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YIELDS OF BLACK LOCUST-TRITICALE ALLEY CROPPING SYSTEMS, BASED ON DIFFERENT PLANTING PATTERNS OF THE TREES

Theses of doctoral (PhD) dissertation

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1. Introduction

Agroforestry in Hungary is a reinvented farming practice, and it is gaining popularity due to its various applications. It is an important research topic, because out of all the agricultural land in the world, over 40% of them have at least a 10% tree cover. The interactions between the trees, the soil, the crops and the animals are multiple, and those can be positive or negative, therefore it is crucial to understand and optimize them. Agroforestry systems could contribute to 9 out of the 17 Sustainable Development Goals, addressing environmental, social and economic challenges.

As agroforestry is a fairly new topic in Hungary, it is necessary to provide information on the performance of agroforestry systems in our country, so that this knowledge then can be implemented in practice. Therefore, field research should take place, merging the knowledge stemming from foreign experience and our traditional knowledge to see what works in our ecosystems. The most important tasks are the following: to establish a network of experimental sites and their monitoring, to refresh and rethink our knowledge on wood pastures and shelterbelts, to found the basis of alley cropping technology, to disseminate knowledge and to re-form the attitude of the stakeholders.

Agroforestry research and farming is behind in Hungary compared to the international trends. There are several types of agroforestry systems, which relate to different scientific fields, therefore research topics are also very diverse. This dissertation focuses on alley cropping systems – which are also remarkable in the context of forestry – where yield measurements were taken in different spatial arrangements of the trees. When looking at studies about yields in European agroforestry systems, we find that there aren't many, and it's especially true if looking for trials where control plots were also managed for the intercrop.

Regarding the land use in Hungary, mainly extensive and organic growers, and beekeepers are interested in such practices, and perhaps – considering the international space – private foresters will show more interest in the future (eg. intercropping the alleys of the plantations).

Agroforestry could play an important role in public employment programmes of the municipalities (when growing labour intensive cultures), while the research results could provide relevant information for decision makers and for the professional administration regarding food security, biodiversity conservation and climate actions. The Hungarian Ministry of Agriculture supports the establishment of agroforestry systems since 2014 through the Common Agricultural Policy and its incentives. Amongst the calls, alley cropping systems were also supported within the framework of the 2014-2021 Rural Development Programme.

2. Aim of research

Although there is a wealth of knowledge in the scientific field of agroforestry, there are still plenty of questions to answer, from tree-crop combinations to economy, which will differ depending on the given location. The aim of this study is to investigate an alley cropping system in Hungary (the first of its kind in the country) where crop and tree production was managed with different tree spacings, with replications. Based on the yields of the components of the agroforestry system (wood and crop), its land equivalent ratio (LER) can be calculated, which refers to the productivity (and the profitability) of the land use system. This study is looking to answer the question of which planting pattern is the most productive, where the highest yields can be attained. The results can serve innovative farmers, as well as it could be a relevant input when formulating the new Common Agricultural Policy's specifications for the support of agroforestry systems in the future. In this study I publish new scientific results regarding black locust (*Robinia pseudoacacia* L.), and triticale (× *Triticosecale* Wittm. ex. A. Camus) production in alley cropping systems. The plant combination and the investigated planting patterns has not so far been studied internationally.

I hypothesised the following:

H1: The tree spacing affects the individual tree yield

H2: The larger the growing space, the lesser the total volume in widely spaced black locust stands

H3: The tree spacing affects the yield of the intercrop

H4: The yield of the crop is less between the black locust trees compared with the crop yield in the open field

H5: The yield of the triticale decreases with an increase in the number of trees per hectare

H6: The total above ground biomass of the investigated agroforestry systems exceeds that of the conventional crop production

H7: Land equivalent ratios are favourable in the investigated agroforestry systems, meaning that when the trees were 5 years old the total yield (grain yield and wood, or total above ground biomass) of the alley cropping systems are higher on a given land unit than growing the trees and crops separately

3. Materials and methods

The investigations took place at the former Institute of Agricultural Engineering of the National Agricultural Research and Innovation Centre (today MATE) in Gödöllő (land registration number 080/7) between 2017 and 2019. We transformed an existing black locust (*Robinia pseudoacacia* L.) energy plantation to alley cropping systems (wood production) with multiple replications, which were planted on chernozem brown forest soil. Due to the transformation, I could investigate the yields of 3, 4 and 5 years old black locust stands, and the yields of the triticale (× *Triticosecale* Wittm. ex. A. Camus) 'GK Maros' intercrop between the tree lines and in a control plot (without trees), and I statistically analysed the results. The treatments are shown in *Table 1*. After the dendrometric measures I predicted the volume and absolute dry mass of the individual trees and of the entire stands, and I looked for variance between the treatments and also tested for correlations. In the case of triticale, after collecting the samples, I predicted the grain yield and the above ground biomass by square meter and by (agroforestry) hectare, and I also calculated the relative yield (to the control plot) in absolute dry mass.

	In-row spacing (m)			Control
Row sapcing (m)	1	2	3	No trees
9	**9 × 1** (9 m^2)	**9 × 2** (18 m^2)	**9 × 3** (27 m^2)	**FS** (Full Sun)
15	**15 × 1** (15 m^2)	**15 × 2** (30 m^2)	**15 × 3** (45 m^2)	
21	**21 × 1** (21 m^2)	**21 × 2** (42 m^2)	**21 × 3** (63 m^2)	

1. table: Tree spacings of the black locust stands, which are the treatments of the experiment

I tested for correlation and regression between the number of trees per hectare and the grain yields, as well as with the above ground biomass of triticale. To count the land equivalent ratio, in the case of triticale the data of the control plot was used, while for the black locust it was based on literature (of 5 years old trees). STATISTICA Version 11 and Microsoft Excel version 2016 was used for the statistical evaluation.

4. Results

Following the logic of the hypotheses phrased in the section 'Aim of the research', my results are:

1. The analysis of variance showed significant differences between the yield of trees in the different planting spacings. However, when examining the relationship between diameter and the number of trees per hectare and between diameter and growing space at three, four and five years of age, no relationship was detected. So, the number of trees per hectare or the growing space do not explain the differences in yields of young black locust stands at such wide planting spacings.

2. The total volume of wood per hectare of black locust stands decreases with the increase of the size of the growing space, which is known from the forestry context and I confirmed it in the case of alley cropping systems with wide planting spacings. The relationship between the two parameters at 3, 4 and 5 years of tree age can be described as an exponential equation at $p=0.01$ significance level with R^2 values 0.81; 0.93; 0.90, respectively.

3. The planting spacing of the trees affects the yield of the intercrop. Significant differences were found for triticale yields, both for grain yield and above ground biomass ($p=0.05$). There was no significantly lower yield per square metre among the tree rows, but in several instances yields of triticale were significantly higher in the alleys compared to the yields in the open field. In 2018 the yield of the control was 335,1 g/m^2, while in they alleys it ranged between 280,9-425,8 g/m^2. In 2019 the average yield of the control was 192,6

g/m^2, while it ranged between 110,9-262,1 g/m^2 in the alleys. In terms of the above-ground biomass, the yield in the control area in 2018 and 2019 was 774.8 and 484.7 g/m^2, respectively, and in the alley it is ranged from 704.0 to 938.9 g/m^2 and from 151.4 to 681.5 g/m^2, respectively.

4. Between the rows of black locust, the yield of triticale varies depending on the planting spacing and on the year of the actual production, when compared to the yield of the control area. In terms of yields per hectare in the agroforestry plots, yields were not reduced in the presence of trees in some treatments, so that the higher yields of triticale in a smaller area unit could compensate the reduction in the sown area. At four years of age, the yields of trees in both the 15 × 2 and 21 × 2 treatments were similar to conventional arable production, with yields of around 3.4 t/ha, despite the fact that only 81% and 86% of the areas were sown, with a stocking rate of 322 and 230 trees per hectare, respectively. Biomass yields were also similar to the control yields for these treatments, at 7.8 t/ha. When the trees were 5 years old, in the 15 × 2 (322 trees/ha), 15 × 3 (217 trees/ha) and 21 × 1 planting spacings (455 trees/ha) triticale biomass production was similar to that of the control field, while biomass yields in treatment 15 × 2, 15 × 3 and 21 × 3 exceeded those of the control. While for grain yield, there was a difference of up to 1 t/ha between the different tree spacings compared to each other, for biomass there was a difference of up to 2 t/ha between the different planting spacings. For the two years, the relative yields in grain yields per square metre were 5-36% higher and 1-49% lower, depending on the planting spacing, compared to the results of conventional cultivation. For biomass, the yields ranged from +1-41% and -2-69% respectively. On a per

hectare basis, relative yields varied between +1-10% and -7-60% for grain and between +1-14% and -11-73% for biomass. The majority of alley cropping systems showed a yield reduction compared to arable production on a hectare basis. This was due to the reduction in the sown area between the trees, but in some cases higher yields per m^2 compensated for the loss of area, resulting in overall yields similar to or even higher than the control area. In some cases, in the triticale-black locust alley cropping system, 0.81 and 0.86 ha yielded the same or higher than 1 ha of conventional production, i.e. a smaller area yielded a higher yield, demonstrating the positive effect of black locust on the yield of the intercrop depending on the planting spacing.

5. The grain and biomass yield of triticale show a decreasing trend with increasing number of trees per hectare, as described in the international literature, but only in 2018 there was a significant relationship at a significance level of $p=0.1$. For grain yield $R2=0.31$ and for biomass $R2=0.38$. The relationship can be described by linear regression. In some cases, higher number of trees per hectare was associated with higher triticale yields, and in all cases, yield reduction was observed between the narrowest tree rows.

6. The total aboveground biomass of the investigated agroforestry systems exceeds the amount of the arable biomass. In contrast to the biomass of the conventional arable crops, agroforestry systems can achieve up to double the yield at four years of age, depending on the number of trees per hectare.

7. In the investigated agroforestry systems, the land equivalent ratio (LER) at the tree age of 5 is favourable

in certain planting spacings, meaning that overall higher yields (grain yield and wood yield and biomass) can be achieved in an intercropping system on a given area unit than by growing the two crops in separate areas. Based on the results, the land equivalent ratio of the intercropping systems varied between 0.64 and 1.35 for triticale grain yield and between 0.53 and 1.38 for above-ground biomass. In all cases, LER values for black locust were obviously lower compared to forestry practices, due to the significantly lower number of trees per hectare, but in some cases triticale showed positive LER values in the alley cropping system alone (without considering the wood production). Out of the nine planting networks studied, the LER values of the intercropping systems were above 1 in five stands for grain and in six stands for biomass. I confirmed that up to 35% on the basis of grain yields, and up to 38% if based on the biomass yields, higher yields can be achieved in black locust-triticale alley cropping systems compared to conventional production systems (growing the tree and crop component separately) on chernozem brown forest soils in Hungary, with appropriate spatial arrangement, at five years of tree age (2019).

5. New scientific results

The new scientific results concern the agroforestry alley cropping systems of black locust (*Robinia pseudoacacia* L.) and triticale (× *Triticosecale* Wittm. ex. A. Camus) 'GK Maros' variety in temperate zone, in the forest climate class of turkey-oak, on chernozem brown forest soils. In 2018, the trees were 4 years old, the annual precipitation was 519.6 mm and the mean annual temperature was 11.8 °C. In 2019, the trees were 5 years old, the annual precipitation was 545.3 mm and the mean annual temperature was 12.0 °C.

1. The Land Equivalent Ratio (LER) values for 2019 in the black locust-triticale alley cropping systems were as follows:

1.1 On the basis of triticale grain yield, at planting spacing 15 × 2, 21 × 1, 15 × 3, 9 × 1, and 15 × 1, the values were 1.35; 1.29; 1.19; 1.07 and 1.07, respectively, which means an increase by 7-35%, while the values of planting spacing 21 × 3, 21 × 2, 9 × 2, and 9 × 3 were 0.99, 0.96; 0.94, and 0.64, respectively, which means a decrease by 1-36% when grown together.

1.2 On the basis of triticale biomass yield, at planting spacing 15 × 2, 15 × 3, 15 × 1, 9 × 1, and 21 × 3 the values were 1,38; 1,22; 1,22; 1,11; 1,08, respectively, which means an increase by 8-38%, while the values of planting spacing 21 × 2, 9 × 2, 9 × 3 and 21 × 1 the values were 1,00; 0,99; 0,67; 0,53, respectively which means a decrease of 1-47 % when grown together.

Overall, the LER values were favourable for 5 planting spacings in terms of grain yield and 6 planting spacings in terms of above-ground biomass yield, indicating that black locust and triticale can be grown successfully in alley cropping systems.

2. Triticale 'GK Maros' can be successfully grown in alley cropping systems, with the potential for additional yields compared to conventional arable production, between four and five years old black locust trees in a suitable planting spacing. In the case of 9, 15 and 21 m row spacings, 70, 81 and 86% of the total area was sown respectively. The reduction in the sowing area due to the presence of trees was compensated by the triticale, with higher production per square metre.

2.1 In 2018, the conventional arable crop production yielded 3.35 t/ha of grain, while planting spacing 15 × 2 and 21 × 2 yielded 3.44 and 3.39 t/ha, representing yield increases of 3% and 1%, respectively, while the planting spacing 21 × 1, 15 × 3, 21 × 3 and 15 × 1 yielded 3.04; 2.68; 2.43 and 2.40 t/ha, representing yield decreases of 9%, 20%, 28% and 28%, respectively. Biomass was 7.75 t/ha for conventional cropping and 8.09 t/ha for the planting spacing 21 × 2, representing 4% yield increase, while planting spacing 15 × 2, 21 × 1, 15 × 3, 15 × 1 and 21 × 3 produced 7.59; 6.76; 6.39; 6;17 and 6.08 t/ha of biomass, representing yield decreases of 2%, 13%, 18%, 20%, 22%, respectively.

2.2 In 2019, the grain yield was 1.92 t/ha for conventional arable crops while planting spacing 15 × 2, 21 × 1 and 15 × 3 yielded 2.12; 2.01 and 1.98 t/ha, respectively, representing yield increases of 10%, 4% and 3%, respectively, while the planting spacing 21 × 3, 21 × 2, 15 × 1, 9 × 2, 9 × 1, and 9 × 3 produced 1.78; 1.64; 1.40; 1.21; 1.06 and 0.78 t/ha, representing yield decreases of

7%, 15%, 27%, 37%, 45% and 60%, respectively. Biomass was 4,85 t/ha in conventional arable cropping, while for planting spacing 15 × 2, 15 × 3 and 21 × 3, it was 5,51; 5,15; and 4.93 t/ha, representing 14%, 6% and 2% excess yields, respectively, while the planting spacing 21 × 2, 15 × 1, 9 × 2, 9 × 1, 9 × 3 and 21 × 1 produced 4.32; 4.27; 3.34; 2.87; 2.15; 1.31 t/ha biomass, representing 11%, 12%, 31%, 41%, 56% and 73% yield reductions, respectively.

3. The yields of widely spaced industrial black locust plantations in alley cropping systems were as follows:

3.1 The total volume of black locust stands at the age of four was 16 .5, 10.7, 10.6, 7.8, 6.9, 8.0, 3.9, 3.8 and 2.7 m^3/ha for 9, 15, 18, 21, 27, 30, 42, 45 and 63 m^2 of growing spacing, respectively.

3.2 The total volume of black locust stands at the age of five was 22,9; 15,1; 14,6; 11,2; 9,4; 11,6; 5,2; 8,1 and 3,6 m^3/ha at the growing space of 9, 15, 18, 21, 27, 30, 42, 45 and 63 m^2, respectively.

6. Conclusions and suggestions

The results of the study are valid for the given site, years and species, so we can only conclude that the combination of black locust and triticale seems promising in the first few years after establishment, especially for the larger row spacings (>9 m). Presumably, the yields of the field crop are even more favourable when the trees are younger, as there is less competition for water, light and nutrients. There was no nutrient supply in the experiment, and even better results can be expected if it is applied. Regarding the tree yields, the lack of correlation between diameter and growing space and between diameter and number of trees per hectare highlighted that the method of estimating tree volume in forestry is probably not appropriate for yield estimation in agroforestry systems (alley cropping) and that future work should focus on the construction of specific tree yield tables for agroforestry systems. My PhD thesis, as a foundational study, aims to contribute to domestic agroforestry research, which in the future should be extended in space and time, and in terms of species, with particular attention to their yield and economic implications, and their role in adaptation and mitigation in the light of climate change.

As trees grow over the years, the yield performance of agroforestry systems will undoubtedly change. Therefore, well-planned pruning and thinning should be part of the long-term maintenance to maximise the potential of the system through favourable tree-plant interactions. As long as it is worthwhile for the farmer to maintain the agroforestry system, either for financial reasons or for the benefits of ecosystem services.

In practice, the most appropriate spatial arrangement of the trees depends on how the farmer defines the main purpose of the agroforestry system (which may also change over time as the system evolves). This may be crop, wood or biomass production, biodiversity enhancement, creating habitat for wildlife, soil conservation, or other. In the future, the role of agroforestry systems may be enhanced by their carbon sequestration potential, as the wood and the uncultivated soil under the trees can also act as long-term carbon sinks, providing additional income for the farmers through the carbon market. Another important role of trees in agriculture is their influence on microclimate, which can be a crucial tool for climate adaptation. A further conclusion of the dissertation is that while it is justified to set the number of trees per unit area in line with agricultural policy objectives, it is important to be flexible in terms of spatial distribution. In the current scheme (in 2022), the spacing is fixed at a minimum of 5 × 5 and a maximum of 10 × 10 m, which shall be reviewed.

7. Publications

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