Marginal lands for Growing Industrial Crops

D4.5. – Report on "Comparative studies on selected industrial crops grown on large scale fields on marginal land"

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DEC	Websites, patent fillings, videos, etc.	☐
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1. Executive summary

The scope of the Task 4.4 was to gain new insights into industrial crops (camelina, crambe, safflower, castor, switchgrass, miscanthus, tall wheatgrass, willow, poplar and Siberian elm) grown at farm-scale under different pedo-climatic and marginality conditions across Europe. Large demo fields (not replicated) were established in Italy, Spain, France, Greece, Poland, Ukraine and Latvia and carried out under real operational conditions. At least two different industrial crops were tested in each country. The results show that marginality conditions can dramatically affect the productivity depending on species and marginality factor; however, some crops seem to have great potentials on marginal land if adequate agricultural practices are properly addressed for the specific marginal conditions.

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2. Introduction

Despite there is much talk of the opportunities for the deployment of industrial crops on marginal land, scientific literature is still very limited and real data on crop productivity on marginal land are still partial and not very representative are (Pari et al., 2022; Reinhardt et al., 2022, 2021; Scordia et al., 2022).

The MAGIC project selected a considerable number of promising industrial crops to be tested in different marginality conditions in Europe under real operational conditions (farm-scale) aimed at collecting real productivity data to be used for integrated assessment in WP7 and for the value-chain analysis in WP6. Seven partners (UNIBO, CRES, CIEMAT, NOVABIOM, 3B, SILAVA and IBC) established large field trials for at least two growing seasons (Table 1).

Table 1. Marginality factors and crops.

Partner	Country	Marginality factor	Crop	Crop type*	Crop cycle**	Trials duration***
UNIBO	Italy	Steep slope 25%	Camelina	O	A	3
			Crambe	O	A	3
			Safflower	O	A	2
			Switchgrass	L	P	1
		Steep slope 15%	Camelina	O	A	2
			Crambe	O	A	2
			Safflower	O	A	2
			Switchgrass	L	P	1
CRES	Greece	Unfavourable soil texture (acid or saline) combined with slope	Camelina	O	A	3
			Crambe	O	A	2
		Poor chemical composition (sandy)	Safflower	O	A	2
			Castor bean	O	A	3
CIEMAT	Spain	Limitation rooting and poor chemical composition	Tall wheatgrass	L	P	3
		Limitation rooting and poor chemical composition	Siberian elm	W	P	3
NOVABIOM	France	Poor chemical composition (sandy)	Miscanthus	L	P	2
		Poor chemical composition	Miscanthus	L	P	1
			Miscanthus	L	P	1
3B	Poland	Poor chemical composition (sandy)	Camelina	O	A	2
			Willow	W	P	3
			Poplar	W	P	3
		Poor chemical composition (clay)	Camelina	O	A	2
			Willow	W	P	3
			Poplar	W	P	3
SILAVA	Latvia	Limitation in rooting depth	Willow	W	P	2
			Poplar	W	P	3
IBC	Ukraine	Poor chemical composition	Willow	W	P	2

*L= lignocellulosic, O= oilseed crops, W = woody species, C = carbohydrate crops

** A= annual, P = perennial

***number of growing seasons

Crops were grown by using local most conventional practices and available machineries.

Refences:

Pari et al. 2022. The Eco-Efficiency of Castor Supply Chain: A Greek Case Study. DOI: 10.3390/agriculture12020206

Reinhardt et al. 2022. Yield performance of dedicated industrial crops on low-temperature characterized marginal agricultural land in Europe – a review. DOI: 10.1002/bbb.2314

Reinhardt et al. 2021. A review of industrial crop yield performances on unfavorable soil types. DOI: 10.3390/agronomy11122382

Scordia et al. 2022. Towards identifying industrial crop types and associated agronomies to improve biomass production from marginal lands in Europe. DOI: 10.1111/gcbb.12935

3. UNIBO trials

The UNIBO's activities within T 4.4 focused on steep slope land (>12%), that is a very common marginal land in Italy. The majority of sloping land are currently fallow. Two trials were carried out in Ozzano dell'Emilia (44° 24' N, 11° 28' E) with 15% and 25% slope (Fig. 1 UNIBO).

Figure 1 UNIBO. Experimental fields with different slopes during camelina harvest in 2020.

1. METHODOLOGY

Table 2 UNIBO. Soil physic-chemical characteristics in the two fields.

Slope	Soil type	pH	Total N (g kg^{-1})	Available P (mg kg^{-1})	Exchangeable K (mg kg^{-1})	Organic C (g Kg^{-1})	SOM (%)
Field 25%	Silt loam	8.09	0.78	25	161	5.91	1.02
Field 15%	Silty clay loam	8.08	0.87	16	213	7.70	1.33

Ozzano dell'Emilia is characterized by a long-term mean annual temperature of 14°C and a cumulative annual precipitation of 786 mm. Within oilseed crops, one winter crop, camelina, and one spring crop, crambe were tested, while among lignocellulosic species, switchgrass was chosen as reference crop basing on our previous successfully experiences. High oleic safflower was also included starting from the third year to contribute to WP6 assessments (Table 3 UNIBO).

Table 3 UNIBO. Commercial varieties used in UNIBO's trials

Crop	Cultivar	Seed provider	Reason behind the choice
Camelina	Cypress	Smart Earth Camelina (Canada)	Best performing cultivar from previous projects
Crambe	Galactica	Wageningen University and Research (The Netherlands)	Available within the MAGIC consortium
Switchgrass	Alamo	Desert Sun (USA)	Best performing cultivar from previous projects
Safflower	CW99OL	MAS Seeds (Italy)	Commercial high oleic winter hybrid

Crop were never irrigated and grown according to organic farming procedures (the experimental farm is organic). Because a major constraint under steep slope is the achievement of an optimal plan density, some improvements were made to sowing techniques. At this respect, two sowing densities were compared: HD (= high density, corresponding to broadcasting for camelina and crambe and, for safflower, to a close interrow distance of 17 cm) and TD (= traditional density, corresponding to 17 cm interrow distance for camelina and crambe, and 45 cm for safflower). Within each plot, 4 to 10 sampling areas were manually harvested to collect data on potential seed and straw yields, as well as representative sub-samples to be analysed for seed weight, oil content and fatty acid profile.

The key dates and main meteorological data of the trials for each growing season, crop, and experimental site are reported in the table below (Table 4 UNIBO).

Table 4 - UNIBO. Main dates and meteorological parameters characterizing the trials of UNIBO

Crop	Slope (%)	Growing season*	Sowing date	Harvest date	Mean T (°C)**	Cumulative precipitation (mm)**
Camelina	25	1	16/11/2018	14/06/2019	5.1	229
	25	2	10/11/2019	05/06/2020	3.6	227
	15		07/01/2020	05/06/2020	5.8	200
	25	3	23/10/2020	25/05/2021	7.1	259
	15		20/01/2021	03/06/2021	10.1	176
Crambe	25	1	05/03/2019	20/06/2019	11.1	166
	25	2	26/02/2020	28/06/2020	9.5	213
	15		26/02/2020	28/06/2020	9.5	213
	25	3	03/03/2021	25/06/2021	14.4	157
	15		03/03/2021	29/06/2021	14.8	157
Safflower	25	2	07/01/2020	17/07/2020	8.6	349
	15		07/01/2020	17/07/2020	8.6	349
	25	3	21/01/2021	22/07/2021	14.0	208
	15		21/01/2021	22/07/2021	14.0	208

* Growing season was as follows: 1 = 2018/19 for camelina, 2019 for crambe; 2 = 2019/20 for camelina, 2020 for crambe and safflower; 3) 2020/21 for camelina, 2021 for crambe and safflower

** calculated from sowing to harvest of each crop

Switchgrass generally proved unsuitable for such a marginal condition in both years (2019 and 2020) mostly due to its poor competitiveness against weeds (Fig. 2 UNIBO).

Figure 2 UNIBO. Switchgrass (cultivar Alamo) in the foreground. It was sown in spring 2020 in a 15% slope field (photo taken on 20th April 2021 in Ozzano dell'Emilia).

2. MAIN RESULTS

<u>Camelina</u>

Camelina (cultivar Cypress) confirmed its vigour and it was able to provide interesting seed yields despite extreme conditions (steep slope of 25%). When the slope was reduced to 15%, although still marginal, seed yield remarkably increased far above 1 Mg DM ha^{-1}(Fig. 3 UNIBO).

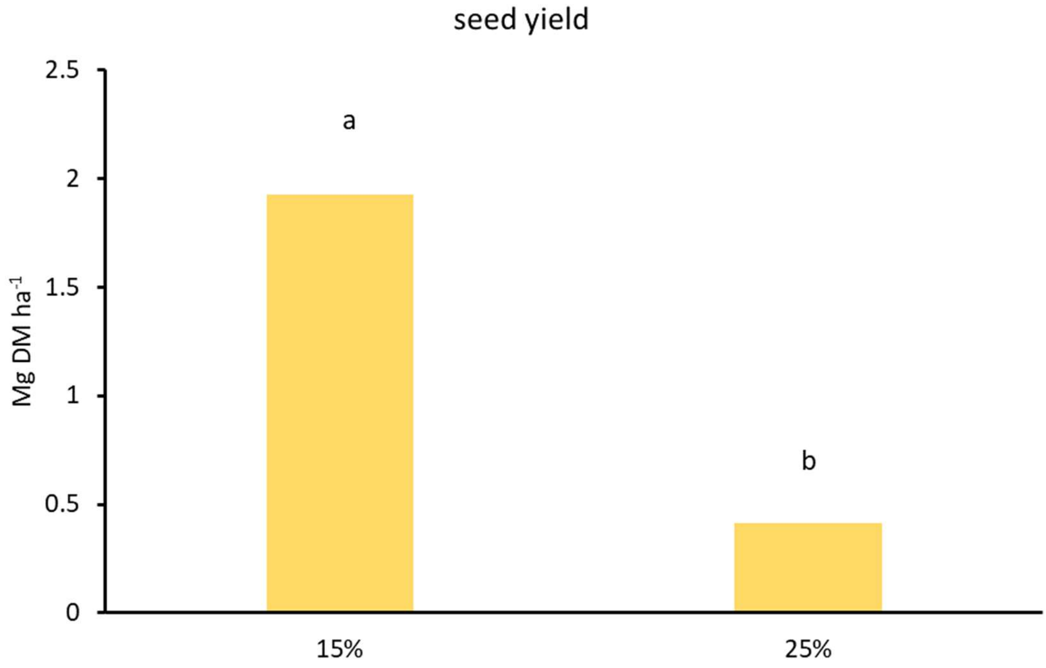

Fig. 3 UNIBO. Camelina seed yield in response to slope. Different letters: statistically different means (*P*≤0.05, LSD test).

Seed oil content was also significantly affected by marginality increasing from 37.5% under 15% slope to almost 40% in 25% slope land (Fig. 4 UNIBO). This was likely due to a compensation effect (i.e., less seeds with higher oil content).

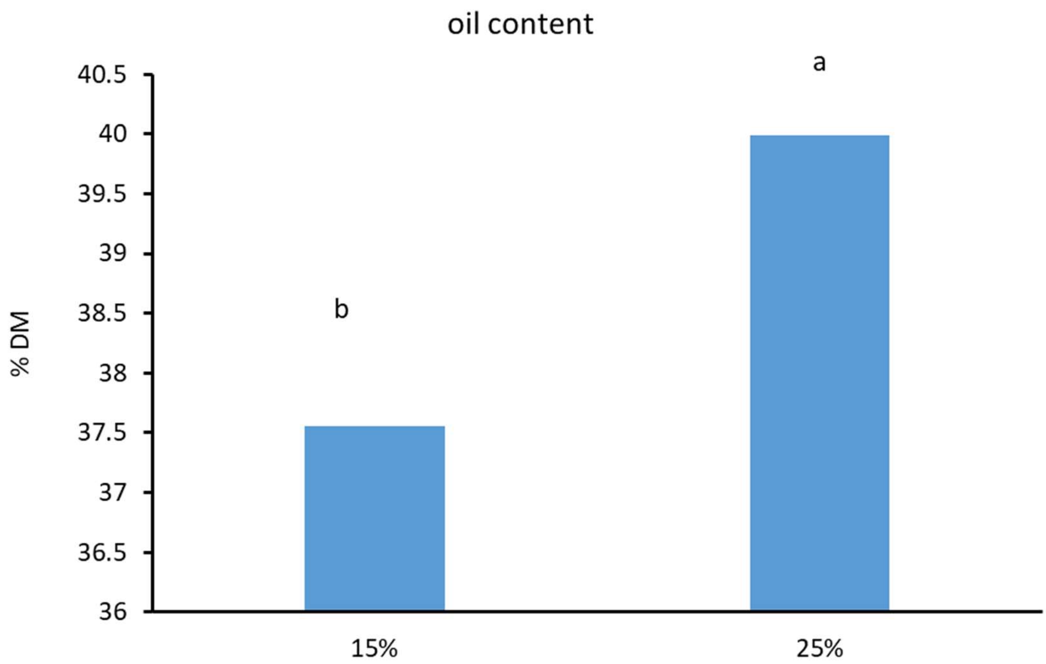

Figure. 4 UNIBO. Camelina seed oil content in response to slope.

Finally, the main fatty acids (i.e., oleic, linoleic, linolenic and eicosenoic acid) , except eicosenoic acid, were all significantly affected by marginality level (Table 5 UNIBO). In particular, under 25% slope, camelina oil was richer in linolenic acid, while oleic and linoleic acids were promoted at 15% slope.

Table 5 UNIBO. Camelina Seed oil composition as affected by slope

Slope	Oleic acid	Linoleic acid	Linolenic acid	Eicosenoic acid
		% DM		
15%	13.5 a	19.2 a	37.6 b	14.4
25%	12.9 b	17.0 b	39.6 a	14.5

Different letters: statistically different means ($P \leq 0.05$, LSD Fisher's test).

When comparing the different sowing techniques (HD vs. TD) and the marginality conditions in the 2nd and 3rd growing season, a significant interaction emerged for seed yields (Fig. 5 UNIBO).

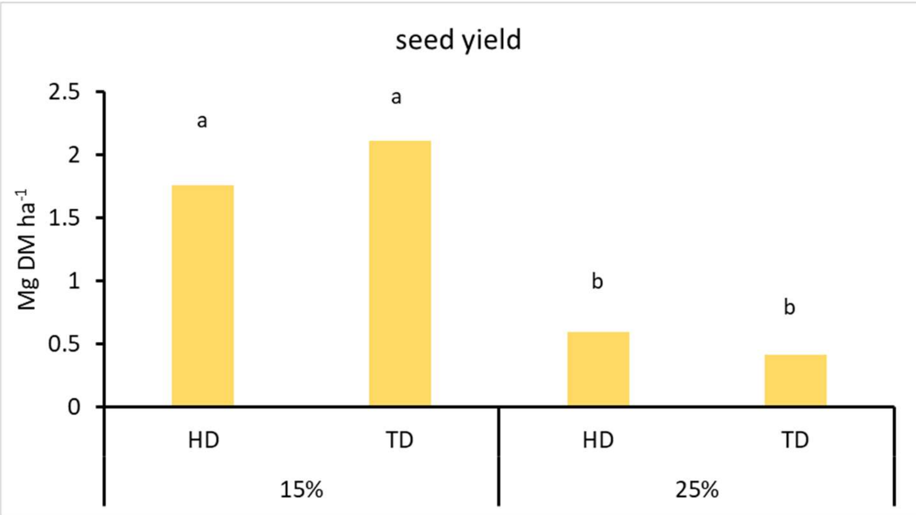

Fig. 5 UNIBO. Camelina seed yield in response to the interaction slope x sowing technique. Different letters: statistically different means ($P \leq 0.05$, LSD test).

Interestingly, while in mild slope the traditional sowing technique (row-seeding) gave the highest seed yield, in steep slope, broadcasting with higher seeding rate permitted to reach higher seed yields. All the other considered qualitative traits of camelina were not significantly affect by seeding technique (row or broadcasting).

<u>Crambe</u>

The crambe cultivar Galactica confirmed its good suitability to northern Italy environmental conditions, as previously tested in the framework of the COSMOS project. Also, under marginal conditions, Galactica was able to produce and the sowing in late winter (end of Feb/beginning of march) allowed crambe to complete its growing cycle in less than 4 months. As expected seed yield was significantly affected by marginality conditions. The comparison between steep (25%) and mild (15%) slope was possible only in 2020 and 2021, as presented in Fig.6 UNIBO. In general, under steep slope crambe produced less, but a significant interaction between slope and growing season emerged.

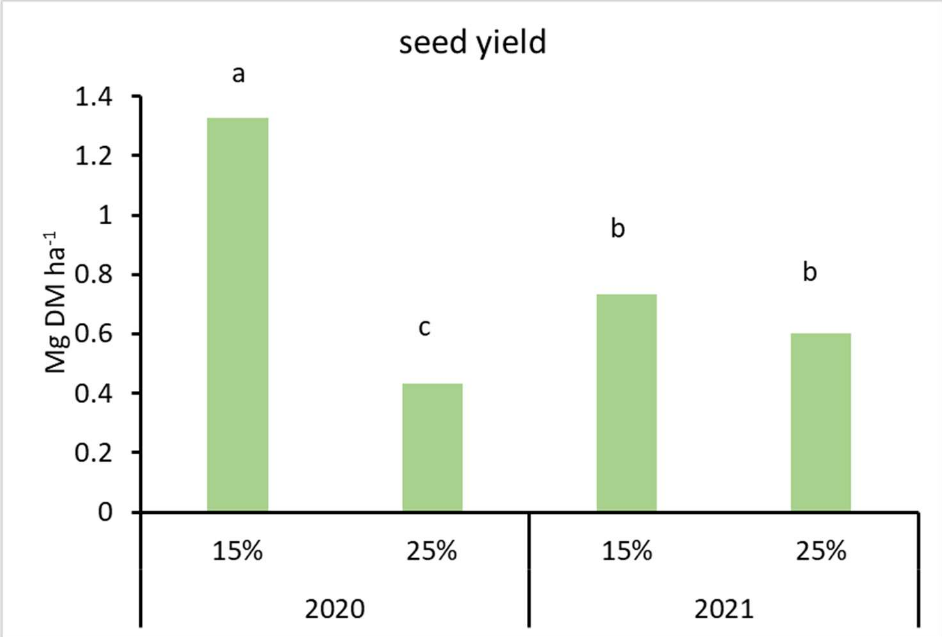

Fig. 6 UNIBO. Crambe seed yield in response to slope and growing season. Different letters: statistically different means (*P*≤0.05, LSD test).

Interestingly, while in 2020 crambe seed yield significantly decreased under steep slope, in 2021 when the meteorological conditions were rather negative, with prolonged drought, the differences between the two sites were no longer significant, demonstrating that it was more impacting the weather than the marginality on crambe productive performance. When comparing the 3-year data from steep slope with the 2-year data of the 15% slope, crambe seed yield resulted affected by the slope reporting a significant lower yield (0.43 vs. 1.06 Mg DM ha^{-1}, under 25% vs. 15% slope, respectively, *P*≤0.05). A seed yield of 1 Mg DM ha^{-1}, can be considered a breakeven yield for this crop, as reported by Berzuini et al. (2021), thus at least under the less severe slope crambe attained a yield in line with expectation. Also, for crambe differences in seed yield in response to sowing technique were not significant and in general broadcasting seemed not a good option for crambe, since it assured a very shallow sowing and in case of prolonged drought as in 2021, the establishment of the stand was slow and uneven.

Crambe seed quality, analysed in terms of seed oil content and erucic acid content, which is the main fatty acid characterizing crambe oil, resulted not affected by marginality condition or growing season. Crambe seed oil content was on average 35.8 %, while erucic acid content confirmed to be elevate and a mean value of 55.9% was surveyed, irrespectively of growing season and marginality conditions.

<u>Safflower</u>

Safflower performed well in both growing seasons. The anticipation of sowing in January permitted the crop to establish well also in case of extreme drought (i.e. 2021). Safflower cycle length was definitely longer than the other oilseed crops tested, but this may represent an added value in case of sloppy areas since the soil will remain covered for longer period thus preventing erosion and other types of soil degradation issues. Seed yield was different between slopes, and growing season, and a significant interaction “slope x growing season” emerged (*P*≤0.05). As evident in the figure 7 UNIBO, safflower seed yield remained stable under steep slope (25%), while in the milder slope (15%) it was affected by meteorological conditions, being significantly lower in 2021 which was a much drier year.

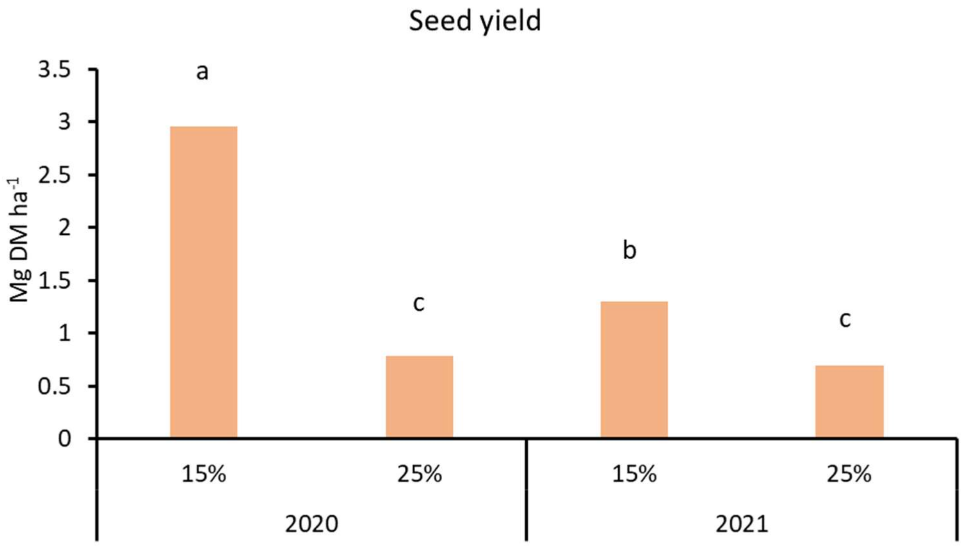

Fig. 7 UNIBO. Safflower seed yield in response to slope and growing season. Different letters: statistically different means (*P*≤0.05, LSD test).

When comparing the two different sowing techniques in 2021 (HD vs. TD), seed yield resulted not significantly affected by them.

Safflower seed oil content was on average 36.7% and resulted not affected by any of the considered factors. The main fatty acids characterizing safflower oil, namely oleic and linoleic acid, were not affected by slope nor growing season and on average oleic acid represented 78.6% of total safflower lipid fraction, and linoleic was 11.8%. Thus, despite being seed yield reduced under steep slope, the qualitative traits of safflower remained stable and this might be of interest for the biobased industry which is looking for feedstock with stable composition.

3. CONCLUSIONS

- Camelina, crambe and safflower showed interesting potentials to be grown in marginal sloping land
- Seed yields of all the three crops was reduced by the steep slope of 50% to 75%, depending on growing season and crop, compared with usual production under non-marginal conditions.
- Camelina was the only crop in which seed quality improved when grown under steep slope conditions
- Safflower and crambe had stable seed quality in response to steep slope, without reporting any significant difference in terms of oil content and fatty acid composition
- The new sowing techniques (i.e. broadcasting) showed positive effects only in camelina at 25% slope.

References

Berzuini et al. (2021). 10.1016/j.indcrop.2021.113880

4. Report from CRES

1. Introduction

CRES in the view of task 4.4 carried out field trials on selected annual industrial oilseed crops for three subsequent years. In total ten field trials were carried out (5 in 2018-19, 3 in 2019-20 and 2 in 2020-21); the crops tested were camelina, crambe, safflower and castor bean (oilseeds). The carried-out trials are presented in the table 1 CRES.

Table 1 CRES: Overview of CRES field trials

Growing seasons	MARGINALITY FACTORS	CROPS	KEY MANAGEMENT ISSUES
2018-19	Unfavorable texture (soils with increased pH) Place: Thessaloniki (Thermi)	Oil crops (Camelina & Crambe)	• Minimum/no tillage • reduced fertilization • No irrigation
	Soils with unfavorable soil texture (acidity) and slope Place: Keramos (close to Orestiada; northern Greece)	Oil crops (crambe, camelina & safflower)	• Minimum/no tillage • reduced fertilization • No irrigation
2019-20	Soils with unfavorable soil texture (sandy)	Oil crops (camelina, crambe & safflower)	• Minimum/no tillage • reduced fertilization • No irrigation
2020-21	Two places; a) Volos-Velestino in an area that was uncultivated for more than a decade, b) Koutso-Xanthi in a sandy area (unfavourable soil tecture).	Oilseeds (castor bean)	• In first place the cultivation was done with no tillage (sowing with special machinery) and reduced irrigation and fertilization and in the second place reduced fertilization and irrigation.

In figure 1 CRES presented the sites of the field trials. In each trial the size of each crop trial had a size from 0.3 to 1.0 ha.

Camelina was always tested as winter crop and the variety tested was Luna [the sowing each time took place from the end of November (20th of November) till early days of December (up to 10th of December)]. Crambe was established at the end of winter till the beginning of March and the variety used was Galactica. Safflower (high oleic variety) was grown as spring crop. It should be pointed out that it was tried to be grown as winter crop but due to heavy rainfalls at the wintertime it was failed. The above-mentioned crops had been grown without irrigation. Castor bean was tested in two places (Volos for one year and Xanthi for two subsequent years) as spring crop. In castor bean trial it was sown the hybrid C1012 provided by Kaiima company (Israel).

Figure 1 CRES: Sites of CRES field trials for task 4.4.

2. Camelina

In Figure 2 CRES presented photos from camelina trials carried out in 2018-19. In the case of Thessaloniki, the field was quite good with high density compared to the second site. In the second site that the soil was acid and stony weed problems were recorded and the camelina density was lower than the recommended one.

Figure 2 CRES: Camelina in Thessaloniki (on the left) and in Orestiada (on the right).

As expected the camelina productivity in Thessaloniki was higher than in Orestiada (seed yields: 1.45 t/ha vs. 1.26 t/ha). In the case of Thessaloniki trial lodging problems had been recorded (Figure 2 CRES on the left). When the camelina trial was repeated in 2019-20 in Orestiada the seed yields were higher than the 1st year and come up to 1.4 t/ha. In all camelina trials the harvesting carried out by using existing machinery for cereals.

In Orestiada in 2020 (Fig. 3 CRES), before the final harvest, five areas randomly chosen 4m^2 each were marked for manual harvesting. In these areas the camelina seed yields were higher 1.50 t/ha in 2019 and 1.71 t/ha in 2020. In the same trials the plantation height was 72 cm in 2019 and 82 cm in 2020. The remaining biomass as harvested was 4.1 t/ha in 2019 and 3.7 t/ha in 2020. The moisture of the remaining biomass was 15% in 2019 and 12% in 2020.

Figure 3 CRES: View of camelina in Orestiada (26.5.20); the soil was acid, stony and slope.

It should be noted that the farmers in the area of Orestiada were quite interested in camelina since it is cold resistant, has short growing period and it can be harvested 2 to 3 weeks earlier than wheat. A national workshop had been organised in the area prior to the establishment of the camelina field trials in order to attract the farmers and during that day several questions had been raised such as:

how the crop should grow, are available varieties in the market, if chemical weed control is needed and if yes are any registered herbicides, can harvesting can be done with existing machinery, etc.

3. Crambe

In total three crambe trials had been carried out; one in Thessaloniki (2019), in Orestiada (2020) and in Xanthi (2021) (Figure 4 CRES). In all trials the variety was Galactica and crambe was grown as spring crop.

At all sites crambe developed quite well, although in some spots of the field the density was not as high as needed. It was proven that the high density is quite important in order to have a good establishment and improve its crop ability to compete the weeds. It was also found that the sowing date should be as early as possible in spring in order the crop to be able to have a proper rosette phase before the flowering initiation. The plant height varied from 60-80 cm.

In each site before the final harvesting (that took place mechanically using the existing machinery for cereals) three areas of 10 m^2 randomly chosen was marked. In these areas the harvesting took place manually for detailed measurements. In the figure 5 CRES the yields (seeds and straw) as estimated at the manual harvests is reported.

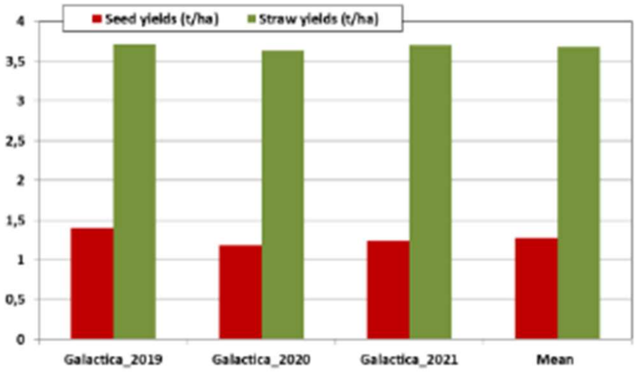

Figure 5 CRES: Seeds and straw yields in the three crambe trials.

Figure 4 CRES: View of crambe trials in Thessaloniki (above), in Orestiada (middle) and in Xanthi (below)

The highest seed yields were recorded in Thessaloniki (1.40 t/ha) and the least in Orestiada (1.18 t/ha). In all sites the remaining biomass was around 3.7 t/ha (as harvested) having moisture content 10-15%.

When the harvesting took place mechanically, using the existing machinery, the seed yields were lower than the ones recorded in the plots that manually harvested. Thus, the seed yields in Thessaloniki was 1.05 t/ha (25% lower), in Orestiada 0.98 t/ha (17% lower) and in Xanthi 1.02 t/ha (18% lower).

4. Safflower

In total two safflower trials had been established; in Orestiada (2019, Fig. 6 CRES) and in Xanthi (2020, Fig. 7 CRES). In both sites a high-oleic variety was sown in the beginning of spring. The trials were rainfed. The crop had a very good development with very good soil cover and was able to complete the weeds successfully. The final harvest took place in the first half of August.

Figure 6 CRES: View of safflower field in Orestiada (2019) in spring and in summer

Figure 7 CRES: View of safflower field in Xanthi (2020) in spring and in summer

Before the final harvesting 6 areas randomly chosen per trial had been marked with an area 4 m^2 each. In these areas, the harvesting took place by hand in order to estimate the potential seeds and straw yields. In figure 8 CRES the yields (seeds and straw) in both sites is presented based on the manual harvests.

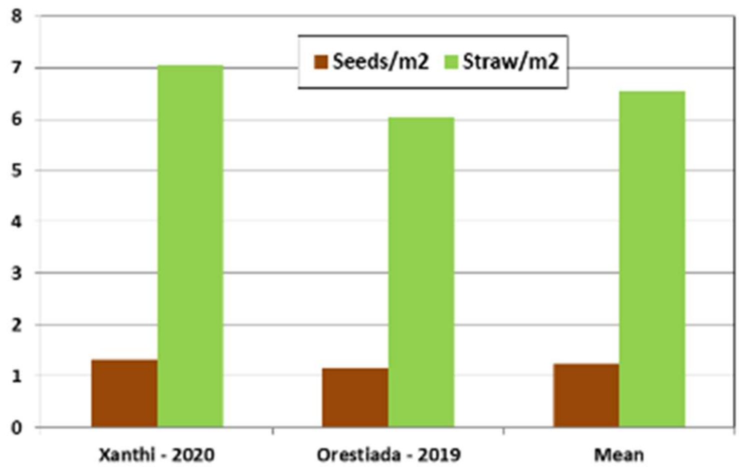

Figure 8 CRES: Safflower yields (seeds and straw; t/ha) in Orestiada-2019 & Xanthi-2020.

Higher seeds and straw yields were recorded in Xanthi (seed yields: 1.34 t/ha). In Orestiada the seed yields were 1.15 t/ha (16% lower than Xanthi). When the harvesting took place mechanically the seed yields were lower and were 1.13 t/ha in Xanthi and 1.02 in Orestiada.

5. Castor bean

Three field trials were established in Greece for castor: the first in Volos (2021) and the other two in Xanthi (2020 & 2021, Fig. 9 CRES). In all trials the used castor hybrid was C1012 imported from Kaiima company (Israel). Both trials had been sown mechanically at the end of April 2021 (24/4/21 in Volos and 30/4/21 & 22/4/20 in Xanthi). In the case of Volos the area used had been left fallow for many years and the sowing was carried out by using a sowing machine for sod-seeding. In the case of Xanthi the soil was a sandy poor soil that usually is used for sunflower cultivation.

Figure 9: View of the castor bean trial in Volos 2021 (first row) and in Xanthi 2021 (second row).

In Xanthi the seeds productivity of castor bean varied 2.2 to 2.35 t/ha, increasing when a sunflower header in the harvesting machine was adopted. In Xanthi two types of harvesting machines were tested; one for sunflower and one for cereals. By far, sunflower header was more appropriate for castor bean, although further improvements are needed. In this trial the plantation was sprayed with REGLONE 20 SL in order to stop the crop grow and get prepared for the mechanical harvesting.

In Volos the mean seed yields based on the manual sampling was 2.16 t/ha (varied from 1.49 to 3.2 t/ha). The manual harvests took place in 16 areas with total size 6 m^2 each. In this trial three different chemicals for growth termination have been tested namely Glyphosate, Spotlight© BASF and Diquat. In this site due to lack of available sunflower header for the mechanical harvest a cereal one was used.

5. Report from CIEMAT

a. Introduction

CIEMAT's contribution to Task 4.4 within the scope of the MAGIC project focused on siberian elm and tall wheat grass crops. The crops were located on marginal land of CEDER-CIEMAT in Soria (North Central Spain). In Spain, marginal agricultural lands are rainfed croplands where annual herbaceous crops frequently provide low economic yields, which is conditioned by pedoclimatic constraints. In this context, the search for perennial species with the ability to grow in cold winter and long, dry summers may be necessary. This resistance of the species makes necessary its study in marginal agricultural lands under on large-scale fields in Spain. In some marginal rainfed areas, they are presented as an alternative to traditional agricultural crops.

The general objective of the trials was to study on large scale fields on marginal agricultural land the performance of siberian elm and tall wheatgrass with minimum tillage and under rainfed conditions.

b. Material and methods

Siberian elm

- Soil biophysical constraint: unfavorable texture, stoniness and organic matter low

- Key management issues: Minimum tillage, inorganic fertilization and rainfed condition

- Established: 2-5 May 2018
- Parcel total surface: 1,440 m^2
- Planting density: 3,333 plants ha^{-1} (placed at 3 x 1 m planting frame)
- Basal fertilization (May 2018): inorganic fertilization (50:90:90 kg NPK ha^{-1}).
- Average soil characteristics were (0-30 cm): pH (H_2O), 6.15; EC, 35 µS/cm; Nt, 0.03%; K (assimilable), 3 cmol·kg^{-1}; sand, 85.8 %; clay, 10 %; 28 % coarse elements; oxidable organic matter (0.4%)

Tall wheatgrass

- Soil biophysical constraint: texture and organic matter low

- Key management issues: Minimum tillage, inorganic fertilization and rainfed

- Established: 22-23 October 2018
- Plots surface: 1,800 m^2
- Variety: *Elytrigia elongata* variety Alkar; doses seeds to 20 kg ha^{-1}
- Basal fertilization: October 2018: 24:72:24 kg NPK ha^{-1}
- Inorganic Nitrogen fertilization (each growing season in the spring): 80 kg N $ha^{-1}y^{-1}$
- Harvested in July: 2019, 2020 and 2021
- Soil conditions (0- 30 cm): 84% sand, 6% clay, 10% silt, 0.69% organic matter, 0.06 g kg^{-1} total N, 10.25 mg kg^{-1} available P.

Climate conditions were Continental Mediterranean with cold winters, warm summers and low rainfall level. Climate data were taken from the National grid of meteorological stations (AEMET) nearest to the experimental fields. Average annual rainfall was 668.7 mm in 2018, 529.3 mm in 2019, 420.0 mm en 2020 and 489.7 mm in 2021 (from January to October). Annual average temperature was 10.4 ºC, 11.1 ºC, 11.3 ºC, 11.7 ºC in 2018, 2019, 2020 and 2021, respectively. Free frost period was from late May to early October and drought conditions usually appeared in summer. **Figure 1 CIEMAT** shows the monthly rainfall and average temperature during the experiment in experimental plots.

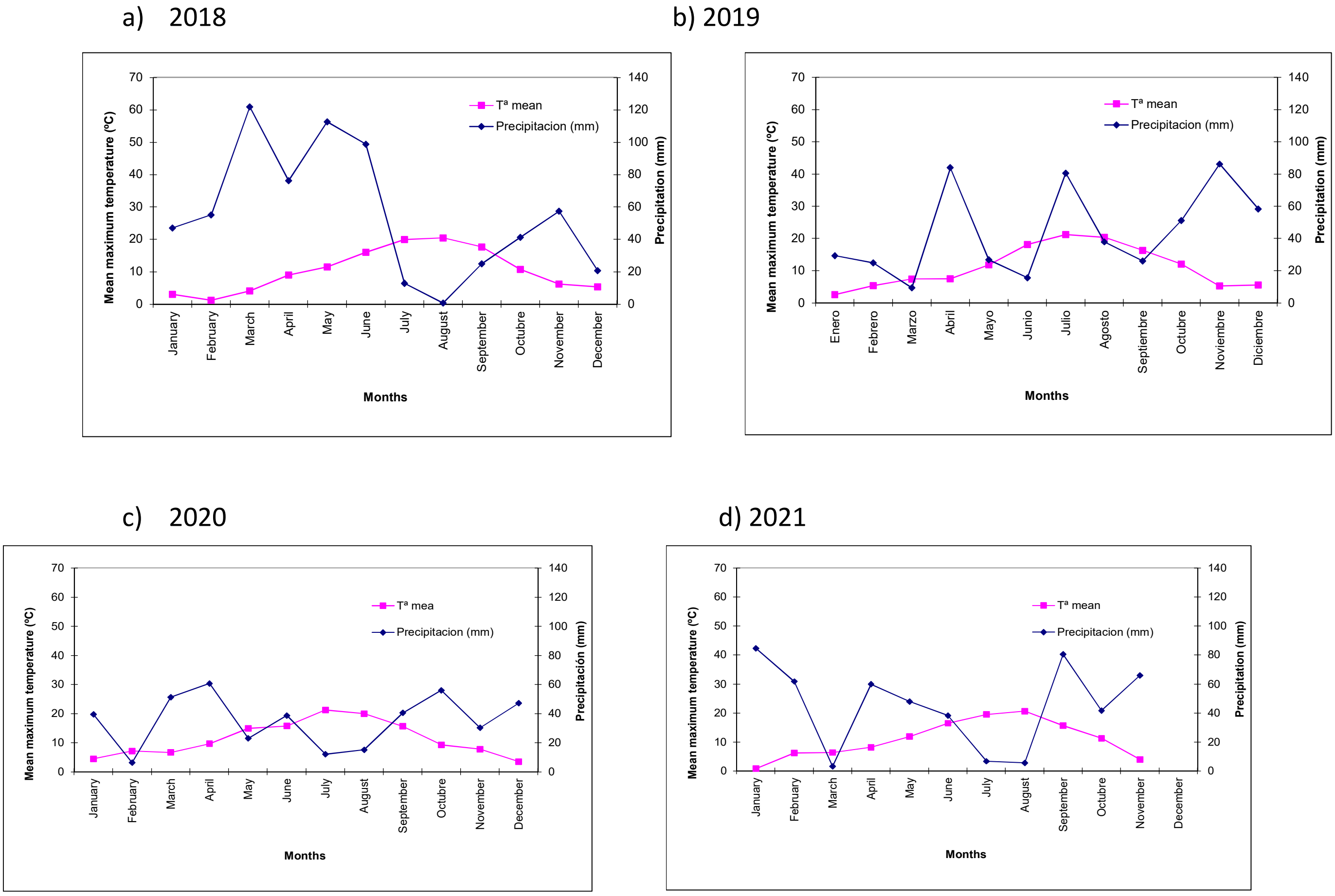

Figure 1 CIEMAT: Ombrothermic diagram, Lubia (Soria), 2018-21 season. a) 2018, b) 2019, c) 2020 and d) 2021.

Results and discussion

The results confirmed that siberian elm is a species adapted to the hard climate of Soria, cold winters, frosts and wind. It is also resistant to pests and diseases because no pesticide treatment has been carried out. It prefers well-drained soils, although it tolerates a wide variety of adverse conditions, such as soils with low organic matter content and flooding situations.

Due to the development of the crop in these years, the cutting period should be more than three years, therefore the data on growth assessment of Siberian elm for each year are shown at the time of the report (Figure 2 and 3 CIEMAT). Productivity biomass will be determined in 2023, when the plants will be 4 years.

In studies carried out same location in rainfed conditions, the yields biomass was at the end of the second growth cycle, 1.65 Mg DM ha^{-1} y^{-1} while 2.15 Mg DM ha^{-1} y^{-1} was in Almazán (Soria) (Perez et al., 2012) with density of 3,333 trees per ha.

The average composition of the biomass was 3.0 % ash, 48.0 % C, 6.0 % H, 0.6 % N, 0.04 %S, 0.02 % Cl and GCV of 19.2 MJ.kg-1.

The highest mean height was 158.0 cm in 2021, (Figure 2 CIEMAT) and the basal diameter is greater in stems over 130 cm in length than in stems less than 130 cm in length, with the largest mean diameter being 33.5 cm in 2019 (Figure 3 CIEMAT).
Photos of trials are in Annex (Figures 5 & 6 CIEMAT).

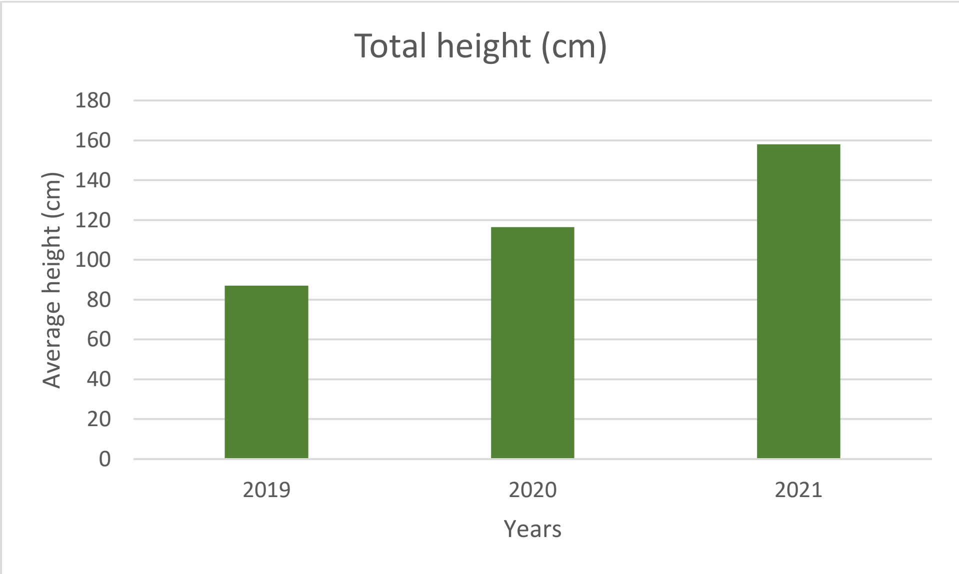

Figure 2 CIEMAT. Average total height of siberian elm from 2019 to 2021

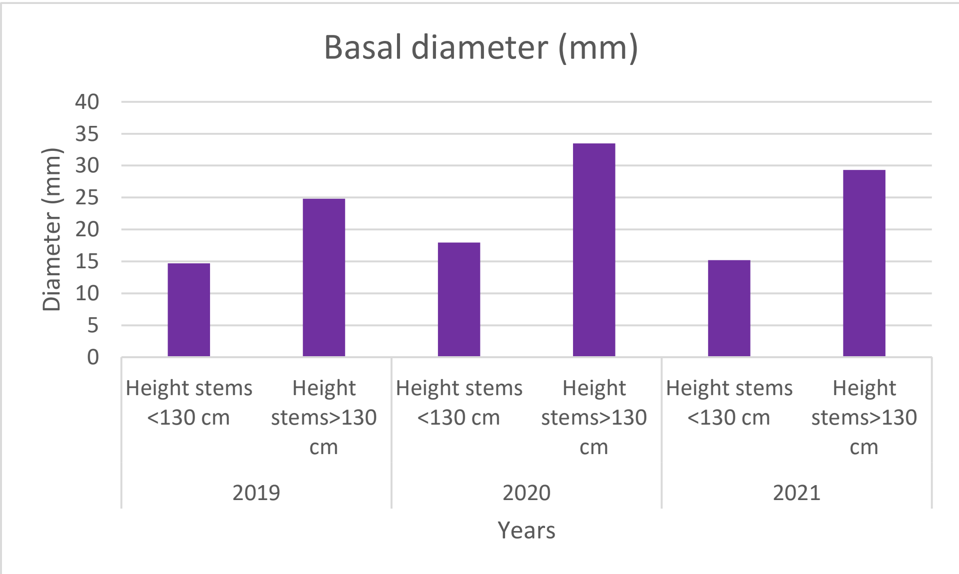

Figure 3 CIEMAT. Basal diameter of siberian elm from 2019 to 2021

In relation to tall wheatgrass, so far three harvests have been completed: 2019, 2020 and 2021, which correspond to the 2018/19, 2019/20 and 2020/21 agricultural seasons, respectively. The highest biomass yields were registered in 2021, 9 Mg DM ha^{-1} **Figure 4 CIEMAT**.

Other studies performed during eight years in marginal lands in Spain with three varieties of tall wheatgrass had an average biomass yield of 4.4 Mg DM ha^{-1} y^{-1} (Ciria et al., 2020a). Besides tall wheatgrass is better option than annual grass because increase of soil organic matter.

Photos of trials are in Annex (**Figure 6**)

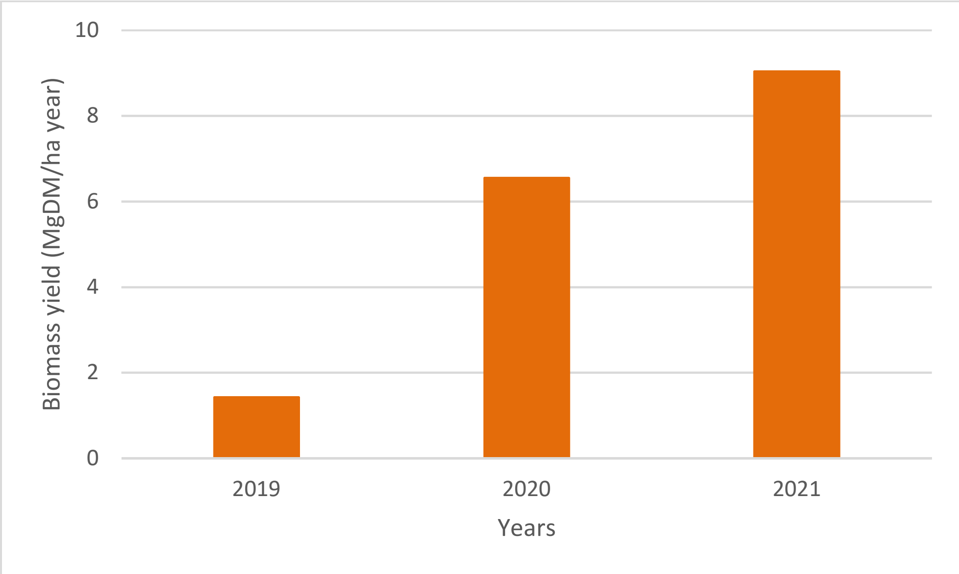

Figure 4 CIEMAT. Dry matter biomass yield of tall wheatgrass (Mg DM ha^{-1} year^{-1}) (2019- 2021)

CONCLUSIONS

The selected crops adapted well to the climatic condition of Soria (Spain) on marginal agricultural land. Taking into account the environment constraints, the results are promising and show the great potential of this species as an energy crop. The experiments were conducted in accordance to what was planned. Siberian elm crop was established in north central Spain at a planting density of 3,333 trees per ha in order to study its performance as a short rotation coppice in rainfed conditions. The crop performed well along the 3-year experiment duration. Siberian elm exhibits a very good plant survival; it reached 91.25% in the experiment conditions. Its growth has been low (diameters between 5.06 and 61.63 mm and heights between 15 and 350 cm), so it was considered to extend the cycle one more year (4-year cycle). Studies carried out during three years in marginal land in Soria with tall wheatgrass (*Elitrygia elongata* var. Alkar) had an average biomass yield of 1.4 Mg DM ha^{-1} y^{-1} in 2019, 6.5 Mg DM ha^{-1} y^{-1} in 2020 and 9.0 Mg DM ha^{-1} y^{-1} in 2021. Tall wheatgrass is a perennial grass so that biomass yield in first year is low. Average biomass yield obteined 2021 was high. The results showed that there are differences betwen annual biomass yield. Tall wheatgrass and Siberian elm proved to be a drought tolerant crops, withstanding harsh crop conditions. As a rainfed crop, yields of this crop depend mostly on the rainfall regime (amount and distribution) during the agricultural season. These species have interesting characteristics for industrial cultivation such as the following: woody plant, easy regrowth after harvest, broad ecological value and resistant to biotic and abiotic stress.

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Photographic Annex

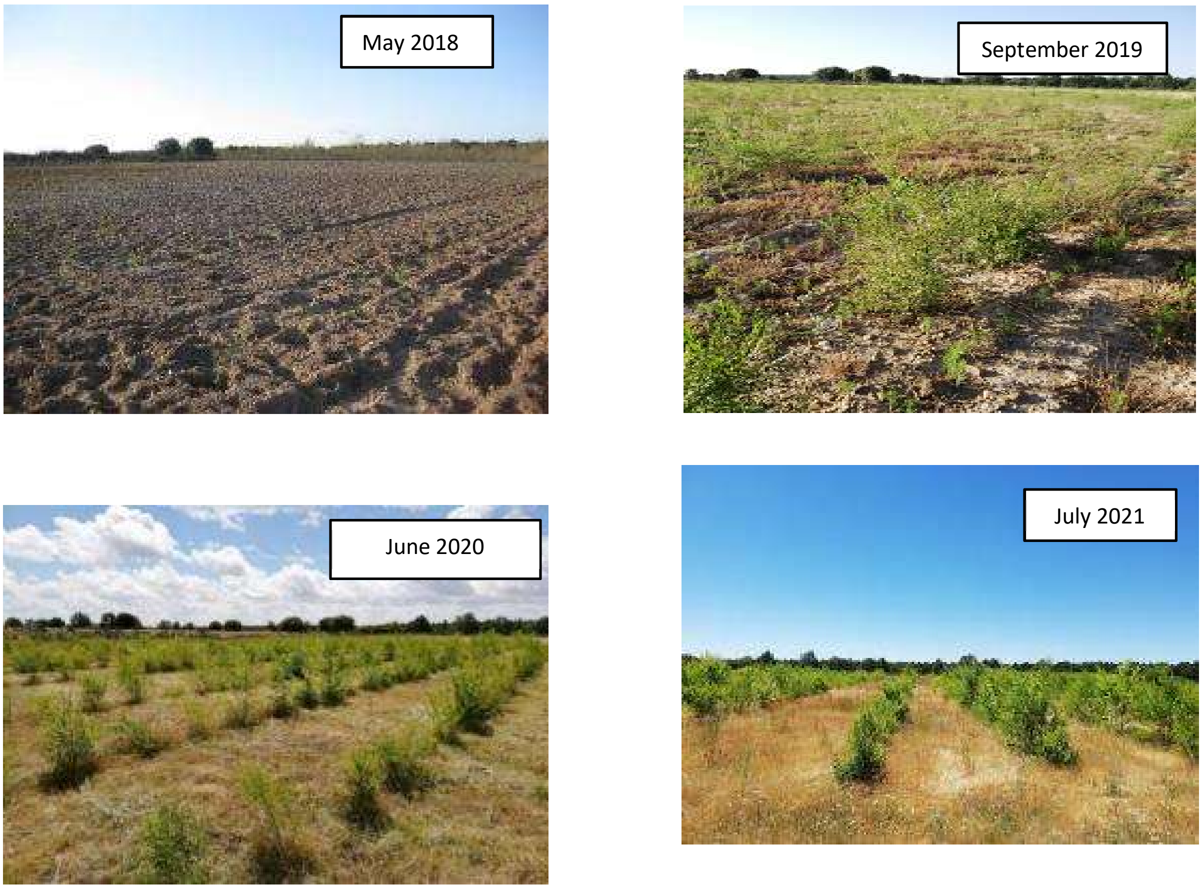


Figure 5. **CIEMAT.** Demostration field of siberian elm. Top left: May/2018. Top right: September/2019. Bottom left: June/2020. Bottom right: July/2021.

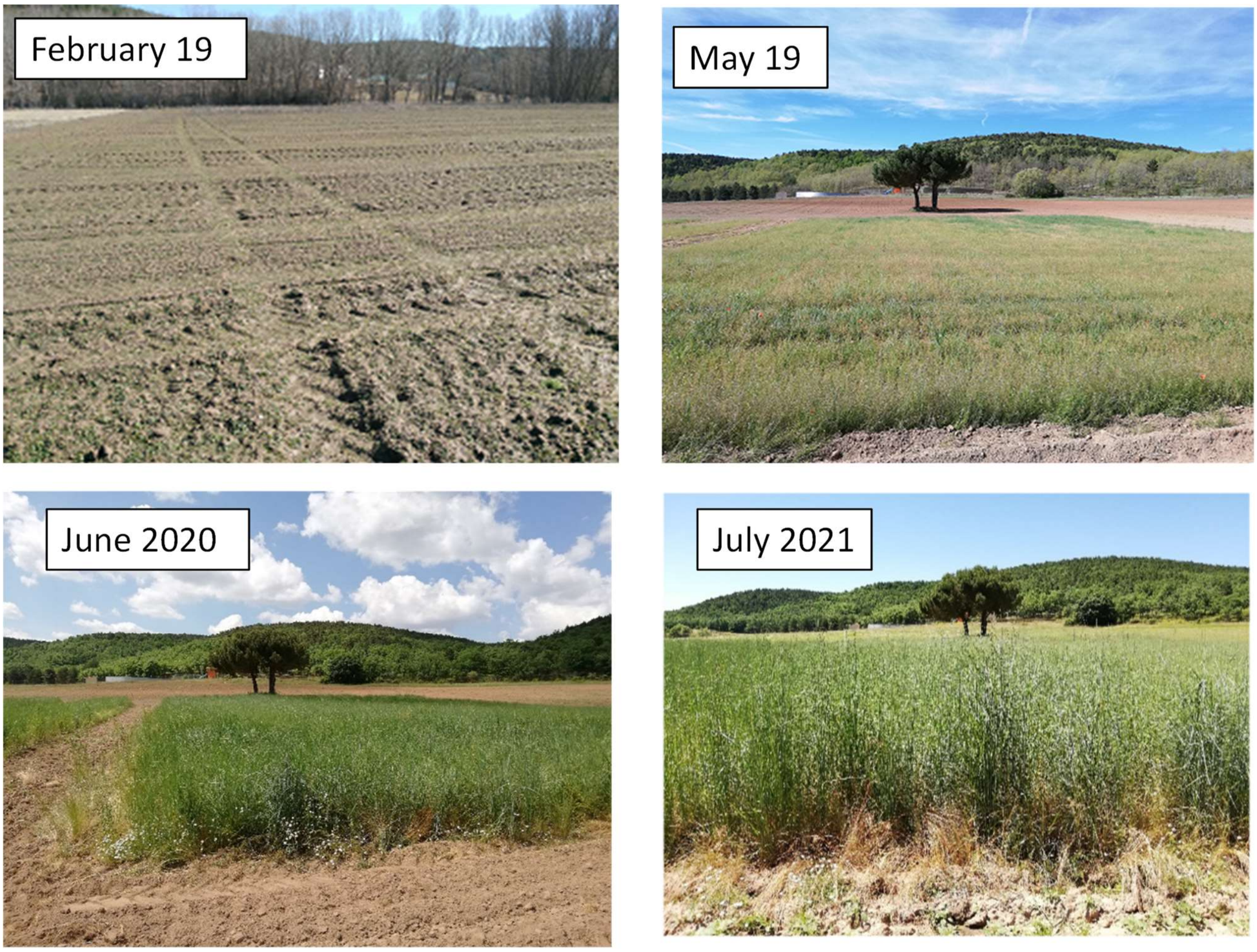


Figure 6. **CIEMAT.** Demonstration field of tall wheatgrass. Top left: February/2019. Top right: May/2019. Bottom left: June/2020. Bottom right: July/2021.

6. Report from NOVABIOM

Trial 1: Planned activities from the DoA

The aim is to grow *Miscanthus* x *giganteus* on marginal soil in the Loire river valley in France. It has very sandy soils that are often abandoned when irrigation is not possible. *Miscanthus* x *giganteus* (MxG) is a more drought resistant plant that creates possibilities due to its perennial character which allows it to establish over time and seek water where annuals can't grow. No inputs are required. No fertilizers, and no herbicides after year 1. For MxG to be a success, establishment is crucial.

Actual activities carried out, with the methodological details

Therefore, NOVABIOM developed a trial to evaluate if MxG could be established in these sandy soils without irrigation, fertilizer, pesticides and herbicides in Mezieres lez Cléry on 1 ha of sandy soil. 50 % was rainfed, 50% irrigated. 50 % of the weeds were mechanically destroyed, 50% would be chemically destroyed. No pesticides were used against wireworms (MxG's only establishment predator), and half of the fields had potatoes added to the interrow to distract wireworms from attacking.

<u>Planting date : 14/5/2018</u>

Fertilization :
- 20t of FYM compost applied 2/05 on whole parcel.
- 60:120:120 kg of NPK (chemical) = control

Weed control :
- Mecanical :
  - Harrowing 24th may
  - Interrow cultivation 20th june and 4th july.
- Chemical : Anti germinative « S metolachlore » 28th may

Wireworm ctrl :
- control vs 1t/ha potatoes interrow at planting. (25cm deep) wireworm trapping.

Irrigation vs rainfed :
- 20mm of water applied every 15 days on the irrigated side

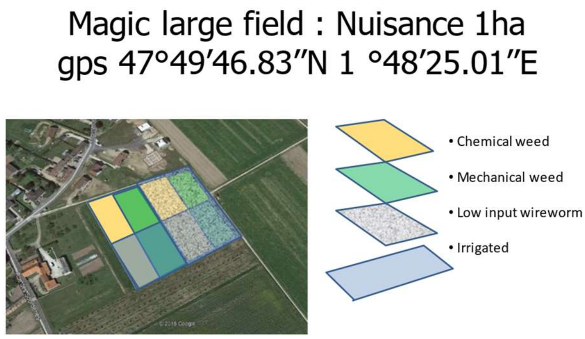
Obstacles and deviations

During the trial we noticed not a single wireworm attack. Therefore we couldn't get any results on the efficiency of our potato intercropping.

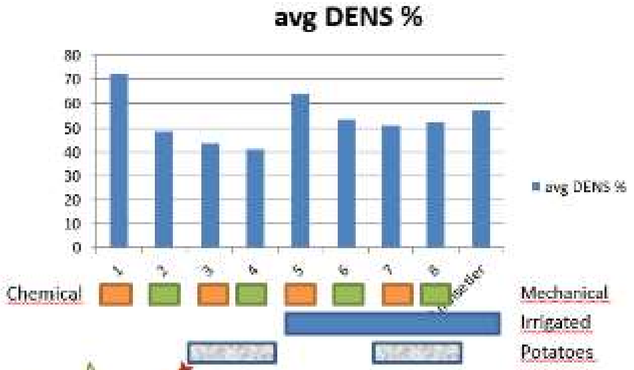
Main results, conclusions and lesson learnt

After maintaining these conditions over 2 years, the following results were found: The wireworm population was not strong enough to show a significant difference. The MxG establishment rates in irrigated + herbicide were highest (67,5%) and lowest in the rainfed + mechanically weeded part (42,5%). However irrigation in the first year of MxG establishment, can compensate the dry out effect of mechanical weeding in the sandy soil (52% est.), 50 % establishment is the minimum to have 10 000 plant/ha. These trials showed that we can establish MxG in sandy soils. No herbicide, no fertilizers and only mechanical weeding in the first year, are enough to establish MxG on these marginal soils. Also, instead of using a row crop cultivator, a sprint tine harrow should be used, which reduces water evaporation and is still efficient enough to destroy weeds when they're small.

Photos from the trials



On average 53% of the plants survived.
Maximum number of 72,5% in Tr1, minimum of 41% in Tr4, 44% Tr3.



Traitement	DENSITY 10m		
	A	B	avg DENS %
1	26	32	72,5
2	21	18	48,75
3	14	21	43,75
4	17	16	41,25
5	27	24	63,75
6	22	21	53,75
7	23	18	51,25
8	17	25	52,5
9 noisetier	27	19	57,5

Trial 2: No-till covercrop in Miscanthus x giganteus establishment year

Planned activities from the DoA

Miscanthus x *giganteus* (MxG) is a perennial plant that is seeing a strong development in France over the last 15 years. Its benefits are multiple, but can be summarized as: low inputs and high yields. Miscanthus does not require herbicide, except during its first year. We developed a trial to see if a cover crop could further reduce herbicide use by suppressing winter weeds without affecting miscanthus growth.

Actual activities carried out, with the methodological details

To do this, 6 different mixes of cover crops were sown in a 5-month-old MxG plantation (April 2019) measuring up to 150cm in September 2019. We used a no-till disc drill to sow. MxG stems were slightly affected, but straightened back up after sowing.

Obstacles and deviations

There was a technical issue during the sowing off the clover which caused an uneven spreading of the seeds. This made one of the 6 treatments results hard to use.

Main results, conclusions and lesson learnt

Clover was too slow to establish due to a dry September and was not able to suppress ray grass. The cover crop mixtures including flax showed very good results. Also daikon radish, mustard and phacelia proved to establish quick enough to suppress winter weeds in a sufficient manner. however, daikon radish overgrew MxG in spring time and should be destroyed (FACA roller) before next year. Lastly, biodiversity increased; a lot of insects and mammals were observed. To conclude: cover crops can be an efficient way to manage weeds in a first year MxG planting, depending on weather conditions during and after sowing.

Photos from the trials

Trial 3: Boosting Miscanthus on Marginal Land

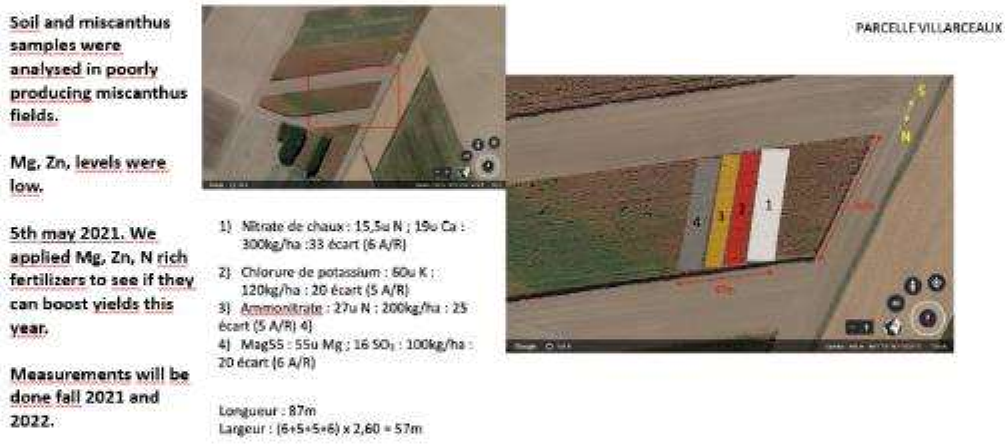
Planned activities from the DoA

Miscanthus x *giganteus* (MxG) is a perennial plant that is seeing a strong development in France over the last 15 years. It has been implanted in France on all latitudes, and adapts well to different soil and climate conditions. However, on marginal lands, we've observed rare cases of lowering yields. The trial we developed was created to define the factors that can cause this phenomenon.

Actual activities carried out, with the methodological details

To do so, soil and plant matter analyses were done to expose any deficiencies. The, apparently missing elements were then added by the means of fertilizers. In 2019 Urea was applied on 2 10x10m squares. In 2020 N, P, K, Mg and Zn were applied in strips, next to a control strip.

1. Autumn plant matter (stem and rhizome) indicated a lack of Mg
2. Soil analyses show no deficiency
3. Repeated winter plant matter analyses show various element deficiencies in low yielding MxG.
4. Application of different fertilizers (Mg, Zn, N, P, K)
5. Final analyses showed: beneficial effect of N fertilizer on Miscanthus in year 1 and 2. (without 2nd application) rhizome recycles nutrients over several years.



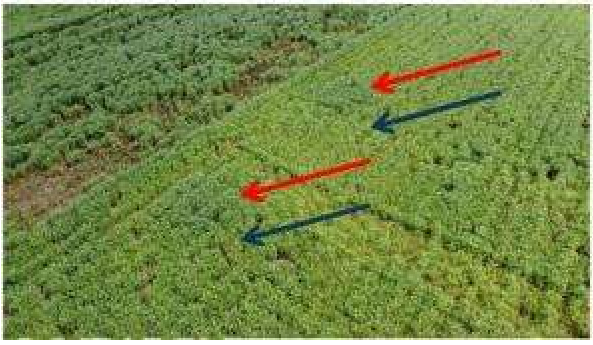
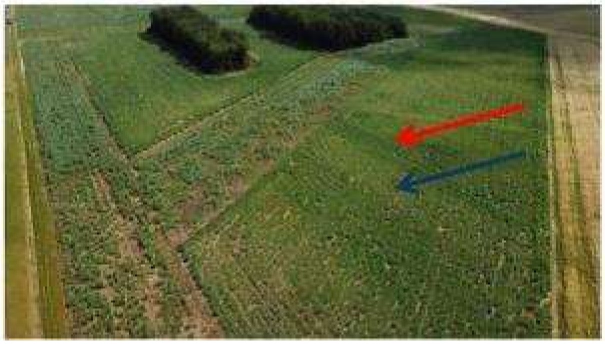
Obstacles and deviations

No obstacles or deviations have been encountered**.**

Main results, conclusions and lesson learnt

The results show that Miscanthus x Giganteus responded very well to N-rich fertilizers. A dark green color was observed on the leaves, as well as an increase in stem height by 29,4%. What was most interesting, is that the effects were again clearly visible in the 2nd year, without receiving a 2nd application of N. This leads us to conclude that in some cases, a one-time N-rich fertilizers application can boost Miscanthus yield to increase to regular standards again**.**

Photos

7. Report from 3B

3B established large field trials in the north-eastern Poland with one annual oil crop and two perennial lignocellulosic crops. Marginality factor for these trials was unfavourable texture and stoniness.

Marginality factor for these trials is unfavourable texture and stoniness. Our experiments can be divided into two trials:

1. Cultivation of lignocellulosic crops on heavy and sandy soil with two factors. The first factor of this trial were species: willow (*Salix viminalis)* Ekotur variety and poplar (*Populus nigra* x *P. Maximowiczii*) clone Max 5. The second factor were soil types: heavy (clay) and sandy (sand) soils.
2. Cultivation of camelina (*Camelina sativa*) with one factor: heavy (clay) and sandy (sand) soils.

Field trials' location

Field trials established in northeast Poland in Reszel commune (Fig. 1 3B) in two locations: Leginy and Fingaty village. The locations are about 5 km away from each other. The Reszel commune is in the central part of the Masurian Lake District (post-glacial area). This land is located higher than its neighbouring regions and, in many places, exceeds 200 m above sea level. Area is undulating (Fig. 2 3B). The recognizable feature of this region is the meridian-oriented glacial erosion and chains of 7 glacial moraines. Soil types are loams, loamy sands, sands and organic soils. Quality of soil can be uneven within one field.

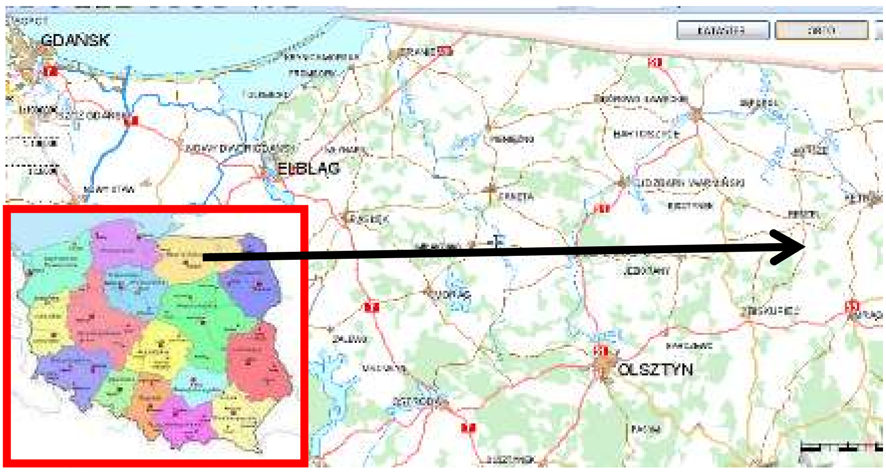


Fig. 1 3B. Localisation of the field trials

Fig. 2 3B. A landscape of Reszel Commune

Leginy site

The site in the village of Leginy (N:53°59’58’’ E: 21°8’30’’) was located on heavy soil made of clay (Fig. 3 3B, Fig. 4 3B). This soil belongs to nutrient and potentially fertile soils. Its excessive periodic humidity or dryness (in absence of precipitation) hinder proper soil management and limits the selection and growth of plants. The structure of these soil prevents capillary action of water in the soil. When the soil is too wet it becomes tacky, and when it is too dry it is strongly compacted. The soil in Leginy location was quite rich in nutrients, the pH was 6.8, and the organic carbon content was quite high (2.41%) (Table 1).

In Leginy two field experiments were established, on an area of 5,000 m^2, including 4,400 m^2 of trials and about 600 m^2 of technical area (roads and technical paths, etc.). Trials with perennial plants were located on the slope, and trial with oil crop partly on the slope and top of the elevation.

1. The first trial with an area of 2,200 m^2 with two species of perennial lignocellulosic plants (poplar and willow) was established on 21/04/2018. The planting density was 18,000 per hectare. Plants were planted from cuttings in a twin row arrangement. Inter-row spacing was 1.50 m, and the distance between double rows was 0.75 m, the distance of plants in a row was 0.5 m. Cuttings were planted manually, no fertilization was applied. During the plant growth, manual weeding was performed two times. The area of trials for each species was 1100 m^2.
2. The second trial in Leginy was established on 21/04/2018, also on the area of 2,200 m^2. In this case, the study species was an annual oil plant camelina. Seeds were sown with drill at rate of 6 kg/ha. Plants were sown in single rows; the distance between rows was 13 cm. Nitrogen fertilization in a rate of 100 kg ha^{-1} was applied.

Fingaty site

The site in the village of Fingaty (N: 54°0’54’’ E:21°12’7’’) was located on light soil made of sand (Fig. 5 3B, Fig. 6 3B). In Poland, it is classified as one of the weakest soils usually made of sands and loamy sands that pass into sand or gravel. Such soils are poor in nutrients, permanently too dry, hence the fertilization gives a slight increase in yields. These soils have low capillary action and mainly use rainwater. In the case of prolonged rainfall, these soils have very limited water resources available for plants. The soil site in Fingaty was quite rich in nutrients, as for light soil, the pH was 6.3, and the organic carbon content was low (1.22%) (Table 1).

In the Fingaty location, as in the Leginy, two field experiments were established on an area of 5,000 m^2, including 4,400 m^2 of trial area and about 600 m^2 of technical area (technical roads, etc.). Trials with poplar and willow were located at the bottom and slope of the elevation, and trial with camelina mainly at the top of the elevation. Both trials were located in the vicinity of a large forest complex.

1. The first trial with an area of 2,200 m^2 with a poplar and willow was set on 14/04/2018. The planting density of the trial (in twin row spacing) was the same as at the Leginy site. Cuttings were planted manually and no fertilization was used. During the plant growth, manual weeding was performed two times. The area of the trials for each species was 1100 m^2.
2. The second trial at the position in Fingaty was established on 14/04/2018 also on the area of 2,200 m2. Camelina was sown at a rate of 6 kg/ha. The distance between rows was 13 cm. Nitrogen fertilization in a dose of 100 kg/ha was applied.

Table 1. Soils characteristics in Leginy and Fingaty

Site/soil	pH in KCl	available forms (mg/100 g soil)			N-tot. (%)	C (%)
		P_2O_5	K_2O	Mg		
Leginy (clay)	6.6	10.6	35	19.7	0.279	1.82
Fingaty (sand)	5.8	16.3	11	5.6	0.095	1.13

Fig 3 3B. Location of the trial on heavy soil (clay) in Leginy village

Fig 4 3B. Heavy soil (clay) at Leginy site

Fig. 5 3B. Location of the trial on sandy soil (sand) in Fingaty village

Fig. 6 3B. Sandy soil (sand) at Fingaty stand

Methods

POPLAR AND WILLOW TRIAL

Weed infestation was monitored during plant growth. Observations of the growth and development of plants and the occurrence of diseases and pests on willow and poplar were carried out as well. After the end of the plant growth, the number of plants per area unit (hectare) was determined, and plants survival (%) was calculated in relation to the initial density. In addition, the number of shoots per plant (pieces), height (m) and stem diameter (mm) were measured. Subsequently, 30 plants were cut down for each species and site and weighted for calculation of fresh biomass yield. Samples of biomass were collected and delivered to a laboratory for assessment of dry biomass yield, energy value of the yield and thermophysical features namely: moisture, higher heating value (HHV), lower heating value (LHV), ash, fixed carbon, volatile matter, and elements: C, H, S and N. The data collected from the trial and laboratory assays were analysed statistically with multifactorial ANOVA test with significance level α=0.05. The Tukey (HSD) test was used to determine homogeneous groups.

CAMELINA TRIAL

The trial was run in years 2018-2020. In the first year in spring, before sowing, the site was sprayed with Roundup 360 SL (glyphosate) in dose of 5 dm^3/ha, then soil was ploughed and tilled with cultivating unit. In next years soil was only prepared with cultivation unit. Seeds (Omega variety) were sown with drill at rate of 6 kg/ha. Plants were sown in single rows; the distance between rows was 13 cm on the area of 2,200 m^2. Nitrogen fertilization in a rate of 100 kg ha^{-1} N was applied as ammonium nitrate. No pesticides were used. In 2018 camelina seeds were sown on 21.04 and on Fingaty site and on 14.04 on Leginy site. In 2019 seeds were sown on 11.04 on both sites. However, due to drought and no emergence the trial were resown on 1.06. In 2020 the trial was established on 17.04 on both sites. Harvest dates: 2018.08.30, 2019.08.28 and 2020.08.07.

Table 1. Soils characteristics in Leginy and Fingaty

Site/soil	pH in KCl	available forms (mg/100 g soil)			N-tot. (%)	C (%)
		P2O5	K2O	Mg		
Leginy (clay)	6.6	10.6	35	19.7	0.279	1.82
Fingaty (sand)	5.8	16.3	11	5.6	0.095	1.13

In the period of camelina growth, observations of the growth and development of plants as well as the occurrence of diseases and pests were monitored. During the maturity of plants, just before their harvest, their height (cm) was measured. Subsequently, camelina seeds were harvested by combine harvester. The collected seeds were weighed and on this basis the seed yield was calculated per 1 hectare. In the laboratory the purity of the seeds was determined and, on this basis,, the yield of pure seeds was calculated from the area of 1 hectare.

RESULTS

POPLAR AND WILLOW TRIAL

All years except 2021 were much warmer and drier compared to the years 1998-2018 with average air temperature higher by 1.1-1.5°C for 2018 and 2019, respectively (Table 2). The year 2021 was warmer just by 0.2°C than multiannual period. In 2018 the sum of precipitation was 45% lower than from multiannual period. In April, the month in which the trials were set up, the air temperature was on average 3.4°C higher, and rainfall 28% lower than for 1998-2018. The same occurrence was found in May. These unfavourable conditions could influence the acceptance of cuttings and their further development. In the following years, the rainfall was also lower than the multi-year period by 14-33%. Their unfavourable distribution was noticed especially in the first months of poplar and willow development. Every year in May-June, beetles *Chrysomela populi*, which caused damage to poplar leaves, were recorded on poplar in Fingaty site (Fig. 7 3B). To protect plants from, spraying with the insecticide Decis 2.5 EC was carried out at a dose of 0.25 dm^3 ha^{-1} on young plants in 2018. Since July, at Fingaty site, which is located next to the forest complex, willow plants were notoriously browsed by roe-deer and deer. From October/November, however, animals also browsed plants also at Leginy site (Fig. 8 3B). Therefore, in spring 2019 both trials were fenced.

Fig. 7 3B. *Chrysomela populi* damaging poplar leaves in Fingaty

Table. 2. Meteorological conditions in years 2018-2021 and from multiannual period

	Year	January	February	March	April	May	June	July	August	September	October	November	December	total/mean
mean temperature (°C)	2018	-0.59	-4.75	-0.94	11.85	16.9	18.17	20.62	19.99	15.4	9.5	3.66	0.7	9.2
	2019	-3.00	1.93	4.69	9.05	12.4	20.8	17.6	19	14.1	10.1	5.5	3	9.6
	2020	2.70	3.10	3.9	7.6	10.5	18.2	17.8	18.6	16	10.4	5	0.5	9.5
	2021	-3.30	-5.60	1.4	5.6	12.2	18.4	20.3	17	13.2	8.3	3.9		8.3
	1998-2018	-2.5	-1.6	2.0	8.4	13.4	16.1	18.8	18.0	13.6	8.1	3.5	-0.2	8.1
precipitation (mm)	2018	20.4	2.4	4.4	27.2	40.8	22.6	64.4	50.6	26.2	47.4	19.2	33.0	359
	2019	25.2	20.7	31.0	3.4	68.4	81.8	82.2	48.4	62.8	32.0	18.6	19.4	494
	2020	38.9	26.2	21.6	2.8	75.0	134.4	33.4	86.8	16.2	79.0	28.4	24.4	567
	2021	25.4	0.6	1.2	5.6	39.0	30.4	141.0	124.0	25.4	22.8	21.0		436
	1998-2018	39.8	30.9	40.2	37.7	57.0	78.2	88.2	83.0	48.4	59.4	50.2	43.0	656

Fig. 8 3B. Willow browsed by roe-deer and deer in Fingaty and Leginy sites

The number of plants was significantly differentiated by the species and soil type and by the interactions between these main factors (Table 3). After the first year of cultivation, the plants were cut down during in winter to stimulate branching in the following cultivation years. In the fourth year of cultivation, the number of willow plants (in the three-year harvest cycle) was significantly higher than that of poplars (Table 4). However, in general, it should be stated that the willow survival was low and amounted to 66.9%, and for poplars it was very low: 57.8%. This low survival rate resulted from unfavourable weather conditions, especially the lack of precipitation in the first year of growth. Interestingly, significantly more plants survived on light soil than on heavy soil. This was because on heavy soil, due to its very compactness, there was no water percolation in the soil profile and the plants could only use rainwater. Willows planted on light soil endured these conditions exceptionally well; its survival in this variant was almost 92%, whereas for poplars the value of this feature was less than 70%. On the other hand, on heavy soil, after four years of cultivation (in the three-year harvest cycle), the survival rate of willow and poplar was the lowest and amounted to only 42 and 46%, respectively.

Table 3. ANOVA results for tested features

	Number of plants	**Survival**	**No. of shoots**	**Height**	**Diameter**	**Fresh biomass yield**	**Moisture**	**Dry biomass yield**	**HHV**	**LHV**	**Energy yield**	**Ash**	**Volatile matter**	**Fixed carbon**	**C**	**H**	**S**	**N**
Species	**0,018**	**0,018**	**<0,001**	0,41	**0,013**	0,76	**<0,001**	0,98	**<0,001**	**<0,001**	0,99	**<0,001**	**<0,001**	**0.002**	**0.002**	**0.03**	**0.03**	**<0,001**
Soil	**<0,001**	**<0,001**	**0,032**	**0,008**	**0,039**	**<0,001**	**0,004**	**<0,001**	0,64	**0,004**	**<0,001**	**<0,001**	0,09	0,73	0.94	0.44	0.62	**<0,001**
Species x Soil	**0,003**	**0,003**	0,36	0,43	0,93	0,47	**0,022**	0,33	**<0,001**	0,06	0,32	**<0,001**	0.77	**0.02**	0.81	0.46	0.07	**<0,001**

Table 4. Number and survival of willow and poplar plants cultivated on sandy and clay soils harvested in triennial harvest cycle

Species	Soil	No. of plants per ha	Survivability (%)
Poplar	sandy	12519 ± 1683 b	69.5 ± 9.3 b
Poplar	clay	8296 ± 339 c	46.1 ± 1.9 c
Willow	sandy	16519 ± 559 a	91.8 ± 3.1 a
Willow	clay	7556 ± 588 c	42.0 ± 3.3 c
Mean sand		14519 ± 2461 A	80.7 ± 13.7 A
Mean clay		7926 ± 591 B	44.0 ± 3.3 B
Mean Poplar		10407 ± 2555 *B*	57.8 ± 14.2 *B*
Mean Willow		12037 ± 4936 *A*	66.9 ± 27.4 *A*
Mean		11222 ± 3843	62.3 ± 21.3

The number of stems per plant ranged from 1 to 4. A significant influence of the species and soil on the number of stems was found (Table 3). The willow developed more shoots (2.0) than the poplar, (1.3) on average (Table 5).

In the case of plant height, only the type of soil significantly differentiated this feature, and in the case of the stem diameter, the species and type of soil had a significant impact (Table 3). In general, three-year-old plants grown on light soil were significantly higher (5.01 m) compared to those grown on heavy soil (Table 5). The tallest three-year-old plants in the entire trial were found for poplar cultivated on light soil, 5.02 m, while the lowest were willow plants on heavy soil, 3.08 m.

The diameter of three-year-old poplar stems, 30.7 mm on average, was significantly higher than that of willows (21.0 mm) (Table 5). Moreover, plants grown on light soil developed significantly thicker shoots, on average 29.6 mm compared to those grown on heavy soil. Throughout the experiment, the value of this feature ranged from approximately 17 mm to 34 mm for willow on heavy soil and poplar on light soil, respectively.

Table 5. Number of shoots, height and diameter for three-year-old willow and poplar plants grown on clay and sandy soil

Species	Soil	No. of stems	Height (m)	Diameter (mm)
Poplar	sandy	1.4 ± 0.1	5.02 ± 1.14	34.3 ± 6.2
Poplar	clay	1.2 ± 0.1	3.83 ± 0.72	27.1 ± 3.8
Willow	sandy	2.2 ± 0.3	5.00 ± 0.21	24.9 ± 2.4
Willow	clay	1.8 ± 0.2	3.08 ± 0.71	17.2 ± 7.2
Mean sand		1.8 ± 0.5 A	5.01 ± 0.73 A	29.6 ± 6.7 A
Mean clay		1.5 ± 0.4 B	3.46 ± 0.76 B	22.2 ± 7.5 B
Mean Poplar		1.3 ± 0.1 *B*	4.43 ± 1.07	30.7 ± 6.1 *A*
Mean Willow		2.0 ± 0.3 *A*	4.04 ± 1.15	21.0 ± 6.4 *B*
Mean		1.7 ± 0.4	4.23 ± 1.08	25.9 ± 7.8

The yield of fresh and dry biomass was significantly differentiated only by the type of soil, while the moisture of the biomass was significantly differentiated by the species, type of soil and the interactions of these factors (Table 3).

The yield of fresh biomass of three-year-old poplar plants (24.4 Mg/ha on average), was higher by approx. 1.4 Mg/ha than in willow (Table 6). The yield of fresh biomass obtained from light soil, 40.1 Mg/ha on average, was over 5 times higher than that obtained from heavy soil. It should be emphasized that the moisture of three-year-old poplar shoots, 52.2% on average, was significantly higher by over 2 percentage points compared to willow. After considering the moisture content of the biomass, it turned out that three-year-old willow and poplar plants yielded on average at a similar level, about 3.8 Mg/ha/year DM. on average. A significant influence of the type of soil on the amount of dry biomass yield was found. On light soil, the value of this characteristic was 6.46 Mg/ha/year DM, while on heavy soil, the dry biomass yield was as much as 5 times lower.

Table 6. Moisture, yield of fresh and dry biomass, energy value of the yield of three-year-old willow and poplar plants cultivated on two soil types

Species	**Soil**	**Yield (Mg/ha FM)**	**Moisture (%)**	**Yield (Mg/ha/year DM)**	**Yield Energy value (GJ/ha/year)**
Poplar	sandy	39.11 ± 10.39	53.20 ± 0.34 a	6.10 ± 1.61	103.89 ± 27.38
Poplar	clay	9.75 ± 4.06	51.28 ± 0.85 b	1.59 ± 0.66	27.21 ± 11.38
Willow	sandy	41.10 ± 10.15	50.23 ± 0.17 c	6.82 ± 1.67	117.02 ± 28.53
Willow	clay	4.95 ± 3.07	49.89 ± 0.27 c	0.83 ± 0.52	14.34 ± 8.94
Mean sand		40.10 ± 9.25 A	51.71 ± 1.65 A	6.46 ± 1.52 A	110.45 ± 26.02 A
Mean clay		7.35 ± 4.16 B	50.59 ± 0.95 B	1.21 ± 0.67 B	20.77 ± 11.55 B
Mean Poplar		24.43 ± 17.56	52.24 ± 1.20 *A*	3.84 ± 2.71	65.55 ± 45.99
Mean Willow		23.03 ± 20.9	50.06 ± 0.27 *B*	3.82 ± 3.46	65.68 ± 59.34
Mean		23.73 ± 18.42	51.15 ± 1.41	3.83 ± 2.96	65.61 ± 50.62

Based on the yield of fresh biomass and its lower heating value, the energy value of the yield was calculated. It turned out that this value for three-year-old willow and poplar plants was at a similar level, about 66 GJ/ha/year (Tab. 6). A significant influence of soil on this feature was found. On light soil, this value amounted to 110 GJ/ha/year, while on heavy soil it was only 21 GJ/ha/year.

Thermophysical features of willow and polar biomass are presented in table 7. HHV of biomass was significantly differentiated by the species and the interactions between the main factors. On the other hand, LHV was significantly differentiated only by the main factors, i.e., plant species and soil type. The poplar was characterized by a significantly higher HHV (19.77 GJ/Mg d.m.) compared to the willow However, due to the lower moisture, the willow biomass was characterized by a significantly higher LHV (8.60 GJ/Mg) compared to poplar (8.17 GJ/Mg).

Volatile matter was significantly different for species only. Willow (78.8% d.m.) had more volatile matter than poplar (78.0% d.m.). In contrast, the content of fixed carbon varied by both species and species × soil interaction. More fixed carbon (by 0.4 p.p.) contained poplar biomass. Considering the interaction of factors, the significantly highest value of this feature was determined for poplar cultivated in heavy soil, and the lowest for willow cultivated on the same site. The content of C, H and S elements in biomass was differentiated only by species. On the other hand, the ash and nitrogen content in biomass was significantly differentiated by the main factors and their interaction.

Table 7. Thermophysical and elemental analysis of poplar and willow biomass cultivated on heavy and light soils

Species	Soil	HHV (GJ/Mg DM)	LHV (GJ/Mg)	Ash (% DM)	Volatile matter (% DM)	Fixed carbon (% DM)	C (% DM)	H (% DM)	S (% DM)	N (% DM)
Poplar	sandy	19.81 ± 0.03 a	7.97 ± 0.07	1.72 ± 0.06 a	78,15±0,17	20,3±0,11 ab	52,4±0,63	6,16±0,02	0,017±0,002	0.71 ± 0.01 b
Poplar	clay	19.72 ± 0.02 b	8.36 ± 0.19	1.70 ± 0.04 a	77,93±0,31	20,6±0,28 a	52,5±0,25	6,24±0,06	0,015±0,001	0.77 ± 0.02 a
Willow	sandy	19.63 ± 0.02 c	8.55 ± 0.04	1.18 ± 0.03 c	78,86±0,03	20,2±0,03 b	51,3±0,21	6,08±0,13	0,018±0,001	0.47 ± 0.01 c
Willow	clay	19.71 ± 0.03 b	8.66 ± 0.06	1.57 ± 0.01 b	78,7±0,03	20,0±0,04 b	51,2±0,64	6,08±0,08	0,019±0,001	0.72 ± 0.01 b
Mean sand		19.72 ± 0.10	8.26 ± 0.32 B	1.45 ± 0.30 B	78,5±0,40	20,3±0,10	51,8±0,75	6,12±0,10	0,017±0,002	0.59 ± 0.13 B
Mean clay		19.72 ± 0.02	8.51 ± 0.21 A	1.64 ± 0.08 A	78,3±0,46	20,3±0,40	51,8±0,82	6,16±0,11	0,017±0,002	0.75 ± 0.04 A
Mean Poplar		19.77 ± 0.05 *A*	8.17 ± 0.25 *B*	1.71 ± 0.05 *A*	78,0±0,25 *B*	20,5±0,24 *A*	52,4±0,43*A*	6,20±0,06 *A*	0,016±0,002 *B*	0.74 ± 0.04 *A*
Mean Willow		19.67 ± 0.05 *B*	8.6 ± 0.08 *A*	1.37 ± 0.22 *B*	78,8±0,10 *A*	20,1±0,13 *B*	51,2±0,43*B*	6,08±0,10 *B*	0,018±0,001 *A*	0.59 ± 0.14 *B*
Mean		19.72 ± 0.07	8.38 ± 0.29	1.54 ± 0.23	78,4±0,43	20.3±0,28	51,8±0,75	6,14±0,10	0,017±002	0.62± 0.11


a) b)


c) d)

Fig. 9 3B. Poplar (a) and willow (b) on clay soil and polar (c) and willow (d) on sandy soil in the end of August 2018


a) b)


c) d)

Fig. 10 3B. Poplar (a) and willow (b) on clay soil and polar (c) and willow (d) on sandy soil in September 2021

CAMELINA TRIAL

In 2018, in the first three months of growth, precipitation was significantly lower than for multiannual period 1998-2018 (Tab 2). In April and May precipitation was 30% lower, and in June as much as 70% lower than from the years 1998-2018. In 2019 there was only 3.4 mm of rainfall in April. The first significant precipitation occurred only in the second half of May, which resulted in the lack of seeds' emergence. So, a decision was made for camelina re-sowing, which was done on June 1st, 2019. In the following months, the precipitation was sufficient and the temperatures were higher than in the multi-year period (except for July), which enabled the proper development of plants. Also in April 2020, rainfall was low (5.6 mm), but in May it was as much as 75 mm, which allowed proper plant development. However, worse emergence on clay site than sandy site was noted, which was basically the rule every year (Fig. 11 3B). In June, rainfall was very high and accounted for 171% of the multiannual period, while in July it was already very low (33.4 mm), which significantly influenced the yield of plants.

There were no insect pests on camelina plants at both Leginy and Fingaty sites. However, downy mildew disease was found on some plants. Since June, the rapid growth and development of pigweed (*Chenopodium album*), particularly on sandy soil, was noticed every year. Therefore, Fingaty site was strongly occupied by pigweed, and since beginning of July this weed successfully competed with camelina plants. In 2019 on Leginy site was slightly infested by *Polygonum persicaria*, which completely dominated this field trial in 2020, causing complete termination of camelina plants.

Fig. 11 3B. Camelina plants in Leginy (left) and Fingaty (right) in May 2018


Fig. 12 3B. Camelina plants on clay (left) and sandy soil (right) in July 2018


Fig. 13 3B. Harvest of camelina on clay (left) and sandy soil (right) on 30.08.2018


Fig. 14 3B. Harvest of camelina on clay (left) and sandy soil (right) on 28.08.2019

Fig. 15 3B. Camelina on sandy soil (left) on 07.08.2020 and condition of the clay site (right) on 16.06.2020

In the first year, camelina was harvested on August 30th, the next year on August 28th, and in the last year of the research on August 7th. The crops were harvested from the entire plot area using a combine harvester. In 2018, the yield of camelina seeds was low and amounted to 0.42 and 0.50 Mg/ha DM, respectively for sandy and clay site (Table 8). Higher yields were obtained in the subsequent year, 0.53 and 0.99 Mg/ha DM, respectively for sandy and clay site. It is worth noting that despite the delay in sowing (the resowing of the trials), the yields for clay sites were acceptable and comparable to those from plantations on weaker soils, typical for this species. In the last year of the research, clay sites were completely infested by the weed *Polygonum persicaria*, which completely dominated the crop (Fig. 15 3B). However, the harvest of camelina from sandy site was very low and amounted to only 0.18 Mg/ha d.m. The reason for this was very low precipitation in July and very high infestation of the trial with *Chenopodium album*. Summing up, it can be noted that despite the traditional opinion that camelina can be grown on sandy soil, clay soil was better suited for its cultivation. The soil made of sand allowed for better plant emergence and development in the first half of plant growth, but then the lack of water in the soil prevented further proper development of the crop.

Tab. 8. Camelina seed yield from clay and sandy sites from years 2018-2020

	Seed yield (Mg/ha d.m.)			
Site/year	2018	2019	2020	**Mean**
Fingaty (sand)	0.42	0.53	0.18	**0.38**
Leginy (clay)	0.50	0.99	0.00*	**0.75**

*Plantation failure due to complete field domination by *Polygonum persicaria*

In 2019, an analysis of the properties of seeds from both sites was also performed. The content of protein, fat and thousand seed weight (TSW) were assessed (Table 8) and the composition of fatty acids was analysed (Table 9). Significantly higher protein and fat content was determined for camelina seeds harvested from clay site (26.87 and 41.85%, respectively) than for sandy site. On the other hand, TSW did not differ statistically and amounted to 1.01 g on average.

The fatty acid composition was not differentiated by the type of soil. The most abundant acid in camelina oil was linolenic acid (30.2%), followed by linoleic acid (20.6%). There was also a substantial amount of eicosenoic and oleic acid as well, 15.65 and 15.46%, respectively. The tested seeds contained little erucic acid (2.66%).

Tab. 9. Camelina seed properties from 2019 trials

Location	Protein (% d.m.)	Fat (% d.m.)	TSW (g)
Fingaty 2019 (sand)	23.91±0.21**b**	40.70±0.25**b**	0.99±0.02
Leginy 2019 (clay)	26.87±0.02**a**	41.85±0.17**a**	1.04±0.03
mean	**25.39±1.63**	**41.27±0.33**	**1.01±0.03**

±: standard deviation, a, b: homogenous groups

Tab. 10. Main fatty acid composition in 2019

Location	C16:0	C18:1	C20:1	C22:1	C18:2	C18:3	SFA (%)	MUFA (%)	PUFA (%)
Fingaty (sand)	5.96	15.35	16.01	2.73	20.10	30.05	9.17	35.76	53.79
Leginy (clay)	6.07	15.56	15.29	2.59	21.06	30.28	9.28	35.11	54.83
mean	**6.02**	**15.46**	**15.65**	**2.66**	**20.58**	**30.17**	**9.23**	**35.44**	**54.31**

8. Report from IBC

INTRODUCTION

Within the Task 4.4, IBCSB worked on establishing energy willow plantations on marginal lands in the soil and climatic zone of Forest-Steppe under the conditions of sufficient soil moisture. In Ukraine, willow is better to cultivate in regions with sufficient or excess soil moisture. In such regions, a common type of soil is acid soil with low organic matter content. Therefore, the goal of the Task 4.4 was studying peculiarities of growth and development of energy willow cultivated on low-fertile acid soils (Table 1 IBC).

MATERIAL AND METHODS

In the course of the project, demonstration willow plots were planned to establish to show the best low-input agronomic practices on the land with unfavourable chemical composition (acidity) + low SOM. However, we failed to establish the trial in 2018 and then in 2109. Weather conditions in the autumn of 2018 and spring 2019 did not allow to establish plots due to excess rainfall (122 mm above long-term mean in autumn of 2018 and 112 mm in spring of 2019). Water logging resulted from excessive precipitation and continued through spring of 2019 made establishing plot impossible. We decided to abandon that plot and establish another plot on the similar marginal land.

The willow plot was eventually established in spring 2020 at the land of the Yaltushkiv Experimental Breeding Station IBCSB.

Average soil characteristics were (0-30 cm): organic matter 1.1 %, total mineral nitrogen 25.0 ppm, nitrate + nitrite nitrogen 13.0 ppm, ammonium nitrogen (NH_4) 12.0 ppm, phosphorus P_2O_5 39.0 ppm, pH 5.40.
Willow cuttings of 22 cm in length were planted straight to a planting depth of approximately 20 cm so that 2–3 cm was left aboveground. The distance between cuttings was 60 cm and between rows 70 cm. Planting density was 12 000 plants per hectare.

Table 1 IBC. Marginality factor and agronomic practices

Crop	Marginality factor	Agronomical practices
Willow	Unfavourable chemical composition (acidity), pH<5.5 Eroded land with low SOM content	Mini-till, reduced fertilisation, mulching, rainfed **Treatment 1**. Quantum-Humate, concentrated potassium humate enriched with the soluble forms of silicon to strengthen plant immunity and reistance to stress (SiO_2 10 g/l; K_2O 50– 60 g/l; fulvic acid 150– 180 g/l) **Treatment 2.** Mulching with straw (10 cm) **Control**

Spraying (foliar fertilisation) was performed at a spray liquid rate of 200–400 l/ha. Spray liquid was prepared prior to spraying. Sprayings were performed in the morning or evening hours under the optimal conditions – air temperature from 10 to 25°C and wind speed up to 5 m/s.
Assessment of dry biomass accumulation was performed at the end of the 2nd vegetation year by sampling willow plants in 4 points along a diagonal of a plot. Harvesting of the whole plot is planned to carry out at the end of the 3rd vegetation year (2022).

RESULTS AND DISCUSSION

Weather conditions in the years of research were typical for the Forest-Steppe zone of Ukraine, with moderately warm spring, hot summer and sufficient rainfall (Table 2 IBC).

Table 2 IBC. Air temperature and rainfall in the vegetation seasons of 2020 and 2021, Yaltushkiv Experimental Breeding Station IBCSB

Month	2020				2021			
	Rainfall (mm)	Deviance from long-term values	Temperature (°C)	Deviance from long-term values	Rainfall (mm)	Deviance from long-term values	Temperature (°C)	Deviance from long-term values
April	13.3	-28.7	8.1	+0.8	21.0	-21.0	6.8	-0.5
May	75.0	+13.0	11.4	-2.1	52.0	-10.0	13.5	0.0
June	84.5	+10.5	19.9	+3.5	43.0	-3.1	19.6	+3.2
July	16.8	-71.2	20.1	+1.6	60.0	-28.0	22.6	+4.1
August	21.0	-34.0	19.9	+2.2	90.2	+35.2	18.8	+1.1
September	51.2	+2.2	16.9	+3.5	25.0	-24.0	12.2	-1.2
October	90.5	+60.5	11.9	+4.0	0.0	-30.0	7.1	-0.8

In 2020, in the period from April to October the amount of rainfall was 352.3 mm (close to long-term value), while in 2021, the amount of rainfall was only 291.2 mm. However, there was no any significant difference in growth and development patterns of willow thanks to higher daily mean temperatures compared to long-term values. This allowed willow plans to continue vegetation until November and form powerful root system.
Due to favourable weather conditions in the 1st year of the experiment (sufficient amount of rainfall and long vegetation period including October) plants rooted and developed well (Table 3 IBC).

Table 3 IBC. Parameters of willow plants in 2020 (measured 23.09.2020), Yaltushkiv Experimental Breeding Station IBCSB

Agronomical practices	Parameter		
	Plant height (cm)	Diameter of the main stem (cm)	The number of shoots
Treatment 1.	162	1.20	1.70
Treatment 2	176	1.20	1,81
Control	145	1.10	1.32
$LSD_{0.05}$	5	0.3	0.09

The most influential factor of cultivation on low-fertile land is maintaining field clear of weeds. Young willow plants in the 1st year are not strong enough to compete with weeds for nutrients and light. Foliar fertilisation appeared to be a successful practice for plant adaptation to acid soil. It may be either a sufficient agronomic practice or combined with mulching.
Parameters of willow plants at the end of vegetation season of 2021 is shown in Table 4 IBC.

Table 4 IBC. Parameters of willow plants (measured 15 November 2021), Yaltushkiv Experimental Breeding Station IBCSB

Agronomical practices	Parameter		
	Plant height (cm)	Diameter of the main stem (cm)	The number of shoots
Treatment 1.	362	2.25	2.00
Treatment 2	386	2.45	1.95
Control	344	2.17	1.43
$LSD_{0.05}$	8	0.5	0.10

The demonstration experiment was laid down in 2020; therefore, we had no opportunity to determine the potential productivity of willow in the 3-year cycle. Nevertheless, analysis of plant biometric parameters confirms the positive effect of applied by us practices (Fig. 1 IBC).

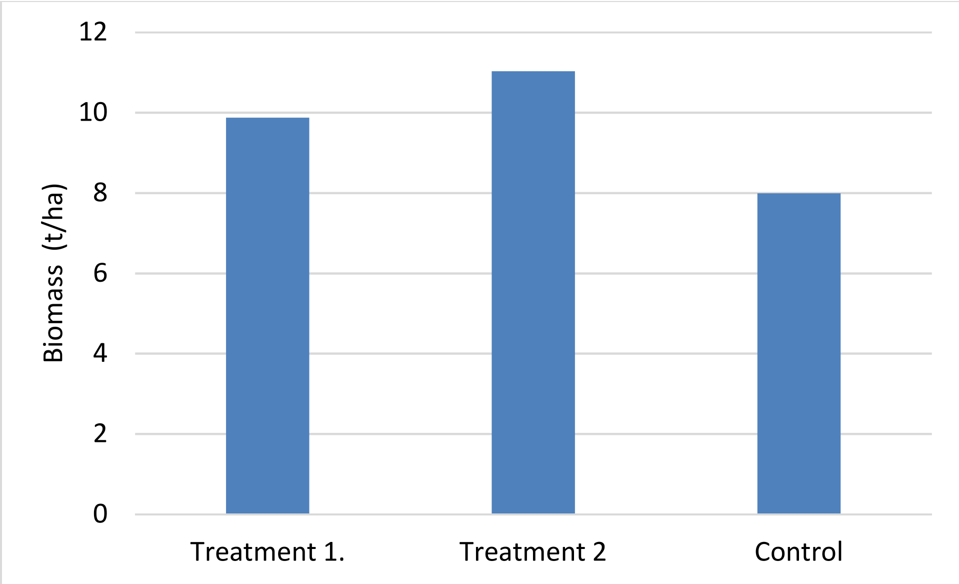


Fig. 1 IBC. Assessment of accumulated dry biomass of willow at the end of vegetation year 2021

The higher potential of biomass accumulation was obtained in the treatment with mulching. It exceeded control by 3.04 t/ha. In the treatment with foliar fertilisation, yield increase was 1.88 t/ha. Mulching with straw of wheat positively affected plant growth and development in the 1st year by suppressing weeds which compete with crop for nutrients. 99% of weeds are not capable of sprouting through 10-cm mulch layer. Mulching is a good alternative to chemical weed control and hand weeding. In our experiment, mulch worked even on the 2nd year. The layer thickness decreased to 5 cm. Nevertheless, it was enough to block sprouting of weeds (Fig 2 & 3 IBC).

CONCLUSIONS

Mulching has some limitations though, since tt cannot be applied on steep slopes because of a risk of moving along with water during heavy rainfalls. In addition, there is a risk of propagation of gnawing animals (mice etc.) in the straw and damaging bark of young trees. That is why it is recommended to use the straw of legumes (soybean, pea, etc.) for mulching.

Foliar fertilisation using humic products alleviate stress in plants caused by acclimatization to soil conditions when the soil is acid. To reach the maximum efficiency of humic products, sprayings are recommended to carry out in the period of intensive leaf formation at the beginning of vegetation with one more spraying at the time of rapid stem elongation. Humic products will work on the 2nd year too, if sprayed.
To sum up, when growing energy willow on marginal lands, it is recommended to apply mulch (10 cm) from straw of legumes as an effective method of weed control and humic products. For foliar fertilisation twice over the vegetation – in the stages of intensive leaf growth and stem elongation.

a) b)

Fig. 2 IBC. Energy willow in late September 2020: (a) control; (b) mulching with straw

a) b)

Fig. 3 IBC. Energy willow in late September 2021: (a) control; (b) mulching with straw

9. Report from SILAVA

The geographical coordinates of the Kalsnava experimental plot are 56.68744 N, 25.93979 E, 100 meters above sea level. The experimental field was on sandy, stony soil, lower part of field heavy clay. Before the establishment of the MAGIC trial, the field was fallow. In 2015 overgrowth was cleaned, in 2016 different willow and poplar clones were planted to test growing and biomass yields.

<table>
<tr><td>14</td><td colspan="2">Visvaldis</td><td colspan="2">Monika</td><td colspan="2">Visvaldis</td><td></td><td></td><td></td><td></td></tr>
<tr><td>13</td><td>0217A/ S.viminalis</td><td>0212T/ S.alba x S. vittelina</td><td>0224H/ S.viminalis</td><td>0216Z/ S.viminalis</td><td colspan="2">Monika</td><td colspan="2">SIS</td><td></td><td></td></tr>
<tr><td>12</td><td>0210R/ S.viminalis</td><td>0225K/ S xdasyclados</td><td>0222F/ S.alba</td><td>0215X/ S. x aquatica</td><td>0226G/ S.viminalis</td><td>0213V/ S.malisii</td><td>0221E/S. x helix</td><td>0218B/ S.alba</td><td></td><td></td></tr>
<tr><td>11</td><td>ALBA</td><td>0205K/S. alba</td><td>0209P/S x dasyclados</td><td>0219C/S. x rubens</td><td>0214W/S. Alba</td><td>0208N/S. alba</td><td>0207M/ S.alba</td><td>0220D/ S.alba</td><td>2011S/ S.alba</td><td>0206L/ S.alba</td></tr>
<tr><td>10</td><td colspan="2">Olof</td><td colspan="2">Lisa</td><td colspan="2">Sven</td><td colspan="2">Visvaldis</td><td colspan="2">Biminalis/ S.viminalis</td></tr>
<tr><td>9</td><td colspan="2">Winter</td><td colspan="2">Emma</td><td colspan="2">Bella</td><td colspan="2">Monika</td><td colspan="2">Visvaldis</td></tr>
<tr><td>8</td><td colspan="2">Estelle</td><td colspan="2">Wilhelm</td><td colspan="2">Birgit</td><td colspan="2">Erik</td><td colspan="2">Ester</td></tr>
<tr><td>7</td><td colspan="2">2SL2/</td><td colspan="2">AUCE 1</td><td colspan="2">OE1PL</td><td colspan="2">PPO + AUCE1+AUCE C + BAUSKA</td><td colspan="2">FERMA</td></tr>
<tr><td>6</td><td colspan="2">LV 10</td><td colspan="2">LV 11</td><td colspan="2">LV 12</td><td colspan="2">LV 14</td><td colspan="2">KR02</td></tr>
<tr><td>5</td><td colspan="2">LV 3</td><td colspan="2">LV 4</td><td colspan="2">LV 5</td><td colspan="2">LV 7</td><td colspan="2">LV 9</td></tr>
<tr><td>4</td><td colspan="2">OUDENBERG</td><td colspan="2">VESTEN</td><td colspan="2">H8 (balts+melns)</td><td colspan="2">LV 1</td><td colspan="2">LV X</td></tr>
<tr><td>3</td><td colspan="2">Matrix 11</td><td colspan="2">Matrix 24</td><td colspan="2">Matrix 49</td><td colspan="2">OP 42</td><td colspan="2">INCOGNITO</td></tr>
<tr><td>2</td><td colspan="2">AF Zils/18</td><td colspan="2">AF Sarkans/16</td><td colspan="2">MAX 1</td><td colspan="2">MAX 3</td><td colspan="2">MAX 4</td></tr>
<tr><td>1</td><td colspan="2">AF 2</td><td colspan="2">AF 6</td><td colspan="2">AF 7</td><td colspan="2">AF 8</td><td colspan="2">Hybride 275</td></tr>
<tr><td>row</td><td colspan="2">MAX/Matrix 11</td><td colspan="2">MAX/ Matrix 24</td><td colspan="2">MAX/Matrix 11</td><td colspan="2">MAX/ Matrix 24</td><td colspan="2">MAX/Matrix 11</td></tr>
</table>

Figure xx Experimental design of willow and poplar garden.

The large-scale experimental plots were established in 2016, planting was done in strips 3.5 x 0.5m, 20 cm long cuttings of willows and poplar planted at least 50 per clone. No fertilizer was used before planting. In the beginning 27 different willow clones and 26 poplar clones were planted, clone Baldo did not survived because of high frost sensitivity.

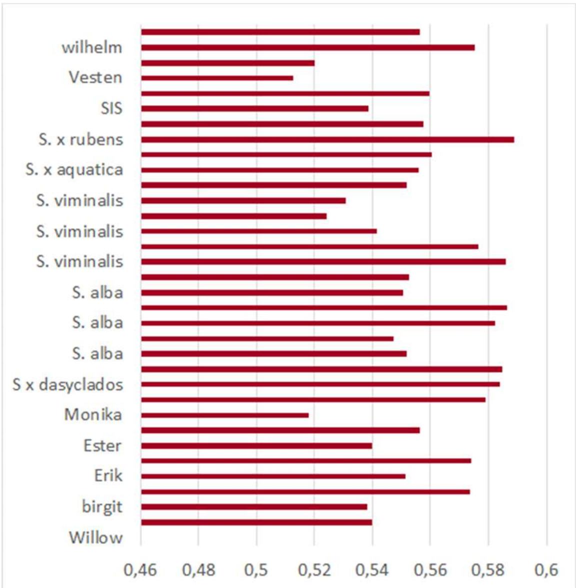
Figure 1 SILAVA Field before planting 2015 / planting 2016/ willows 2018

First harvest and biomass measurements were done on the fourth year, in spring 2020. The aim of the study was to obtain yields and moisture content of different willow and poplar clones. All harvested stems were weighted right after harvest to obtain wet biomass, samples for moisture determination were taken from stems upper, middle and lower parts. In every sampling plot moisture was taken from 9 trees. Later moisture samples were dried 105°C and Odt ha^{-1} calculated. Both species were grown for 4 years before measurements.

Figure 2 SILVA. Willow and poplar biomass harvesting

For the most more productive clones, the biomass of trees and bushes were measured. Moisture content of clones varied, and presented in the figure below (Fig. 3 SILAVA).

Willows



Poplars

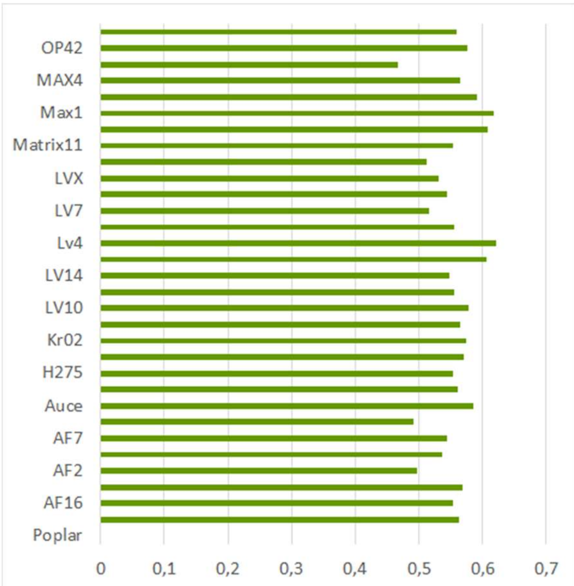


Figure 3 SILAVA. willow and poplar clones moisture content - Kalsnava experimental plot

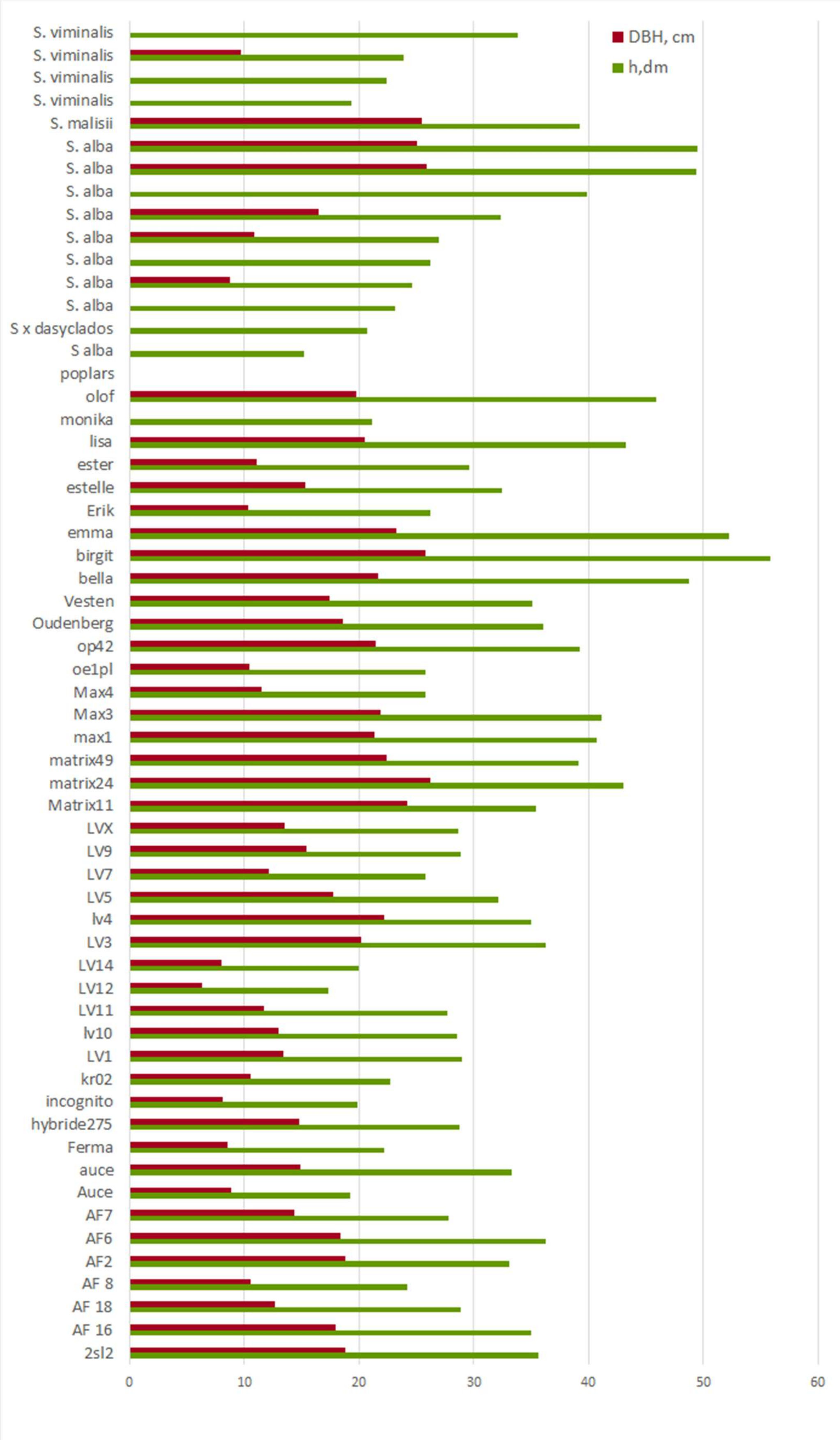

DBH, cm
h,dm
S. viminalis
S. viminalis
S. viminalis
S. viminalis
S. malisii
S. alba
S. alba
S. alba
S. alba
S. alba
S. alba
S. alba
S. alba
S x dasyclados
S alba
poplars
olof
monika
lisa
ester
estelle
Erik
emma
birgit
bella
Vesten
Oudenberg
op42
oe1pl
Max4
Max3
max1
matrix49
matrix24
Matrix11
LVX
LV9
LV7
LV5
lv4
LV3
LV14
LV12
LV11
lv10
LV1
kr02
incognito
hybride275
Ferma
auce
Auce
AF7
AF6
AF2
AF 8
AF 18
AF 16
2sl2
0
10
20
30
40
50
60

Figure4 SILAVA. Willow, poplar height and diameters in 4 years old plantations in Kalsnava experimental plot

Difference between height of the best clone and the worst clone are almost 1 -2 times. Results showed that not all poplar clones were suitable for growing on sandy soils. Willows and poplars were planted in one set and there was the impact of microsite effect, since growth conditions were not the same in all field.

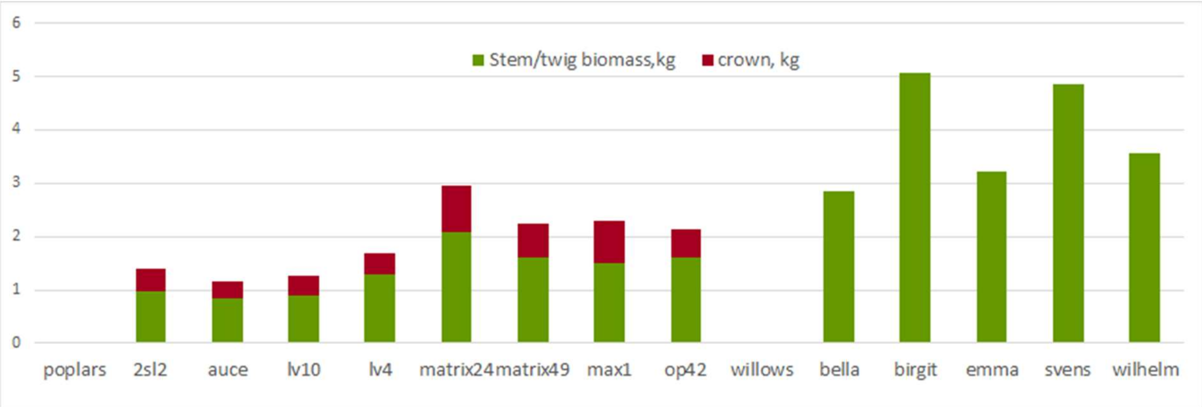


Figure 5 SILAVA Fresh biomass of one plant poplars and willows, fourth year after planting.

On sandy soils, poplars and willows can be productive even without fertilization, however, there is high difference between clones. The best ones were Max 3e *S. alba* and *S.aquatica* in terms of height, but more dry mass per stem produced Willows Birgit and S

10. Main conclusions and lesson learnt from task 4.4

All the tested species were able to establish and produce some biomass (lignocellulosic crops) or seeds (oil crops) under severe marginal conditions. Only in few cases the establishment failed (e.g. switchgrass in Italy and camelina in Poland, where weeds could not be controlled). Nevertheless, the ability of a crop to develop under marginal condition not necessarily means that the crop is sustainable and profitable. Sustainability and profitability, in fact, will depend on crop productivity, but also on the effectiveness of cropping techniques and strategies, including the adaptability of farm machines to specific marginal conditions. For example, even in the case of high productive crop the final yield can be unsatisfactory due to considerable seed losses during the harvest caused by operating difficulties on irregular and slope land or rocky terrain. The importance of task 4.4. lies precisely in this, that is to assess the real productivity in marginal land depending on both crop resilience, agronomic strategies and efficiency of agricultural machines, particularly the harvest machines. In general, all the species produced well below their potential in term of lignocellulosic biomass or seed yield. This was clear from hand collected samples in which we could avoid all the losses due to agricultural mechanization. There were only few exceptional cases, such as that of camelina of which we observed very interesting yields despite severe marginal conditions (i.e., 15% of slope in Italy, soil with poor chemical composition in Greece). On the mechanization, a lesson learned is that seed losses could be even lower than under non-marginal conditions since the operational speed is often reduced by the marginality, but only a careful setting up of the equipment is needed to attain satisfactory yields. Not only seed yield but also seed quality was sometimes significantly affected by the marginality condition, but in many cases, however, seed quality (oil content and fatty acid composition) remained similar across years and locations which should be considered a very positive outcome from an industrial point of view as stable quality feedstock is generally highly appreciated by industries. For perennial and woody species, the establishment, survival rate and productivity resulted significantly affected by growing conditions and age, confirming that a clear time plan should be set up for biorefinery willing to use such feedstock.

We can conclude therefore that marginal land is undoubtfully an opportunity to, on one hand, mitigate the soil abandonment risks, and on the other hand, to develop innovative non-food crops and related value chains with positive social, economic and environmental impacts in Europe. The MAGIC project tested several crops and agricultural strategies which revealed that the selected crops are generally suited to marginal land, but their yields are well below the potential, and improving agronomic practices, including mechanization, is an urgent matter to guarantee satisfactory yields to farmers and industries. Hence, if we want to make full use of this opportunity, we should mainly invest on that.

The main MAGIC yield results obtained in Task 4.4 in comparison with productive data from non-limiting conditions are reported in the table below, including either literature data and partners’ knowledge, when data were not available.

Partner	Country	Marginality factor	Crop	Mean yield in MAGIC trials (Mg $ha^{-1}y^{-1}$)	Mean yield under non-limiting conditions (Mg $ha^{-1}y^{-1}$)
UNIBO	Italy	Steep slope 25%	Camelina	0.50	1.87[a]
			Crambe	0.52	2.12[b]
			Safflower	0.72	1.70[c]
			Switchgrass	Failed	
		Steep slope 15%	Camelina	1.92	1.87[a]
			Crambe	1.03	2.12[b]
			Safflower	1.85	1.70 [c]
			Switchgrass	Failed	12.0 [d]
CRES	Greece	Unfavourable soil texture (acid or saline) combined with slope	Camelina	1.35	1.20[a]
			Crambe	1.30	1.97[b]
		Poor chemical composition (sandy)	Safflower	1.25	3.85[e]
			Castor bean	2.20	2.77 [f]
CIEMAT	Spain	Limitation rooting and poor chemical composition	Tall wheatgrass	5.61	8.31*
		Limitation rooting and poor chemical composition	Siberian elm	NA. Plots are not harvested yet. Height: 160 cm Diameter: 3 cm	20.7*
NOVABIOM	France	Poor chemical composition (sandy)	Miscanthus	8 (estimated)	12.8[g]
		Poor chemical composition	Miscanthus	NA	
			Miscanthus	NA	
3B	Poland	Poor chemical	Camelina	0.38	1.65[a]
			Willow	6.82	11.50[i]

		composition (sandy)	Poplar	6.10	9.21[l]
		Poor chemical composition (clay)	Camelina	0.75	1.65[a]
			Willow	0.83	11.50[i]
			Poplar	1.59	9.21[l]
SILAVA	Latvia	Limitation in rooting depth	Willow	6	7-9 [m,n]
			Poplar	5	6-9[o,p]
IBC	Ukraine	Poor chemical composition	Willow	9,63	12,66[g]

NA = not available

* Data from experts' view

[a] Zanetti et al. 2017. Agronomic performance and seed quality attributes of Camelina (*Camelina sativa* L. crantz) in multi-environment trials across Europe and Canada. DOI: 10.1016/j.indcrop.2017.06.022.

[b] Berzuini et al. 2021. Optimization of agricultural practices for crambe in Europe. DOI: 10.1016/j.indcrop.2021.113880

[c] Zanetti et al. 2022. Safflower (*Carthamus tinctorius* L.) a winter multipurpose oilseed crop for the Mediterranean region: Lesson learnt from on-farm trials. DOI: 10.1016/j.indcrop.2022.115042

[d] Alexopoulou et al. 2020. Long-Term Productivity of Thirteen Lowland and Upland Switchgrass Ecotypes in the Mediterranean Region. DOI: 10.3390/agronomy10070923

[e] Dordas & Sioulas, 2009. Dry matter and nitrogen accumulation, partitioning, and retranslocation in safflower (Carthamus tinctorius L.) as affected by nitrogen fertilization. DOI: 10.1016/j.fcr.2008.06.011

[f] Alexopoulou et al. 2015. Comparative studies on several castor (Ricinus communis L.) hybrids: Growth, yields, seed oil and biomass characterization. DOI: 10.1016/j.indcrop.2015.07.015

[g] Lesur-Dumoulin et al. 2016. Analysis of young Miscanthus x giganteus yield variability: a survey of farmers' fields in east central France. Global Change Biology - Bioenergy, 2016, 8 (1), pp.122-135. ff10.1111/gcbb.12247ff. ffhal-01532528f

[h]Celma et al. 2022. Yield Performance of Woody Crops on Marginal Agricultural Land in Latvia, Spain and Ukraine. Agronomy, 12(4), 908; https://doi.org/10.3390/agronomy12040908

[i] Stolarski et al. 2014. Energy intensity and energy ratio in producing willow chips as feedstock for an integrated biorefinery. DOI 10.1007/s12155-015-9681-3

[l] Stolarski et al. 2015. Effect of Increased Soil Fertility on the Yield and Energy Value of Short-Rotation Woody Crops. DOI 10.1007/s12155-014-9567-9.

[m] Makovskis K., Ātraudzīgo kokaugu izvērtējums koksnes biomasas ražošanai neizmantotās lauksaimniecības zemēs Latvijā (Fast-growing woody crops evaluation for biomass production on unused agricultural lands in Latvia), PhD thesis, DOI: 10.22616/llthesis/2021.002

[n] Makovsksis K, Lazdina D., Bite L., Economic Calculation of Short Rotation Willow Plantations in Latvia, Proceedings of Research for Rueal development 2012, Vol 2, 2012, 224-229,online https://www2.llu.lv/research_conf/Proceedings/18th_volume2.pdf

[o] Šēnhofa, S., Lazdiņa, D., un Jansons, Ā., 2019. Papeļu (*Populus* spp.) stādījumu ierīkošana un apsaimniekošana. (*Establishing and management of Poplar plantings in Latvian*) Salaspils: LVMI Silava, DU AA Saule. eISBN 978-9984-14-883-0, online http://silava.lv/userfiles/file/Info%20materi%C4%81li/2019_Papelu_Populus_spp_stadijumu_ierikosana_un_apsaimniekosana_www.pdf

[p] Šēnhofa S. PhD thesis Meteoloģisko faktoru un stādmateriāla ietekme uz papeļu augšanu (Effect of planting material and meteorological factors on Poplar growth),Latvian State forest research institute SILAVA & University of life sciences and technologies, 2021, 89 pp, online https://llufb.llu.lv/dissertation-summary/forestry/Silva_Senhofa_prom_darba_kopsavilkums2021_LLU_MF.pdf