

# Fertilizer and intercropped legumes as nitrogen source for Jerusalem artichoke (*Helianthus tuberosus* L.) tops for bioenergy

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Jerusalem artichoke (*Helianthus tuberosus* L.) produces substantial shoots not used as food. To test its potential as a sustainable bioenergy crop, we studied the effects of synthetic fertilizer and intercropped legumes as nitrogen (N) sources on the growth, aboveground biomass dry matter yield and energy qualities of this crop. Plant height, leaf area index (LAI), SPAD-value, biomass yield, ash content and mineral element composition were determined. Mean aboveground biomass yields were not significantly affected by N source (legume intercrops and synthetic fertilizer) and ranged from 13 to 17 t ha<sup>-1</sup>. Remarkably, plants given no fertilizer yielded equally to plants given 90 N kg ha<sup>-1</sup>. These results confirm that Jerusalem artichoke, compared to other energy crops, have less need for N and can potentially be sustained by N fixing legumes in an intercropped system. This could reduce or eliminate production and environmental cost in cultivation of biomass feedstock for energy use.

**Key words:** *Helianthus tuberosus*, synthetic nitrogen fertilizer, intercropping, legumes, biomass, mineral element composition

## Introduction

Jerusalem artichoke (*Helianthus tuberosus* L.) is an herbaceous perennial plant, related to sunflower (*Helianthus annuus* L.), and has long been grown for its edible tubers, as livestock feed and as an ornamental (Ben Chekroun 1990, Rodrigues et al. 2007, Ma et al. 2011). The main industrial use of the crop is centred on its fructan-rich tubers hydrolysed to produce fructose (Monti et al. 2005). A recent review by Johansson et al. (2015) detailed the potential of Jerusalem artichoke as a source of protein and a biorefinery crop. The plant grows rapidly, requires minimal pesticides, fertilizer and water, tolerates marginal land and produces plentiful biomass (Long et al. 2014, Yang et al. 2015). Although often managed as an annual, the crop is perennial, and there is potential to manage it in that way in order to maximize the production from a single set of establishment costs. It is highly frost-tolerant (Negro et al. 2006), being native to eastern North America as far north as the province of Quebec.

The crop has bioenergy potential. This would require managing the crop as a perennial and annual nutrient replenishment. Efforts to lower energy input by reducing fertilizer use in bioenergy crop production could improve sustainability. Jerusalem artichoke is a good candidate for this purpose because it is less responsive to N fertilization than most energy crops (Slimestad et al. 2010).

The above-ground biomass of Jerusalem artichoke can be used to produce biogas and bioethanol (Cervigni 1990, Tuck et al. 2006) with heating value of 15.5 MJ kg<sup>-1</sup> (Tencl and Sladky 2001), and could be burnt for combined heat and power production (CHP) or fermented after acid hydrolysis to break down the ligno-cellulosic biomass to fermentable carbohydrate for transportation biofuel (Philp et al. 2013). Baldini (2004) recorded above-ground biomass of 25 t ha<sup>-1</sup> dry matter. Mays et al. (1990) reported a biomass yield of 30.7 t ha<sup>-1</sup> when 56 N kg ha<sup>-1</sup> fertilizer was applied. Legumes biologically fix N and their inclusion into cropping systems, particularly as intercrops, can reduce energy use by reducing the need for N fertilizer of the co-crop (Jensen and Hauggaard-Nielsen 2003).

Partly due to its potential as a bioenergy crop, the cultivation of Jerusalem artichoke as a specialty crop is increasing (Yang et al. 2015). Information on field performance at high latitudes is scarce and there are few studies on this crop's response to mineral nutrition, especially synthetic N fertilizer. There is even less information on the potential responses of Jerusalem artichoke to intercropping with legumes. According to Curt et al. (2006), studies on Jerusalem artichoke for bioenergy use have not been exhaustive and this is still true. The objective of the study was to assess the effects of synthetic fertilizer and legume intercrops on growth, aboveground biomass yield, mineral element composition and energy quality of Jerusalem artichoke.

## Materials and Methods

### Experimental site

Field studies were conducted in 2009 to 2011 at the Viikki Research Farm, University of Helsinki, Finland (60°13' N 25°02' E; 3 m a.s.l.). Soils in this area are silty clay loam with 6–12% organic matter content and pH 6 (Mokma et al. 2000). The weather data (Table 1) was recorded each year at the Finnish Meteorological Institute (FMI), Kaisaniemi station, 9 km from the experimental site. Mean temperatures in 2009 and 2011 were higher than long-term average, whereas 2010 was cooler than the long-term average. The wettest year was 2011 with a total precipitation of 748 mm.

Table 1. Mean air temperature (°C) and total monthly precipitation (mm) in Helsinki from 2009 to 2011, and the long-term averages (1981–2010) (Finnish Meteorological Institute)

Month	Mean air temperature (°C)				Total monthly precipitation (mm)			
	1981–2010	2009	2010	2011	1981–2010	2009	2010	2011
January	-3.9	-2.8	-10.4	-4.4	52	33	30	70
February	-4.7	-3.6	-8.1	-9.9	36	20	45	24
March	-1.3	-0.9	-1.8	-1.0	38	34	54	15
April	3.9	4.5	4.6	5.6	32	7	42	29
May	10.2	11	11.5	9.9	37	45	59	27
June	17.8	14.1	14.6	16.7	63	75	33	49
July	16.3	17.2	21.7	20.6	80	131	49	56
August	15.8	16.7	18.1	17.5	79	49	97	173
September	11.5	13.5	12.2	13.6	56	40	50	88
October	6.6	4.2	6.0	8.5	76	90	29	69
November	1.6	3.6	-0.5	5.3	70	86	89	27
December	-2.0	-3.6	-7.5	3.4	58	51	87	121
Average/Total	5.9	6.2	5.1	7.2	677	661	664	748

### Establishment of intercropping experiment

In May 2009, seed tubers of Jerusalem artichoke cultivar “French white” were manually planted 10 cm deep into 12 m<sup>2</sup> plots, 30 cm within and 60 cm between rows. Five treatments were studied: sole-cropped Jerusalem artichoke fertilized in the first year shortly after planting and in the second year in May with 60 N kg ha<sup>-1</sup> fertilizer (EY Lannoite NPK 16-7-13, Cemagro Oy, Lohja, Finland) and four pre-inoculated legumes each sown into the Jerusalem artichoke plots. The legumes were goat’s rue (*Galega orientalis* L.), red clover (*Trifolium pratense* L.), sweet clover (*Melilotus alba* Medik.) and vetch (*Vicia sativa* L.) sown at 23, 7, 20 and 49 kg ha<sup>-1</sup>, respectively. Goat’s rue was inoculated with *Rhizobium galegae*, red clover with *R. leguminosarum* biovar *trifolii*, sweet clover with *Sinorhizobium meliloti*, and vetch with *R. leguminosarum* biovar *viciae*. No fertilizer was applied in legume plots. Weeds were manually removed when necessary. The treatments were arranged in a randomized complete block design with four replicates.

### Establishment of N fertilizer experiments

In May 2010 and 2011, seed tubers of equal sizes were manually planted in 1 m × 3 m plots with the same plant spacing as in 2009. Prior to planting, 0, 30, 60 and 90 N kg ha<sup>-1</sup> (EY Lannoite NPK 16-7-13, Cemagro Oy, Lohja, Finland) was applied and harrowed in the soil. The experiment was arranged in a randomized complete block design with four replications. Weeds were manually removed when necessary.

### Growth measurements

At the onset of flowering during each growing season, plant height (cm) from soil surface to the highest point of the canopy was measured. Leaf Area Index (LAI) was measured between 0900 and 1100 during the day by a Sun-

Scan Canopy Analysis System equipped with a BF3 sunshine sensor (SS1-UM-2.0, Delta-T Devices Ltd, Cambridge, UK). The SPAD-values of fully expanded young leaves were measured (SPAD-502 Chlorophyll meter, Minolta, Japan).

At the end of September, above-ground biomass from 1 m<sup>2</sup> area was manually harvested from each plot. In the legume intercropped trial, the rest of the plots were cleared to allow regrowth in the following growing season. The tubers were harvested with a potato harvester in each year, and fragments missed by the harvester re-established the plots in the following spring. The harvested samples were dried at 70 °C for 3 days and weighed. Dried samples were crushed and ground (0.5 mm sieve, ZM 200 centrifugal mill, Retsch GmbH, Haan, Germany) and stored at room temperature in sealed plastic bags until further analysis.

### Analysis of mineral elements and energy

Ground samples were subsequently used to determine ash content, energy value and mineral element composition of the biomass. Ash content was determined by burning one gram of dried ground samples in a muffle furnace (LV 15/11/P320, Nabertherm GmbH, Germany) for 12 h at 575 °C, cooled in a desiccator and weighed. A bomb calorimeter (Parr 1241EA, Parr Instrument Co., Moline, IL, USA) was used to determine the energy value as described by Seleman et al. (2013). Total C and N concentrations were determined using a Vario Max CN (Elementar Analysensysteme GmbH, Germany). The concentration of chloride (Cl) was analysed according to Mäkelä et al. (1998) using a chloride analyser (Model 926, Sherwood Scientific Ltd., Cambridge, U.K.). Concentrations of calcium (Ca), magnesium (Mg), potassium (K) and sulphur (S) were determined with an Inductively Coupled Plasma Optical Emission Spectrometer (iCAP 6200, Thermo Fisher Scientific, Cambridge, UK) after microwave-assisted digestion with nitric acid as previously described by Epie et al. (2014).

### Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using SPSS version 24 statistical software (IBM, Armonk, NY, USA). Levene’s test of homogeneity of variance of two-year data for all variables was not significant, so a combined ANOVA was performed (Gomez and Gomez 1984). Tukey’s b test was used to separate means at probability level of 5%.

## Results

Legumes in the intercrops did not have a significant effect on total above-ground biomass and energy yields of Jerusalem artichoke (Table 2). Above-ground biomass yields ranged from 13 to 17 t ha<sup>-1</sup>. Plants fertilized with synthetic N grew taller than those intercropped with legumes although significantly so with only vetch ( $p < 0.05$ ). Goat’s rue and sweet clover intercrops or fertilized Jerusalem artichoke had significantly ( $p < 0.05$ ) higher LAI values than the other two treatments.

Table 2. Leaf area index (LAI), height, aboveground biomass and energy yield of Jerusalem artichoke treated with N fertilizer or intercropped with legumes during two growing seasons (2009 and 2010) in Helsinki, Finland.

Treatment	Height (cm)	LAI	Biomass (t ha <sup>-1</sup> )	Energy yield (GJ ha <sup>-1</sup> )
60 N kg ha <sup>-1</sup>	176b	9.4b	17	268
Goat’s rue	164ab	9.5b	14	223
Red clover	161ab	7.4a	15	239
Vetch	152a	7.0a	13	213
Sweet clover	163ab	9.5b	14	217
<i>p</i> -value	**	***	ns	ns

Means in the same column followed by the same letter(s) are not different at  $p \leq 0.05$  probability levels by Tukey b; ns=not significant; \*\*, \*\*\*  $p \leq 0.01$ ,  $p \leq 0.001$ , respectively

N fertilizer and intercropping with legumes did not significantly influence the ash, Cl, Ca, Mg concentrations and C:N ratio of Jerusalem artichoke (Table 3). Mean ash content was 7.1%. K) concentration was significantly higher in the N-fertilized treatment than in the goat’s rue and vetch treatments, and S concentration was higher in the synthetic fertilizer treatment than in three of the legume treatments. The C:N ratio averaged 68.

Table 3. Ash content and mineral element composition of Jerusalem artichoke treated with N fertilizer or intercropped with legumes during two growing seasons (2009 and 2010) in Helsinki, Finland. Data shown are means, n = 8.

Treatment	Ash (%)	Cl (g kg <sup>-1</sup> )	Ca (g kg <sup>-1</sup> )	K (g kg <sup>-1</sup> )	Mg (g kg <sup>-1</sup> )	S (g kg <sup>-1</sup> )	C:N ratio
60 N kg ha <sup>-1</sup>	7.1	1.9	12.2	27.8b	1.8	1.4b	58
Goat's rue	6.6	1.7	9.5	18.5a	1.3	0.7a	75
Red clover	7.4	2.0	11.7	22.2ab	1.7	0.9ab	66
Vetch	6.8	1.8	10.5	19.6a	1.5	0.8a	68
Sweet clover	7.4	2.0	11.8	22.2ab	1.7	0.7a	75
<i>p</i> -value	ns	ns	ns	***	ns	*	ns

Means in the same column followed by the same letter(s) are not different at  $p \leq 0.05$  probability levels by Tukey b. ns=not significant; \*, \*\*\*  $p \leq 0.05$ ,  $p \leq 0.001$ , respectively

In the second year of the experiment, and also in the year following the experiment, the Jerusalem artichoke plots re-established naturally from tuber fragments left after machine harvesting. Goat's rue re-established in the second year, but the other three legume co-crops did not (data not shown).

In the second study, different rates of synthetic N fertilizer did not have significant effects on height, SPAD-value, LAI, biomass and energy yields, ash content and mineral element composition of above-ground biomass of the Jerusalem artichoke plants (Table 4 and 5). Shoot biomass yield averaged 11.6 t ha<sup>-1</sup> and ash content averaged 10.6%.

Table 4. Height, SPAD-value, leaf area index (LAI), above-ground biomass and energy yield of Jerusalem artichoke grown at four N fertilizer rates during two growing seasons (2010 and 2011) in Helsinki, Finland.

N fertilizer treatment (kg ha <sup>-1</sup> )	Height (cm)	SPAD-value	LAI	Biomass yield (t ha <sup>-1</sup> )	Energy yield (GJ ha <sup>-1</sup> )
0	160	34.8	5.8	11.1	190
30	161	34.9	6.3	11.5	182
60	155	34.8	5.8	12.0	190
90	159	35.7	6.1	11.7	186
<i>p</i> -value	ns	ns	ns	ns	ns

ns=not significant

Table 5. Ash content and mineral element composition of Jerusalem artichoke grown at four N fertilizer rates during two growing seasons (2010 and 2011) in Helsinki, Finland. Data shown are means, n = 8.

N fertilizer treatment (kg ha <sup>-1</sup> )	Ash (%)	Cl (g kg <sup>-1</sup> )	Ca (g kg <sup>-1</sup> )	K (g kg <sup>-1</sup> )	Mg (g kg <sup>-1</sup> )	S (g kg <sup>-1</sup> )	C:N ratio
0	11.1	2.4	8.0	23.6	1.2	1.3	30.2
30	10.6	2.2	7.8	24.3	1.1	1.4	29.6
60	10.3	2.1	8.0	25.2	1.2	1.5	30.5
90	11.3	2.4	7.7	23.5	1.1	1.4	31.3
<i>p</i> -value	ns	ns	ns	ns	ns	ns	ns

ns=not significant

## Discussion

According to the results Jerusalem artichoke tolerated both low rates of N fertilization and the presence of co-crops, and that key aspects of composition of the above-ground matter and yield were relatively unchanged by the treatments studied.

The low N fertilizer requirement of Jerusalem artichoke shown in this study has been reported in earlier studies (Duke 1983, Slimestad et al. 2010). SPAD-value, which is often used as an indicator of N deficit in tuberous crops (Rodrigues et al. 2005), was consistent across treatments in this study, as previously shown in Spain by Rodrigues et al. (2007). Elsewhere, high N fertilizer rates were associated with increased tuber yield in Spain (Rodrigues et

al. 2007) and above-ground biomass yield in France (Barloy 1988), but this was not the case in this study. Jerusalem artichoke has shown a strong ability to extract nutrients from soils (Cors and Falisse 1980) and it may be that its root exudates are effective at promoting the breakdown of soil organic matter, freeing mineral N that is then taken up. The literature on root exudates from *Helianthus* species is surprisingly scarce (Bowsher et al. 2016). Soil organic N concentrations are high on the Viikki farm, following five centuries of cattle farming (Tammeorg et al. 2014). Although, there was no response to N fertilizer in this study, the results tend to indicate 60 N kg ha<sup>-1</sup>, where soil N content is low, in line with previous recommendations of a maximum application for Jerusalem artichoke tuber yields (Schittenhelm 1999). Increasing N fertilizer rates also showed little effect on mineral element composition of the Jerusalem artichoke tops.

In both experiments, Jerusalem artichoke crop yields were highly variable between replicates as well as between treatments, in line with previous studies (Denoroy 1996). Furthermore, there was a large difference in yields between the experiments, although they were only about 200 m apart and grew in overlapping years as the legume experiment was conducted in 2009 and 2010 while the fertilizer experiment was conducted in 2010 and 2011. The year 2009 had more precipitation in June and July than the other two years. Jerusalem artichoke is considered to be sensitive to soil moisture (Mezencev 1985), and high precipitation was associated with the greater plant height and higher LAI in the intercropped experiment than in the fertilizer experiment. Barloy and Fernandez (1991) reported a five-fold difference in tuber yields of Jerusalem artichoke, depending on growing conditions. Maybe harvesting the above-ground dry matter late in October when high shoot biomass yields are obtained in Jerusalem artichoke (Gunnarson et al. 2014) could have mitigated the yield differences in this study.

The legume intercrops were poorly durable in the dense shade (high LAI) of the Jerusalem artichoke. LAI values in this study were in line with those reported for normal growing conditions (Hay and Offer 1992). The vetch chosen was an annual, but there was no evidence of re-establishment from self-sown seed. The soil disturbance during harvesting with the mechanical potato harvester would have resulted in further weakening of the co-crops. The scarcity of related literature suggests that the high LAI of this crop and the annual disturbance of soil during harvest together preclude long-term intercropping of Jerusalem artichoke.

When this work started, sustainable sources of N for energy crops were sought in order to minimize the fossil fuel usage and greenhouse gas release attendant on fertilizer synthesis (Stoddard 2007), and biological N fixation by legumes was seen as appropriate. Since that time, it has become clear that N for bioenergy crops can be obtained from biogas plant digestate and other recycled sources.

The experimental treatments had little significant effect on the mineral element composition of the above-ground biomass of the Jerusalem artichoke. There was a difference between the experiments, with the N-fertilized experiment showing higher ash content than the intercropping experiment. Part of this difference may be due to the provision of P, K and S and trace elements in the fertilizer used in the study. Rodrigues et al. (2007) found that mineral element composition of leaves of Jerusalem artichoke was not affected by cropping practices including N fertilizer application. Concentrations of ash-forming elements in the intercropping Jerusalem experiment were similar to values of some perennial grasses grown for bioenergy (Epie et al. 2014). Low ash content is desirable for biomass intended for burning in combined heat and power plants. The high C:N ratio obtained at harvest is associated with high calorific values in combustion systems (Oberberger and Thek 2004), also indicative of high potential methane yield in a digester or bioethanol yield.

Jerusalem artichoke produced equally good yields with little or no synthetic fertilizer, confirming its low nutrient requirement, so it could serve as a good source of biomass feedstock for energy production. When intercropped with legumes, artichoke grew well and yielded equally well as with fertilizer. The lack of significant differences between intercropped and fertilized plants suggest that legumes can potentially sustain Jerusalem artichoke during the establishment year. Further studies with no fertilizer and no legume control treatments are recommended before definite conclusions can be made.

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