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*Original Research*

# Virginia Fanpetals (*Sida hermaphrodita* Rusby) Cultivated on Light Soil; Height of Yield and Biomass Productivity

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## Abstract

This paper presents results of research on the impact of two levels of Nitrogen (N) and Phosphorus (P) fertilization use on population, height of plants, and biomass yield of Virginia fanpetals cultivated on light sandy loam, during four consecutive years of research: 2004-07.

Results indicate that stem density and height grew systematically during consecutive years of production. Nitrogen treatment did not influence density, but it increased height of plants. A larger quantity and height of stems was observed after using a higher dose of Phosphorus. Virginia fanpetal biomass yield was not affected by different amounts of Nitrogen applied, whereas more intensive Phosphorus treatment resulted in increased biomass yield. In the third and fourth years of production an average yield of dry matter of over 11 t·ha$^{-1}$ was obtained; energy productivity level was 219.5 GJ·ha$^{-1}$.

**Keywords:** Virginia fanpetals, biomass yield, energy productivity level, light soil, Nitrogen fertilization, Phosphorus fertilization

## Introduction

A gradual reduction in fossil fuel sources, accompanied by an increase in price and, as a result of use, environmental threat, gives rise to growing interest in renewable sources of energy and in the concept of sustainable development introduced by the Brundtland Commission [15].

According to the World Energy Council, appropriate use of renewable energy sources potential, including energy biomass, would satisfy most world energy demand in the second half of the 21st century [9]. Biomass takes a significant place among renewable energy sources. Consecutive EU directives indicate necessary growth of biomass share by 20% in the EU energy balance until 2020 [5-7, 13, 14].

In the future, energy biomass could be applied in many sectors of power engineering: heat engineering, electricity in cogeneration (CHP), biogas sector and transport biofuel of the 1st and 2nd generations [11, 12]. Maintaining energy competitiveness of biomass energy production depends to a large extent on the use of energy plant yield potential.

In recent last years there has been numerous research conducted on plants of large energy biomass production potential. Non-food perennial species of agricultural plants are especially interested in, Willow (*Salix* sp.), Miscanthus

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Table 1. Monthly average air temperatures (ºC) and total rainfall (mm) in 2004-07 for Uhnin, the meteorological station of the Research Centre for Cultivar Testing (COBORU) in Słupia Wielka.

| Months | Temperatures | | | | Rainfall | | | |
|---|---|---|---|---|---|---|---|---|
| | years | | | | years | | | |
| | 2004 | 2005 | 2006 | 2007 | 2004 | 2005 | 2006 | 2007 |
| January | -5.7 | 0.4 | -8.8 | 2.3 | 28 | 42 | 8 | 80 |
| February | -1.3 | -4.6 | -5.4 | -2.3 | 46 | 32 | 23 | 36 |
| March | 3.0 | -0.9 | -2.2 | 5.8 | 20 | 42 | 35 | 29 |
| April | 7.8 | 8.5 | 8.7 | 7.8 | 43 | 17 | 29 | 19 |
| May | 11.8 | 13.6 | 13.6 | 15.2 | 49 | 81 | 66 | 111 |
| June | 16.1 | 16.1 | 17.3 | 18.8 | 41 | 90 | 55 | 43 |
| July | 18.6 | 20.6 | 22.7 | 19.6 | 86 | 42 | 19 | 99 |
| August | 18.6 | 17.2 | 18.2 | 18.8 | 65 | 64 | 262 | 20 |
| September | 12.7 | 14.1 | 14.6 | 12.8 | 12 | 18 | 16 | 74 |
| October | 9.7 | 8.3 | 9.8 | 7.3 | 26 | 5 | 27 | 14 |
| November | 3.3 | 2.6 | 5.1 | 1.0 | 61 | 24 | 38 | 37 |
| December | 1.6 | -0.8 | 2.7 | -1.1 | 34 | 71 | 23 | 15 |
| January – December | 8.0 | 7.9 | 8.0 | 8.8 | 511 | 528 | 601 | 577 |

(*Miscanthus x giganteus* Greef et Deu.), Amur silvergrass (*Miscanthus sacchariflorus* L.), Virginia fanpetals (*Sida hermaphrodita* L. Rusby), Jerusalem artichoke (*Helianthus tuberosus* L.), Prairie cordgrass (*Spartina pectinata* Bosc.), Switchgrass (*Panicum virgatum* L., Poiret), and Big bluestem (*Andropogon gerardii* Vitman) [2, 10, 16].

The European Union expects east-central European countries to exploit their environmental and agricultural potential, significantly larger than in Western Europe, for biomass production on energy purposes [8].

Plants cultivated for energy biomass production should not be competitive with food and fodder species having a high yield on fertile, heavy enough soil. This type of soil, being useful for most highly efficient food cultivation, constitutes only app. 40% of total arable land; the remaining 60% is airy light soil, and poor in growth elements. In this condition particular importance is gained research on energy species able to produce a satisfactory yield on rye complex soil, for the choice of cultivations in this class of soil food and fodder plants is not wide. Those poor areas most often were excluded from cultivation for a long time, usually transformed into waste, margin land.

Virginia fanpetals is one of the perennial species adjusted to over ten years of cultivation tolerant to quality of soil. Although, this species comes from the United States of America, research on height of yield and quality of its raw material for energy purposes is being carried out in Poland exclusively. The first scientific research place, which started and still continues research on a large scale, is the University of Life Sciences in Lublin. Results to date indicate high efficiency of lignin-cellulose biomass yields and, comparable to other energy species, heat of combustion (over 18.7 $MJ \cdot kg^{-1}$ of dry matter). Low and natural decreases of biomass moisture content at harvesting time, from app. 40% in November to app. 20% in January-February, is worth particular attention [2]. So far the gathered Virginia fanpetals yield data based on two completely different ground conditions, that is on clay loam soil and on sewage sludge. Biomass yield cropped on clay loam soil amounted to 15-20 $t \cdot ha^{-1}$ of dry matter [4], in hard growing conditions on sewage sludge its yield ranged from 9 to 11 $t \cdot ha^{-1}$ [1].

Table 2. Selianinov coefficient (K)* values for vegetation period of Virginia fanpetals in years of research.

| Months | Years | | | |
|---|---|---|---|---|
| | 2004 | 2005 | 2006 | 2007 |
| April | 1.83 | 0.66 | 1.11 | 0.81 |
| May | 1.34 | 1.92 | 1.56 | 2.36 |
| June | 0.85 | 1.86 | 1.06 | 0.76 |
| July | 1.49 | 0.66 | 0.27 | 1.63 |
| August | 1.12 | 1.20 | 4.64 | 0.34 |
| September | 0.31 | 0.42 | 0.36 | 1.93 |
| October | 0.86 | 0.19 | 0.89 | 0.62 |

*K = quotient of total rainfall and 0.1 of sum of average temperatures. K < 1.0 –deficit of rainfall, K < 0.5 – drought.

Table 3. Stem densities of Virginia fanpetals (stems·m$^{-2}$) during the first four years of production depending on the level of N and P fertilization (kg·ha$^{-1}$ of pure constituent).

| Level of fertilization | | Year of production | | | | Four year average |
|---|---|---|---|---|---|---|
| N | P | I (2004) | II (2005) | III (2006) | IV (2007) | |
| 100 | 39.28 | 9.2 | 18.0 | 22.6 | 21.8 | 17.9 |
| | 52.38 | 9.8 | 22.6 | 24.8 | 25.4 | 20.6 |
| Average for N | | 9.5 | 20.3 | 23.7 | 23.6 | 19.3 |
| 200 | 39.28 | 9.6 | 20.0 | 23.0 | 25.1 | 19.4 |
| | 52.38 | 10.5 | 22.6 | 25.2 | 25.8 | 21.0 |
| Average for N | | 10.1 | 21.3 | 24.1 | 25.4 | 20.2 |
| Average for P | 39.28 | 9.4 | 19.0 | 22.8 | 23.4 | 18.7 |
| | 52.38 | 10.1 | 22.6 | 25.0 | 25.6 | 20.8 |
| Year of production average | | 9.8 | 20.8 | 23.9 | 24.5 | 19.7 |
| $LSD_{(0.05)}$ for: N fertilization level | | | | | | n.s. |
| P fertilization level | | | | | | 1.18 |
| year of production | | | | | | 3.30 |
| interaction effect of N and P fertilization | | | | | | n.s. |
| interaction effect of N fertilization level and year of production | | | | | | n.s. |
| interaction effect of P fertilization level and year of production | | | | | | n.s. |
| interaction effect of P and N fertilization level and year of production | | | | | | n.s. |

n.s. – non-significant difference.

Table 4. Height of Virginia fanpetal plants (cm) during the first four years of production, depending on the level of N and P fertilization (kg·ha$^{-1}$ of pure

| Level of fertilization | | Year of production | | | | Four year average |
|---|---|---|---|---|---|---|
| N | P | I (2004) | II (2005) | III (2006) | IV (2007) | |
| 100 | 39.28 | 152.0 | 230.8 | 248.3 | 290.0 | 230.3 |
| | 52.38 | 153.8 | 221.8 | 271.3 | 298.0 | 236.2 |
| Average for N | | 152.9 | 226.3 | 259.8 | 294.0 | 233.2 |
| 200 | 39.28 | 171.5 | 235.3 | 279.8 | 296.5 | 245.8 |
| | 52.38 | 191.3 | 241.8 | 297.5 | 298.8 | 257.3 |
| Average for N | | 181.4 | 238.5 | 288.6 | 297.6 | 251.5 |
| Average for P | 39.28 | 161.8 | 233.0 | 264.0 | 293.3 | 238.0 |
| | 52.38 | 172.5 | 231.8 | 284.4 | 298.4 | 246.8 |
| Year of production average | | 167.1 | 232.4 | 274.2 | 295.8 | 242.4 |
| $LSD_{(0.05)}$ for: N fertilization level | | | | | | 11.79 |
| P fertilization level | | | | | | 5.95 |
| year of production | | | | | | 22.97 |
| interaction effect of N and P fertilization | | | | | | n.s. |
| interaction effect of N fertilization and year of production | | | | | | n.s. |
| interaction effect of P fertilization and year of production | | | | | | n.s. |
| interaction effect of P and N fertilization level and year of production | | | | | | n.s. |

n.s. – non-significant difference

Table 5. Dry matter yield (t·ha$^{-1}$) of Virginia fanpetals during the first four years of production depending on P and N fertilization (kg·ha$^{-1}$ of pure constituent).

| Level of fertilization | | Year of production | | | | Four year average |
|---|---|---|---|---|---|---|
| N | P | I (2004) | II (2005) | III (2006) | IV (2007) | |
| 100 | 39.28 | 2.44 | 6.71 | 10.46 | 10.29 | 7.47 |
| | 52.38 | 2.79 | 9.52 | 11.48 | 11.71 | 8.87 |
| Average for N | | 2.61 | 8.12 | 11.98 | 11.00 | 8.17 |
| 200 | 39.28 | 2.79 | 7.63 | 10.76 | 11.47 | 8.16 |
| | 52.38 | 3.86 | 9.56 | 11.63 | 11.75 | 9.19 |
| Average for N | | 3.32 | 8.60 | 11.19 | 11.61 | 8.68 |
| Average for P | 39.28 | 2.61 | 7.17 | 10.61 | 10.87 | 7.82 |
| | 52.38 | 3.33 | 9.54 | 11.55 | 11.74 | 9.03 |
| Year of production average | | 2.79 | 8.36 | 11.08 | 11.30 | 8.43 |
| $LSD_{(0.05)}$ for: N fertilization level | | | | | | n.s. |
| P fertilization level | | | | | | 1.188 |
| year of production | | | | | | 1.905 |
| interaction effect of N and P fertilization | | | | | | n.s. |
| interaction effect of N fertilization and year of production | | | | | | n.s. |
| interaction effect of P fertilization and year of production | | | | | | n.s. |
| interaction effect of N and P fertilization, and year of production | | | | | | n.s. |

n.s. – non-significant difference

To obtain similar yield levels of sewage sludge in light soil seems possible. Considering the high combustion heat, this would let us achieve energy productivity higher than from any other plant cultivated in such conditions. A valuable merit is that Virginia fanpetal plantations do not need any yearly cultivation treatment typical for annual plants. Difficult is only the year of establishing the plantation as the first year of cultivation with no biomass yield, which is very typical for perennial species [2]. The outlook of the 2nd generation biofuel production from lignin-cellulose biomass gives particular importance to research on possibilities of cultivation and obtaining high yield of Virginia fanpetals on less fertile soil.

Our work objective was to determine the influence of Nitrogen and Phosphorus fertilization on height of biomass yield of Virginia fanpetals during the first four years of production on light soil.

## Material and Methods

In 2003 on the scientific research farm of University of Life Sciences in Lublin, a trial experiment on Virginia fanpetals was conducted, in randomized blocks designed for planting, with every combination replicated four times (plots were – 12.6 m$^{-2}$ in size). The experiment comprised two levels of Nitrogen (100 and 200 kg·ha$^{-1}$ N) and Phosphorus (39.28 and 52.38 kg·ha$^{-1}$ P) fertilization, and the same level of Potassium fertilization (83.02 kg·ha$^{-1}$ K). In the last decade of April 2003, Virginia fanpetals were sown, keeping the same density throughout the whole experiment (25 seeds per m$^{-2}$). After vegetation season (the end of November) the average plant density was 9.2 plants per m$^2$. In 2004-07 (from the first to the fourth year of production) after vegetation season (second half of November) before harvesting, stem density and height of ten plants from every plot were collected.

Directly after harvesting, stems from each plot were weighed and sampled in order to measure moisture content, (dried to constant mass at 105ºC), on that basis dry matter yield was calculated. Results were statistically handled and significance of differences were determined using Tukey's test.

Soil in Parczew is classified as light sandy loam (sand – 1.0-0.1 mm – 67%; dust – 0.1-0.02 mm – 20%; fluming parts – <0.02 mm – 13%), content of elements 46.8 P; 85.5 K; 23.0 (mg·kg$^{-1}$), pH 4.6 determined in KCl 1 mol·dm$^{-3}$ solution.

Monthly average air temperatures and total rainfall are presented according to data of the Research Centre for Cultivar Testing (COBORU) at the meteorological station in Uhnin, app 10 km from the scientific research farm in Parczew.

Data presented in Table 1 indicates significant differences in temperatures during the period of intensive growth and development of Virginia fanpetals. In 2004-05 average temperatures in June were by 2.7ºC lower than in 2007.

More significant difference appeared in July, in a period of 2004-06 (4.1ºC). Annual total rainfalls were not low; however, rainfall deployment during the vegetation season was not favourable. The light soil was not able to store the excess of water from intensive stormy rainfall. Simultaneously, every year in June or in July saw a period of rainfall deficit (K< 1.0) and even drought as took place in July 2006 (K = 0.27) (Table 2).

## Discussion of Results

Virginia fanpetals is perennial species able to yield a biomass crop through between ten and twenty years, however in the year of sowing (first year of cultivation), yield would be low and not taken into consideration as such. Plants growing from seeds produce one stem only in the first year. In following years, the amount increases to a few tens [2]. According to Table 3, the second year of cultivation and first of production (2004), average stem density was poor (9.8 stems per $m^{-2}$). Already in the next year (2005, second year of production) stem density increased twice and in the following years a rise of stems density was observed. Significant differences in number of stems, however, happened still between the second and fourth years of production, whereas in 3rd (2006) and 4th (2007) the number of stems per plot remained almost the same. Bigger stem density in consecutive years of production is typical for this species, one plant of Virginia fanpetals can produce from several to over twenty stems [2].

High levels of Nitrogen fertilization applied in experiment – 200 kg·ha$^{-1}$ – in comparison to a lower dose by half, did not affect plant density significantly. More intensive Phosphorus fertilization (from 39.28 to 52.38 kg·ha$^{-1}$ P) caused an increment in development of stems by two per 1 $m^{-2}$ in four year average, that was counted as 20,000 stems per hectare.

Stem density, similar to plant height, grew higher in consecutive years of production. The shortest plants were observed in the first year of production, while in the second year plants were 39% higher (Table 4). Differences in height of stems in the 2nd and 3rd years of production were still significant, but between the 3rd and 4th years this significance was not determined, yet plants were app. 20 cm higher.

The significant yield of Virginia fanpetals is already cropped in just the second year of cultivation on good soil (first year of biomass production), but the matured abundance of yield take place in the 3rd-4th year of production [2, 3]. According to Table 5, Virginia fanpetals cultivated in soil classified as light sandy loam, does not produce a good yield of dry biomass. In the first year of production, average yield was over twice lower than that obtained on clay loam [2]. In following years of production yields grew significantly; in 3rd and 4th year of production over 11 t·ha$^{-1}$ was collected. Comparable yield was obtained from Virginia fanpetals cultivation on sewage sludge [1]; yield on clay loam was almost twice as much only in the 2nd year of production [4].

Table 6. Energy productivity (GJ·ha$^{-1}$) of Virginia fanpetals biomass during first four years of production.

| Year of production | | | | Four year average |
|---|---|---|---|---|
| I (2004) | II (2005) | III (2006) | IV (2007) | |
| 52.301 | 178.462 | 215.204 | 219.516 | 166.277 |

Low productivity of Virginia fanpetals on light soil is probably mostly due to deficiency of water, which is typical for this kind of soil. Moreover, during June and July, in the period of highest water demand (intensive growth, biomass development, flower bud forming and blooming), significant deficits of water and drought happened every year (Tables 1 and 2).

No significant difference in height of biomass yield, stem density and its height in the 3rd and 4th years of production, indicate maturity of yield attained. To date research carried out in different soil conditions, clay loam, indicates similarly that Virginia fanpetals attain the height of yield in 3rd-4th year of production [2]. Experiments in which vegetative reproduction method (root cuttings) were used, were the only exceptions. In those trials yields amounted to 20 t·ha$^{-1}$ of dry matter just were obtained in the 2nd year of production [4]. This reproduction method might give positive effects in Virginia fanpetals cultivation on light and margin soils and encourages research of this kind.

In case of water deficiency, plants usually are not able to use nutrient elements delivered in mineral fertilizers. Lack of significant influence of two different nitrogen doses on biomass yield might serve as an example. Occasional heavy rains, during last years, might have had an additional influence on high releases of Nitrogen out of sandy soil. However. increasing app. 12 kg·ha$^{-1}$ dose of Phosphorus resulted in significant rise of yields averaged from four years of research. Although statistical analysis did not prove the influence of interaction effect of Nitrogen and Phosphorus fertilization, certain tendency of increase in yields might be indicated after broadcast of 200 kg·ha$^{-1}$ N and 39.28 kg·ha$^{-1}$ P, in comparison with the same level of Phosphorus fertilization and lower doses of Nitrogen. For lack of significant influence of level of Nitrogen fertilization on biomass yield, on light soils, energy productivity was estimated on yields obtained after the use of 100 kg·ha$^{-1}$ N and 52.38 kg·ha$^{-1}$ P in separate years of research. For calculation of productivity per hectare, combustion heat of Virginia fanpetals amounted to 18.746 MJ·kg$^{-1}$ in dry matter [2] set by the Institute for Wood Technology in Poznań was used.

In the first year of production, energy productivity of Virginia fanpetals biomass harvested from 1 ha$^{-1}$ was not high (Table 6), but in only the next year twice or three times as much energy was obtained than, on average, during a year from several years old pine or spruce forest (annual average – 25-year-old pine forest – 69 GJ, 35-year-old spruce forest– 93 GJ·ha$^{-1}$) [2]. The following two years indicate the possibility of obtaining even higher energy productivity from biomass from Virginia fanpetals cultivated in light sandy loam.

However, Virginia fanpetal yields in conditions of this experiment were not high, in comparison to cultivation on good soil, the energy output of such cultivation seems to be very interesting and makes it as sensible and promising for further research of Virginia fanpetals yield potential in light soil.

## Conclusions

1. The largest stem density (23.9 and 24.5 stems per 1 $m^{-2}$) and height of plants (274.2 and 295.8 cm) were observed in 3rd and 4th year of Virginia fanpetals production.
2. In 3rd and 4th year of production, biomass yields of Virginia fanpetals cultivated in light soil exceeded 11 $t \cdot ha^{-1}$.
3. Level of Nitrogen fertilization (100 and 200 $kg \cdot ha^{-1}$) did not affected biomass yield.
4. Higher dose of Phosphorus fertilization significantly increased Virginia fanpetals yields.
5. Yield of Virginia fanpetals cultivated in light soil could supply approximately two or three times as much energy as tens-year-old forest wood per year.

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