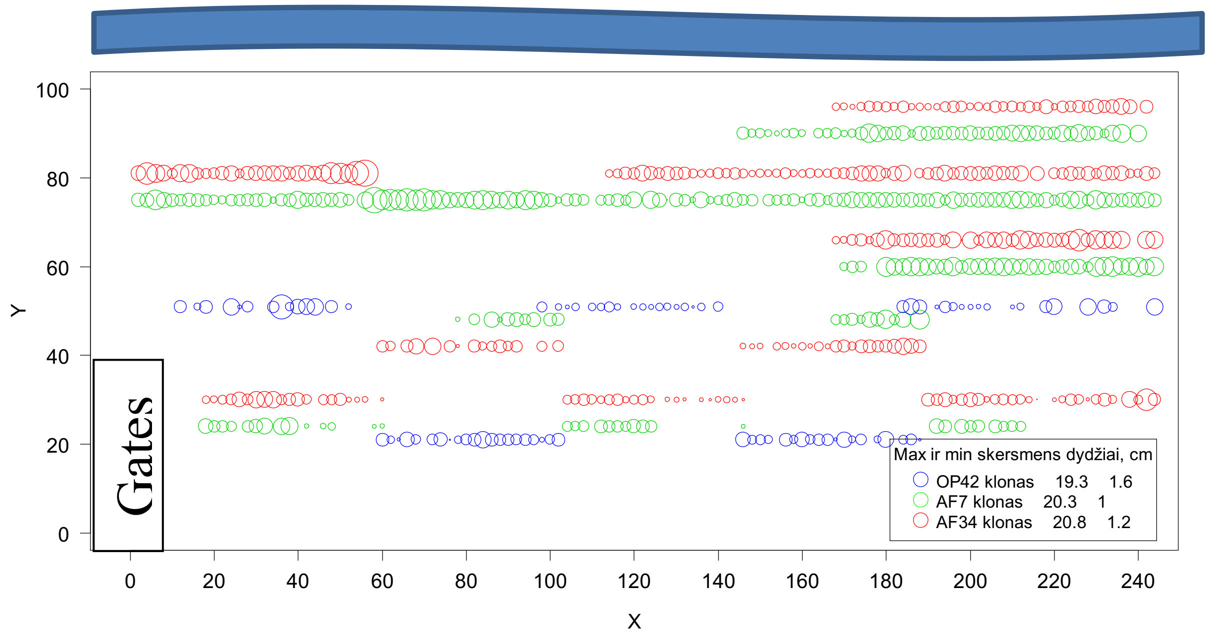
Picture 1-4. ***Distribution of poplar clone AF7 according to diameters in Marijampole***



Accordingly, this plantation could also be divided according to the sizes of tree diameters. Although the maximum measured diameter of the AF7 clones in the accounting rows was 11.3 cm, the diameters of the trees in the short rows are significantly larger than in the long rows. Moreover, in the row farthest from the road, the survival rate decreases.

Distribution of poplar clones according to diameters in Kaišiadorys field presented in Picture 1-5. In this plantation, different poplar clones were planted using certain experimental schemes, which can be seen quite well in the picture bellow. Although the field is quite small (length about 100 meters and width 240 meters), the diameters of the trees of clones AF7, AF34 and OP42 studied in it were measured by continuous measurement method. Trees of other clones were not measured, so the longer empty bands seen in the plantation, between the circles of the same colour, should not be considered as areas of complete mortality of analysed clones.

Picture 1-5. ***Distribution of poplar clones OP42, AF7 and AF34 according to diameters in Kaišiadorys***

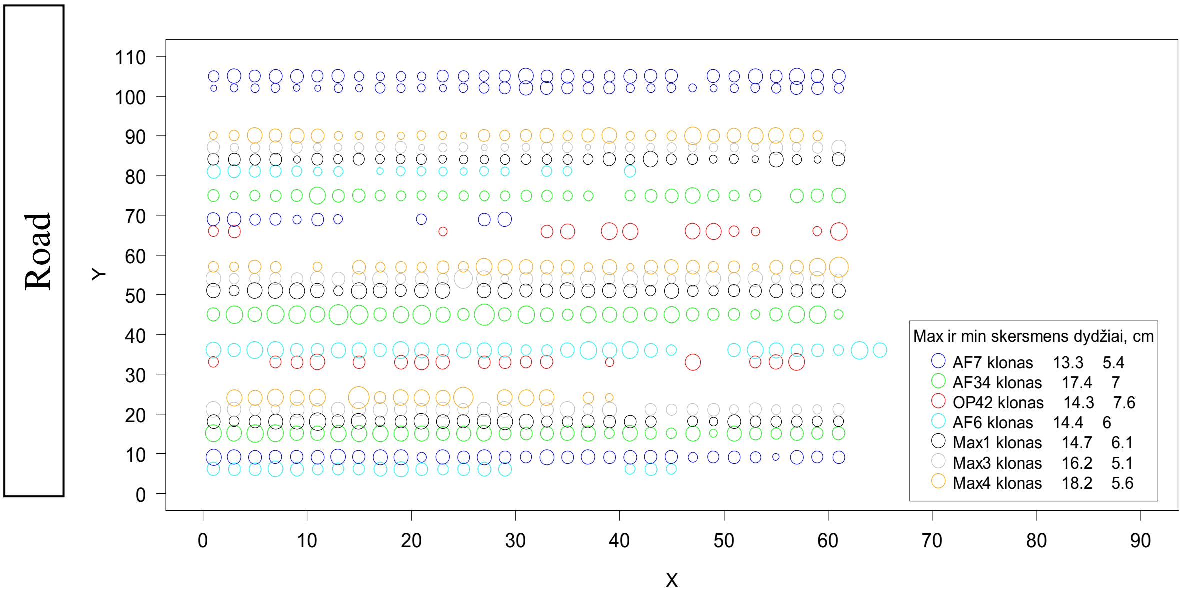


Evaluating the growth characteristics of individual clones in this plantation, it can be said that clone AF34 performed the best, although clone AF7 was slightly behind it. The growth results of clone OP42 were slightly worse than the mentioned clones of AF7 and AF34. This is also shown by the maximum diameters reached by the trees: AF34 was 20.8 cm, AF7 20.3 and OP42 19.3 cm. Also, in the Picture 1-5, it can be seen that the red circles representing the AF34 clone and the green circles representing the AF7 clone are noticeably larger than the blue circles visualizing the OP42 clone. The latter clone and the empty spaces between the blue circles are the most.

Distribution of trees according to diameters and clones in Anykščiai experimental plantation is presented in Picture 1-6. Clone repetitions are also clearly visible. It is noticeable that the AF34 clone was characterized by particularly good survival and growth. The most empty rows of the OP42 clone are also visible.

It is worth noting that the diameters of all clones up to the Y coordinate of 50 m were significantly larger than those beyond Y 50 meters. This is due to the fact that the plantation is not planted in a flat field. Perpendicular to the direction of planting clones, the relief of the plantation changes, the altitude increases, it goes uphill.

Picture 1-6. ***Distribution of poplar clones according to diameters in Anykščiai experimental field***



1.3.2 Biomass models, created for each field based on clones

Fresh branches, fresh stem, fresh total tree weight, dry branches, dry stem, dry total weight biomass models, separately for each field and separately for each clone, were made from tree diameter and tree height. For the clones of the Anykščiai experimental field, only biomass models of fresh total tree weight and dry total weight were made. The suitability of the selected models was assessed using the coefficient of determination R2.

The coefficients a1 and a2 of the completed models and their R2 are presented in Tables 1-7 and 1-8. First, we will examine biomass models based on tree diameter and tree height separately, then we will compare the results with each other.

Thus, the limits of variation of R2 when modelling the biomass of fresh branches, fresh stems, fresh total tree weight, dry branches, dry stems, dry total weight from tree diameter were 0.941-0.999. The lowest value of R2 was obtained by modelling the biomass of freshly cut branches of Šilute No.8 clone. In general, when comparing R2 values between different biomass models, there is a tendency for R2 values o be slightly lower for modelling branch biomass than for stem or total weight biomass. However, they are also very high, more than 0.9.

When modelling the biomass of fresh cut branches, fresh stems, fresh total tree weight, dry branches, dry stems, dry total weight from tree height, the variation limits of R2 were from 0.384 to 0.989. In tables 1-7 and 1-8, R2 values less than 0.9 are highlighted in red. Most of the R2 values lower than 0.9 were obtained by modelling the biomass of fresh cut branches or dry branches from tree height. It should also be noted that the simulation results obtained when simulating the tree biomass of Šilute No.9 clone and Kaišiadorys OP42 clone from tree height are quite poor. Here, R2 values, taking all models, reach up to 0.884.

It should also be noted the extremely poor results of the modelling of the dry total weight of the fresh total weight of the trees in the Anykščiai experimental field, modelling from the height of the trees (R2 value of about 0.5). These results may have been due to the exceptional branching of these clones.

Table 1-7. Model parameters of the biomass models generated for each field, by clone

Model parameters				Biomass: Fresh branches	Fresh stem	Fresh total weight	Dry branches	Dry stem	Dry total weight
Šilutė	Clone 8	Modeling from d, cm	a1	0.036368	0.123859	0.160207	0.012201	0.040885	0.053204
			a2	2.448740	2.437336	2.439999	2.595969	2.591533	2.591703
			R2	0.982	0.998	0.999	0.986	0.997	0.998
		Modeling from h, m	a1	0.003613	0.009317	0.012877	0.001085	0.002686	0.003748
			a2	3.336526	3.439261	3.414755	3.527467	3.646485	3.618133
			R2	0.920	0.977	0.967	0.928	0.980	0.972
	Clone 9	Modeling from d, cm	a1	0.054936	0.271856	0.293328	0.019187	0.092679	0.100827
			a2	2.431760	2.079009	2.206811	2.547918	2.203044	2.328160
			R2	0.981	0.991	0.993	0.978	0.988	0.990
		Modeling from h, m	a1	0.002270	0.007201	0.008985	0.000737	0.002048	0.002695
			a2	3.972895	3.741546	3.831134	4.134021	3.951709	4.021552
			R2	0.891	0.968	0.944	0.889	0.966	0.942
Anykščiai	Clone 8	Modeling from d, cm	a1	0.041678	0.193102	0.234453	0.017853	0.085502	0.103103
			a2	2.386150	2.211786	2.249274	2.424501	2.237069	2.277243
			R2	0.941	0.998	0.994	0.947	0.998	0.996
		Modeling from h, m	a1	0.018439	0.034670	0.052164	0.007607	0.014591	0.021960
			a2	2.708094	2.912049	2.859463	2.762608	2.958636	2.905868
			R2	0.820	0.948	0.924	0.829	0.953	0.930
	Clone 9	Modeling from d, cm	a1	0.028905	0.726469	0.387252	0.012373	0.296308	0.159080
			a2	2.725821	1.758341	2.151851	2.772410	1.820026	2.211366
			R2	0.976	0.964	0.992	0.974	0.965	0.991
		Modeling from h, m	a1	0.000014	0.001195	0.000561	0.000004	0.000383	0.000180
			a2	5.878600	4.371691	4.846364	6.035673	4.528736	5.003409
			R2	0.681	0.820	0.755	0.679	0.810	0.747
Kelmė	Clone 8	Modeling from d, cm	a1	0.032260	0.280468	0.288912	0.013796	0.125496	0.130154
			a2	2.701481	1.950581	2.133785	2.734141	1.953631	2.132366
			R2	0.956	0.973	0.972	0.960	0.979	0.978
		Modeling from h, m	a1	0.000656	0.016368	0.013450	0.000046	0.002911	0.003451
			a2	4.401210	3.193088	3.470459	5.421960	3.715418	3.780686
			R2	0.959	0.966	0.968	0.944	0.957	0.964
	Clone 9	Modeling from d, cm	a1	0.105748	0.254976	0.346731	0.047260	0.114836	0.155611
			a2	2.305959	1.962134	2.109004	2.331441	1.983521	2.132268
			R2	0.966	0.991	0.984	0.967	0.992	0.985
		Modeling from h, m	a1	0.002765	0.013018	0.013347	0.001202	0.005742	0.005845
			a2	4.200850	3.507962	3.802161	4.240272	3.539896	3.837864
			R2	0.966	0.989	0.983	0.966	0.988	0.982
Marijampole	AF7 clone	Modeling from d, cm	a1	0.043075	0.479277	0.434677	0.014598	0.173085	0.153352
			a2	2.386828	1.725545	1.920468	2.518174	1.832514	2.036514
			R2	0.993	0.990	0.996	0.994	0.993	0.997
		Modeling from h, m	a1	0.000093	0.001099	0.000626	0.000039	0.000411	0.000157
			a2	5.541541	4.749997	5.185414	5.602291	4.855460	5.473419
			R2	0.862	0.950	0.926	0.856	0.946	0.921
Kašiadorys	AF7 clone	Modeling from d, cm	a1	0.084086	0.303767	0.387396	0.036195	0.121824	0.157703
			a2	2.080084	2.004030	2.022379	2.122282	2.039438	2.060924
			R2	0.982	0.988	0.989	0.982	0.990	0.990
		Modeling from h, m	a1	0.003137	0.009172	0.012279	0.001295	0.003764	0.005069
			a2	3.587310	3.587625	3.588528	3.650292	3.617451	3.625398
			R2	0.929	0.961	0.955	0.927	0.957	0.951
	AF34 clone	Modeling from d, cm	a1	0.016892	0.353779	0.303428	0.007248	0.116190	0.101411
			a2	2.643674	1.934267	2.096540	2.701958	2.045552	2.212980
			R2	0.972	0.978	0.980	0.968	0.981	0.982
		Modeling from h, m	a1	0.000035	0.000366	0.000447	0.000054	0.000125	0.000274
			a2	5.423786	4.909885	4.948613	4.970779	5.016990	4.833114
			R2	0.841	0.938	0.917	0.816	0.925	0.897
			a1	0.047911	0.395198	0.408283	0.019153	0.165728	0.169548

		Modeling from d, cm	a2	2.323673	1.867129	1.984044	2.432144	1.951774	2.074156
			R2	**0.962**	**0.993**	**0.993**	**0.959**	**0.993**	**0.994**
		Modeling from h, m	a1	0.002289	0.007982	0.010156	0.000920	0.003413	0.004227
			a2	3.816979	3.677045	3.717313	3.935940	3.761455	3.814861
			R2	0.753	0.884	0.852	0.746	0.871	0.843

Table 1-8. Model parameters of biomass models created for each field, according to clones, in the Anykščiai experimental field.

Model parameters				Biomass					
				Fresh branches	Fresh stem	Fresh total weight	Dry branches	Dry stem	Dry total weight
Anykščiai experiment	AF7 clone	Modeling from d, cm	a1			1.309732			0.418657
			a2			1.486546			1.658604
			R2			**0.946**			**0.918**
		Modeling from h, m	a1			0.190510			0.048941
			a2			2.404097			2.681028
			R2			0.800			0.777
	AF34 clone	Modeling from d, cm	a1			0.229994			0.158404
			a2			2.227606			2.051341
			R2			**0.979429**			**0.983612**
		Modeling from h, m	a1			0.002510			0.002182
			a2			4.209698			3.927231
			R2			0.744			0.768
	OP42 clone	Modeling from d, cm	a1			0.456456			0.178811
			a2			1.966274			2.034526
			R2			**0.977**			**0.968**
		Modeling from h, m	a1			0.016498			0.005050
			a2			3.400155			3.573992
			R2			0.695			0.705
	AF6 clone	Modeling from d, cm	a1			0.490652			0.206621
			a2			1.961308			2.001425
			R2			**0.973**			**0.968**
		Modeling from h, m	a1			0.071100			0.030794
			a2			2.768719			2.797077
			R2			0.726			0.709
	Max1 clone	Modeling from d, cm	a1			0.479376			0.240927
			a2			1.952582			1.917521
			R2			**0.951**			**0.959**
		Modeling from h, m	a1			0.066443			0.042500
			a2			2.849070			2.710522
			R2			0.544			0.521
	Max3 clone	Modeling from d, cm	a1			0.534456			0.295360
			a2			1.923858			1.859859
			R2			**0.954**			**0.944**
		Modeling from h, m	a1			0.085789			0.054405
			a2			2.725333			2.601367
			R2			0.384			0.380
	Max4 clone	Modeling from d, cm	a1			1.079843			0.354537
			a2			1.644631			1.786545
			R2			**0.920**			**0.953**
		Modeling from h, m	a1			0.055572			0.014321
			a2			3.001578			3.257125
			R2			0.492			0.517

Next, we will compare with each other the simulation results of fresh branches, fresh stems, fresh total weight of trees, dry branches, dry stems, dry total weight biomass from tree diameter and tree height (Table 1-7 and Table 1-8). Based on the results, it can be stated that biomass models based on tree diameter explain more variation in dependent variables than biomass models based on tree height. In all cases, except for one (in the field located in Kelmė district, for clone 8, marked in blue in the table), R2 of biomass models from tree diameter were higher compared to R2 of biomass models from tree diameter height. What's more, where height-based biomass models performed rather poorly, when simulating the biomass of Šilute No.9 clone and Kaišiadorys OP42 clone, tree diameter models performed reliably, taking all diameter-based biomass models in these fields, the lowest R2 was 0.959.

In some fields, for example Anykščiai field, the biomass models for both diameter and height gave fairly similar R2 results. The scatter of rhombuses (measured points) about solid lines is quite similar. Meanwhile, in Šilutė field, when modelling biomass from tree height, the results for clone No. 9 are much worse. If when modelling tree biomass from tree diameter, the measured points are nicely arranged around the continuous model line, then when modelling tree biomass from tree height, the measurement points are widely scattered around the model line. This is especially true for branch patterns. This happened due to the fact that, for example, the weight of the biomass of wet branches increases from 100 to 200 kg, while the height of the trees remains relatively stable at about 15 meters, in other words, does not change. The same happens when modelling stem or total weight biomass from tree height.

Summarizing the results of this section, it can be said that biomass models based on tree diameter are more accurate compared to biomass models based on tree height, but the latter generated very similar R2 values in most fields as biomass models based on tree diameter. Therefore, these models can also be used to predict tree biomass.

1.3.3 Patterns of tree height in each field by clone

Tree heights were measured only for model trees, so to use biomass models from tree height, it is necessary to model the heights of all trees in the plantation from tree diameter. For that purpose [25] formula was used, coefficients of which estimates according to fields and clones are presented in Table 1-9. The reliability of the selected models was also assessed using the coefficient of determination R2. Visualizations of the models are presented in Pictures 1-7 to 1-13.

When assessing the suitability of the models, it was found that all the studied models, except for Šilutė field, clone No.9, and the Antykščiai experimental field clones AF7, OP42 and AF6, R2 was higher than 0.94, which shows the good ability of these models to predict tree heights from tree diameters. In Šilutė field, the R2 of the height model of clone 9 was only 0.824, while the R2 of clones AF7, OP42 and AF6 of the Antykščiai experimental field was 0.843, 0.819 and 0.869, respectively. This was because the measured heights of trees with diameters greater than 20 cm were smaller and did not maintain the same growth trends as trees with diameters up to 20 cm (Picture 1-9).

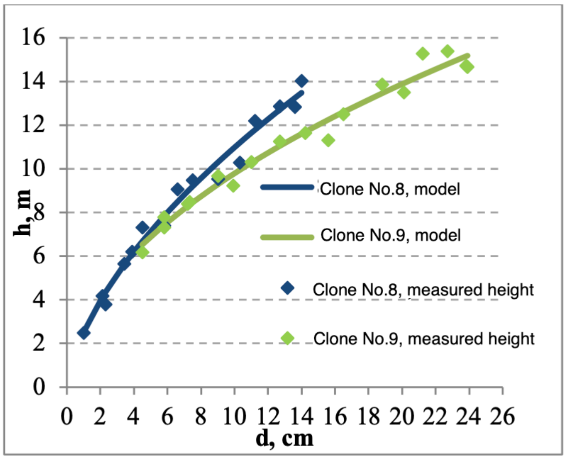
Table 1-9. Coefficient estimates of height models in each field by clone

Field	A clone	a1	a2	a3	R2
Šilutė	8	0.922463	0.665908	-0.011250	0.981
	9	1.107072	0.514556	-0.001993	0.974
Anykščiai	8	0.925687	0.551560	0.027098	0.982
	9	-0.891534	2.355042	-0.390044	0.824
Kelmė	8	0.992028	0.523821	0.008671	0.986
	9	0.953612	0.363541	0.074372	0.984
Marijampole	AF7	0.993549	0.611894	-0.053560	0.980

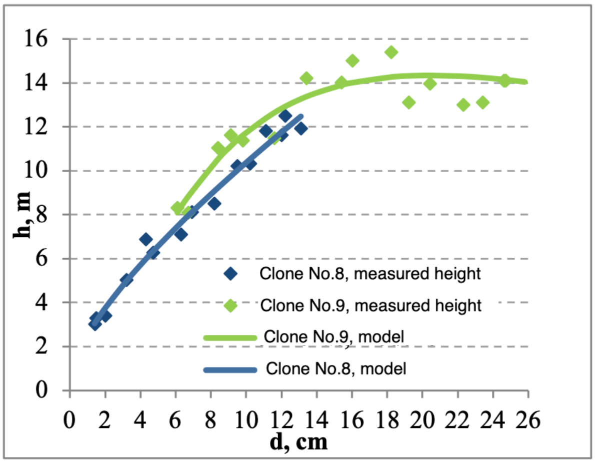
Kašiadorys	AF7	0.910238	0.631685	-0.018241	0.972
	AF34	0.584761	1.007284	-0.115501	0.961
	OP42	0.783405	0.861653	-0.095276	0.941
Anykščiai experiment	AF7	-0.312662	1.769420	-0.284927	0.843
	AF34	-0.237701	1.665597	-0.244296	0.965
	OP42	-2.488629	3.756464	-0.718407	0.819
	AF6	-0.433040	1.935027	-0.313830	0.869
	Max1	1.771156	0.110007	0.058184	0.985
	Max3	-0.657134	2.333953	-0.446697	0.940
	Max4	2.108174	-0.140968	0.096371	0.979

Picture 1-7, Picture 1-8 and Picture 1-9 show tree height versus diameter patterns for hybrid aspen clones No.8 and No.9. The blue and green diamonds represent the measured height values, while the solid lines represent the modelled values. It is clear that the tree diameters of clone No.9 reach much larger values in all fields compared to the tree diameters of clone No.8. However, for the same diameter, in two of the three fields (Picture 1-7 and Picture 1-9), tree heights are higher in clone No.8. This is especially evident in Picture 1-7. For example, a clone 8 tree with a diameter of 14 cm will reach a height of 14 meters, whereas a clone 9 tree with the same diameter will only reach a height of 12 meters.

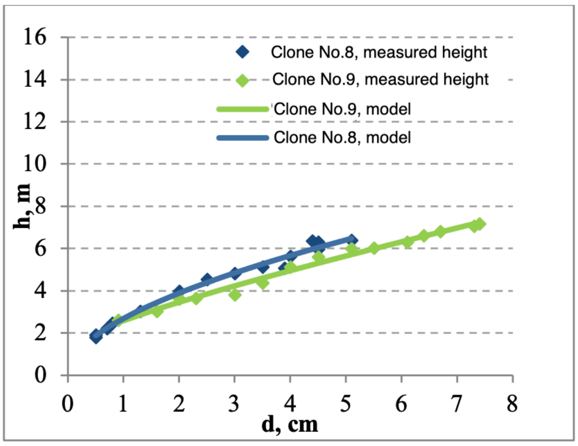
Picture 1-7. Models of hybrid aspen clone height based on tree diameter, Anykščiai



Picture 1-8. Models of hybrid aspen clone height based on tree diameter, Šilute



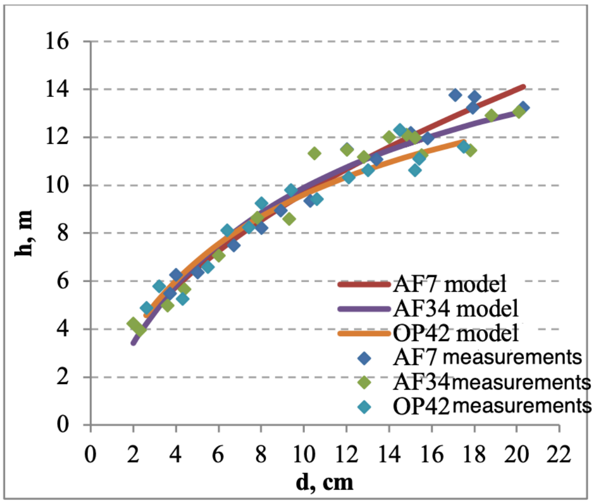
Picture 1-9. Models of hybrid aspen clone height based on tree diameter, Kelmė



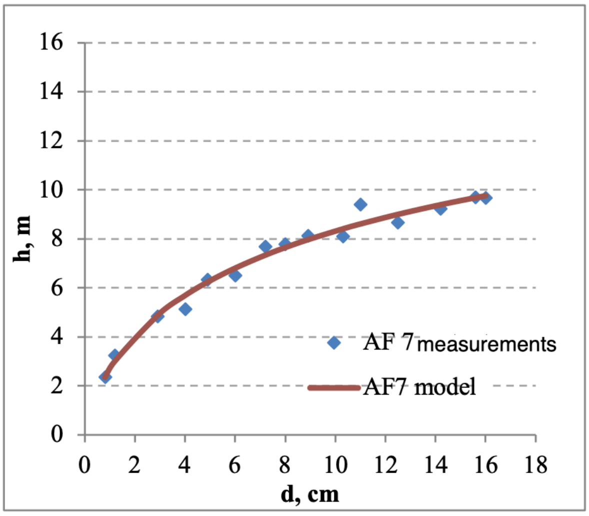
It is also important to emphasize that in all three fields during the analyzed period, the growth of clone No.8 in diameter in centimetres is very similar to its growth in height in meters, which would indicate high wood efficiency due to low subsidence. This feature is much less expressed in the analyzed clone No.9 and the poplar clones shown in the Pictures bellow.

In Kaišiadorys field (Picture 1-10) , poplar clones AF7, AF34 and OP42 trees with a maximum diameter of 12 cm had a very similar height growth of about 10 meters. However, the growth in height of the largest trees, whose diameter was over 16 cm, was different. While the 20 cm diameter AF7 Clone trees reached about 14 meters in height, the AF34 trees of the same diameter reached about 13 meters, while the OP42 trees only reached about 12 meters in height.

Picture 1-10. Models of poplar height based on tree diameter, Kaišiadorys



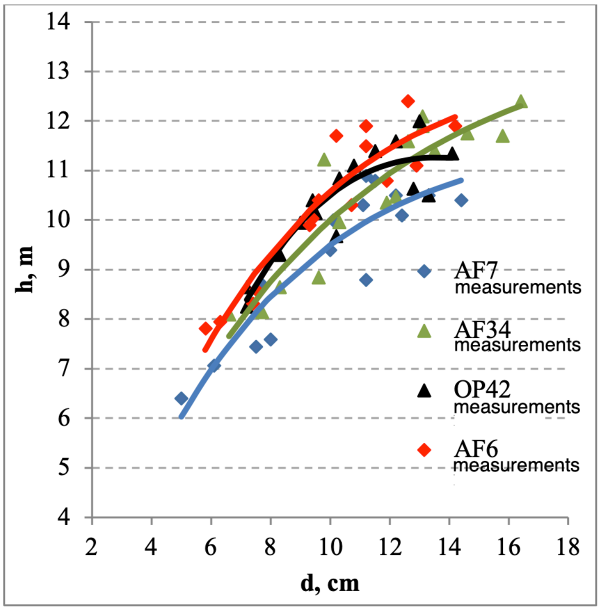
Picture 1-11. Models of poplar height based on tree diameter, Marijampolė



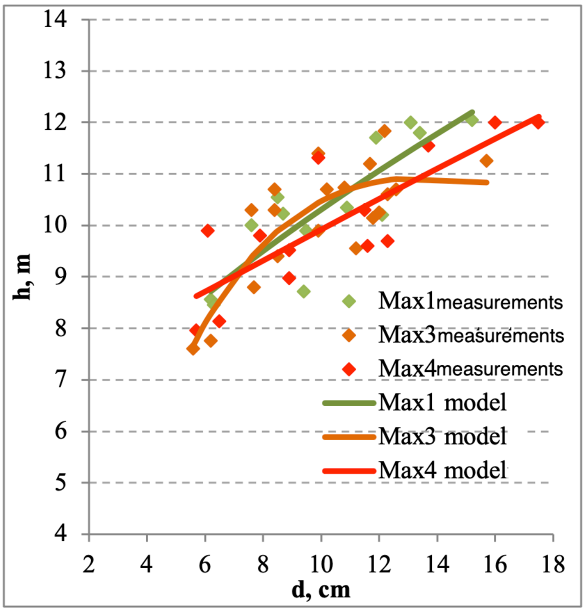
In Marijampole field (Picture 1-11) poplars of clone AF7 with a diameter of 16 cm reached a height of 10 meters. In comparison, in Kaišiadorys field poplar AF7 clone in the field, the corresponding diameter trees had already reached 12 meters. It should be noted, that, Kaišiadorys field, was planted 2 years earlier than that in Marijampolė.

Picture 1-12 and Picture 1-13 show height models of poplar clones AF7 AF34 OP42 and Max clones from Anykščiai experiment. It should be noted that poplar AF6 clone had the highest height (Picture 1-12 red curve). For this clone, trees with a diameter of 14 cm were modelled at a height of about 12 m. Meanwhile, clone AF7 had the lowest height (blue curve in Picture 1-12), for this clone, trees with a diameter of 14 cm were modeled with a height of about 10.7 m.

Picture 1-12. Models of poplar height based on tree diameter, Anykščiai experimental field



Picture 1-13. Models of MAX clone height based on diameter, Anykščiai experimental field



1.3.4 Comparison of biomass curves of experiments planted in Kaišiadorys and Anykščiai

The same poplar clones were established in the experimental fields of Kaišiadorys and Anykščiai. Anykščių experimental field was intensively fertilized with sludge. Therefore, it became possible to assess whether fertilization with sludge changes the allometric relationships of trees between tree diameter at breast height and biomass, and tree height and their biomass. Since the biomass study was conducted only for AF7, AF34 and OP42 clones in Kaišiadorys field, the biomass curves of fresh total weight and dry total weight of these clones from the Anykščiai and Kaišiadorys experimental fields were put together in common graphs and compared with each other. The biomass curves must coincide when there is no significant differences.

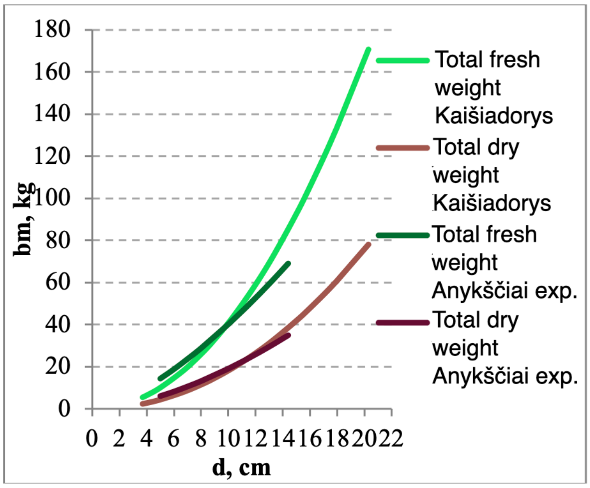
The results are shown in Pictures 1-14 through 1-19. It should be noted that, when modelling dry biomass from tree diameter, the curves overlapped each other for all clones. Therefore, it can be stated that the dry biomass models established in the Kaišiadoriu field can be applied to the modelling of the dry biomass of the corresponding clones AF7, AF34 and OP42 in the Anykščiai experimental field based on tree diameter. As a result, it can be concluded that fertilization in the Anykščiai experimental field significantly increased tree biomass, but did not change the ratio of tree biomass to diameter size.

Simulating total fresh weight of biomass in these fields yielded insignificant differences, especially for the AF7 clone (Picture 1-14). In this picture, the light and dark green patterns differ a bit. Meanwhile, AF34 and OP42 clones (Picture 1-16 and Picture 1-18) have almost identical patterns of total fresh biomass weight versus diameter. These small differences could have occurred due to uneven moisture content of the wood, as the measurements were taken at the beginning of 2019 and at the end of 2019 in the experimental fields of Anykščiai and Kaišiadorių, respectively.

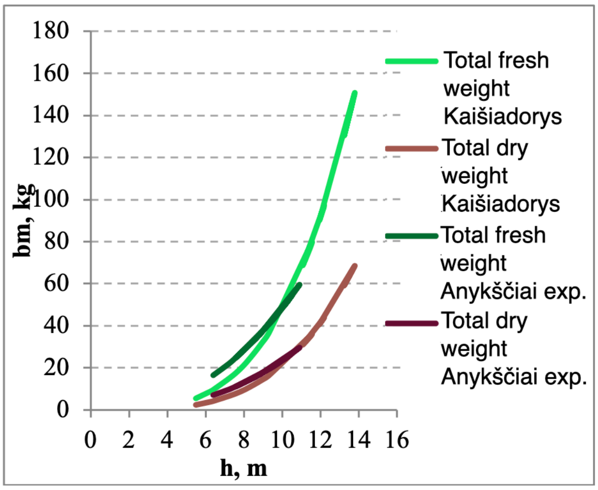
Modelling dry biomass with tree height showed more pronounced differences, especially for the OP42 clone, Picture 1-19. Both the fresh and dry biomass models based on height do not co-inside.

Meanwhile, for the AF7 clone and the AF34 clone, when modelling both fresh and dry biomass based on height, no significant differences were found. Therefore, it can be stated that the dry biomass models based on tree height developed in the Kaišiadorys field can be applied to the dry biomass modelling of the respective clones AF7 and AF34 in the Anykščiai experimental field. As a result, it can be concluded that fertilization in the Anykščiai experimental field significantly increased tree biomass, but did not change the ratio of tree biomass to height.

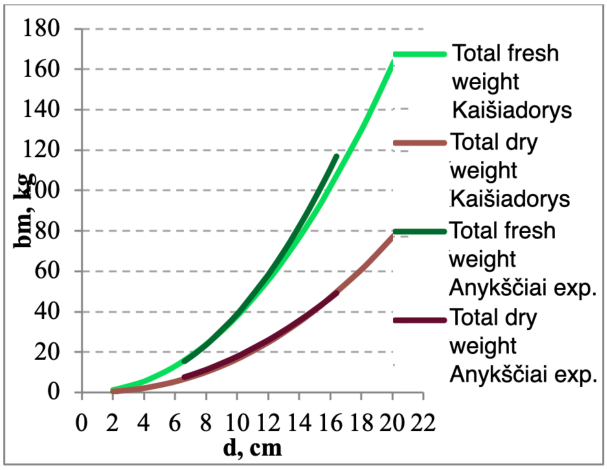
Picture 1-14. AF7 biomass models based on diameter, Anykščiai experimental and Kaišiadorys fields



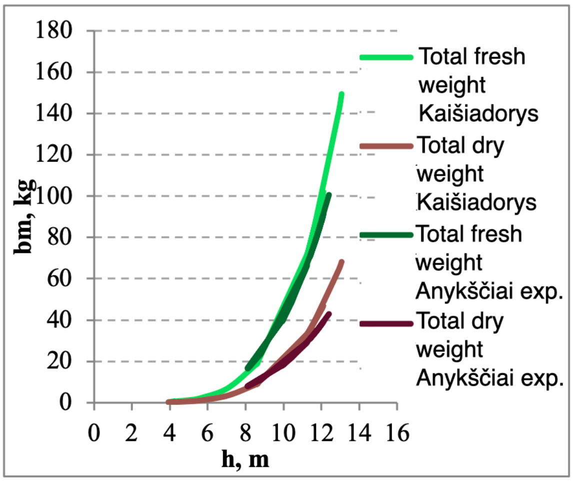
Picture 1-15. AF7 biomass models based on height, Anykščiai experimental and Kaišiadorys fields



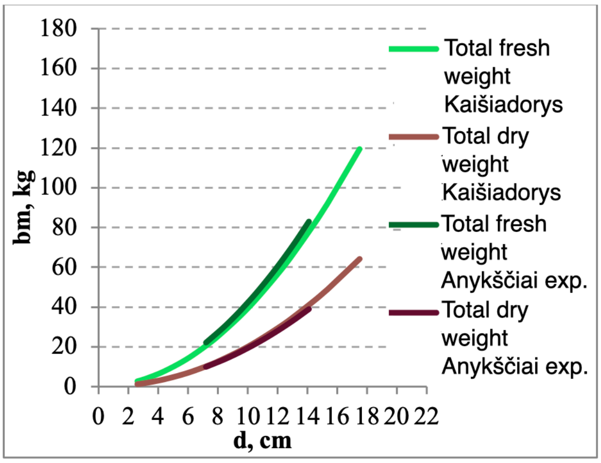
Picture 1-16. AF34 biomass models based on diameter, Anykščiai experimental and Kaišiadorys fields



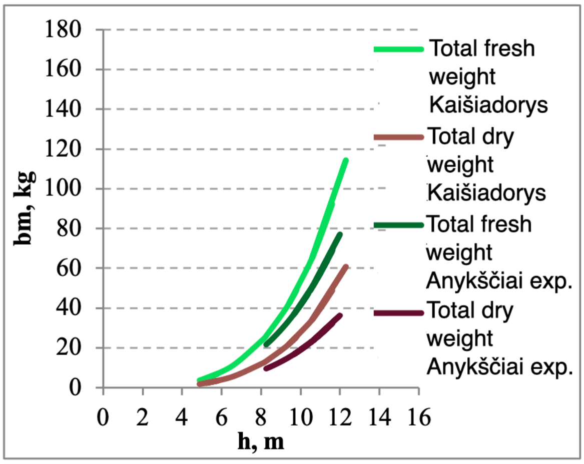
Picture 1-17. AF34 biomass models based on height, Anykščiai experimental and Kaišiadorys fields



Picture 1-18. OP42 biomass models based on diameter, Anykščiai experimental and Kaišiadorys fields



Picture 1-19. OP42 biomass models based on height, Anykščiai experimental and Kaišiadorys fields



1.3.5 General models of biomass

Fresh branches, fresh stems, total fresh tree weight, dry branches, dry stems, total dry tree weight biomass models for clones No.8, No.9, and AF7 versus based on diameters and tree height were developed using all measurements of the same clone from different fields, excluding Anykščiai experimental field data.

In addition, we present general patterns of fresh and dry biomass weight for clones AF7, AF34, and OP42. These models were obtained by including data from the Anykščiai experimental field.

The reliability of the selected models was also assessed using the coefficient of determination R2. The coefficients a1 and a2 of the constructed models and their R2 are presented in Table 1-9. It should be noted that the coefficient of determination R2 of all general biomass models based on tree diameter was higher than that of general biomass models based on tree height.

Also, the variation limits of R2 when modelling biomass from tree diameter were 0.9671-0.994. Meanwhile, when modelling biomass from tree height, R2 varied between 0.688-0.972.

Table 1-10. Model parameters for biomass generic models built using data from all fields where the clone grows

Model parameters			Biomass					
			Fresh branches	Fresh stem	Total fresh weight	Dry branches	Dry stem	Total dry weight
Clone 8, Kelmė, Šilutė, Anykščiai	Modeling from d, cm	a1	0.041027	0.125734	0.166815	0.014421	0.044026	0.058473
		a2	2.397911	2.413254	2.409405	2.522853	2.54047	2.536013
		R2	**0.972**	**0.993**	**0.994**	**0.975**	**0.990**	**0.992**
	Modeling from h, m	a1	0.007847	0.015026	0.022427	0.002597	0.004727	0.007154
		a2	3.041224	3.25241	3.199651	3.191121	3.422859	3.364465
		R2	0.899	**0.972**	**0.960**	**0.907**	**0.974**	**0.963**
Clone 9, Kelmė, Šilutė, Anykščiai	Modeling from d, cm	a1	0.032183	0.358021	0.31072	0.012117	0.139508	0.119296
		a2	2.627561	1.998778	2.202458	2.717371	2.077443	2.285982
		R2	**0.971**	**0.988**	**0.990**	**0.971**	**0.987**	**0.989**
	Modeling from h, m	a1	0.00018	0.003027	0.002243	5.27E-05	0.000904	0.000663
		a2	4.872218	4.019551	4.303627	5.068516	4.207023	4.495635
		R2	0.782	**0.912**	0.870	0.781	**0.907**	0.866

AF7 clone, Marijampole, Kaišiadorys	**Modeling from d, cm**	a1	0.100624	0.177448	0.275784	0.041312	0.083883	0.125119
		a2	2.029158	2.174004	2.131056	2.088037	2.156879	2.135801
		R2	**0.978**	**0.967**	**0.985**	**0.977**	**0.980**	**0.990**
	Modeling from h, m	a1	0.050835	0.041791	0.081009	0.02121	0.02259	0.040864
		a2	2.516988	3.002835	2.861606	2.576045	2.926913	2.821809
		R2	0.784	**0.939**	**0.908**	0.782	**0.921**	0.889
AF7 clone, Marijampole, Kaišiadorys, Anykščiai experiment	**Modeling from d, cm**	a1			0.299987			0.152823
		a2			2.097752			2.064309
		R2			**0.977**			**0.982**
	Modeling from h, m	a1			0.048449			0.027635
		a2			3.052546			2.967639
		R2			0.889			0.874
AF34 clone, Kaišiadorys and Anykščiai experiment	**Modeling from d, cm**	a1			0.354208			0.123499
		a2			2.044863			2.143549
		R2			**0.980**			**0.981**
	Modeling from h, m	a1			0.000807			0.000281
		a2			4.690862			4.796021
		R2			0.854			0.842
OP42 clone, Kaišiadorys and Anykščiai experiment	**Modeling from d, cm**	a1			0.513498			0.147905
		a2			1.906284			2.120966
		R2			**0.986**			**0.988**
	Modeling from h, m	a1			0.011053			0.003763
		a2			3.614884			3.770975
		R2			0.748			0.688

It is also necessary to note that when modelling the biomass of fresh branches or dry branches from based on height for clone No.9 and AF7, the values of the coefficients of determination R2 were only about 0.78 (they are highlighted in red in Table 1-10). Meanwhile, when modelling the same biomass of fresh branches and dry branches based on tree diameter, R2 values were about 0.97.

Thus, total biomass based on tree diameter models were more accurate and explained more of the variation in the dependent variable.

Summarizing the modelling results, it can be stated that the general biomass models based on tree diameter explain more of the variation of the dependent variable compared to the general biomass models based on tree height. This is also reflected in their R2. However, the coefficients of determination of the general biomass models based on tree height in most cases reached more than 0.9. This confirms their suitability for modelling tree biomass. However, it should be noted that for hybrid aspen clone No.9 and poplar clones AF7, AF34 and OP42, these models generated lower biomass values compared to biomass models generated based on tree diameter.

1.3.6 General patterns of tree height by clone

Overall patterns of height versus tree diameters were constructed for hybrid aspen clones No.8 and No.9 and poplar clones AF7, AF34 and OP42 using all measurements of the same clone from different fields. The coefficients of the created models are presented in Table 1-11. The coefficient of determination R2 was also used to evaluate the models. It should be noted that the developed models were characterized by very high R2 values. The lowest R2 value was determined for the AF7 clone and reached 0.913, when data from Marijampolė, Kaišiadorių and Anykščiai experimental fields were used.

Table 1-11. Model parameters for generic models based on tree height created using data from all fields in which the clone grows

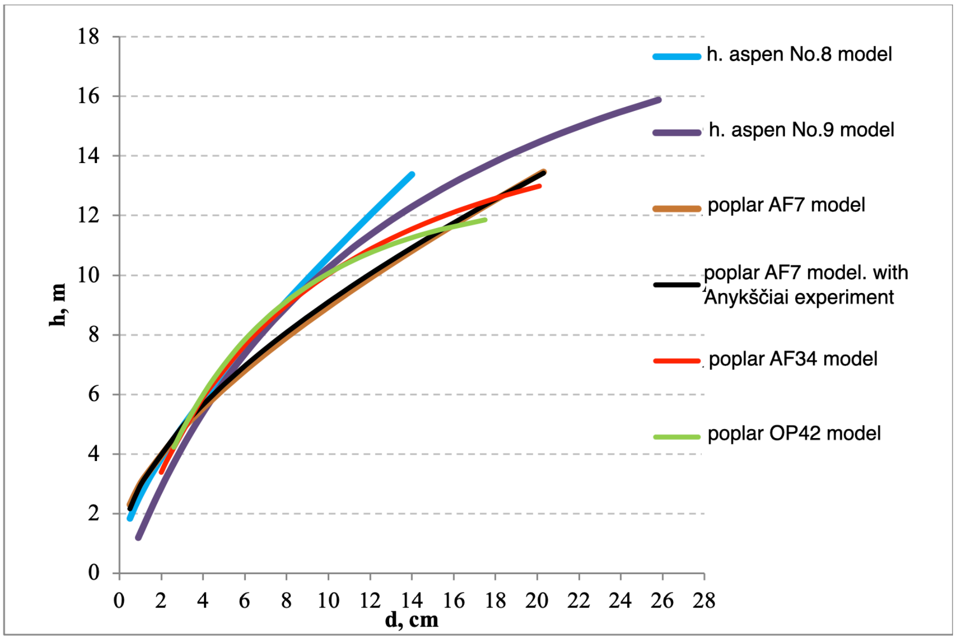
Coeffi-cients	Clone 8, Kelmė, Šilutė, Anykščiai	Clone 9, Kelmė, Šilutė, Anykščiai	AF7 clone, Marijampole, Kaišiadorys	AF7 clone, Marijampole, Kaišiadorys, Anykščiai experiment	AF34 clone, Kaišiadorys and Anykščiai experiment	OP42 clone, Kaišiadorys and Anykščiai experiment
a1	0.964751	0.304044	1.095472	1.074266	0.540437	0.421688
a2	0.533649	1.173956	0.399812	0.449505	1.071702	1.242952
a3	0.031683	-0.128235	0.033197	0.018697	-0.132399	-0.183877
R2	**0.982**	**0.940**	**0.923**	**0.913**	**0.926**	**0.905**

Picture 1-20 visualizes the measured and modelled (solid line) values by clone. Using all the data, it is clearly seen that the hybrid aspen No.9 trees for which heights were measured had a maximum diameter of about 26 cm. Meanwhile, hybrid aspen No.8 trees are only 14 cm, and clone AF7 is about 20 cm. Accordingly, the AF34 clone is about 20 cm, and the OP42 clone is about 18 cm.

It is Šilutė that No. 9 had the highest measured maximum heights of about 16 m, while clone 8 and AF7 had about 13 m. Meanwhile, the oldest No. 9 and No.8 trees were 9 years old, while AF34, AF7 and OP42 clones were only 6 years old.

However, if we compare the heights of the trees at a fixed diameter of 14 cm for example, the height of clone No. 8 clones was about 14m, clone No. 9 trees about 13 meters, AF7 clone about 11 meters, AF34 clone almost 12m, and OP42 clone about 11.5m.

Picture 1-20. Models of generic models of tree height created using data from all fields in which the clone is present



Summarizing the obtained modelling results, it can be stated that the general models of tree height versus tree diameter explain more than 90% of the variation in tree height for all studied clones. Therefore, these models are suitable for modelling tree height.

1.3.7 Biomass patterns from mean plantation rates by clone

Fresh branches, fresh stems, total fresh biomass weight, dry branches, dry stems, total dry biomass weight models, which represent biomass amounts in kilograms per hectare, were also constructed from the average plantation values based on average tree diameter and average tree height, depending on the clones. Since hybrid aspen clones No.8 and No.9 were planted in three fields, and poplar clone AF7 in two fields, biomass models for clones No.8 and No.9 were constructed using these 3 field measurements, while only 2 field measurements were used for clone AF 7.

Additionally, biomass models for stem, total fresh tree weight, and total dry tree weight were constructed by adding measurements from the Anykščiai experiment to the AF7 clone. Also having the data form the Anykščiai experiment, the mentioned biomass models for AF34 and OP42 clones were created.

The coefficients a1 and a2 of the created models and their coefficients of determination R2 are presented in Table 1-12. Although the coefficients of determination of biomass models from both mean diameter (Dq) and mean height (Hq) are very high (minimum R2 value 0.897), they should be evaluated and used with great caution and limitations due to the very small number of measurements. Especially when there are only two field measurements for AF7, AF34 and OP42 clones.

Due to the lack of measurements and the location of the measurement points, the dependences of the biomass models for clone No.8 are linear up to the Dq value of 7 cm. Bending of the curves occurs only when the Dq value is greater than 7 cm. Basically, this form of the models does not correspond to the form of the gradual interdependence of biomass and diameter. Modelling biomass from Hq kept the shape of the models the same.

Table 1-12. Model parameters of biomass per hectare accumulated based on average diameter Dq and average height Hq

Model parameters			Biomass, kg/ha					
			Freshly cut branches	**A freshly cut stem**	**Fresh total weight**	**Dry branches**	**Dry stem**	**Dry total weight**
clone 8, Kelmė, Šilutė, Anykščiai	**Modeling from Dq, cm**	a1	2.361513	32.785266	29.151916	0.476221	5.552363	5.096752
		a2	3.800169	3.055604	3.253910	4.224512	3.570835	3.752625
		R2	**1,000**	**0.9998**	**0.9998**	**0.9996**	**0.9995**	**0.9995**
	Modeling from Hq, m	a1	7.621415	23.588471	31.153236	3.694681	11.843297	15.544756
		a2	2.906975	2.932075	2.927288	2.882711	2.892108	2.890223
		R2	**0.922**	**0.938**	**0.934**	**0.914**	**0.927**	**0.923**
clone 9, Kelmė, Šilutė, Anykščiai	**Modeling from Dq, cm**	a1	0.606252	6.779487	5.398017	0.218509	2.443122	1.959584
		a2	3.583687	2.886209	3.142017	3.694428	2.993958	3.247861
		R2	0.997	0.998	0.989	0.997	0.998	0.998
	Modeling from Hq, m	a1	0.873261	3.207397	3.157792	0.381860	1.258306	1.289293
		a2	3.661955	3.362959	3.554442	3.701462	3.442598	3.619380
		R2	**0.999**	**0.9996**	**0.999**	**0.999**	**1,000**	**0.999**
AF7 clone, Marijampole, Kaišiadorys	**Modeling from Dq, cm**	a1	37.356000	157.910000	188.480000	12.596000	69.151000	76.275000
		a2	2.531900	2.389200	2.435300	2.675800	2.389300	2.477200
		R2	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**
	Modeling from Hq, m	a1	3.801500	5.434900	6.779100	1.649500	2.946300	3.611700
		a2	3.622500	3.929000	3.960200	3.665100	3.840100	3.858300
		R2	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**
AF7 clone, Marijampole, Kaišiadorys,	**Modeling from Dq, cm**	a1			363.171973			189.033536
		a2			2.183787			2.130674
		R2			**0.975**			**0.951**

Anykščiai experiment	**Modeling from Hq, m**	a1			26.314615			22.510917
		a2			3.403712			3.116904
		R2			**0.960**			0.897
AF34 clone, Kaišiadorys and Anykščiai experiment	**Modeling from Dq, cm**	a1			84.094142			36.225501
		a2			2.840940			2.852816
		R2			**1,000**			**1,000**
	Modeling from Hq, m	a1			1.045137			1.768312
		a2			4.761695			4.197422
		R2			**0.998**			**0.998**
OP42 clone, Kaišiadorys and Anykščiai experiment	**Modeling from Dq, cm**	a1			14500,150549			18356.702863
		a2			0.446874			0.031007
		R2			**1,000**			**1,000**
	Modeling from Hq, m	a1			68388.964279			256620,278291
		a2			-0.206185			-1.080357
		R2			**0.983**			**0.999**

The shape of the biomass models from Dq and Hq for clone 9 looks a little better. Basically, they correspond to interdependencies between biomass and tree diameter and height. The curves have a shape characteristic of a stepwise model. However, these models should also be of very limited use due to the very small number of measurements.

Meanwhile, the forms of the biomass models from Dq and Hq for clone AF7, using only data from Marijampole and Kaišiadorys, are completely linear. It is because of the two measurements that the curves acquire the shape characteristic of a linear relationship. Of course, this form is not acceptable for stepwise dependence models. After additional data from the Anykščiai experiment, the curves acquire the shape characteristic of a stepwise model. However, only fresh and dry weight biomass models are available in Anykščiai experiment.

Models for fresh and dry weight biomass patterns for clone OP42 versus Dq and Hq were built with only 2 measurements. The models are linear and have no practical relevance. These models should also have very limited or no use due to the very small number of measurements.

1.4 Discussion

The successful development of plantation of the genus Populus, also depends to a great extent on the ability to quickly and reliably assess the productivity of available plantations. It is necessary to know the amount of biomass grown at a given moment, using the created biomass models for that purpose.

In Lithuania, Populus trees have been grown for more than 10 years. However, their productivity in our country is relatively little studied. Until now, there are no available biomass assessment tools in our country. Therefore, one of the tasks of this work was to study the condition, growth and biomass accumulation of Populus tree plantations planted in various parts of Lithuania and to develop general models of biomass assessment based on empirical degree functions, which would help to easily calculate the amount of biomass grown in plantations in order to estimate biomass yield improvement while fertilizing with nutrient rich municipal water treatment sludge and CO2 accumulations in NutriBiomass4LIFE project and thereafter.

To achieve this goal, measurement work was carried out in six plantations located in Anykščiai, Šilutė, Kelmė, Marijampole and Kaišiadorių district fields whose area varied from 0.38 to 60 ha. In total, two hybrid aspen clones No.8 and No.9 and seven poplar clones AF7, AF34, OP42, Max1, Max3 and Max4 were studied. The largest increase in total weight of dry biomass was determined in Kaišiadoys field in the poplar plantation, for clone AF34, which reached 7912.6kg/ha. Meanwhile, in Kelmė r. field the annual increase of the total weight of dry biomass was only 128.3 kg/ha (Table 1-3). In other hybrid aspen plantations, the annual increase of total dry biomass varied from 1462 to 2600 kg/ha. These quantities were significantly lower compared to the annual increase of 4.2-9.8 tons of dry biomass of Populus genus hybrids in Latvia[8], or Populus nigra L. annual dry biomass increase of 4.2 tons per hectare in Lithuania. Not to mention the annual gains of 14 tons of dry biomass of Populus hybrids in the Czech Republic[9].

Several factors could have contributed to these biomass results. First, Röhle et al.[22],[23]found that the amount of dry biomass accumulated by Populus trees strongly depends on the number of trees planted. The results of the authors show that with the same average height of dominant trees of 15 meters, when the density of trees increases from 1150 units/ha to 13000 units/ha, the amount of accumulated biomass increases from 50 to 160 tons/ha.

Populus trees were planted in Latvia at a density of 5000-7000 units/ha[8], while in the Czech Republic at a density of even 10,000 units/ha[9]. Thus, the density of planted trees is a very important indicator that determines the amount of biomass accumulated in plantations. It should also be emphasized that in the analyzed plantations, with the exception of Kaišiadorys poplar plantation and the Anykščiai experiment, the percentage of surviving trees varied between 64 and 77% (Table 1-6). Knowing that 1650 units/ha were planted in these plantations (Table 1-1), the percentage of surviving trees is really low at this initial density. It is well known that when planting at a lower density, tree diameter growth peaks later. Cultivation rotations are also longer. Therefore, it is likely that in the next few years, the amount of biomass accumulated in these plantations will increase significantly.

Biomass yield in short-rotation plantations depends to a large extent on the genotypes of the cultivated tree species[6]. Therefore, it is worth discussing the planting material in more detail, especially in hybrid aspen plantations. They mainly planted hybrid aspen clone 8. Rytter and Stener[27] the results show that when planting hybrid aspens in southern Sweden (Populus tremula Lx P.Tremuliodes Michx.) at a density of 1960 units/ha, after ten years of growth, the average diameter of the trees reaches 13-14 cm, and the average height is about 10-12 m. Meanwhile, the average diameter of hybrid aspen clone 8 in Lithuania, after 9 growing seasons, was about 7cm and the average height was about 8 m (Table 4-4). Meanwhile, hybrid aspen clone 9 had very similar average diameter and average height compared to Swedish hybrid aspen. Thus, the genetic characteristics of clone 8 that determine the growth rate of the trees are in serious doubt. In Silutė and Kelmė plantations, there were a number of cases where clone 8, due to its uniform diameter and height, was in intense competition with native birches, which could be the same age or younger than the hybrid aspens. Similar growth results as clone 8 could easily be generated by common aspen.

Another, very important aspect of this work was the preparation of models for calculating the accumulated biomass in each field separately, as well as the creation of general biomass models based on tree diameter and tree height.

Röhle et al. al[22]investigated a number of functions that could be used to model biomass and concluded that a power function, from tree diameters, is the most appropriate.

Meanwhile, rank functions of biomass versus tree height are rarely or never applied for a simple reason. In order to use these models in practice, it is quite simple to delineate a sampling plot and measure the diameters of all the trees in it and model their biomass. Measuring heights is not a common and rather complicated process for farmers. During measurements, significant errors are possible that would distort the results. However, with remote sensing methods, diameters can only be measured indirectly by first measuring the tree crowns and then modelling the tree diameters. Meanwhile, with the remote method, tree heights can be measured directly. Therefore, biomass models from tree height are gaining more and more importance.

When modelling tree biomass in each field, by clone, in most cases, biomass models based on tree height performed nearly as well as biomass models based on tree diameter (Table 1-3 and Table 1-4). Although, when modelling from tree height, the coefficients of determination were slightly lower than when modelling from tree diameter, but still higher than 0.9. However, when modelling the biomass in Šilutė for clone 9, a potentially negative aspect of modelling from height emerged, which was completely irrelevant when modelling biomass from tree diameter. In this field, as the diameters of clone 9 trees increase from 16 to 26 centimetres, the height of the trees remains stable at about 14 meters. Meanwhile, the total dry biomass of trees increases from 80 to 200 kg. Due to an increased dispersion of the measured data about the models, and a decreased part of the variation of the dependent variable explained by the models, the coefficient of determination reaches only 0.747. This may have occurred purely due to the ecophysiological properties of the trees. It is well known that trees, in the face of competition, try to grow taller first, as this guarantees the trees direct sunlight[28]. Growing without competition “wolf” trees do not try to grow very high, but rather generate an increase in the diameter of the trees. Because the large diameter of the trees is necessary to maintain the deciduous canopy[28]. Thus, the height growth of very large trees slows down, while the diameter growth of trees slows, and the amount of biomass accumulated by trees increases at an exponential rate. These differences could also be caused by changes in the micro-relief (micro-elevations or lower waterlogged areas) or changed soil properties. It is also well known that trees growing in micro-slopes grow taller in order to reach direct canopy light than trees growing in micro-elevations[28].

If the biomass models created for each field separately are suitable only for modeling the biomass of that field, then the general biomass models are created to be applied to other fields of the same tree species and clone.[22].

When creating common biomass clones for hybrid aspen clones 8, 9 and AF7, data from the same clones from different fields were brought together. In this way, biomass general models for clones 8 and 9 were created using about 50 biomass measurements, while for clone AF7 about 30 measurements, excluding additional measurements, including the Anykščiai experiment. In statistics, 30 measurements are considered a minimum reliable sample.[26]. However, in order to achieve a higher accuracy of the models, there should be a correspondingly larger data sample. The coefficient of determination R2 was used to evaluate the general models of biomass. This is a fairly reliable and easy-to-understand estimator of the models. For this parameter, total biomass models based on tree diameter were more accurate than total biomass models based on tree height (Table 1-7). Other methods are often used to evaluate models. One such is the error, accuracy, and precision of the models when testing them against data from other fields that were not included in the overall model development.[28]. However, in this case, it was not possible to do so due to the amount of data available. In the further development of these models, it is necessary to collect more biomass data of the same clones and to test the models based on them.

The practical application of these general biomass models is quite simple. In order to estimate the accumulated amounts of biomass, using the general biomass models from the diameter in the existing plantation, the location of the temporary research sampling plots is first selected randomly and its edges are marked. The right size of the sampling plot is to hold at least 200 trees[16]. After marking the edges of the sampling plot, measure the length and width of the sampling plot. Next, the diameter of each tree is measured at breast height (1.3m) by holding the short legs of the stakes perpendicular to the rows of trees. It should be noted that in case of large, non-homogeneous plantations, the number of temporary research sampling plots increases. In this case, 3-5 temporary research sampling plots are evenly placed in the plantation, trying to eliminate the influence of the human factor (by moving the sampling plots to very productive or poorly growing areas of the fields).

With the measured diameters of the trees in the sampling plot, the biomass of freshly cut branches, freshly cut stems, fresh total tree weight, dry branches, dry stems or dry total weight of trees is also modelled by applying Equation 1 and using the coefficients of equation a1 and a2 given in Table 1-7, modelling from d. Next, knowing the area of the accounting sampling plots and the biomass accumulated in them, it is easy to recalculate everything for one hectare of field or the entire field area.

To calculate biomass using general biomass models from tree height, the calculation algorithm is very similar. In the limited sampling plots, instead of the diameter of the trees, their height is measured, and having tree heights, the biomass of freshly cut branches, freshly cut stems, fresh total tree weight, dry branches, dry stems or dry total weight of trees is also modelled by applying Equation 2 and using 4 Equation coefficients a1 and a2 given in Table 1-7, modelling from h. Of course, measuring the height of trees is much more labour-intensive than measuring tree diameters. Therefore, two-stage biomass modelling can also be applied. In this way, the diameters of the trees would be measured first, then their heights would be modelled by applying Equation 3 and using the a1, a2 and a3 coefficients in Table 1-8. After modelling tree heights, tree biomass can also be modelled by applying Equation 2 and using the equation coefficients a1 and a2 presented in Table 1-7, modelling from h. Further, using remote sensing technologies, tree heights could be measured using, for example, LIDAR or other technologies. Again, with the heights measured in this way, it is easy to calculate the biomass of the trees as well. However, in this case, it would be very important to accurately mark and determine the areas and boundaries of the accounting sampling plots. It should also be remembered that remote measurement devices have their own measurement errors, which may make the results not very accurate.

Biomass models from average diameter and height indicators are reliable and quite widely used in practice[14]. However, building reliable models requires large amounts of data. After all, the same minimum reliable sample rule of 30 measurements applies in this case as well[26]. In this work, only three measurements were used for clones 8 and 9 and AF7, and only two for clones AF34 and OP42, when developing models of accumulated biomass per hectare from mean diameter or mean height. As a result, the curves for 8 clones AF7, AF34 and OP42 did not retain the shapes typical of the power function. Therefore, these models are only indicative for now to be used for NutriBiomass4LIFE project.

They need to be improved to be used for larger scale. When applying these models in other fields in practice, errors can reach tens of percent.

Further research is necessary to improve both general tree biomass models and models based on average tree dimension indicators, collecting and using more data for modelling. Also, testing models with independent data is essential. When saving resources, it would be worth checking the biomass models or methods applied in other countries in Lithuanian conditions. It is also worth paying attention to the "Yield estimation" method[16]. Of course, this method could be adapted and its accuracy increased for Lithuanian conditions by reparametrizing its coefficients. Of course, the application of remote methods for biomass estimation looks very attractive, due to their work efficiency. However, in this case, the measurement accuracy of remote methods becomes very important, as well as the completeness of the method itself, which is sometimes very expensive.

2 Assessment of biomass yield improvement due to fertilization with municipal waste-water treatment sludge

2.1 Introduction

Biomass plantation establishment on agricultural soil faces numerous challenges. Typically, biomass plantations are established on low fertility agricultural soils, which are not suitable to intensive conventional agriculture and food production. This leads to the situation that biomass crops established on low fertility agricultural soils lack nutrients that limits their growth yields and make the growth of such crops economically unattractive to farmers and landowners.

Nutrient rich waste recycling in biomass plantations may provide win-win situation both to farmers / landowners and the society by empowering circular environmentally safe waste management practices. In addition, nutrient rich waste recycling in biomass plantations may provide economically feasible solutions to nutrient rich waste producers such as municipal waste-water treatment plants and biomass boilers.

2.2 Methodology

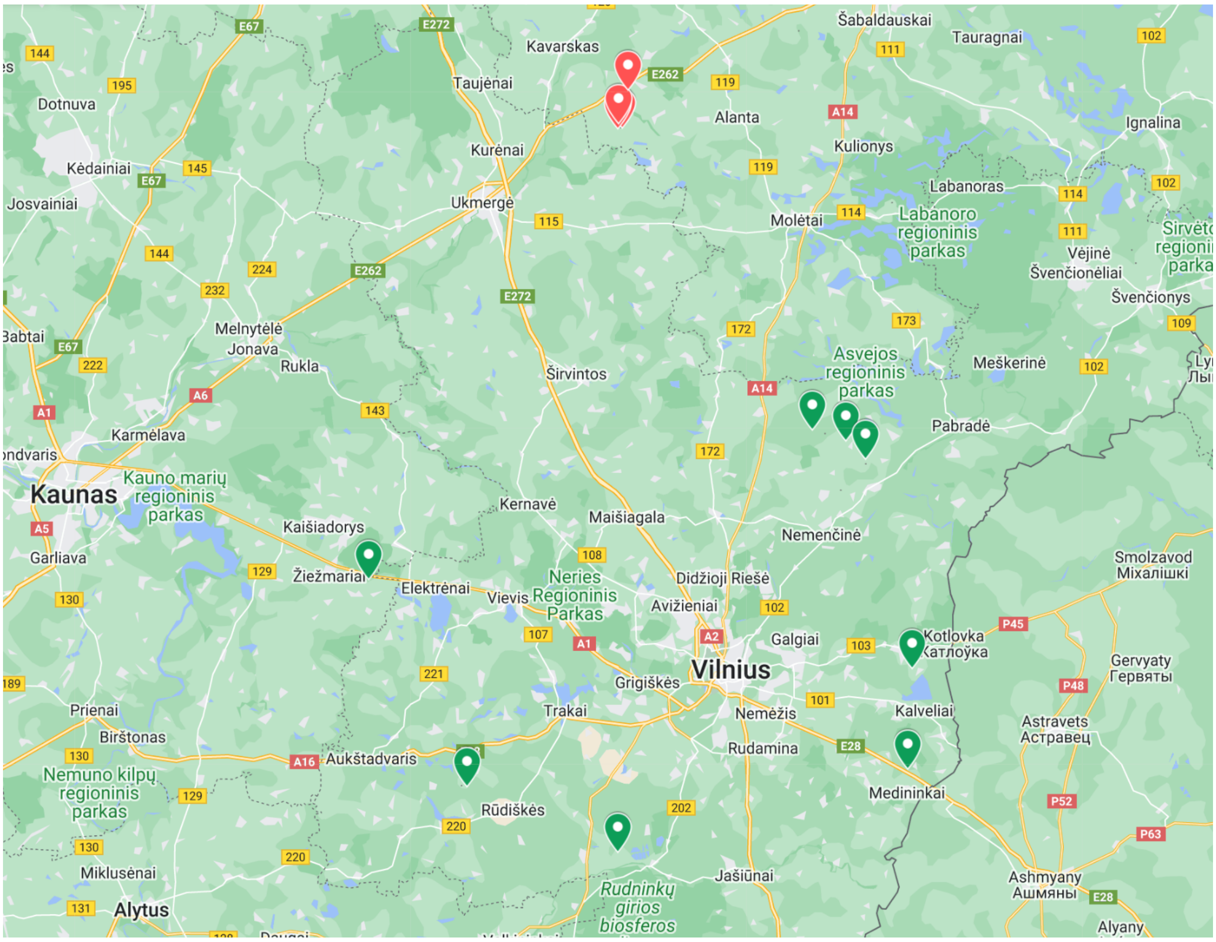
2.2.1 Research objects

Biomass quality monitoring studies were carried out in Eastern Lithuania - in Trakai, Vilnius and Anykščiai municipal districts - in areas planted with biomass plantations of *Populus spp*. species. 24 research sites have been installed on different types of soil for monitoring and evaluating the impact on biomass yield while fertilizing with DMWTSD. Additionally, one more (25th) research site was established to estimate root and leaf biomass in Kaisiadorys region.

Populus spp. species - hybrid poplars (sites from 1 to 16 and 25) and hybrid aspen (sites from 17 to 24) were established on the analysis sites. Hybrid poplars (AF7 clone) established on sites from 1 to 16, were planted from 2015 to 2016 and were established with long poles (180 cm) at a density of 1600 plants/ha. Hybrid poplars (Snowtiger clones no. 2, 3, 4 and 6) established on site 25, were planted in 2014 and were established with different types of seedlings - long poles (180 cm), short cuttings, bare root and containerised plants - at a density of 1600 plants/ha. Hybrid aspen (Lithuanian clones No.8 and No.9) established on sites from 17 to 22, were planted in 2011 (autumn) and on sites 22-23 were planted in 2012 (autumn) and were established with containerised plants at a density of 1200 plants/ha.

It is necessary to notice, that hybrid polar sites established with AF7 in 2015 year were heavily effected by intolerable climatic conditions in 2015. Heavy 2015 summer drought decreased AF7 hybrid poplar survival rate to 70-75% and the following heavy early autumn frost in 2015 completely destroyed the first year yield of biomass.

Picture 2-1. General overview of biomass yield improvement research sites



Sites for biomass yield improvement assessment were selected after analysis of prevailing soil types and granulometric composition. Based on this, several soil types and granulometric composition were distinguished and monitoring sites were installed (Table 2.1).

The biomass yield improvement assessment sites were established were selected based on prevailing soil types: Arenosols (sites 7–8, 15-16 and 23-24), Albeluvisols (sites 3-4, 5-6 and 17-18), Luvisols (sites 9-10 and 19-20), Gelysosls (sites 11-12 and 21-22), Planosols (sites 13-14) and Histosols (sites 1-2).

Productivity score of soils of biomass yield improvement assessment sites varies from 21 to 43 points, with the lowest (from 21 to 24) on Arenosols and highest (42-43) on Luvisols. The majority of selected sites were of slight humidity, while Arenosols can be characterised as dry sites.

Table 2-1.Soil and plantation characteristics of biomass yield improvement research sites

SIte	Fertilization	Location	Year of establishment	Fertilization year	Age at start of fertilization	Species/ clones	Soil productivity score	Soil type	Soil texture	Soil moisture	Planting density	Seedling types	Soil preparation
1	F	Trakai distr., Paluknis reg., Mamavys village,	2015	2020	5	Hybrid poplar/ AF7	38	Hs	d/d	M	1600	AT	N
2	N												
3	N	Vinius distr., Medininkai reg., Dvarčiai village,	2015	2020	5	Hybrid poplar/ AF7	36	AB	ps/ps	S	1600	AT	N
4	F												
5	N	Vinius distr., Medininkai reg., Dvarčiai village,	2015	2020	5	Hybrid poplar/ AF7	37	AB	sp/sp	S	1600	AT	N
6	F												
7	N	Vinius distr., Nemenčinė reg., Voskonys village,	2016	2020	4	Hybrid poplar/ AF7	23	AR	ps/s	D	1600	AT	N
8	F												
9	N	Vinius distr., Sužionys reg., Griciūnai village,	2016	2020	4	Hybrid poplar/ AF7	38	LV	sp/p2	S	1600	AT	N
10	F												
11	N	Vinius distr., Lavoriškės reg., Petruliškės village,	2015	2020	5	Hybrid poplar/ AF7	27	GL	pv/p1	M	1600	AT	N
12	F												
13	N	Vinius distr., Sužionys reg., Kalniškės village,	2016	2020	4	Hybrid poplar/ AF7	27	PL	ps/s/sp	S	1600	AT	N
14	F												
15	F	Trakai distr., Rūdiškės reg., Gerviniai village,	2015	2020	5	Hybrid poplar/ AF7	24	AR	s1/s	D	1600	AT	N
16	N												
17	N	Anykščiai distr., Kurkliškės reg., Vilkiškės village	2012	2019	7	Hybrid aspen/ 8 and 9	36	AB	ps/p1	S	1200	KS	V
18	F												
19	N	Anykščiai distr., Kurkliškės reg., Vilkiškės village,	2012	2019	7	Hybrid aspen/ 8 and 9	42	LV	ps/sp2	S	1200	KS	V
20	F												
21	N	Anykščiai distr., Kurkliškės reg., Vilkiškės village,	2012	2019	7	Hybrid aspen/ 8 and 9	40	GL	sp1/ p1	S	1200	KS	V
22	F												
23	F	Anykščiai distr., Kurkliškės reg., Sargūnai village,	2013	2019	6	Hybrid aspen/ 8 and 9	21	AR	ps/s	S	1200	KS	V
24	N												
25	N	Kaišiadorių distr., Žiežmariai reg., Bačkonys	2014		6	Snowtiger 2, 3,4,6	43	LV	ps/sp	S	1600	AT TA KS	IS

Fertilization: F – Fertilized with DMWTSD, N – Not fertilized (control).
Soil typ: Luvisols (LV), Gleysols (GL), Podzols (PZ), Arenosols (AR), Albeluvisols (AB), Planosols (PL), Histosols (HS)
Soil texture: z – gravel; s – loose sand; s1 – cohesive sand; ps – sand; sp- sandy light loam; sp2 - sandy heavy loam; p – light loam; p1 – medium loam; p2 – heavy loam; m - light clay; m1 – medium clay; m2 - heavy clay; pv - peavan; d - peat. dp1 – dusty medium loam; dm - dusty clay
Soil moisture: D - dry; S - slightly humid; M – moist; W - wet.
Seedling types: KS - containerized plants, AT - 1.8m long poles, TA - 30 cm cuttings.
Soil preparation– V-soil prepared with furrows, IS-soil completely plowed, N-soil not prepared, planted in a meadow.

2.2.2 Fertilization with DMWTSD

Sites for assessment of biomass yield improvement while applying DMWTSD were established based on prevailing soil type and biomass plant species. On each location two assessment sites (from 1 to 24) were established – one to be fertilized with DMWTSD and another without fertilization – for control. In total 12 sites were fertilized with DMWTSD and 12 sites were left unfertilized for control.

Hybrid aspen yield assessment sites (sites 18, 20, 22 and 23) were fertilized with DMWTSD in the beginning of August 2019. Hybrid poplar yield assessment sites (sites 1, 4, 6, 8, 10, 12, 14 and 15) were fertilized with DMWTSD in the beginning of August 2020.

On each fertilized site, two neighbouring rows with 20 trees in each row (or total 40 trees) were fertilized using DMWTSD, the nutrient parameters of which are presented in the table 2-2. Biomass yield assessment sites were fertilized using 19 t dmt/ha of UAB "Vilniaus vandenys. Based on fertilization rate and nutrient concentrations in DMWTSD the following nutrient quantities were applied: total nitrogen (N) – 850 kg/ha on hybrid poplar sites and 750 eur/kg on hybrid aspen sites (among that Ammonia nitrogen (N-NH4) – only 26 kg/ha), total phosphorus (P) – 547 kg/ha on hybrid poplar sites and 466 eur/kg on hybrid aspen sites, total potassium (K) – 60 kg/ha on hybrid poplar sites and 66 eur/kg on hybrid aspen sites.

Table 2-2.Nutritional parameters (concentrations) of DMWTSD used in biomass yield improvement analysis sites

Chemical parameters	Site No.											
	1	4	6	8	10	12	14	15	18	20	22	23
pH	7,3	7,1	7,2	7,5	7,5	7,6	7,5	7,6	7,1	7,1	7,09	7,3
Total organic matter, %	59,64	58,31	58,63	60,35	58,85	59,96	59,76	58,8	56,74	56,74	58,58	54,76
Total sulphur (S), mg/kg	9158	3510	5237	8238	11231	10108	9794	10088	3437	6611	3713	6855
Total nitrogen (N), mg/kg	42141	41716	46026	45812	46659	47411	46292	42581	39982	41747	39930	37163
Ammonia nitrogen (N-NH4), mg/kg	1113	1360	1616	1297	2136	1436	1374	1173	1281	1686	1255	1391
Nitrate nitrogen (N-NO3), mg/kg	17	66,8	180,2	17	806	1849	146	136	2,83	6,17	9,40	7,11
Total phosphorus (P), mg/kg	27893	28896	31995	29154	28039	28039	28266	28093	21219	27046	23820	26040
Total potassium (K), mg/kg	3098	1795	3669	3343	3294	3313	3357	3395	3318	3239	3805	3583
Total calcium (Ca), mg/kg	54792	54750	57500	59500	62667	66667	52417	57542	57750	68917	61167	66333
Total Magnesium (Mg), mg/kg	10000	10833	10750	10542	11583	11792	10042	11042	10708	14500	10917	12500
Total Manganese (Mn), mg/kg	294	302	316	294	304	310	309	294	273	278	281	290
Total boron (B), mg/kg	<4,1	4,37	<4,1	<4,1	<4,1	<4,1	<4,1	<4,1	8,87	5,77	11,2	3,73
Total organic carbon (Corg), %	22,29	22,72	23,60	20,22	22,23	20,35	19,67	17,01	20,21	27,3	22,4	28,7

DMWTSD on trial sites was applied manually, directly from big bags as shown in the picture 2-3. After spreading, DMWTSD was inserted into the soil by disking.

Picture 2-2. DMWTSD application on biomass yield improvement research sites

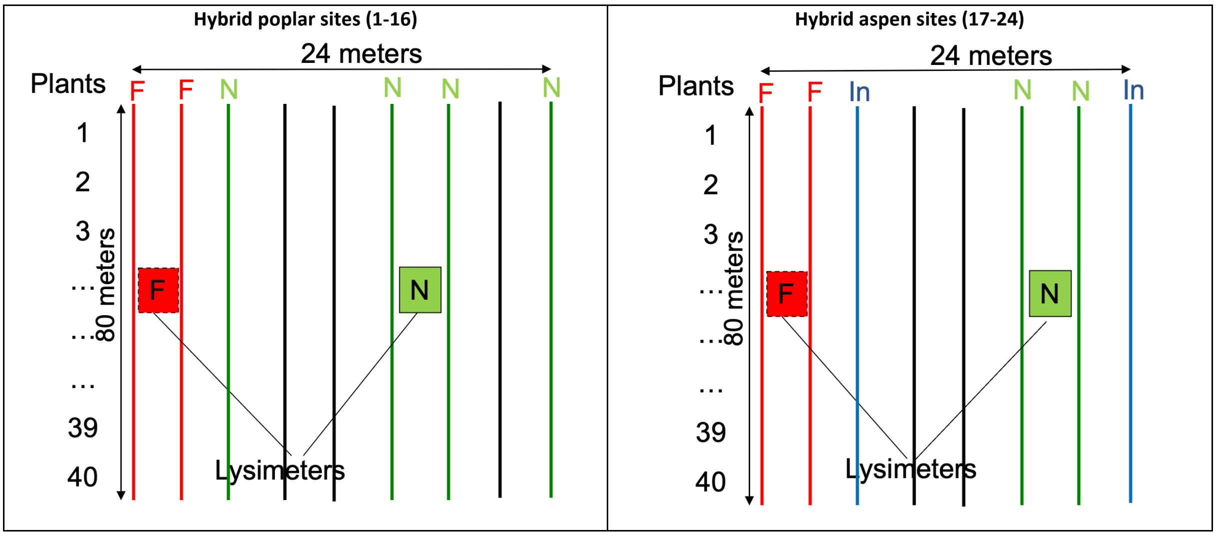
2.2.3 Data collection methods

Biomass yield improvement assessment at NutriBiomass4LIFE plantation was carried out using the biomass assessment model presented in this report (formula (6) and average coefficients developed for hybrid poplar AF7 clone and hybrid aspen clone No. 8 as presented in Table 1-10.

According to the methodology, research sampling sites are first established, which are used to assess the tree diameters in the field – both for fertilized and non- fertilized (control) sites. For hybrid poplar (sites 1-16) on each land type plot 2 fertilized lines and 4 non-fertilized lines have been measured. For hybrid aspen (sites 17-24) on each land type plot 2 fertilized lines and 2 non-fertilized lines have been measured. All these measuring sites were marked with marking line.

Each measuring line contains appr. 40 vital trees, therefore appr. 80 fertilized trees on each fertilized site and appr. 160 trees on each poplar site and appr. 80 trees on each hybrid aspen site. The real measured number of trees may vary site by site depending on survival rate of trees in sample plot.

Picture 2-3. Schemes of biomass yield improvement research sites



Measurements: F – Fertilized with DMWTSD, N – Not fertilized (control). In – half fertilized

In all biomass yield improvement research sites total 931 fertilized trees and 1491 unfertilized trees were measured.

The overall survival rate was 85% with much higher (96%) survival on hybrid aspen sites and lower (80%) on hybrid poplar sites. The characteristics of accounting rows of biomass yield improvement research sites are presented in Table 2-3.

Table 2-3.Acounting characteristics of biomass yield improvement research sites

Site	Total number of rows in the site	Number of fertilized accounting rows	Number of non-fertilized accounting rows	Number of fertilized accounting trees,	Number of non-fertilized accounting trees,	Initial survival rate of the site	Total length of accounting rows, m	Total accounting row site area, m2
1-2	9	2	4	80	117	53%	740	2220
3-4	9	2	4	78	160	75%	632	1896
5-6	9	2	4	81	163	66%	734	2202
7-8	9	2	4	80	166	89%	550	1650
9-10	9	2	4	80	157	91%	518	1555
11-12	9	2	4	80	155	96%	488	1464
13-14	9	2	4	76	155	94%	494	1482
15-16	9	2	4	62	122	75%	492	1476
17-18	9	2	2	80	79	100%	319	1277
19-20	9	2	2	80	78	99%	320	1282
21-22	9	2	2	80	76	98%	319	1275
23-24	9	2	2	74	63	87%	318	1271
total	**108**	**24**	**40**	**931**	**1491**	**85%**	**5924**	**19050**

Next, the following measurements are performed in each accounting row. First, the clone to which the tree belongs is determined. The diameter of each tree at breast height (dbh) is also measured (exactly 1.3 m, a 1.3 m stick is used to determine the measurement location) while holding the legs of the calliper perpendicular to the direction of the row. The dbh measurements for hybrid aspen (sites 17-24) have been performed as initial for the year 2018 end and for the yield increase for the year 2019, 2020, 2021 and 2022. The dbh measurements for hybrid poplar (sites 1-16) have been performed as initial for the year 2019 end and for the yield increase for the year 2020, 2021 and 2022.

Additionally, tree height measurements on biomass yield improvement research sites have been performed for the same years, except for the year 2022 yield measurements.

2.2.4 Yield data analysis methods

Biomass yields in biomass plantations has been calculated based on formula (6), defined during development of biomass yield assessment model.

$$BM = a_1 \cdot D_q^{a_2} \tag{6}$$

Where, BM- Fresh or dry quantities of branches, stem or total weight of biomass in kg/ha,
Dq – average tree diameter in cm,
a1 and a2 equation coefficients.

And where average diameter of trees (Dq) is calculated as the root mean square of tree diameters using the following formula:

$$D_q = \sqrt{\frac{\sum_{i=1}^{K} d^2}{K}} \tag{4}$$

Where Dq is the average diameter of the trees in cm,
d- the diameter of the trees in cm,
K- the number of trees for which d was measured.

Where coefficients a1 and a2 were provided in Table 1-12 while defining model parameters of biomass per hectare accumulation based on average diameter Dq:

- For hybrid poplar AF7 clone, based on combined Marijampole, Kaišiadorys, Anykščiai experiment data, fresh weight a1 totalled **0.299987**, and a2 totalled **2.097752**
- For hybrid aspen No.8 clone, based on combined Kelmė, Šilutė, Anykščiai experiment data, fresh weight a1 totalled **0.166815**, and a2 totalled **2.409405**

2.2.5 Destructive biomass yield data analysis methods

Additionally to non-destructive biomass yields methods as defined above, destructive measurement methodology was developed and applied at biomass monitoring site 25, established with SnowTiger clones in Kaišiadorys region.

Destructive measurements ware performed with 20 trees (5 trees per 4 different SnowTiger clones) to evaluate full biomass: stem, branches, leaves, stump and root biomass. 20 trees were harvested and weighted and their roots excavated.

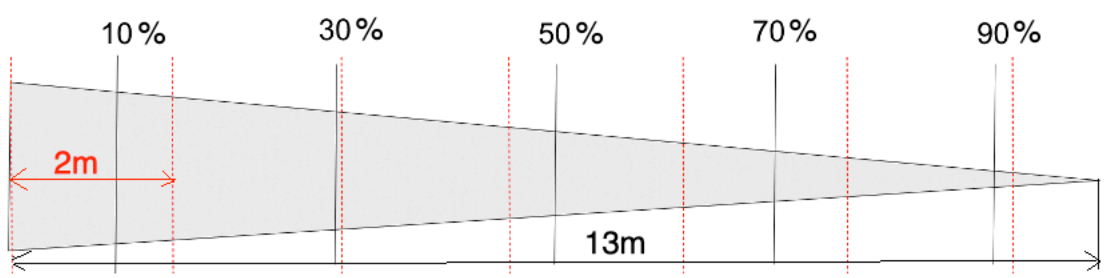
The destructive biomass yield data analysis methodology was used as defined bellow:

1. Selection of trees for destructive measurement
   1.1. The clones were sampled from Establishment trial in Anyksciai are '15.7', '21.9', '23.4' and '26.1' (Snowtiger clones No. 2, 3, 4 and 6).

1.2. Within each Snowtiger clone, five trees across the whole range of that clone's DBh were selected: one at the lower range, two around the average and two large trees. The selected trees should not grow at the open edge, but they can have neighbor trees in clone trial.
1.3. All selected trees were marked at 1.3 m height on the stem.
1.4. All selected trees (total 20 trees) were harvested (fell down) manually with chain saw.

2. Branch sampling
2.1. All the branches along the stem to the very top shoot attached on the top (the top shoot is included into the total height of the tree) were cut and were left beside the stem where they were cut.
2.2. The length of each tree was measured to the very top bud. The measuring tape was be placed so that the mark representing the height of the stump is placed at the bottom cut. This was achieved by placing the mark for 1.3 m on measuring tape at the level of 1.3 m colour mark on the stem (marked on the stem before felling the tree). When the measuring tape was stretched it was possible to read the stump height at the bottom cut.
2.3. Spray colour was used to mark 10, 30, 50, 70 and 90 percent relative heights of the tree.
2.4. One representative sample branch at each level at 10, 30, 50, 70 and 90 percent of the stem length was selected. As the poplar branches often grow so that 3-4 larger branches develop at the level just beneath annual top height the sampling height (relative heights) were moved, if needed, so that these larger branches were sampled. If there were no such branches near certain relative height the representative branch at that height (or couple of them) simply were sampled. All sampled branches of a tree were collected in one heap (ca 5-8 branches from the whole tree).
2.5. All the other branches of a tree were collected and weighed (branches + leaves, without separating them) in the field.
2.6. The selected 5-8 sample branches were defoliated and leaves and branches were weighted separately. This was done in the field.
2.7. From sample branches a representative sample (with regard to branch size) of branch wood (500-800 g) and a representative leaf sample (150-300 g) was cut. Both of these samples were weighted fresh and then dried, branches at 95°C and leaves at 75°C until constant weight.

Picture 2-4. Branch sampling



3. Sectioning of the samples for wood density:
3.1. Diameters at bottom cut, and also at heights at 2, 4, 6, 8 m etc until the top were cross calipered.
3.2. Finally, cross cuts at bottom and 1.3 m height and also at relative heights (10, 30, 50, 70 and 90 percent), ca 2 cm thick were extracted for the measurement of wood and bark density and

bark thickness. All cross cuts were marked to identify by tree and also by relative height and properly packed in closed and marked bags.

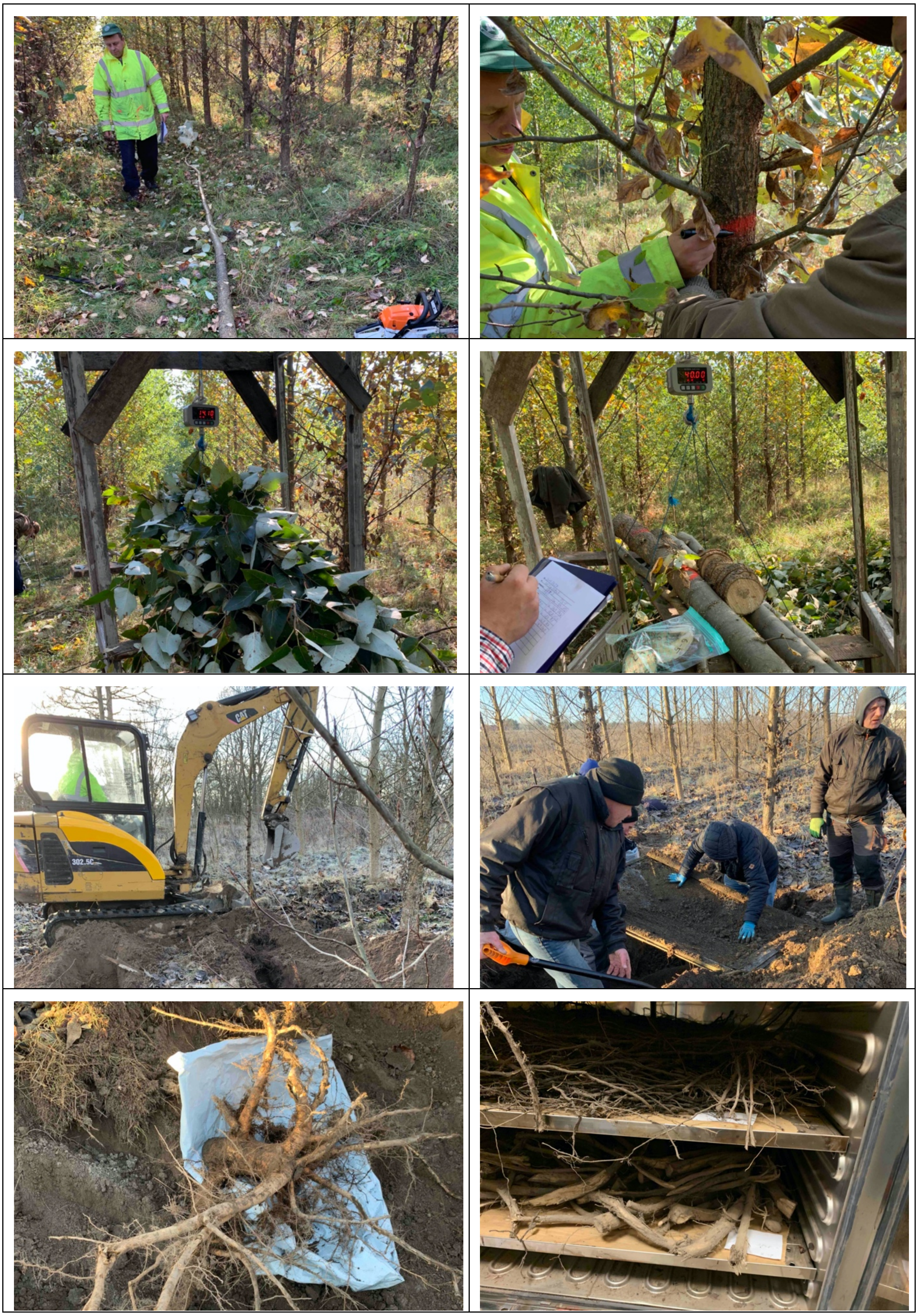
4. Sapling of stem:
   4.1. The tree stems together with cross cuts from the same tree were weighted in the field to get fresh weight of stem of each tree.
5. Sampling of stump and root biomass.
   5.1. Defining root biomass. The main goal was to obtain the total roots biomass: coarse roots (CR) >10 mm, medium roots (MR) 2-10 mm and fine roots (FR) <2 mm. The entire root system of a sample tree was excavated to a depth of 60 cm. Given the 3x2 m planting spacing, the digging area was 1 and 1.5 m on each side from the stump and all the poplar roots including the roots from other trees coming inside this 2x3 m trench were collected.
   5.2. Measurements in the field

- Stump diameter was cross-calipered where it clearly separated from the stump
- Total number of main roots protruding from the stump
- The cross-calipered diameter of main roots coming out of stump (usually 4-6)
- Sample main roots (1-2 per stump). Each sample root were stored separately and marked. The sample roots were selected to cover the range of roots sizes (diameters)
  - Diameter (cross-calipered) of a sample root
  - Length of the main sample root that needs to be pulled up as far as possible (even outside the 3x2 trench)

5.3. Measurements in the laboratory
  - Total dry weight of stump
  - Total dry weight of CR+MR and FR fraction of all the roots
  - Total dry weight of CR+MR and FR fractions of the sample root

5.4. In the case all the stump and root biomass were dried it was not necessary to take any samples. The roots were washed before drying to get rid of soil. If it was not possible to dry the whole biomass, then samples for each fraction, stump, CR + MR and FR, were taken, weighted the fresh and dry weight of samples as well as the total fresh weight of each fraction to be able to calculate the moisture content and thus the total dry biomass.

Picture 2-5. Destructive biomass yield data collection



2.3 Results

2.3.1 Assessment of survival

The survival on trial sites varied much depending on the year of establishment – the first-year climatic conditions may define the success/unsuccess of biomass plantations established.

Poplars established in year 2015 (sites 1-6, 11-2 and 15-16) suffered the first evident climate change impact – start-up of summer droughts. In year 2015 we suffered long droughts in summer vegetation period (in June and August) – during this period established poplars stopped their growth and poplars established on drier sites even started to defoliate, some of newly established poplars even dried out and this resulted in survival rate decrease. Then in September 2015 we experienced historic high temperatures and humid weather – poplars restarted an intensive growth. And finally, at the end of September we experienced big early autumn frost – all growth increment of poplars was completely frozen. In Spring 2016, frozen poplars restarted their growth from bottom, with exception on Histosols (sites 1-2), where we have the lowest survival of polars – close to 50%. Year 2016 can be characterised as normal for poplar growth, therefore poplars established in 2016 have 18% higher survival rate (91%) compared to 2015 establishment year (73%), which was negatively impacted by summer droughts and early autumn frosts.

Sites 11-12 are very distinctive from other poplar sites established in 2015, because it was established on wet Glaysols, therefore sites 11-12 show the highest survival rate (96%) and the highest yield.

Hybrid poplar survival on biomass yield improvement research sites is much higher compared to poplars – about 99%, because hybrid aspen was established in earlier years – 2012-2013, when climatic conditions in terms of humidity were still favourable for broadleaves tree establishment.

Table 2-4.Acounting characteristics of biomass yield improvement research sites

Site	Species/ clones	Type of soil	Year of establishment	Survival, year-end, %				
				2018	2019	2020	2021	2022
1-2	Hybrid poplar/ AF7	Hs	2015		53%	48%	51%	51%
3-4	Hybrid poplar/ AF7	AB	2015		75%	75%	74%	72%
5-6	Hybrid poplar/ AF7	AB	2015		66%	66%	65%	65%
7-8	Hybrid poplar/ AF7	AR	2016		89%	88%	87%	84%
9-10	Hybrid poplar/ AF7	LV	2016		91%	91%	91%	91%
11-12	Hybrid poplar/ AF7	GL	2015		96%	96%	95%	93%
13-14	Hybrid poplar/ AF7	PL	2016		94%	92%	91%	91%
15-16	Hybrid poplar/ AF7	AR	2015		75%	74%	74%	72%
Average poplars, total					**80%**	**79%**	**78%**	**77%**
Average poplars planted in 2015					**73%**	**72%**	**72%**	**71%**
Average poplars planted in 2016					**91%**	**90%**	**90%**	**89%**
17-18	Hybrid aspen/ 8&9	AB	2011 autumn	100%	100%	97%	95%	93%
19-20	Hybrid aspen/ 8&9	LV	2011 autumn	99%	100%	100%	98%	97%
21-22	Hybrid aspen/ 8&9	GL	2011 autumn	98%	98%	98%	96%	97%
23-24	Hybrid aspen/ 8&9	AR	2012 autumn	100%	100%	97%	95%	93%
Average hybrid aspen				**99%**	**99%**	**98%**	**96%**	**95%**

Soil type: Luvisols (LV), Gleysols (GL), Arenosols (AR), Albeluvisols (AB), Planosols (PL), Histosols (HS)

The survival rate was not used to evaluate biomass yield improvement due to fertilization with DMWTSD. Survival rate is used to assess biomass accumulation in older plantations, included in NutriBiomass4LIFE circular economy model to assess yield of fertilized plantations and to assess carbon sequestration by NutriBiomass4LIFE project.

2.3.2 Diameter (dbh) measurements results at research sites

Diameter (dbh) of trees was measured on al 24 sites for consecutive three years (hybrid poplar) and four years (hybrid aspen) following fertilization with DMWTSD.

The initial measurements constitute data of 2018 year growth for hybrid aspen (7 year old (sites 17-22) and 6 year old (sites 23-24)) and 2019 year growth for hybrid poplar (5 year old (sites 17-22) and 4 year old (sites 23-24)).

The lowest (2,7-3,2 cm) initial average dbh in the same age poplar (5 year old) was measured on sites 15-16 (Arenosols) and sites 1-2 (Histosols) – 5-5,2 cm. Sites 15-16 are the driest of all analysed sites, therefor the end of the research (8 year old) dbh remained the lowest, even lower than on year younger sites – 7,2-8,5 cm. While on sites 1-2 (Histosols) the growth in dbh of poplars was the highest of all and reached 13,7 cm – due to sufficient moisture content. But it should be noted that Histosols are not suitable soils for poplar growth, therefore due to autumn frosts, on Histosols poplars do not grow much in height, but rather grow in diameter.

The highest initial and end poplar dbh was observed on sites 11-12, established on moist Glaysols.

Hybrid aspen dbh also varied due to soil moisture – the lowest was recorded on sites 23-24, established on dry Arenosols. In terms of hybrid aspen, significant dhb differences were recorded due to clonal differences – sites 19-20 were mainly composed of very productive clone No 9 comparing to clone No. 8 prevailing in other hybrid aspen sites.

Table 2-5.Changes in average dbh of trees (Dq) at biomass yield improvement research sites

SIte	Fertilization	Year of establishment	Fertilization year	Species/ clones	Soil type	average dbh of trees (Dq), cm				
						2018	2019	2020	2021	2022
1	F	2015	2020	Hybrid poplar/ AF7	Hs		5,2	8,9	11,3	13,7
2	N						5,0	7,9	11,5	13,7
3	N	2015	2020	Hybrid poplar/ AF7	AB		6,4	8,4	9,8	11,0
4	F						6,7	8,8	10,5	11,7
5	N	2015	2020	Hybrid poplar/ AF7	AB		5,9	8,0	9,3	10,7
6	F						7,1	9,1	11,0	12,1
7	N	2016	2020	Hybrid poplar/ AF7	AR		3,4	6,0	7,5	9,0
8	F						3,7	6,4	7,9	9,6
9	N	2016	2020	Hybrid poplar/ AF7	LV		3,1	5,7	7,0	8,4
10	F						3,7	7,1	8,7	10,0
11	N	2015	2020	Hybrid poplar/ AF7	GL		7,4	10,1	12,0	13,2
12	F						5,5	8,4	10,5	12,3
13	N	2016	2020	Hybrid poplar/ AF7	PL		4,4	6,7	8,6	10,3
14	F						3,2	5,8	8,1	10,1
15	F	2015	2020	Hybrid poplar/ AF7	AR		3,2	5,3	6,6	8,5
16	N						2,7	4,3	5,4	7,2
17	N	2011 autumn	2019	Hybrid aspen/ 8 & 9	AB	5,2	6,2	8,0	8,7	10,0
18	F					5,5	6,4	8,3	9,2	10,3
19	N	2011 autumn	2019	Hybrid aspen/ 8 & 9	LV	10,0	10,4	11,8	12,5	13,9
20	F					10,2	11,1	12,8	13,4	14,5
21	N	2011 autumn	2019	Hybrid aspen/ 8 & 9	GL	5,2	6,2	7,8	8,9	10,2
22	F					5,9	6,8	8,7	9,8	11,1
23	F	2012 autumn	2019	Hybrid aspen/ 8 & 9	AR		4,3	6,6	8,1	9,7
24	N						4,1	6,4	7,7	9,4

Fertilization: F – Fertilized with DMWTSD, N – Not fertilized (control).
Soil type Luvisols (LV), Gleysols (GL), Arenosols (AR), Albeluvisols (AB), Planosols (PL), Histosols (HS)

2.3.3 Assessment of actual biomass yield at research sites

Actual biomass accumulations per ha (Table 2-6) at research sites was calculated taking into account average dbh (Dq) of the site and survival rate at the site. The formula (4) was used to calculate fresh weight of aboveground biomass and later it was converted into volume in cub m of biomass, taking into account that dry mass biomass content is 45% and density of wood of AF7 poplars and hybrid aspen is 350 kg/m3.

The highest 8 year-old poplar biomass accumulation (122-141 cub m/ha) in 2022 was on sites 11-12 established on wet Glaysols, which occurred due the highest annual yield increment and highest survival rate. Contrary, the lowest 8 year-old poplar biomass accumulation (31-43 cub m/ha) in 2022 was on sites 15-16 established on dry Arenosols, which occurred due the lowest annual yield increment and one of the lowest survival rate.

The highest 11 year old hybrid aspen biomass accumulation (163-180 cub m/ha) in 2022 was on sites 19-20 established on Luvisols, dominated by very productive clone No 9. Contrary, the lowest 11 year old hybrid aspen biomass accumulation (68-75 cub m/ha) in 2022 was on sites 17-18 established on Albeluvisols and dominated by clone No 8.

Table 2-6. Accumulated actual biomass estimations based on average dbh of trees (Dq)

SIte	Fertili-zation	Year of es-tablishment	Species/ clones	Soil type	Actual fresh weight of biomass, t/ha					Actual volume of biomass, cub m/ha				
					2018	2019	2020	2021	2022	2018	2019	2020	2021	2022
1	F	2015	Hybrid poplar/	Hs		8,0	17,7	39,4	59,0		11,3	25,0	55,7	83,4
2	N		AF7			7,6	17,4	40,7	58,8		10,8	24,7	57,5	83,1
3	N	2015	Hybrid poplar/	AB		17,5	31,5	42,5	52,6		24,7	44,6	60,1	74,4
4	F		AF7			19,3	34,4	49,1	59,8		27,3	48,6	69,4	84,5
5	N	2015	Hybrid poplar/	AB		13,4	24,6	33,7	45,6		18,9	34,7	47,6	64,5
6	F		AF7			19,5	32,3	47,8	58,2		27,5	45,6	67,6	82,3
7	N	2016	Hybrid poplar/	AR		5,7	18,2	28,5	40,7		8,0	25,8	40,2	57,6
8	F		AF7			6,6	20,9	31,9	45,7		9,4	29,6	45,1	64,6
9	N	2016	Hybrid poplar/	LV		4,8	16,9	25,7	38,2		6,8	23,9	36,4	54,0
10	F		AF7			6,8	26,6	41,1	55,2		9,7	37,6	58,1	78,0
11	N	2015	Hybrid poplar/	GL		30,5	58,9	83,2	99,9		43,1	83,2	117,5	141,2
12	F		AF7			16,2	40,0	63,4	86,8		22,9	56,5	89,7	122,7
13	N	2016	Hybrid poplar/	PL		10,2	23,6	39,8	58,2		14,4	33,4	56,2	82,2
14	F		AF7			5,0	17,4	35,7	55,5		7,1	24,6	50,4	78,4
15	F	2015	Hybrid poplar/	AR		4,2	11,7	18,7	30,7		6,0	16,6	26,4	43,4
16	N		AF7			2,9	7,5	12,3	21,8		4,1	10,6	17,3	30,9
17	N	2011	Hybrid aspen/	AB	10,7	16,6	29,9	35,3	48,7	15,2	23,4	42,2	49,9	68,9
18	F	autumn	8&9		12,2	17,5	33,0	40,5	53,1	17,3	24,7	46,7	57,3	75,0
19	N	2011	Hybrid aspen/	LV	52,0	58,7	78,2	89,6	115,7	73,6	83,0	110,6	126,6	163,5
20	F	autumn	8&9		55,3	68,5	96,4	105,8	127,1	78,2	96,7	136,2	149,5	179,7
21	N	2011	Hybrid aspen/	GL	10,7	16,2	28,7	37,8	53,2	15,1	22,9	40,6	53,4	75,2
22	F	autumn	8&9		14,4	20,3	37,4	48,0	65,4	20,4	28,7	52,8	67,8	92,4
23	F	2012	Hybrid aspen/	AR		5,9	16,9	27,5	43,6		8,4	23,8	38,9	61,6
24	N	autumn	8&9			5,3	15,6	24,4	40,3		7,5	22,0	34,5	57,0

Fertilization: F – Fertilized with DMWTSD, N – Not fertilized (control).
Soil type Luvisols (LV), Gleysols (GL), Arenosols (AR), Albeluvisols (AB), Planosols (PL), Histosols (HS)

2.3.4 Assessment of yield improvement due to fertilization with DMWTSD

Yield improvement due to fertilization with DMWTSD is calculated estimating increment in accumulated biomass over monitoring period on specific selected fertilized and non-fertilized sites and comparing these yield changes on fertilized sites vs. non-fertilized sites.

Table 2-7. Biomass yield improvement estimations due to fertilization with DMWTSD based on average dbh of trees (Dq)

Site comparison	Species/ clones	Soil type	Biomass yield improvement estimations due to fertilization, %		
			2020	2021	2022
1 vs. 2	Hybrid poplar/ AF7	Hs	-1%	-5%	0%
4 vs. 3	Hybrid poplar/ AF7	AB	7%	19%	15%
6 vs. 5	Hybrid poplar/ AF7	AB	15%	40%	20%
8 vs. 7	Hybrid poplar/ AF7	AR	14%	11%	11%
10 vs. 9	Hybrid poplar/ AF7	LV	63%	64%	45%
12 vs. 11	Hybrid poplar/ AF7	GL	-17%	-11%	1%
14 vs. 13	Hybrid poplar/ AF7	PL	-8%	3%	5%
15 vs. 16	Hybrid poplar/ AF7	AR	65%	54%	40%
Average hybrid poplar/ AF7			**17%**	**22%**	**17%**
18 vs. 17	Hybrid aspen/ 8&9	AB	9%	15%	8%
20 vs. 19	Hybrid aspen/ 8&9	LV	57%	34%	13%
22 vs. 21	Hybrid aspen/ 8&9	GL	27%	24%	20%
23 vs. 24	Hybrid aspen/ 8&9	AR	6%	13%	7%
Average Hybrid aspen/ 8&9			**25%**	**22%**	**12%**

Soil type Luvisols (LV), Gleysols (GL), Arenosols (AR), Albeluvisols (AB), Planosols (PL), Histosols (HS)

The research results show (Table 2-7) that fertilization of biomass plantations with DMWTSD has a clear positive impact of biomass yield improvement. The yield improvement effect was measured for 3 years following fertilization at hybrid poplar plantations and 4 years at hybrid aspen plantations.

It is estimated that on different types of soils one time fertilization increased biomass yield by 22% at hybrid poplar sites and by 25% at hybrid aspen sites after two years of fertilization. After three years of fertilization, biomass yield impact due to fertilization declined and yield increase was 17% at hybrid poplar sites and 22% at hybrid aspen sites. The declining tendency is more evident after four years of fertilization on hybrid aspen sites, when accumulated yield increase declined to 12%. This shows that in order to maintain significant biomass increase after fertilization it would be reasonable to repeat fertilization with DMWTSD after three or four years after initial fertilization.

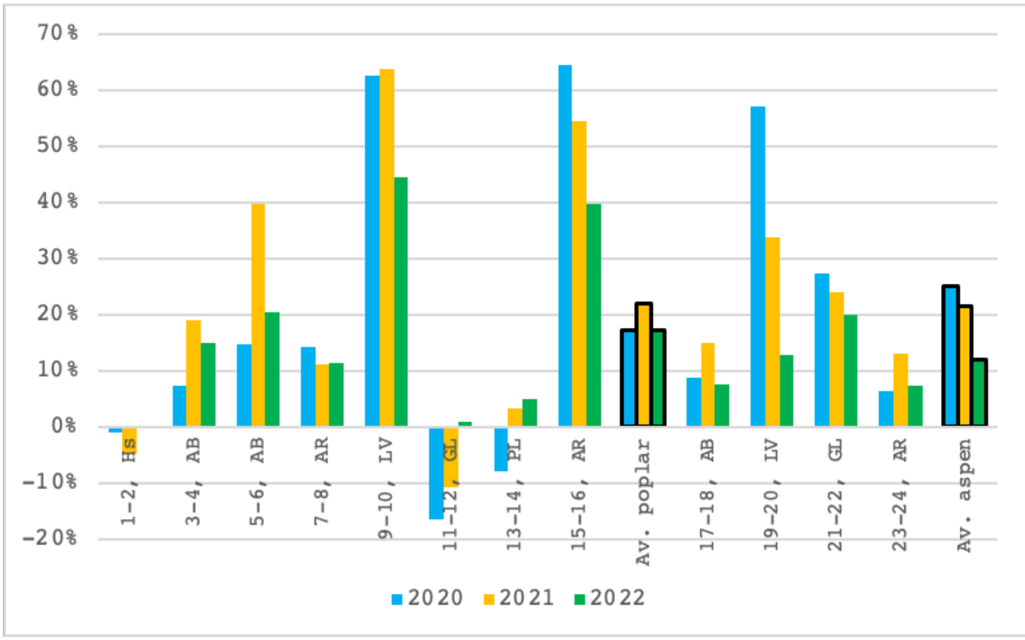
Different types of soils vary in their nutrient content, moisture content and mineralization capabilities, therefore fluctuations in biomass yield improvement can be observed over years.

The largest fertilization with DMWTSD impact was observed on least fertile and very dry Arenosols (sites 15-16), as DMWTSD supplies both missing nutrients (in particular nitrogen) and increases moisture preservation capacities of soil, where poplar biomass yield improvement reached 40% after three years after fertilization. High impact of fertilization with DMWTSD on poplar biomass yield was also observed on fertile Luvisols (sites 15-16), where poplar biomass yield improvement reached 45% after three years after fertilization.

The lowest fertilization with DMWTSD impact was observed on Hostosols (sites 1-2), which is the most problematic soil for poplar establishment, as Hostosols themselves contain large concentrations of organic nitrogen, which is also present in DMWTSD.

On sites 11-12, established on Glaysosl, and sites 13-14, established on Planososl, biomass yield improvement impact developed over time, as due to more significant initial dbh differences (initially higher dbh on non-fertilized sites compared to fertilized sites) initially higher biomass yield on no-fertilized sites later was compensated by fertilization on fertilized sites.

Picture 2-6. Biomass yield improvement estimations due to fertilization with DMWTSD



2.3.5 Assessment of root biomass

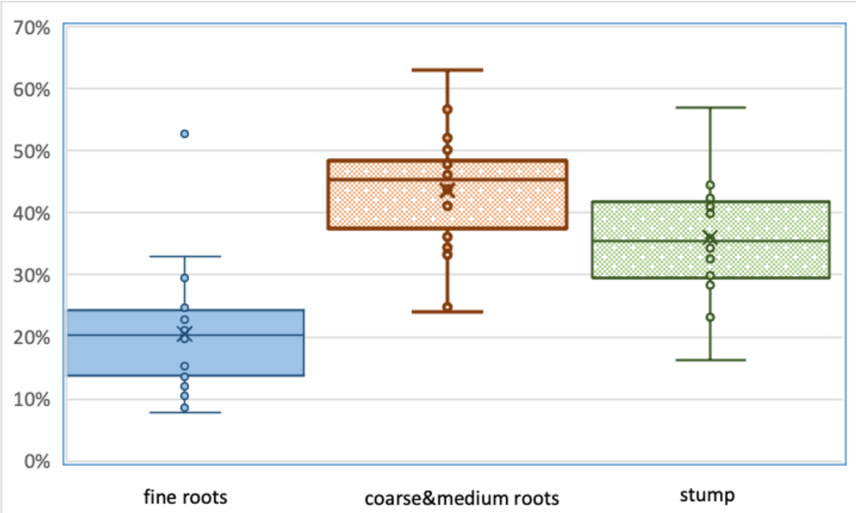
On site 25, below ground biomass (BGB) was estimated by excavating 20 trees with different DBH of Snowtiger clones. Excavated BGB was separated into three fractions: stump, coarse & medium roots and fine roots.

Table 2-8. Root sampling data at site 25

Sampling No. (clones)	Type of sample	Fresh wight with bag, g	Dry weight with bag, g	Weight of bag, g	Type of sample	Fresh wight with bag, g	Dry weight with bag, g	Weight of bag, g	Type of sample	Fresh weight with bag, g	Dry weight with bag, g	Weight of bag, g
2_1	FR	2525	1300	235	CR+MR	1880	775	290	stump	1500	715	245
2_2	FR	2505	1295	265	CR+MR	6845	3735	230	stump	4945	2445	250
2_3	FR	2210	1205	275	CR+MR	5320	3100	270	stump	1750	975	245
2_4	FR	3235	1615	270	CR+MR	3080	2315	230	stump	5480	2595	250
2_5	FR	3355	1735	245	CR+MR	5900	2995	250	stump	3765	1930	255
3_1	FR	2155	955	235	CR+MR	4870	3105	215	stump	10345	5045	255
3_2	FR	1250	995	270	CR+MR	2045	1250	240	stump	1910	960	240
3_3	FR	1720	870	255	CR+MR	5460	2655	300	stump	4995	2380	270
3_4	FR	2135	1470	250	CR+MR	4540	3315	250	stump	7070	3390	230
3_5	FR	2320	1105	270	CR+MR	9505	5380	235	stump	8485	5035	225
4_1	FR	3465	1465	225	CR+MR	9065	4315	250	stump	7505	3800	285
4_2	FR	3825	1760	270	CR+MR	7075	3310	215	stump	5525	2670	185
4_3	FR	1895	905	235	CR+MR	5413	2980	190	stump	2722	1470	0
4_4	FR	1095	685	230	CR+MR	1020	575	235	stump	1730	830	245
4_5	FR	4140	1860	235	CR+MR	6865	5275	240	stump	5700	3610	220
6_1	FR	2280	1775	285	CR+MR	8205	3575	225	stump	6540	2975	265
6_2	FR	1390	690	295	CR+MR	1585	735	205	stump	1620	670	
6_3	FR	3970	1835	275	CR+MR	6725	3555	255	stump	6300	2770	220
6_4	FR	3255	1380	270	CR+MR	5520	2580	230	stump	3640	1580	175
6_5	FR	2680	1305	250	CR+MR	11660	5095	240	stump	8820	4375	245
Total		**51405**	**26205**	**5140**		**112578**	**60620**	**4795**		**112578**	**60620**	**4795**

The parts of the roots in poplars BGB distributed in the following order: coarse & medium roots – 46%, stump – 37% and fine roots – 17%. There is certain patter of BGB part share related to the total weight of the poplars - the share of fine root decreases and share of stump increases as trees are getting bigger/heavier.

Picture 2-7. Share of poplar root parts in BGB weight



2.3.6 Assessment of leaves biomass

Leaves biomass was estimated weighing fresh and dry leaves samples and then adjusting to total weight of branches and leaves of sampled trees. Leaves contribute to 10% of total dry AGB of poplars.

Table 2-9. Leaves sampling data at site 25

Sampling No. (clones)	Leaves sample weight fresh, g	Leaves sample weight, dry, g	Total leaves weight, fresh, g	Total leaves weight, dry, g	Leaves dry to fresh ratio, %
2_1	314	130	957	397	41,5%
2_2	631	254	5200	2091	40,2%
2_3	400	168	2791	1170	41,9%
2_4	474	196	3350	1388	41,4%
2_5	392	158	2248	907	40,3%
3_1	856	333	6601	2564	38,8%
3_2	431	162	1394	524	37,6%
3_3	830	313	4230	1597	37,7%
3_4	708	277	4074	1596	39,2%
3_5	1113	441	9406	3727	39,6%
4_1	414	168	10384	4214	40,6%
4_2	897	354	3073	1212	39,4%
4_3	521	201	2764	1064	38,5%
4_4	263	114	1329	576	43,4%
4_5	710	269	8635	3273	37,9%
6_1	652	211	4762	1539	32,3%
6_2	398	136	1138	388	34,1%
6_3	557	201	4631	1670	36,1%
6_4	398	144	2972	1072	36,1%
6_5	899	321	7613	2719	35,7%
Total	**11860**	**4550**	**87553**	**33686**	**38,6%**

2.3.7 Assessment of total trees biomass at site 25

Total biomass consists of some of above ground biomass (AGB) and below ground biomass (BGB). ABG of poplars has a clear socio-economic value as it is being used as renewable material in renewable energy production and industry. Both AGB and BGB are important for CO2 sequestration purposes as BGB of poplars, which contributes to appr. 25% of total dry tree biomass, has significant carbon sequestration and long term storage capabilities.

Table 2-10. Assessment of fresh biomass weights at site 25

Sampling No. (clones)	h, m	dbh, cm	Stem weight, fresh, kg	Branshes weight, fresh, kg	Leaves, weight fresh, kg	Total AGB, fresh, kg	Fine roots, fresh, kg	Coarse& medium roots fresh kg	Stump, fresh, kg	Total BGB, fresh, kg	Total biomass, fresh, kg
2_1	7,70	5,10	7,80	1,14	0,96	**9,90**	2,29	1,59	1,26	**5,14**	**15,04**
2_2	10,90	9,80	34,10	7,00	5,20	**46,30**	2,24	6,62	4,70	**13,55**	**59,85**
2_3	10,22	8,30	21,70	5,01	2,79	**29,50**	1,94	5,05	1,51	**8,49**	**37,99**
2_4	10,15	8,45	22,40	4,25	3,35	**30,00**	2,97	2,85	5,23	**11,05**	**41,05**
2_5	10,50	8,55	23,50	5,45	2,25	**31,20**	3,11	5,65	3,51	**12,27**	**43,47**
3_1	10,80	11,25	41,40	9,20	6,60	**57,20**	1,92	4,66	10,09	**16,67**	**73,87**
3_2	8,92	8,30	9,80	1,81	1,39	**13,00**	0,98	1,81	1,67	**4,46**	**17,46**
3_3	10,10	8,70	21,50	5,17	4,23	**30,90**	1,47	5,16	4,73	**11,35**	**42,25**
3_4	9,85	9,80	28,60	5,63	4,07	**38,30**	1,89	4,29	6,84	**13,02**	**51,32**
3_5	11,20	12,05	45,50	10,49	9,41	**65,40**	2,05	9,27	8,26	**19,58**	**84,98**
4_1	10,33	12,05	31,80	15,72	10,38	**57,90**	3,24	8,82	7,22	**19,28**	**77,18**
4_2	9,20	8,90	21,40	4,53	3,07	**29,00**	3,56	6,86	5,34	**15,76**	**44,76**
4_3	9,15	7,45	17,10	3,44	2,76	**23,30**	1,66	5,22	2,72	**9,61**	**32,91**
4_4	6,00	5,20	6,30	1,27	1,33	**8,90**	0,87	0,79	1,49	**3,14**	**12,04**
4_5	10,40	12,00	41,40	12,46	8,64	**62,50**	3,91	6,63	5,48	**16,01**	**78,51**
6_1	9,00	9,10	22,00	6,94	4,76	**33,70**	2,00	7,98	6,28	**16,25**	**49,95**
6_2	6,88	4,95	6,90	1,56	1,14	**9,60**	1,10	1,38	1,62	**4,10**	**13,70**
6_3	9,65	10,04	31,60	9,77	4,63	**46,00**	3,70	6,47	6,08	**16,25**	**62,25**
6_4	9,13	8,45	20,60	5,33	2,97	**28,90**	2,99	5,29	3,47	**11,74**	**40,64**
6_5	9,90	11,70	40,20	11,29	7,61	**59,10**	2,43	11,42	8,58	**22,43**	**81,53**
			495,60	**127,45**	**87,55**	**710,60**	**46,27**	**107,78**	**96,04**	**250,09**	**960,69**

Different parts of polars vary in their dry matter content therefore total share of different parts in total fresh and dry biomass vary. The following share of dry to fresh biomass ratio in late autumn was found in the descending order:

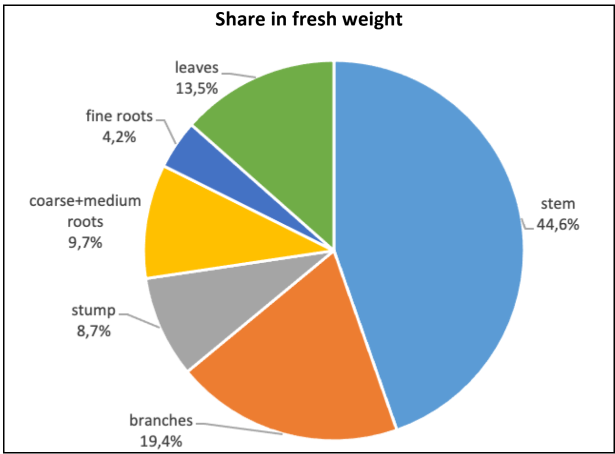
- Branches – 53,3%
- Coarse & medium roots – 51,8%
- Stump – 47,8%,
- Stem and fine roots – 45%
- Leaves – 38,5%

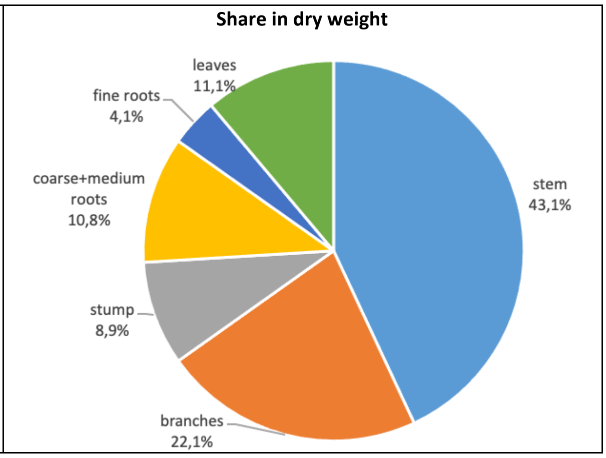
Picture 2-9 illustrates varying dry mass content in different parts of poplars. Total share of different tree parts varies in total fresh and dry biomass, e.g. share of leaves decrease in total dry biomass comparing to fresh biomass and share of branches, contrary, increases in total dry biomass comparing to total fresh biomass.

Table 2-11. Assessment of dry biomass weights at site 25

Sampling No. (clones)	h, m	dbh, cm	Stem weight, dry, kg	Branshes weight, dry, kg	Leaves, weight, dry, kg	Total AGB, weight, dry, kg	Fine roots, weight, dry, kg	Coarse& medium roots weight, dry, kg	Stump, weight, dry, kg	Total BGB, weight, dry, kg	Total biomass, weight, dry, kg
2_1	7,70	5,10	3,51	0,65	0,40	4,56	1,07	0,49	0,47	2,02	6,58
2_2	10,90	9,80	15,35	4,13	2,09	21,56	1,03	3,51	2,20	6,73	28,29
2_3	10,22	8,30	9,77	2,73	1,17	13,67	0,93	2,83	0,73	4,49	18,16
2_4	10,15	8,45	10,08	2,21	1,39	13,67	1,35	2,09	2,35	5,78	19,45
2_5	10,50	8,55	10,58	2,93	0,91	14,42	1,49	2,75	1,68	5,91	20,33
3_1	10,80	11,25	18,63	5,06	2,56	26,26	0,72	2,89	4,79	8,40	34,66
3_2	8,92	8,30	4,41	0,96	0,52	5,89	0,73	1,01	0,72	2,46	8,35
3_3	10,10	8,70	9,68	2,66	1,60	13,93	0,62	2,36	2,11	5,08	19,01
3_4	9,85	9,80	12,87	2,92	1,60	17,38	1,22	3,07	3,16	7,45	24,83
3_5	11,20	12,05	20,48	5,84	3,73	30,04	0,84	5,15	4,81	10,79	40,83
4_1	10,33	12,05	14,31	8,35	4,21	26,87	1,24	4,07	3,52	8,82	35,69
4_2	9,20	8,90	9,63	2,35	1,21	13,20	1,49	3,10	2,49	7,07	20,27
4_3	9,15	7,45	7,70	1,79	1,06	10,55	0,67	2,79	1,47	4,93	15,48
4_4	6,00	5,20	2,84	0,71	0,58	4,12	0,46	0,34	0,59	1,38	5,50
4_5	10,40	12,00	18,63	6,13	3,27	28,03	1,63	5,04	3,39	10,05	38,08
6_1	9,00	9,10	9,90	3,64	1,54	15,08	1,49	3,35	2,71	7,55	22,63
6_2	6,88	4,95	3,11	0,80	0,39	4,29	0,40	0,53	0,67	1,60	5,89
6_3	9,65	10,04	14,22	5,27	1,67	21,16	1,56	3,30	2,55	7,41	28,57
6_4	9,13	8,45	9,27	2,82	1,07	13,16	1,11	2,35	1,41	4,87	18,02
6_5	9,90	11,70	18,09	5,94	2,72	26,75	1,06	4,86	4,13	10,04	36,79
			223,02	**67,88**	**33,69**	**324,59**	**21,07**	**55,83**	**45,92**	**122,81**	**447,39**

Picture 2-8. Share of different poplar parts in total weight





Total biomass consists of various tree parts, some of which are pretty difficult to measure, therefore development various coefficients to asses difficult to measure biomass parts can be very valuable.

The biomass part, which is the easiest to measure is stem dbh. During the project there were developed coefficients, which can be used to measure fresh biomass weight of poplar stem and branches. Therefore, the following coefficients have been developed based on Table 2-10 data to assess different parts of fresh poplar biomass weight based on poplar stem and branches biomass as presented in the Table 2-12.

Table 2-12. Biomass weight coefficients based on combined stem and branches biomass weight

	Stem weight, kg	Branches weight, kg	Leaves, weight, kg	Total AGB, weight, kg	Fine roots, weight, kg	Coarse& medium roots weight, kg	Stump, weight, kg	Total BGB, weight, kg	Total biomass, weight, kg
Fresh biomass			0,141	1,141	0,074	0,173	0,154	0,401	1,542
Dry biomass			0,116	1,116	0,072	0,192	0,158	0,422	1,538
Dry to fresh ratio	0,385	0,385	0,385	0,457	0,455	0,518	0,478	0,491	0,466

3 Carbon footprint

Carbon footprint of Biomass yield improvement assessment action (C.2) was calculated based on car fuel consumption, while travelling to develop biomass yield improvement model for measuring of research sites during NutriBiomass4LIFE project implementation.

It is estimated that carbon footprint from Biomass yield improvement assessment during NutriBiomass4LIFE project implementation **equalled to 5,1 tCO2.**

Table 3-1. Nutribiomass4LIFE carbon footprint from Biomass yield improvement assessment

items	fuel CO2 footprint, kgCO2/l	fuel consumption, l/100km	travel distance, km	CO2 footprint, t CO2
Visiting land plots with petrol cars	2,3	8	27512	5,1
				5,1

4 Continuation

During implementation of NutriBiomass4LIFE project, biomass yield improvement assessment models were developed on limited amount of measurements and data:

- Hybrid poplar plantation biomass yield improvement was assessed for 3 consecutive years following the fertilization till 7-8 year age of plantations – the targeted poplar plantation growth and monitoring period may be up to 20 years.
- Hybrid aspen plantation biomass yield improvement was assessed for 4 consecutive years following the fertilization till 11 year age of plantations – the targeted aspen plantation growth and monitoring period may be up to 30 years.
- Allometric models based on dbh were developed on measurement and assessment of various poplar part biomass were developed on destructive measurements of poplar plantations at 6 year age – the targeted poplar plantation growth and monitoring period may be up to 20 years.
- Allometric models based on dbh were developed on measurement of hybrid aspen plantations at 9 year age – the targeted hybrid aspen plantation growth and monitoring period may be up to 30 years.

Limited amount of data, mainly related to young and medium age biomass plantations) poses certain limitations to apply these models for older plantations and different poplar clones. In order to develop more comprehensive and reliable biomass yield improvement assessment models, the following biomass yield improvement measurement actions will be undertaken as project continuation actions:

- To continue (once in 5 years) measurement (including destructive) at research fields (6) which were used to define a1 and a1 coefficients for formula (4) to assess fresh and dry biomass weight of the plantations based on tree dbh – costs 12,000 EUR once in 5 years
- To continue annual measurements at 1 to 24 biomass yield improvement due to fertilization with DMWTS sites – till biomass on research sites will be harvested – costs 4000 EUR each year
- To continue (once in 5 years) destructive measurements at 25th site to adjust root, leaves and other biomass coefficients – till biomass on research sites will be harvested – costs 6000 eur once in 5 years.

5 Conclusions

Over 4 years of implementation of the project a number of destructive and non-destructive measurements took place to develop models for biomass yield assessment.

The key lessons we learned from biomass yield improvement assessment actions during implementation of NutriBiomass4LIFE project:

- The survival rate is very important for the plantation's overall productivity. The survival rate is mostly dependent on the first-year establishment success, which is heavily impacted by climatic conditions (summer drought and early autumn frost) and clonal selection.
- The productivity of different clones can also vary significantly. During implementation of NutriBiomass4LIFE project, the poplar clones, which proved to be resilient and productive under Lithuanian conditions have been chosen, which is different comparing to initial plantations established in Lithuania.
- Developed biomass models in different fields and for different clones from tree diameter were characterized by a very high coefficient of determination >0.95. It was observed that, when modelling biomass from tree heigh, the values of the coefficient of determination were lower compared to biomass models developed from tree diameter, but still had a high coefficient of determination >0.9.
- The biomass models established in the Kaišiadorys field can be applied to the modelling of the dry biomass of the respective clones AF7, AF34 and OP42 in the Anykščiai experimental field from tree diameter. As a result, it can be concluded that fertilization with DMWTSD in the Anykščiai experimental field significantly increased tree biomass but did not change the ratio of tree biomass to diameter size. That opens opportunity to use developed biomass models for biomass evaluation in plantations fertilized with DMWTSD under implementation of the project NutriBiomass4LIFE.
- Developed models based on tree diameter were used to evaluate biomass yield improvement due to fertilization with DMWTSD at hybrid poplar and hybrid aspen plantations. The following developed coefficients were used while estimating AGB (without leaves) fresh biomass weight:
    - For hybrid poplar AF7 clone, based on combined Marijampole, Kaišiadorys, Anykščiai experiment data, AGB (without leaves) fresh biomass weight calculation is based on coefficient a1 equal to **0.299987**, and coefficient a2 equal to **2.097752.**
    - For hybrid aspen No.8 clone, based on combined Kelmė, Šilutė, Anykščiai experiment data, AGB (without leaves) fresh biomass weight calculation is based on coefficient a1 equal to **0.166815**, and a2 equal to **2.409405.**

- Destructive measurements carried at research site in Kaišiadorys (site 25th) developed the following fresh biomass weight estimations coefficients based on fresh AGB (without leaves) weight:
    - Total fresh AGB weight to combined fresh tree stem and branches biomass weight equals to 1,141;
    - Total fresh BGB weight to combined fresh tree stem and branches biomass weight equals to 0,401;
    - Total fresh biomass weight to combined fresh tree stem and branches biomass weight equals to 1,542.
- It is estimated that on different types of soils one time fertilization with DMWTSD increased biomass yield by 22% at hybrid poplar sites and by 25% at hybrid aspen sites after two years of fertilization. After three years of fertilization, biomass yield impact due to fertilization declined and yield increase was 17% at hybrid poplar sites and 22% at hybrid aspen sites.
- The yield improvement due to fertilization with DMWTSD declining tendency is more evident after four years of fertilization on hybrid aspen sites, when accumulated yield increase declined to 12%. This shows that, in order, to maintain significant biomass yield increase after fertilization with DMWTSD it would be reasonable to repeat fertilization with DMWTSD after three or four years after initial fertilization.
- The research results show that fertilization with DMWTSD has higher positive result on poplar yields established on less fertile soils, which is in line with target to grow biomass crops on less fertile soils to avoid competition with food production.

6 Literature

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