GROWTH, YIELD AND COMPOSITIONAL CHARACTERISTICS OF JERUSALEM ARTICHOKE AS IT RELATES TO BIOMASS PRODUCTION

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Jerusalem artichoke (Helianthus tuberosus L.) has shown excellent potential as a carbohydrate-rich crop. Our initial investigations determined inulin and tuber yields; however, when additional studies showed that good quality pulp remained after inulin extraction and high forage yields per hectare were obtainable, the scope of our investigation was broadened to assess utilization of the total plant. Plant growth, yield and compositional characteristics of Jerusalem artichoke as they relate to biomass production will be reported.

Plant description and characteristics

Jerusalem artichoke is native to temperate North America and adapted to the region circumscribed by the agricultural region contiguous with the northern shore of the Great Lakes, the Red and Mississippi Rivers on the West as far South as Arkansas, eastward to the Piedmont coastal plain of the Eastern seaboard, extending from George north to Quebec. Although often referred to as wild sunflower, it differs from other native Helianthus species by producing perennial, fleshy tubers. Plants grow tall and upright, having either a branching or non-branching form of growth. Small yellow ray and disk florets borne at the end of main stems and branches may produce small, hard seeds although seed production is often poor. Tuber shape, size and display vary from round, knotty clusers to long, smooth single tubers.

Growth begins from tubers early in the season. Maturity is reached within 100 to 130 days. Jerusalem artichoke's moderate tolerance to spring and fall frosts extends its growing season beyond that of conventional field crops. This characteristic aids some experimental lines in achieving high tuber yields. Late maturing genotypes do not mature.

Pest and disease problems are few. Of the diseases, Sclerotinia wilt (Sclerotinia sclerotiorum) is the most efficacious; however, rust, Septoria leaf spot and downy mildew are potential problems. White mold and soft rot tuber diseases may occur in storage. Unharvested tubers winter well in the soil and remain healthy until their removal in the spring. In all respects, Jerusalem artichoke is adaptable and remarkably resilient to damage which explains its high yield potential.

Growth functions

The growth of plant tops and tubers are influenced by the flowering process. Considerable variation in time of flowering occurs within the species, the earliest lines flowering in early July, and the latest at the end of September. When flower buds appeared, the rate of dry matter accumulation in the aerial parts decreased (Fig. 1). Maximum dry matter (DM) yields of plant tops were 12.2 T/ha and occurred after flowering. The subsequent loss of dry matter was, in part, the result of leaf senescence and abscission.

Tubers develop from stolons which enlarge with the onset of flowering (Fig.1). The number of tubers increased until 50 percent flowering occurred and subsequently declined to approximately 25 tubers/plant. During that time, the weight per tuber increased exponentially. It is hypothesized that translocation of material from some tubers, as well as leaf senescence, contributes to increasing the rate of individual tuber dry matter accumulation. Tuber yields were 283.5 g DM/plant which is equivalent to 9450 kg DM/ha (42 T/ha fresh weight). Plant growth was terminated by killing frosts.

Variability in forage yield and composition

Forage composition changes with advancing maturity (Table 1). Protein decreased continually, but between week 6 and 7 there was a significant reduction. Conversely, the ADF and lignin fractions increased between weeks 7 and 8. These changes were associated with cessation of flowering. Cellulose and ash contents remained relatively constant throughout the sampling period.

Considerable variation in dry matter yield and forage composition exists among accessions (Table 2). High forage yielding lines generally were those which flowered late. All accessions were harvested when flowering began so the variability in DM content was not influenced by stage of maturity. Rather, DM content appeared to be associated with prevailing climatic conditions at time of harvest. The low yielding line (NC10-50) is a leafy, relatively fine stemmed accession having the highest protein and lowest ADF and lignin contents among all accessions evaluated. The greatest amount of protein, ADF and lignin in the respective high accession was 1.8, 2.1 and 3.4 times that of the low value accession. Based on the magnitude of variability, it appears that forage composition could be readily improved through plant breeding.

Variability in tuber yield and composition

Total reducing sugar (TRS) content and fructose: glucose (F/G) ratios were used to estimate inulin content and its molecular size. Actual inulin content and molecular size found in Jerusalem artichoke is not clearly understood, but research is currently underway at a western Canadian university to identify degree of polymerization and the changes which occur during tuberization and later during storage.

Ontogenetic changes in carbohydrate content and composition were recorded in two Jerusalem artichoke accessions (Table 3). The native Manitoba accession had a higher average TRS content and a wider range of values over the sampling period than the higher yielding Russian occession. A trend toward lower reducing sugar content and percent fructose was evident in the native strain, whereas TRS content remained relatively constant in the Russian line.

The duration and conditions of storage alter carbohydrate and DM content of the tubers (Table 4). Holding the tubers at 3°C and 75% relative humidity for eight weeks allowed some dehydration of the tubers and the greatest reduction in TRS content. Freezing the tubers caused a small increase in DM content, but the least reduction in TRS of those storage treatments imposed.

The variability in carbohydrate content among several selected accessions ranged from 13.2 to 27.7 percent when harvested late in the season (Table 5). Fructose: glucose ratios also differed, but no relationship existed between high TRS yields and high F/G ratios. In another study to determine composition of the carbohydrated-extracted pulp, significant variability was identified for NDF, ADF, acid-detergent lignin and either extract (Table 6). Neither protein nor digestible energy varied greatly; however, the levels found indicates that the pulp has good feeding value. Amino acid analysis revealed that lysine and methionine contents in the pulp are high (Table 7). Protein quality is considered to be very good.

It is evident that considerable variability in yield and carbohydrate content exists within the species although accessions high in carbohydrate often produce low yields. A small breeding effort showed interesting results. As summarized in table 8, high TRS lines crossed with intermediate carbohydrate-high yielding branching and non-branching lines (standards) produced significant ranges in percent TRS, fructose and protein. This suggests that rapid progress could be made when plant utilization is determined and plant breeding objectives are established.

Production requirements

The highest Jerusalem artichoke yields of 75 tonnes/ha (34 T/ac) occurred in a year when temperatures were below normal and precipitation above normal. Since tubers contain approximately 87.5 percent water, yield is highly dependent on soil water potential throughout the growing season and particularly during tuberization. Production requirements for Jerusalem artichoke are similar to potatoes. Generally, the requirements are:

- soils; sandy-loam, sandy clay loam
- fertilizers (kg/ha); N-90, P_2O_5 - 56, K20-50

  (or according to regional potato recommendations)
- weed control; inter-row cultivation
- fungicide; (possibly)
- pesticides; (none required to date)

Estimated energy requirements for producing the crop are derived using data by Southwell and Rothwell (1978). The data are presented in terms of energy resource depletion (ERD). Distinction is made between fossil fuel and total energy resources consumed in producing the crop (Table 9). ERD is based on colorific values of fuel used (converted from BTU's) times the supply system efficiency factor (i.e., the actual plus energy absorbed in the supply system as losses or expenditures).

Stating Jerusalem artichoke forage and tuber yields in terms of alcohol production, each respective component would yield 4580 and 2880 l/ha (Table 10). The energy output of each is 1181 X 10^6 kcal/ha from the tubers and 1176 X 10^6 kcal/ha from the forage component.

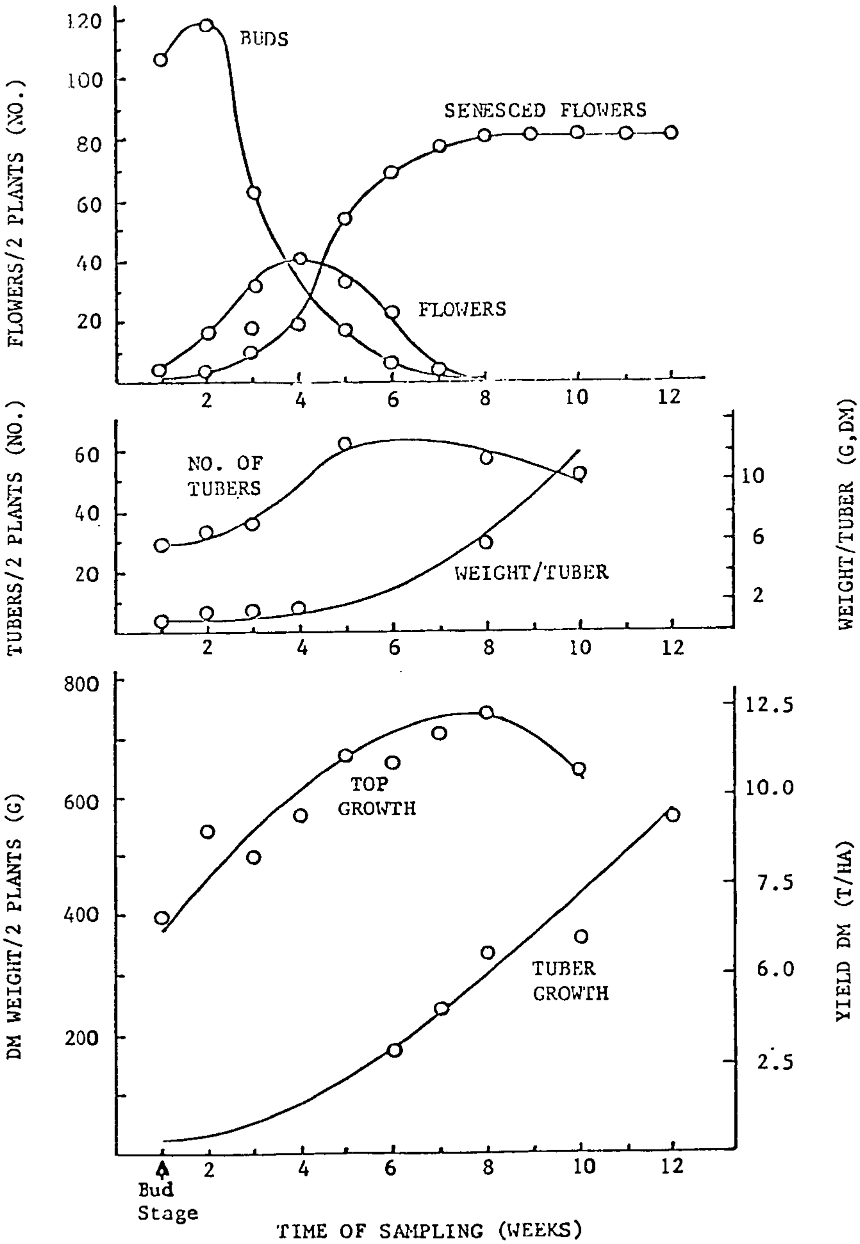

FIGURE 1 -- Flowering pattern and growth rates of tubers and plant tops sampled at weekly intervals beginning at the bud stage.

Table 1. Change in composition and content of Jerusalem artichoke forage sampled at weekly intervals following the flower bud stage of development

Plant Fraction	Sampling Period (Weeks)											
	1[a]	2	3	4	5	6	7	8	9	10	11	12
Protein (% DM)	18.0	17.0	15.0	14.3	13.5	12.5	9.7	9.7		7.9		6.2
ADF (% DM)	35.3	31.8	33.9	31.1	32.1	35.5	35.4	40.9		45.6		46.6
Lignin (% DM)	6.21	6.0	7.2	6.1	6.3	6.9	6.7	7.8		9.4		8.9
Cellulose (% DM)	23.0	23.2	22.3	22.3	23.6	23.9	24.2	-		-		-
Ash (% DM)	2.1	2.0	2.2	2.3	2.3	2.4	2.3	-		-		-

[a] Bud stage

Table 2. Forage content of crude protein (CP), acid-detergent fiber (ADF) lignin (Lig) content of selected Jerusalem artichoke accessions sampled at early flowering or prior to frost.

Accession	DM Yield (t/ha)	DM Content (%)	C P	ADF	Lig
			--------% of Total DM	---------	
NC 10- 5	9.81	32	11.96	52.21	11.40
8	31.78	28	13.85	45.76	8.48
9	8.35	35	10.72	50.69	12.02
13	14.67	38	15.95	42.16	12.77
18	7.26	40	11.92	44.14	7.69
44	22.97	22	9.54	34.37	7.10
50	2.30	23	17.28	25.21	3.78
60	26.04	31	13.21	40.25	7.21

Table 3. The effect of harvest dates on the content and composition of reducing sugars in fresh tubers of two strains of Jerusalem artichoke.

Strain	Harvest date	Reducing sugar %	Fructose %	Glucose %	F/G ratio
Manitoba	Sept. 28	21.5	87.6	9.1	9.6
	Oct. 12	23.3	80.9	12.5	6.5
	20	21.8	81.8	12.0	6.8
	26	19.9	78.7	13.2	6.0
	Nov. 2	22.7	74.3	16.1	4.6
	14	18.5	78.9	12.6	6.3
	23	16.5	76.0	13.6	5.6
MEAN		20.6	79.7	12.7	6.5
Russian	Sept. 28	14.5	82.4	11.2	7.4
	Oct. 12	18.7	78.7	12.9	6.1
	20	16.8	76.8	14.4	5.3
	26	16.2	74.9	14.8	5.1
	Nov. 2	19.9	74.1	14.6	5.1
	14	13.8	79.2	11.8	6.7
	23	18.4	71.8	14.9	4.8
MEAN		16.9	76.8	13.5	5.8

Table 4. Dry matter and total reducing sugar (TRS) content in Jerusalem artichoke tubers stored at different temperatures and relative humidity levels.

	Storage Time and Conditions			
	0 Weeks	8 Weeks		
		$3^{o}C$/95%RH	$3^{o}C$/75%RH	$-40^{o}C$/Ambient RH
Dry Matter (%)	25.8	25.5	28.2	26.5
TRS (% of DM)	78.4	66.7	62.9	72.5

Table 5. Content and composition of reducing sugars in fresh tubers of six strains of Jerusalem artichoke harvested on October 23, 1972.

Strain	Reducing sugar %	Fructose %	Glucose %	F/G ratio
MS #1	27.7	75.3	14.9	5.1
MN #5	20.7	74.7	15.1	4.9
HMR #1	17.1	78.2	13.4	5.8
HMR #2	18.6	71.0	16.1	4.4
HMR #3	17.3	75.2	16.0	4.7
Commercial	13.2	80.6	12.3	6.6

Table 6. Composition of several experimental Jerusalem artichoke accessions.

Accession	Digestible Energy	C P	NDF	ADF	AD Lig	Ether Extract
	Mcal/kg (DM)	% of DM				
Morden #5	3.509	26.9	47.8	34.4	1.43	3.9
Perron	3.551	26.7	45.1	42.8	2.62	2.9
Branching	3.603	25.6	47.6	38.1	0.92	3.3
Non-Branching	3.563	25.4	50.4	38.1	0.60	3.2

Table 7. Amino acid analysis of inulin-extracted Jerusalem artichoke pulp.

Amino Acid	Content (g/100g Sample N)	Amino Acid	Content (g/100g Sample N)	Amino Acid	Content (g/100g Sample N)
Lys.	48.98	Ser.	30.42	Meth.	11.79
His.	13.08	Glut.	71.43	Iso	30.80
NH_3	12.67	Pro.	21.83	Leu	46.45
Arg.	31.70	Gly	32.01	Tyr.	22.37
Asp.	59.52	Ala	35.44	Phe	28.63
Thr	33.36	Vil	38.31		

Moisture 5.9%

Protein (D.B., N X 5.7) 16.16%

Recovery. 86.9%

Table 8. Variability in percent total reducing sugar (TRS), fructose (F) and protein among Jerusalem artichoke advanced selection and new crosses compared to standard branching and non-branching types.

	No. of or Comparisons	Range (%)		
		TRS	F	Prot.
Adv. selections	21	17.4-22.4	68.0-80.4	23.1-27.0
New crosses	41	10.66-22.8	65.9-80.1	21.0-30.3
Branching (standard)		21.2	75.3	25.6
Non-branching (standard)		20.3	75.5	25.4

Table 9. Energy requirements in terms of energy resource depletion (ERD) of fossil fuel (FF) and total (T) to produce 1 hectare of Jerusalem artichoke*

Energy inputs/ha	ERD (FF)	ERD (T)
	(10^3K cal)	
Culivation	81	83
Planting	171	174
Fertilizer**	2327	2402
Inter-row cultivation (2)	145	146
Fungicide	184	193
Sprout inhibition	148	160
Harvesting - tops ***	311	317
- tubers	767	780
Hauling to storage	878	878
Total	5012	5133

* Potato production energy requirements by category according to Southwell, P. H. and T. M. Rothwell.

** Fertilizer rates (kg/ha) in Manitoba: N - 90; $P_2)_5$ - 56; $K_2)$ - 50.

*** Assumes values similar to corn silage.

Table 10. Theoretical yields of ethyl alcohol from several crops (Manitoba yield basis)

Crop	Plant part	Yield		ETOH
		Fresh wt.	Carbohydrate	l/ha
		---------kg/ha---------		
J. artichoke	Tuber	42000	7088	4580
Sugar beet	Root	33600	4930	3185
Corn	Grain	6700	4150	2680
Wheat	Grain	3360	2240	1447