Comparative Assessment of The Quality and Yield of Early-Winter Planted Jerusalem Artichoke Tubers at Different Harvesting Terms

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Abstract
Jerusalem artichoke has multiple valuable economic purposes. To expand the sown area and the production of artichoke culture in the Russian Federation, it is necessary to develop adaptive cultivation technologies considering certain soil and climatic conditions. The harvesting period of tubers of early-winter planted Jerusalem artichoke, spring and autumn, and the green mass harvesting period, 10 and 20 days after the full flowering phase and before tubers harvesting, were studied. The formation of Jerusalem artichoke tubers begins in the budding phase and reaches its maximum in the flowering phase. Up to 33% of tubers die before harvest due to carbohydrate deficiency. Tuber mass formation continues until harvesting. The maximum increase in the average tuber mass by 14.0 g (65-90%) is observed from the budding to the flowering phase. A higher yield of tubers, 16.4 t/ha, is formed during autumn harvesting, which is due to an increase in the productivity of the bush by 435.7 g, the number of its tubers by 12.3 pcs. and the average weight of one tuber by 5.8 g. The maximum yield of Jerusalem artichoke tubers can be obtained by mowing the green mass before their harvesting. This is facilitated by an increase in the productivity of the bush by 78.3-168.9 g, the number of its tubers by 2.0-3.7 pcs. and the average weight of one tuber by 4.5-5.5 g. Jerusalem artichoke has mostly fine tubers – 53-66%. There is a trend towards a decrease in the proportion of small tubers during late harvesting of the above-ground mass and, accordingly, an increase in the proportion of medium and large tubers. During autumn harvesting, Jerusalem artichoke tubers have a higher content of dry matter by 1.9% and protein by 0.3%, while during spring harvesting there is a higher sugar content in them by 5.4%. A trend towards an increase in these biochemical indicators was noted at later terms of harvesting green mass.

Keywords: Jerusalem artichoke, harvesting period, tuber yield, fractional composition, biochemical composition.

Introduction.

Many scientists refer Jerusalem artichoke (Helianthus tuberosus L.) to promising bioenergy crops of various economic purposes [1]. Jerusalem artichoke products can be used for fodder, food, and medicinal purposes [9]. Jerusalem artichoke tubers can be eaten raw, fried, or boiled [10]. They are used in the production of flour, tonic drinks, semi-finished sausages, health food products [11,12]. Jerusalem artichoke tubers are an excellent early spring forage for

cattle. It has been reported that the use of tubers in the diet of cows increases milk yield by 4-5 kg per day [13]. Along with common chicory, Jerusalem artichoke tubers are one of the most cost-effective sources of inulin [14]. Despite a wide range of applications, the sown area of Jerusalem artichoke in the Russian Federation is disproportionately small compared to Europe and the United States and does not exceed 3 thousand hectares [2–4]. Most of the Jerusalem artichoke plantings are concentrated in private subsidiary and small peasant farms [8].

Such low demand for Jerusalem artichoke among the population of Russia is due to the insufficient studies of the crop, the lack of developed adaptive cultivation technologies and, as a result, its low yield and producibility [5,6].

Developing an adaptive cultivating technology for the crop depends much on optimal timing for harvesting tubers and green mass. Despite the harsh Russian climate, Jerusalem artichoke tubers can be harvested in the autumn after the end of the growing season or in the spring after overwintering [15]. The relevance of spring harvesting is determined by the limited duration of the autumn harvesting campaign, the difficulty of separating tubers from stolons, which creates problems during mechanized harvesting [16]. In the northern regions, it is not recommended to leave tubers for overwintering due to the risk of their freezing at low temperatures and low snow cover [17]. During autumn harvesting, preference is given to the latest dates due to the continued outflow of nutrients from the stem to the tubers until the above-ground mass dries up and dies [18]. In this regard, choosing the optimal term for cutting the above-ground mass to obtain both high yield and quality of tubers remains a relevant issue.

Most scientists in Russia, in the Republic of Belarus, in the Republic of Kazakhstan recommend late harvesting of green mass, as they note an increase in the yield of tubers and in their dry matter content [15,19,20].

In this regard, the objective of the study was to determine the optimal time for harvesting tubers and green mass to obtain maximum yield and quality of tubers.

Tasks:

1) determine the yield of Jerusalem artichoke tubers and its structure;

2) identify the features of tuber formation;

3) determine the fractional and biochemical composition of Jerusalem artichoke tubers.

Objects and Methods. Two-year field studies were carried out from 2018 to 2021 on the basis of the Perm Agrarian and Technological University in the Middle Urals of the Russian Federation. We studied two terms of harvesting tubers, spring and autumn, and three options for cutting the green mass, 10 and 20 days after the full flowering phase and before harvesting the tubers.

A two-factor field experiment was carried out using the experimental case method in four replications [21]. The plot area was 20 m^2. The variants were arranged systematically. Skorospelka variety was chosen as the object of research.

The yield of tubers was calculated by a continuous method on the plot, followed by recalculation per 1 ha. Indicators of the yield structure were the density of seedlings and plants before harvesting, field germination and survival of plants during the growing season determined by a continuous method on the plot. The number of tubers in a bush,

their average weight and productivity of a bush were determined on 3 plots with an area of 1 m^2 per plot. The dynamics of tuber formation was determined by one typical plant from the plot according to the phases of development: budding, flowering, or before harvesting. The fractional composition of tubers in the yield was determined by 3 typical plants from the plot. Tubers less than 20 g, 21-80 g and more than 80 g were considered as small, medium and large tubers, respectively. The content of the following biochemical parameters in the tubers was determined: dry matter - according to GOST 28561-90; crude protein - according to GOST 13496.4-2019; crude fiber - according to GOST 31675-2012; crude fat - according to GOST 13496.15-2016; raw ash - according to GOST 32933-2014; water-soluble sugar - according to the Bertrand method. Mathematical data processing was carried out by the method of analysis of variance [21].

For Jerusalem artichoke ridge planting is used. Before planting, the soil was tilled with KPS-4+BZTS-1 and the ridges were cut with KON-2.8. Mineral fertilizers were applied as a background for preplant cultivation with a D-Pol spreader at doses of N221 P74 K374, calculated according to the removal with a tuber yield of 25 t/ha and a corresponding top yield.

Before planting, the tubers were dried, selected by weight of 21-80 g. Tubers were manually planted to a depth of 5-6 cm, 70x40 cm. Planting care included three inter-row treatment with a KOH-2.8 cultivator (before and during germination and at a plant height of 20 cm). The tops were harvested every day with a Husgvarna 128R trimmer. The tubers were harvested by plots with a KTN-2V potato digger with manual picking. The terms of tuber and top planting and harvesting are shown in Table 1.

Table 1 - The actual terms of tuber and top planting and harvesting

Experiment	Tuber planting term	Tuber harvesting term		Top harvesting term		
		spring	autumn	10 days after flowering	20 days after flowering	before the tuber harvesting
1st	10.10.2018	03.05.2020	05.10.2019	06.09.2019	16.09.2019	04.10.2019
2nd	06.10.2019	01.05.2021	26.09.2020	07.09.2020	17.09.2020	25.09.2020

Field studies were carried out on sod-fine-podzolic medium loamy soil with humus content from 1.7% to 2.4% by years. Meteorological conditions varied over the years of research. 2018 was favorable for the cultivation of Jerusalem artichoke. The average daily air temperature was 0.6ºC above the norm, and the amount of precipitation was 28.7 mm lower. The HTI was 1.25, which indicates sufficient soil moisture during the growing season. In 2019, high waterlogging of the soil was noted. The amount of precipitation was significantly higher than the norm - by 213.1 mm, with HTI 2.67. The air temperature during the growing season of 2020 was 1.2ºC above the norm, and the amount of precipitation was at the level of average long-term data. HTI was 1.32.

Results and Discussion.

The sprouting density and field germination power of plants during winter planting were 2.6–2.7 pcs/m^2 and 72–74%, respectively (Table 1). The low field germination power of Jerusalem artichoke is

due to the death of the buds on the planting tuber during the overwintering period

Table 1 - Jerusalem artichoke sprouting density and field germination power

Harvesting term (A)	Top harvesting term (B)						**Average for A**	
	10 days after flowering		20 days after flowering		before the tuber harvesting			
	sprouting density, pcs/m^2	field germination power, %	sprouting density, pcs/m^2	field germination power, %	sprouting density, pcs/m^2	field germination power, %	sprouting density, pcs/m^2	field germination power, %
spring	2.7	73	2.7	73	2.7	74	**2.7**	**73**
autumn	2.7	74	2.6	72	2.7	74	**2.7**	**73**
Average for B	**2.7**	**74**	**2.6**	**72**	**2.7**	**74**		
SSD_{05} of major effects*				A			$F_f < F_{05}$**	$F_f < F_{05}$
				B			$F_f < F_{05}$	$F_f < F_{05}$
SSD_{05} of particular differences				A			$F_f < F_{05}$	$F_f < F_{05}$
				B			$F_f < F_{05}$	$F_f < F_{05}$

* SSD_{05} - the smallest significant difference between the options

** $F_f < F_{05}$ - no difference

Active tuber formation of Jerusalem artichoke begins in the budding phase. A significant increase in the number of tubers in the bush is observed from the budding phase to the flowering phase - by 16.0 pcs. (SSD_{05} = 6.1 pcs) (Fig. 1). After the flowering phase until the first cutting of the green mass, a reduction of tubers by 7.9 pcs. or 33% was noted due to carbohydrate deficiency (SSD_{05} = 6.1 pcs.).

The maximum increase in the average tuber weight was also noted from the budding phase to the flowering phase by an average of 14.0 g (SSD_{05} = 7.8 g). However, after the flowering phase, the average tuber weight slightly continued to increase by 2.8-9.5 g or 10-35%.

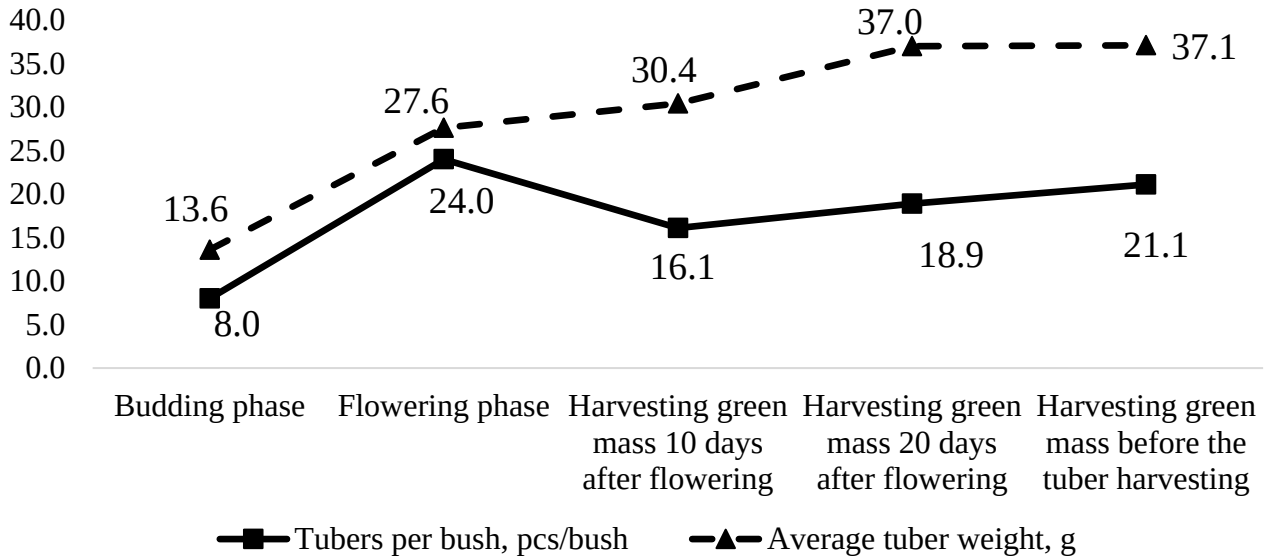

Figure 1 - Increase in the number of tubers and their average weight

During autumn harvesting, the Jerusalem artichoke bush forms on average 18.7 tubers, which is 12.3 tubers more than during spring harvesting (Table 2). This is due to the freezing of tubers during the wintering period. Due to a longer outflow of nutrients during the late top harvesting, the number of tubers in the bush was 2.0-3.7 pcs. more than when harvesting the tops 10 days after flowering. This trend is observed both during the autumn and spring harvesting periods by 2.2-5.0 and 1.8-2.4 tubers respectively.

The average weight of one tuber harvested in autumn was 5.8 g more. This pattern is observed at each time of harvesting the tops: 10 days after full flowering - by 3.5 g, 20 days after flowering - by 7.9 g, before harvesting tubers - by 6.0 g. A significant increase in the average tuber weight was noted at top harvesting 20 days after the full flowering phase - by 4.5-5.5 g.

Table 2 - The number of tubers in the bush and their average weight

Harvesting term (A)	Top harvesting term (B)						**Average for A**	
	10 days after flowering		20 days after flowering		before the tuber harvesting			
	number of tubers, pcs.	tuber weight, g	number of tubers, pcs.	tuber weight, g	number of tubers, pcs.	tuber weight, g	number of tubers, pcs.	tuber weight, g
spring	5.4	26.9	6.0	29.2	7.8	31.1	**6.4**	**29.0**
autumn	16.1	30.4	18.9	37.1	21.1	37.1	**18.7**	**34.8**
Average for B	**10.7**	**28.6**	**12.4**	**33.1**	**14.4**	**34.1**		
SSD_{05} of major effects				A			1.9	4.0
				B			2.3	3.7
SSD_{05} of particular differences				A			3.3	7.0
				B			3.2	5.2

Due to the greater number of tubers in the bush and their average weight, the Jerusalem artichoke bush during autumn harvesting was more productive by 435.7 g or more than three times (Table 3). The productivity of the bush increases with later terms of top harvesting - by 90.6-168.9 g.

Table 3 – Bush productivity, g

Harvesting term (A)	Top harvesting term (B)			**Average A**
	10 days after flowering	20 days after flowering	before the tuber harvesting	
spring	146.8	172.1	256.6	**191.8**
autumn	499.5	655.6	727.6	**627.5**
Average for B	**323.2**	**413.8**	**492.1**	
SSD_{05} of major effects		A	89.4	
		B	102.8	
SSD_{05} of particular differences		A	154.8	
		B	145.4	

During the growing season, plant density decreased by an average of 0.3 pcs/m^2 and amounted to 2.4 pcs/m^2. This is due to a decrease in plant survival by 10% (Table 4).

Table 4 - Plant density before harvesting and the survival rate during the growing season

Harvesting term (A)	Top harvesting term (B)						**Average for A**	
	10 days after flowering		20 days after flowering		before the tuber harvesting			
	plant density, pcs/m^2	survival rate, %	plant density, pcs/m^2	survival rate, %	plant density, pcs/m^2	survival rate, %	plant density, pcs/m^2	survival rate, %
spring	2.4	95	2.4	92	2.2	85	**2.4**	**90**
autumn	2.5	93	2.4	92	2.2	84	**2.4**	**90**
Average for B	**2.4**	**94**	**2.4**	**92**	**2.2**	**84**		
SSD_{05} of major effects				A			$F_f < F_{05}$	$F_f < F_{05}$
				B			0.1	7
SSD_{05} of particular differences				A			$F_f < F_{05}$	$F_f < F_{05}$
				B			0.2	9

During the autumn harvesting period, the tuber yield was 16.4 t/ha, which is 12.2 t/ha more than during spring harvesting (Table 5). When cutting the tops before harvesting the tubers, their yield was 11.4 t/ha, which is 2.7 t/ha more than when it was cut 10 days after the full flowering phase. The tendency to increase the yield from an earlier date of harvesting the tops to a later one is observed during spring and autumn harvesting periods by 0.5-1.0 and 3.7-4.6 t/ha respectively.

Table 5 – Productivity of Jerusalem artichoke tubers, t/ha

Harvesting term (A)	Top harvesting term (B)			**Average A**
	10 days after flowering	20 days after flowering	before the tuber harvesting	
spring	3.7	4.2	4.7	**4.2**
autumn	13.6	17.3	18.2	**16.4**
Average for B	**8.7**	**10.8**	**11.4**	
SSD_{05} of major effects		A	1.4	
		B	2.3	
SSD_{05} of particular differences		A	2.4	
		B	3.3	

A higher yield of Jerusalem artichoke tubers during autumn harvesting is due to the higher productivity of the bush by 435.7 g, the number of tubers in it by 12.3 pcs. and average tuber weight by 5.8 g.

Despite the decrease in plant density by 0.2 pcs/m^2, a higher yield of tubers was noted when the top was cut

before harvesting. This is also due to the high productivity of the bush, the number of tubers and their average weight.

One of the important indicators of the quality of Jerusalem artichoke tubers is their fractional composition. Regardless of the period of harvesting tubers and tops, the studies showed that small tubers predominate in the yield of Jerusalem artichoke - 53-66% (Fig. 2). On average, during spring harvesting, the share of small tubers is higher by 7% (SSD_{05} = 6%). There is a trend towards a decrease in the proportion of small tubers from an earlier term of top harvesting to a later one by 3-4%. This is due to an increase in the average tuber weight by 4.5–5.5 g (see Table 2).

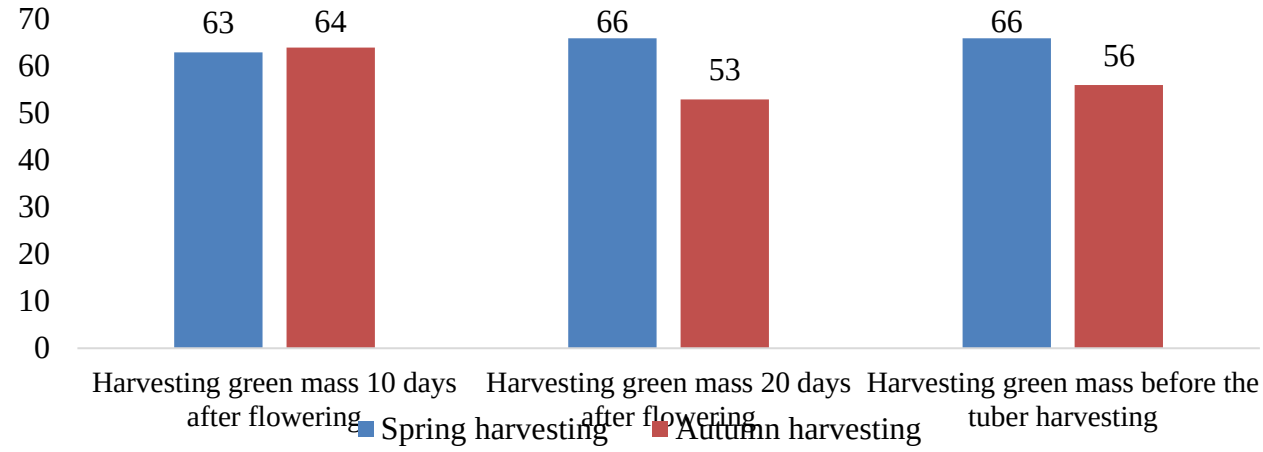

Figure 2 - The share of small tubers in the yield of Jerusalem artichoke, %

With a decrease in the share of small tubers at late top harvesting, the share of medium tubers in the yield of Jerusalem artichoke increases by 1-2% (Fig. 3).

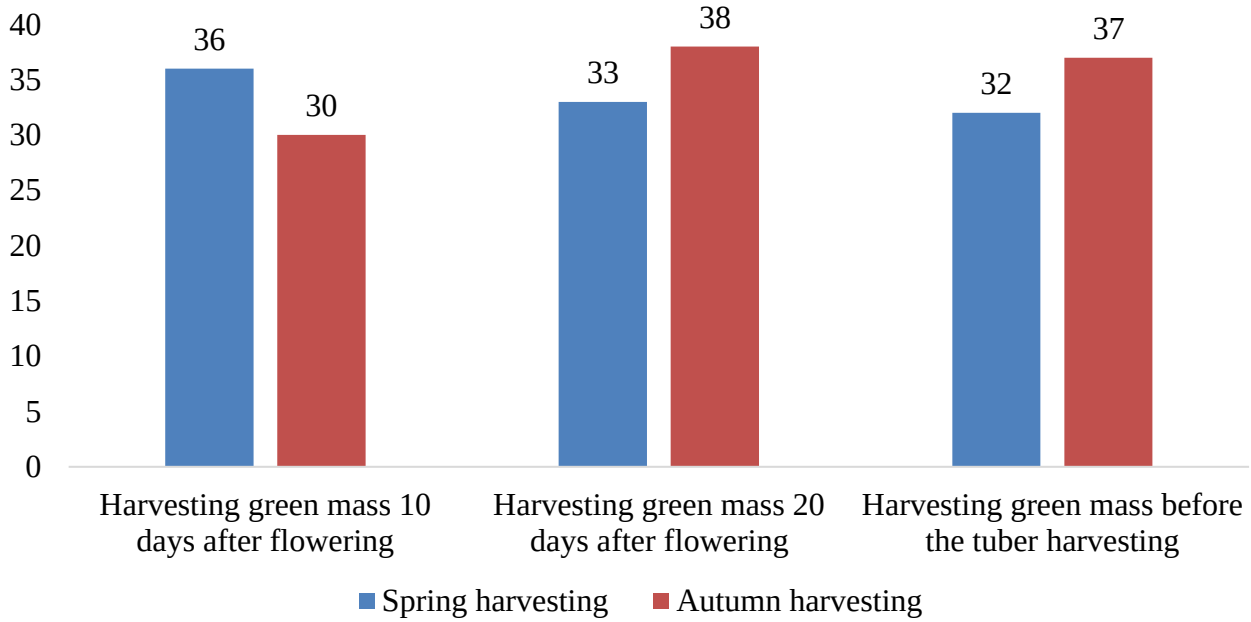

Figure 3 - The share of medium tubers in the yield of Jerusalem artichoke, %

During autumn harvesting in the yield of Jerusalem artichoke, the average share of large tubers was 7%, which is 6% more than during spring harvesting (SSD_{05} = 4%). The trend towards an increase in the share of large tubers continues by 2% with late top harvesting (Fig. 4).

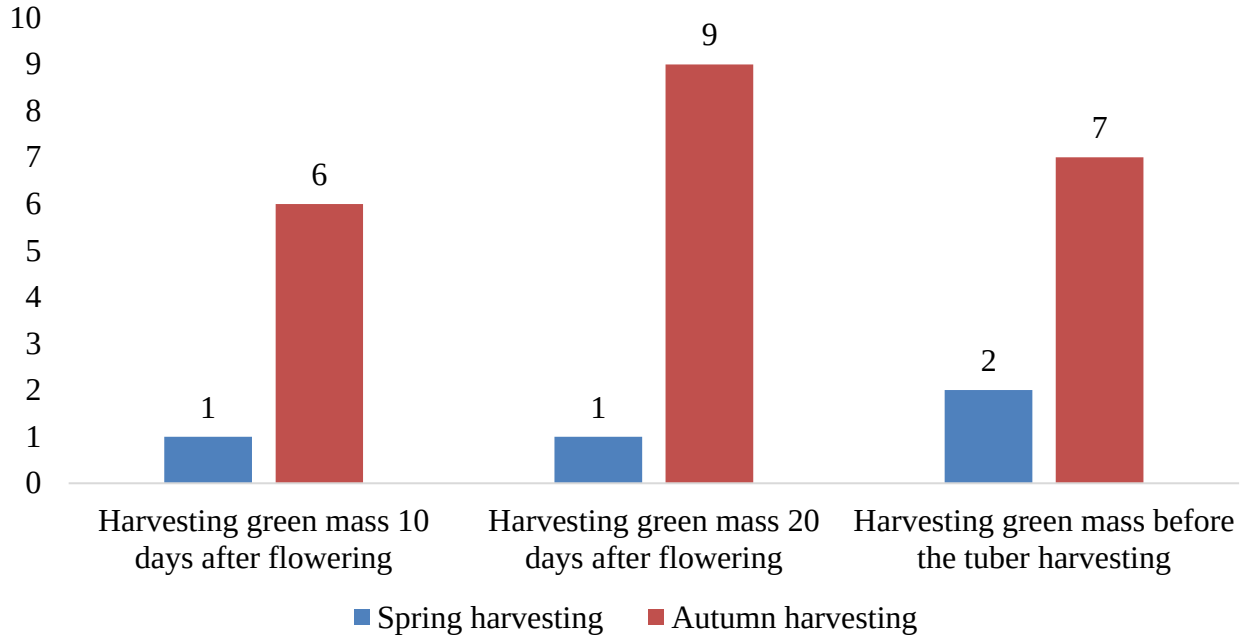

Figure 4 - The share of large tubers in the yield of Jerusalem artichoke, %

During autumn harvesting, the content of dry matter and protein in Jerusalem artichoke tubers increases by 1.9% and 0.3% respectively. The term of harvesting tubers does not have a significant impact on the accumulation of crude fat in them. The content of water-soluble sugar was 5.4% higher during spring harvesting. This is facilitated by the effect of low temperatures during the wintering period. The results of the study of sugar content in Jerusalem artichoke tubers are comparable with the data of scientists from the Republic of Belarus. They reported that the content of the carbohydrate complex in the spring after overwintering was 22-33% higher [2].

The increase in all the studied biochemical parameters was noted at later terms of harvesting green mass: dry matter content - by 0.7-1.9%, water-soluble sugar - by 1.1-2.0%, fat - by 0.44-0.55%, protein - by 0.9-1.1%.

Table 6 - Biochemical composition of Jerusalem artichoke tubers

Harvesting term (A)	Top harvesting term (B)	Biochemical parameters							
		Dry matter, %	**average for A**	sugar, % a.d.m.	**average for A**	oil, % a.d.m.	**average for A**	protein, % a.d.m.	**average for A**
spring	10*	18.0	**19.2**	16.6	**17.8**	1.44	**1.67**	7.5	**8.0**
	20*	19.5		19.0		1.85		8.4	
	before	20.1		17.7		1.71		8.0	

	the tuber harvesting								
autumn	10	20.6	**21.1**	11.5	**12.4**	1.37	**1.79**	7.5	**8.3**
	20	20.5		13.2		2.05		8.3	
	before the tuber harvesting	22.3		12.6		1.96		9.1	
Average for B_1		**19.3**		**14.1**		**1.40**		**7.5**	
Average for B_2		**20.0**		**16.1**		**1.95**		**8.4**	
Average for B_3		**21.2**		**15.2**		**1.84**		**8.6**	
SSD_{05} m.ef. for A		0.6		1.8		$F_f < F_{05}$		0.2	
SSD_{05} p. dif. for A		1.1		3.1		$F_f < F_{05}$		0.3	
SSD_{05} m.ef. for B		0.5		1.4		$F_f < F_{05}$		0.4	
SSD_{05} p. dif. for B		0.6		2.0		$F_f < F_{05}$		0.6	

Note: * – days after the full flowering phase

Summary:

On sod-podzolic soils of the Middle Cis-Urals of the Russian Federation during the early-winter planting Jerusalem artichoke:

1) A higher yield of tubers, 16.4 t/ha, is formed during autumn harvesting, which is due to an increase in the productivity of the bush by 435.7 g, the number of its tubers by 12.3 pcs. and the average weight of one tuber by 5.8 g. The maximum yield of Jerusalem artichoke tubers can be obtained by mowing the green mass before their harvesting. This is facilitated by an increase in the productivity of the bush by 78.3-168.9 g, the number of its tubers by 2.0-3.7 pcs. and the average weight of one tuber by 4.5-5.5 g.

2) The formation of Jerusalem artichoke tubers begins in the budding phase and reaches its maximum in the flowering phase. Up to 33% of tubers die before harvesting due to carbohydrate deficiency. Tuber mass formation continues until harvesting. The maximum increase in the average tuber mass by 14.0 g (65-90%) is observed from the budding to the flowering phase.

3) Small tubers predominate in the yield - 53-66%. During spring harvesting, their share is 7% higher than during autumn harvesting. The share of large tubers is 6% higher during autumn harvesting. At late terms of top harvesting, the share of medium and large tubers increases by 1-2%.

4) Tubers of autumn harvest contain a higher content of dry matter - by 1.9% and protein - by 0.3%, and of spring harvesting - higher water-soluble sugar - by 5.4%. There is an increase in biochemical parameters at later terms of top harvesting.

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