Jerusalem Artichoke (*Helianthus tuberosus* L.), Above-ground Biomass for Solid Biofuels in Jiangsu Province (People´s Republic of China)

Topinambur (*Helianthus tuberosus* L.), využití nadzemní biomasy pro tuhá biopaliva v provincii Jiangsu (Čínská lidová republika)

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Abstract

The research aim of this paper is to analyze potential of the above-ground biomass of Jerusalem artichoke (J.A.) for solid biofuel production in People´s Republic of China (PRC). This research first surveyed amount of biomass produced from Jerusalem artichoke stem (above-ground) parts with regard to different methods of their treatment aiming at their energy use in Dafeng (Jiangsu Province, PRC). 60 samples of J. A. above-ground biomass were gathered in order to measure green as well as dry matter yields. The average yield of biomass was calculated at the level of 8.8 t/ha. Higher yields J. A. of stem biomass originated from the areas where this crop has been cultivated for the production of tubers (14.44 t/ha) whilst lower above-ground biomass yields were found in areas where the plants were cultivated as perenial crop (averaging only 4.22 t/ha of above-ground biomass dry matter).The findings gained by this study can be used to encouraging production of solid biofuels in the form of briquettes/pellets in PRC. Then the research focused on chemical analysis of the J. A. above-ground biomass composition and combustion tests. Contents of elements, moister, ash, volatile matter and dry ash free matter and GCV and NCV were measured according to standards CEN/ EN 14774-2, CEN/ EN 14775, CEN/EN 15148, CEN/TS 14918 respectively. The results were characterised as corresponding to the standard CEN/TS14961 which defines solid biofuels of vegetal origin. Finally, the combustion tests of J.A. above-ground dry matter and biobriqquettes produced from this biomass were conducted; they confirmed suitability of J.A. above-ground biomass for energy purposes (use for the heat production) and thier emissions (CO contents: 6,325.59 mg/m^3 and NO_x: 140.3 mg/m^3) as acceptable.

Abstrakt

Výzkumným cílem této práce je analyzovat potenciál nadzemní biomasy topinamburu pro výrobu tuhých biopaliv v Čínské lidové republice (ČLR). Tento výzkum se zabýval množstvím vyprodukované biomasy z nadzemních částí topinamburu ve spojitosti se způsobem a účelem pěstování této plodiny. Výzkum probíhal na pokusných pozemcích v oblasti Dafeng (provincie Jiangsu, ČLR) . Celkem bylo analyzováno 60 vzorků nadzemní biomasy topinamburu za účelem stanovení výnosu sklizené nadzemní biomasy, jakož i výnosy sušiny. Průměrný výnos biomasy během výzkumu byl 8,8 t / ha. Vyšší výnosy nadzemní biomasy byly zjištěny při intenzivním způsobu pěstování pro produkci hlíz (14,44 t/ ha), zatímco nižší výnosy byly nalezeny v oblastech, kde rostliny regenerovaly z jednoročních hlíz (v průměru pouze 4,22 t /

ha nadzemní biomasy sušiny). Výsledky získané v tomto výzkumu je možné použít k podpoře produkce tuhých biopaliv ve formě briket, pelet v ČLR. Dále bylo stanoveno chemické složení a vlastnosti nadzemních částí topinamburu a byly provedeny spalovací zkoušky. Chemické analýzy, stanovení vody, popelu, prchavé hořlaviny a hořlaviny, stanovení spalného tepla GCV a výhřevnosti NCV byly provedeny v souladu s normami CEN / EN 14774-2, CEN / EN 14775, CEN / EN 15148, CEN / TS 14918, resp. Výsledky splňují normu CEN/TS14961, která definuje tuhá biopaliva rostlinného původu. Spalovací zkoušky nadzemní biomasy topinamburu a spalování briket vyrobených z této biomasy, potvrdily vhodnost nadzemní biomasy topinamburu pro energetické účely (k využití pro výrobu tepla). Naměřené emise (CO 6,325.59 mg/m3 a NO_x: 140,3 mg/m3) jsou srovnatelné s jinými biopalivy rostlinného původu.

Keywords: agricultural residue, above-ground biomass yield, People´s Republic of China, emissions CO and NO_x, Jerusalem artichoke (*Helianthus tuberosus* L.), solid biofuel, standard for solid biofuels

Klíčová slova: posklizňové zbytky, výnos nadzemní biomasy, Čínská lidová republika, emise CO a NO_x, topinambur (*Helianthus tuberosus* L.), tuhá biopaliva, normy pro tuhá biopaliva

Introduction

This paper was produced thanks to the cooperation between Nanjing Agricultural University (NAU) and Czech university of life Science Prague (Faculty of Tropical AgriSciences). It aims at the cultivation of Jerusalem artichoke (J.A.) in PRC and its use for energy production in Jiangsu province (PRC). The NAU is member of the Association of Bio-refinery of Jerusalem Artichoke (ABRJA) which was established in 2007 by a project financed by Government of PRC. Currently the ABRJA project covers cooperation between NAU, Dalian University of Technology, Chinese Academy of Science, Dalian Institute of Chemical Physics and Fudan University (Liu, 2011). However, the interest of the above mentioned institutions on J.A. cultivation and its importance for other downstream industries in China can be dated to 1998 (Liu, 2011). In the first phase the J.A. high soil salinity tolerance has been appreciated as highly suitable for the coastal zones or degraded lands (Zubr, Pedersen, 1993) also the J.A. was planted as fytoremediation crop (Projekt fytoenergo VUZT v.v.i., 2011). The J.A. is one of the high yielding crops of tubers (32 t/ha) and above-ground biomass (34 t/ha of green matter) (Bouma et al., 1995). In Jiangsu province (2011) 10,000 ha of J.A were planted with the total tuber production of 530,000 tons (53 tons of tubers per hectare). It has been reported that totally in China 595,345 ha of J.A. were planted and about 191 millions of tons of tubers produced (32.24 t/ha). The tubers were especially used for inulin production. The agricultural residues originating from above-ground biomass have complex physico-chemical properties which complicate their processing and combustion (as densified solid biofuel from agricultural residues). These physico-chemical characteristics also include moisture and ash contents and energy characteristics (Chen et al, 2009).

In order to contribute to exploring the J. A. energy potential and technological feasibility of densified solid bifuels from above-ground biomass (agricultural residues) this article focuses on the following issues: A) yield of J.A. above-ground biomass in the Jiangsu province as dependent on the planting system; B) J.A. above-ground biomass physico-chemical characteristics; C) CO emissions and their dependence on the moisture contents during combustion.

Materials and methods

All data concerning the yields of J.A. above-ground biomass in Jiangsu province were gained through the field experiments. They were based on samples collected during a 3-year period (Nov. 2009 – Nov. 2011). The data gathering and yields measurements were done in cooperation with NAU. A random quadrate sampling method was used to get a reliable picture on the J. A. above-ground biomass yields.

Figure 1 Research field in Jiangsu province

The quadrates are simple to define their area and require only a centre stake and a tape measure (Fidelius et al., 1993). The yields were grouped according to planting systems (annual and multiannual planting systems) (Bouma et al., 1995).

The Jerusalem artichoke has high abillity to adsoring heavy metals and some other elements from the soil and accummulating them in its tissues (see Projekt fytoenergo VUZT v.v.i., 2011). It is why the chemical composition of the above-ground biomass was analysed (done in the ČVUT laboratory according CEN/TS). The analyses focused on moisture, ash, volatile matter and dry ash free contents, Gross Calorific Values (GCV) and Nett Calorific Values (NCV) measuring, too; the analyses were done according to standards CEN/ EN 14774-2, CEN/ EN 14775, CEN/EN 15148, CEN/TS 14918 respectively. The J.A. above-ground biomass was dried before the burning experiments and emission measurements. Five different substrates were prepared from the J.A. stem/straw which differed by their level of moisture (16.9 %; 27.4 %; 32.4 %; 35.3 % and 47 %).

Figure 2 Testo 350XL portable analyzer

A portable analyzer Testo 350XL (CZ production) as shown in Figure 2 was used for emission measurement tests (conducted during the burning tests); it enabled to find out concentrations of components of exhaust gases, for example CO, O_2, NO, NO_2. The burning tests were conducted under real conditions with use of traditional (and obsolete) Chinese furnace. The results were processed by proper statistical methods.

Results and disccusion

The average yield values of J. A. above-ground biomass for both the annual and multiannual planting systems are shown in Table 1. The values in Table 1 are presented in dry matter (d).

The values of annual planting system are from 2^{nd}, 3^{rd} and 4^{th} year (in research period). Their statistical parameters are: n ... number of samples, SD ... standard deviation, n=10; SD=± 2.7, 1.31 and 1.68 respectively. The yields are remarkably (approx. 3 times) higher than those gained from multiannual crop planting system (Table 1).

Table 1 J.A. Above-ground biomass yields

	2nd year	3rd year	4th year	2nd year	3rd year	4th year
Planting system	average, d [t/ha]			median, d [t/ha]		
Annual	14.4	12.4	13.3	14.9	12.5	13.9
Multiannual	4.4	3.9	4.3	4.1	3.9	4.2

Figure 3 represents 60 samples gathered from the field during the 3 years experiment (Nov. 2009 – Nov. 2011). It is represented by blue curve. The blue curve has been warped which witnesses that the data are model to be distributed as normal distribution. Important point is that two peeks (the second is not very distinctive) represent different planting systems (annual green and multiannual red curve).

Other curves (the green and red ones) represent 30 samples of multi-annual planting system (the green one) and 30 samples (the red one) from the annual planting system.

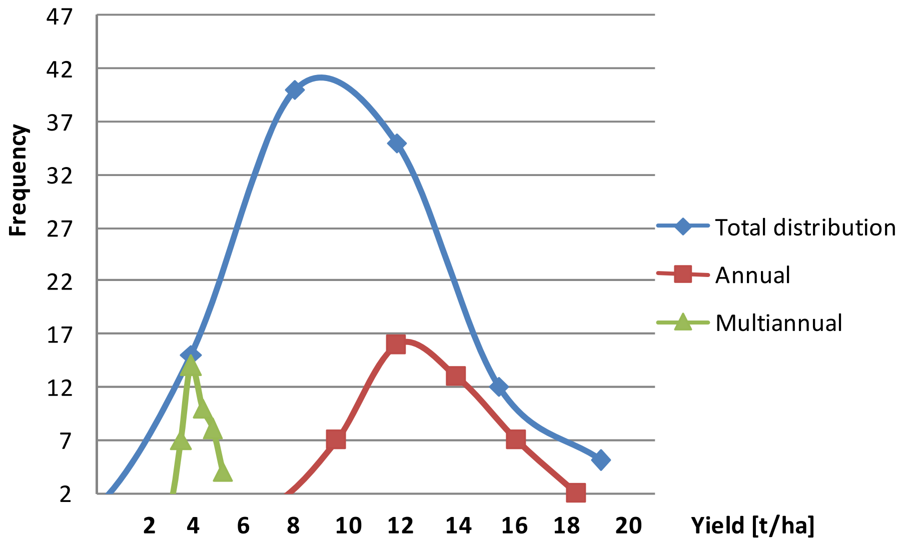

Figure 3 Histograms of J. A. above-ground biomass yields, Yield distribution, annual and multiannual

In Figure 3 the red and green curves show the value distribution as particular cases of the distribution represented by the blue curve. Average yield 14.44 t/ha of dry matter per group designed Annual (annual planting systems) was found in the second year of experiments while the lowest average yield 3.94 t/ha of dry matter was found in the third year at the group Multiannual (multiannual planting systems). The total average yield was 8.8 t/ha of dry matter.

Figure 4 shows the yields of J.A. above-ground biomass according to planting systems. Planting systems based on annual J.A. growing showed significantly higher yields during the experimental period.

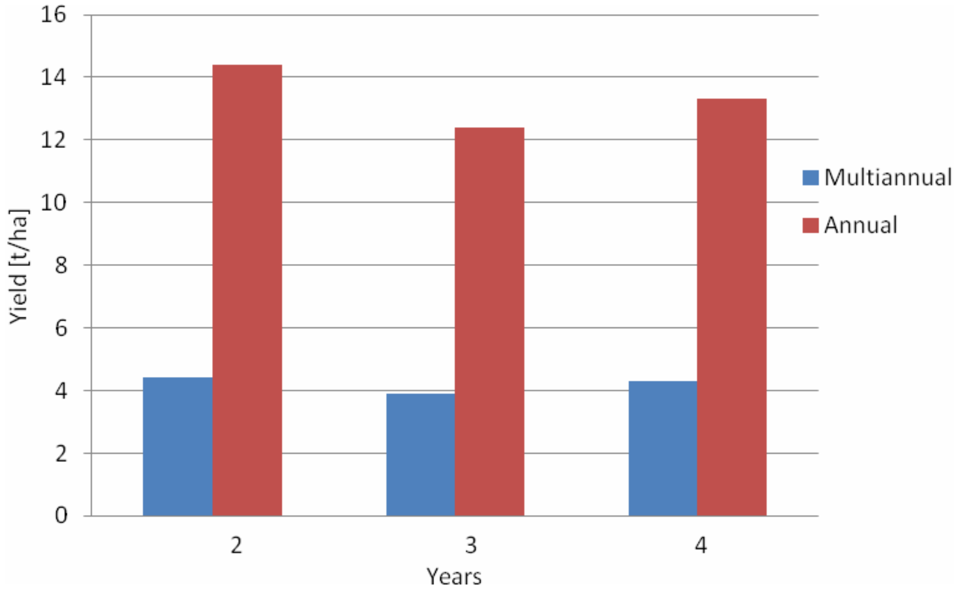

Figure 4 J.A. above-ground biomass yields according to planting systems

The analyses of the J.A. above-ground biomass destined to solid biofuel production discovered a quite high proportion of dry ash free content at the level of 86 and 86.5 % (green columns) while low ash contents at the level of 6.2 and 7 % were found in blue columns (Figure 5) . Moreover, the analyses found only 78.6 and 76.5 % dry ash free substances and ash content 15.9 and 18.3 % in the J. A. leaves. The biomass analyses were done every year mainly for reason to determine contents of chemical elements and heavy metals (see Table 3). By statistical testing (t-test) no significant differences were discovered between groups as to the chemical and matter contents. The analyses showed higher ash contents in leaves in comparison with stems (Figure 5, Blue column). On the other hand, the leaves have higher calorific value than stems (Figure 6 and Table 2).

The J.A. is a crop which can be used for fytoremediation treatment of degraded (marginal) agricultural land with respect to weed infestation. Its remediation effects also manifest absorption of heavy metals in J. A. plants (Projekt fytoenergo VUZT, 2011) which reduces the heavy metal contents in degraded (or misused) lands.

Table 2 J.A. contents and energy values

	Ash contents [%]	Water contents [%]	Dry ash free contents [%]	GCV Values [KJ/g]	NCV Values [kJ/g]
J. A. Stem A	7	7	86	15.679	14.439
J. A. Stem M	6.2	7.3	86.5	15.827	14.587
J. A. Leaf A	18.3	5.2	76.5	16.253	15.013
J. A. Leaf M	15.9	5.5	78.6	16.479	15.239

Data are presented n=5; max. ±SD= 1.07; 2.24 and 4.37 for ashandwater contentsand dry ash free respectively. Data are presented n=5; max. ±SD= 0. 87 to Gross calorific value

Thus the use of the J. A. above-ground biomass for solid biomass production is also advantageous from this point of view.

A risk of vast areas contamination by heavy metals can occur if the J. A. biomass is of origin from the degradable areas with high level of heavy metal contents. In the case study from Dafeng (in Jiangsu province, Figure 1) the heavy metal contamination problem was not subject of research but this risk exists, anyway. It is because in PRC a relatively easy wide spreading of J. A. planting to unused agricultural area in semi-arid regions in Inner Mongolia and Xinjiang province in the western part of the country is in the future possible. Prior to the J. A. growing introduction a responsible evaluation of soil conditions as the heavy metal contamination risk must be done. Different climate and soil conditions (topography, pH reaction, moisture and SOM contents) will influence chemical composition of the above-ground biomass in the plants, too.

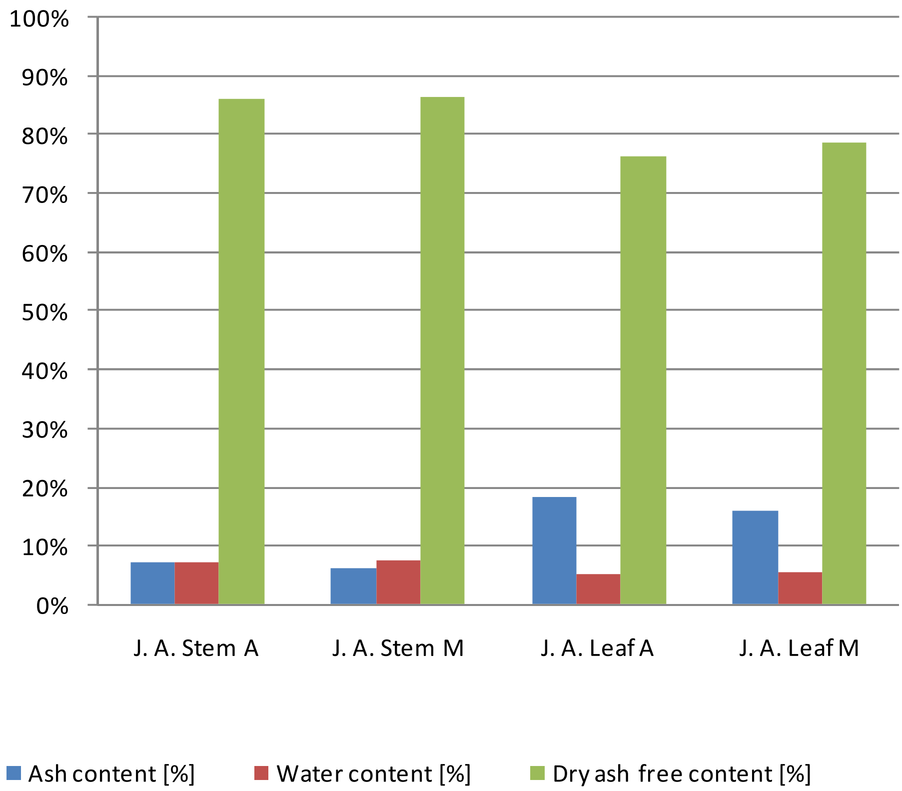

Figure 5 J.A. above-ground biomass contents, Stems and leaves content

As the following step the above-ground biomass of J.A. was pressed to biofuels (briquettes) and burnet for emission measurements. The emission measurement results are shown in Table 4. Figure 7 demonstrates dependence of the CO emissions on the biomass (biofuel) moisture. It was proved that the CO emissions closely depend on the biofuel quality (water contents in this case). The tests manifest that the quantities of CO emissions proportionally vary with moisture contents (see Figure 7).

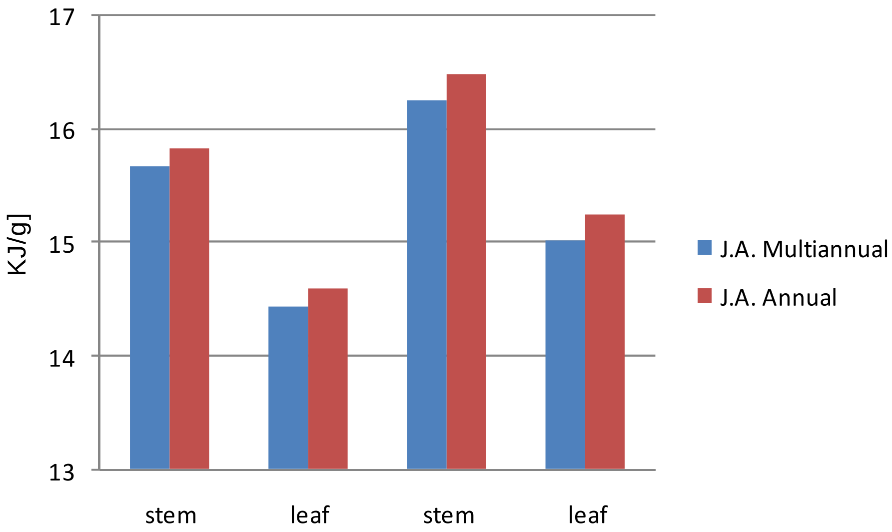

Figure 6 J.A. above-ground biomass energy characteristics, Calorific values

It is possible to make use of the research results for calculation of energy potential in Jiangsu province as could be totally gained from J. A. above-ground biomass. Using the average yield multiplied by the total planting area the total amount potential of J. A. above-ground biomass can be 88,000 tons. Because its GCV is around 15.7 MJ/kg the energy potential produced from the J. A. above-ground biomass in Jiangsu province is 1.3 PJ (petajoules) which is equivalent to 33 x 10^3 toe (tonne of oil equivalent = 42 GJ).

Table 3 J.A. above-ground biomass analysis, Chemical content

Matter	2nd	3rd	4th
Moister content [%]	7.68	7.41	7.75
Ash content [%]	8.22	7.32	8.54
Dry ash free [%]	84.1	85.27	83.71
Volatile matter [%]	68.73	67.98	68.48
Non-volatile matter [%]	15.37	17.29	15.23
C [%] hm	38.62	42.06	40.51
H [%] hm	4.8	5.13	4.91
N [%] hm	2.8	1.49	1.98
S [%] hm	0.07	0.22	0.065
O [%] hm	38.31	36.28	39.29
Cl [%] hm	0.22	0.19	0.17
F [mg/kg]	7	6.8	4
Zn [mg/kg]	20	33	28
Cd [mg/kg]	13	20	14
Pb [mg/kg]	< 0.5	4	< 1
Cr [mg/kg]	< 0.5	< 1	< 0.5
Cu [mg/kg]	38	7.2	41
As [mg/kg]	< 0.5	< 0.5	< 0.5

Hg [mg/kg]	0.49	0.82	0.35
GCV [MJ/kg]	16.3	16.18	15.87
NCV [MJ/kg]	15.7	14.89	14.62

Table 4 Combustion test, Exhaust emission dependence on moisture

Jerusalem artichoke	Total Time [min]	Moister content [%]	Mean CO [ppm]	Mean CO [mg/m3] for 13% O2	Mean NOx[mg/m3] for 13% O2	Mean CO2 [%]	Mean O2 [%]	Mean [°C]
1	17	18.9	2073	6,325.75	140.3	2.78	17.76	182.7
2	15	27.4	2,245.24	8,762.59	164.1	2.33	18.25	144.4
3	5	35.3	4,722	15,582.23	159.46	2.38	18.1	137.7
4	15	47	16,212	19,739	294.59	6.66	12.64	375
5	15	32.4	8,234	15,221.98	157.92	5.6	14.81	299.5

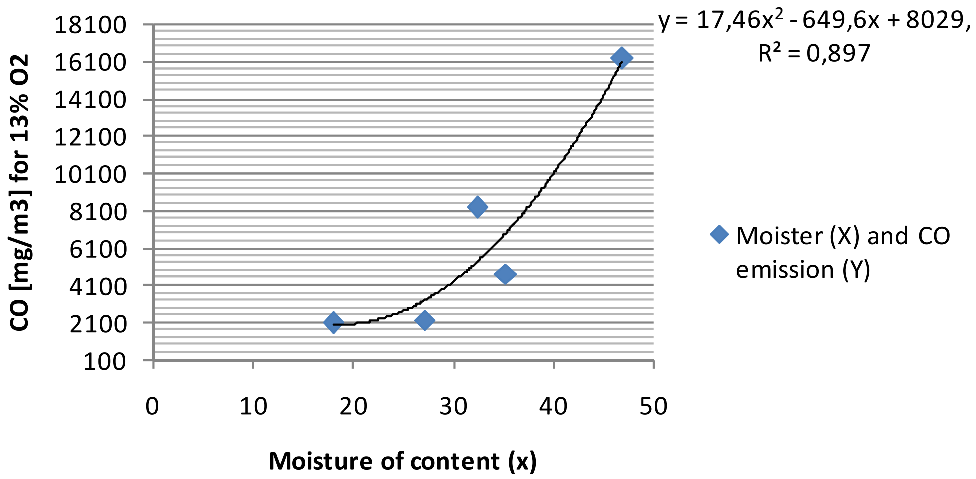

Figure 7 Curve, Emission dependence on moisture

Conclusions

On basis of 3-year research activities with J. A. above-ground biomass the following conclusions can be formulated:

1. A higher yield of dry matter was found in the annual planting group (system) which in average yielded 13.38 t/ha of dry matter. On the other hand as inappropriate method of cultivation was found the extensive way (multiannual) when the plants regenerate themselves and are grown more years. As the result, a higher weed infestation and lower yields can be mentioned which go down to 4.22 t/ha of dry matter in average (data gained

from 3-year experiment). Thus, the proper cultivation method can be recommended the annual planting system.

2. The chemical analyses enabled to characterise contents of elements and compounds in the J. A. above-ground biomass. It was found that the chemical composition of J. A. above-ground biomass is able for its use for solid biofuel production. Particularly important and favourable are: low ash, sulphur and chlorine contents and the energy value (GCV).

3. The combustion testing was part of the field trials. First the local furnace was used which gave very bad exhaust emission composition while the use of modern oven (as VÚZT facility) considerably improved the emission characteristics. Dependence of exhaust emissions on biofuel moisture contents was examined, as well which implicates the rule of well dried raw materiels before the biobriquettes production (under 15 % of moisture contents).

4. As to the J. A. planting prospects in China it can be relatively easy wide-spread on unused agricultural area in marginal regions of Inner Mongolia and Xinjiang province in the western part of the country. Before the J. A. crop is introduced rotation must responsibly be evaluated. It is because the J. A. can absorb many heavy metals from contaminated soils. The climate and soil conditions can heavily influence yields of J. A. above-ground biomass as well as the heavy metal absorption

5. The Jerusalem Artichoke crop has got a great growing potential in Jiangsu province and use of its abouve-ground biomass for solid biofuel production (briquettes) is highly recommended.

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