TOWARDS RISK LIMITATION AND HIGHER BIOMASS QUALITY: IS MIXED CROPPING AN ADVISABLE STRATEGY IN ENERGY CROP PRODUCTION?

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ABSTRACT: Increased payment for energy obtained by renewable resources has made the production of biogas using energy crops economically interesting. As the proportion of maize in crop rotations should not be exceeded any further, alternative crops for biogas production are needed. Mixed cropping offers reduced risk, lower disease infection, a high flexibility concerning the optimal harvest time point, and high plant diversity, which is severely needed in monotonous cultural landscapes. The aim of the presented work is to give farmers site-specific cultivation recommendations to establish energy crop production successfully in their farm management. In total, 34 single and mixed stands were tested at two experimental sites, which represent low mountain range and flood plain conditions. All crops were monitored weekly regarding the state of growth, plant height, and occurrence of weeds, diseases and pathogens. At harvest, biomass yield was measured for each mixture component alone and samples were analysed for their contents to calculate the theoretical biogas production. None of the tested mixed stands produced more biomass than the most productive single stands but for some mixtures, the theoretical biomass production was higher. Many of the tested crops will need further breeding to become an interesting option.
Keywords: biodiversity, biogas, crop cultivation

1 INTRODUCTION

The payment for energy produced by renewable resources has been raised and guaranteed for longer terms by the “Renewable Energy Act (EEG)” in Germany. Now, the cultivation of energy crops as a resource for biogas production is increasing rapidly even if precise recommendations and experience are still missing. Due to its high biomass yield and well-known production technique, maize has become the most utilised crop in biogas production. But as its proportion in crop rotations should not be extended any further for plant productive, phytosanitary and environmental reasons, alternative crops for biogas production and the necessary knowledge for their successful cultivation are required.

Mixed cropping means the concurrent cultivation of two or more species in one area. Mixed stands are assumed to

- show good adaptation to the site conditions,
- have a reduced plant productive risk,
- have lower disease and pest infection rates,
- show a better weed suppression which leads to a reduction of herbicide application,
- be flexible concerning the harvest time point,
- show a higher stableness in the field,
- lead to higher plant diversity in the agricultural landscape,
- have a higher biomass quality as resource for biogas production due to synergistic effects between plant contents of different species.

The presented work examined whether the supposed advantages of mixed stands are useful in energy crop production. Though the mixed stands are assumed to need less herbicide treatments than single stands, the tolerance of the productive species concerning herbicide application had to be tested as only little experience on this was available. The aim is to develop site-specific cultivation recommendations for useful mixed stands that could support farmers choosing alternative energy crops for biogas production.

2 MATERIALS AND METHODS

2.1 Field trials

In 2006, the field trials were performed at two experimental sites: Aholfing and Ascha. Aholfing is located about 10 km distance to Straubing and represents Danube meadow and flood plain conditions. Whereas Ascha, approx. 20 km apart from Straubing, stands for foreland and low mountain range areas.

Table I: Tested winter crops

Winter crops	Abbreviation	Variety or Seed rate [%]
winter barley	B	Merlot
winter barley + herbicide	B	Merlot
winter rye	R	Rasant
winter rye + herbicide	R	Rasant
winter rapeseed	RA	Elektra
winter rapeseed + herbicide	RA	Elektra
winter turnip rape	TRA	Perko PHV
common vetch	V	Dr. B. Ostsaat
ryegrass	RG	Taurus
sweet clover	SC	Steinklee gelb
crimson clover	CC	Linkarus
winter rye + common vetch	R + V	80 + 40
ryegrass + common vetch + crimson clover	RG + V + CC	85 + 40 + 30
barley + turnip rape + common vetch	B + TRA + V	60 + 40 + 30
barley + turnip rape	B + TRA	70 + 50
winter rye + sweet clover	R + SC	80 + 80
rapeseed + common vetch	RA + V	60 + 40

At site Aholfing, both winter and summer crops were tested, at site Ascha only winter crops were cultivated. All experiments were performed in a Latin Rectangle Design for 17 variants with 4 replications. Each parcel consisted of three parts, the outer two were used as border parcels to minimise the influences between the variants. Of each middle parcel, an area of 10.5 m² was harvested.

All crops in mixed stands were also tested as single stand. Seed rates of the mixed stands were modularly composed: not additional (e.g. 100 % + 100 %) nor substitutive (e. g. 50 % + 50 %) but individually depending on the requirements of the species. In Table I and II all variants are listed, for the mixed stands the seed rates are given in percentage of the respective single stand seed rate.

The more productive crops were also tested for their tolerance to herbicide application. The respective summer crops were treated as following: pea and blue lupine with 4.0 l ha^{-1} Bandur, false flax with 2.0 l ha^{-1} Butisan and summer barley with 20 g ha^{-1} Pointer plus 1.5 l ha^{-1} U46M-Fluid. In the winter crops, winter barley and winter rye were treated with 0.8 l ha^{-1} Bacara, whereas in winter rapeseed 1.2 l ha^{-1} Butisan was applied.

Table II: Tested summer crops

Summer crops	Abbreviation	Variety or Seed rate [%]
summer barley	B	Djamila
summer barley + herbicide	B	Djamila
pea	P	Santana
pea + herbicide	P	Santana
blue lupine	L	Borlu
blue lupine + herbicide	L	Borlu
false flax	F	Ligena
false flax + herbicide	F	Ligena
mustard	M	Samba
safflower	S	Sabina
barley + pea	B + P	75 + 75
barley + false flax	B + F	80 + 50
pea + false flax	P + F	100 + 50
blue lupine + safflower	L + S	60 + 50
barley + blue lupine + safflower	B + L + S	50 + 50 + 50
barley + mustard	B + M	80 + 50
barley + pea + mustard	B + P + M	50 + 30 + 50

2.2 Data collection and analyses

During the growing time, growth stage, plant density and plant dominance (for the stands, the crop species and all important weed species), infection with diseases and pests were monitored continuously. Mass fractions of species in mixed stands were estimated to be able to calculate the yield fraction of every mixture partner.

The crops were harvested in milk ripe stage, except for the mixed stand with ryegrass, crimson clover and common vetch which was harvested shortly before full flowering. Samples were taken to obtain the dry matter content (desiccation at 105 °C) and for Weender analysis (desiccation at 60 °C). The following parameters were analysed: crude ash, crude protein, crude fat, crude fibre, N-free extracts, C, N, P, K, Mg, S, and Ca.

Some of these plant content values were used to calculate the theoretical biogas and methane production using the formula of Baserga [1]. The calculation of the theoretical biogas output and biogas production was complicated as necessary digestibility coefficients for some species were missing in the DLG Futterwerttabellen [2]. These values were completed using [3], [4] and [5].

3 PRELIMINARY RESULTS

Due to harsh winter conditions, the variants sweet clover, crimson clover, ryegrass + crimson clover + common vetch, as well as rye + sweet clover failed at site Ascha. Thus, only results of site Aholfing are presented in this paper.

3.1 Biomass yield winter crops

As shown in Figure 1, none of the single or mixed stands was as productive as winter rye in single stand with a dry matter yield of 178 dt ha^{-1}. In the mixture rye + sweet clover, the sweet clover could not be established sufficiently, leading to a mass fraction of only 1 %. Therefore, this variant is rather considered a single stand rye with a reduced seed rate of 80 %, leading to a dry matter yield of 174 dt ha^{-1}. The third-highest yield was achieved by the mixed stand rye + common vetch with 160 dt ha^{-1}. Barley in single stand produced a yield of 130 dt ha^{-1}. All other single and mixed stands had dry matter yields between 59 to 94 dt ha^{-1}.

Crimson clover, the mixed stand ryegrass + common vetch + crimson clover, and ryegrass had only very low dry matter contents with 15.6 %, 19.8 %, and 20.6 %, respectively. For all other variants, the dry matter contents ranged between 32.7 % (turnip rape) and 53.7 % (mixed stand barley + turnip rape + common vetch).

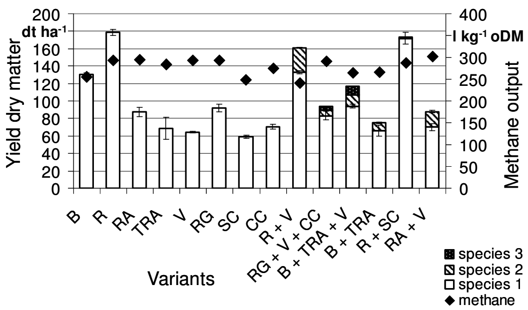

Figure 1: Dry matter yield (dt ha^{-1}) and methane output (l kg^{-1} oDM) of tested winter crops at site Aholfing in 2006. Shown are arithmetic means with $n = 4$ and the respective standard errors

3.2 Biomass yield summer crops

As expected, the summer crop yields (Figure 2) were less than those of the winter crops. The most productive variants were as following: barley 123 dt ha^{-1}, barley + false flax 118 dt ha^{-1}, barley + mustard 108 dt ha^{-1}, and safflower in single stand with 104 dt ha^{-1}. All other single and mixed stands had dry matter yields between 67 to 103 dt ha^{-1}.

The dry matter contents ranged between 32.7 % (blue lupine) and 62.9 % (mixed stand barley + pea + mustard).

3.3 Biogas and methane production

Figures 1 and 2 also contain the methane output per kilogram organic dry matter for the different crops as calculated depending on the substances of content. These range between 241 – 301 l kg^{-1} oDM for winter crops, and 254 – 316 l kg^{-1} oDM for summer crops. Surprisingly, the methane output of the mixed stand rye + common vetch was definite lower than the output parameters of rye and common vetch in single stands.

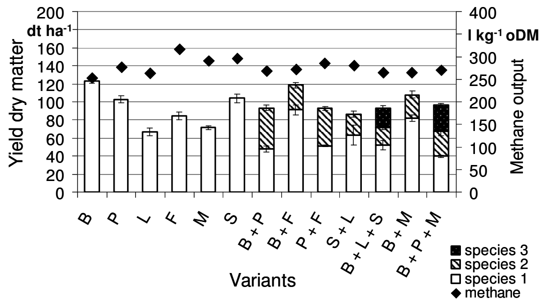

Figure 2: Dry matter yield (dt ha^{-1}) and methane output (l kg^{-1} oDM) of tested summer crops at site Aholfing in 2006. Shown are arithmetic means with $n = 4$ and the respective standard errors

As the biogas production per area correlates highly with the amount of biomass yield per area, the most productive crops had also the highest biogas production. Only one mixed stand had a higher biogas production than the corresponding single stand of the more productive mixture partner: barley + false flax (Figure 3). Though the biomass yield of this mixed crop was slightly lower than that of barley in single stand, the biogas output per kilogram organic dry matter was higher, resulting in about 300 m^3 more biogas per hectare.

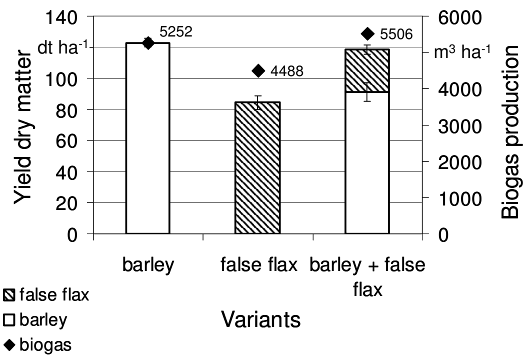

Figure 3: Dry matter yield (dt ha^{-1}) and biogas production (m^3 ha^{-1}) of barley, false flax and barley + false flax at site Aholfing in 2006. Shown are arithmetic means with $n = 4$ and the respective standard errors

3.4 Herbicide treatments

In both experiments, the more productive single stands were tested for their tolerance to herbicide treatments. The tested winter crops winter rye, winter barley and winter rapeseed did only show minor changes in yield if herbicides were used.

However, the tested summer crops showed remarkable yield depression after herbicide application, even in summer barley and pea (Figure 4). The weed dominance values were significantly different between both treatments of barley, pea and blue lupine. The yield reductions seemed to be caused solely by damage of the crop.

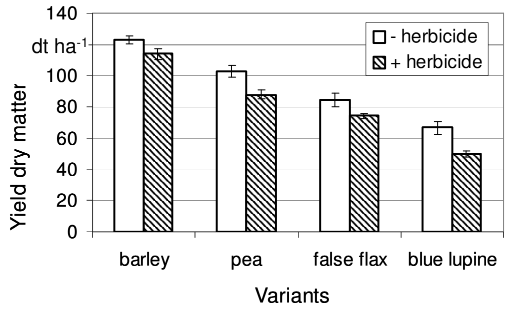

Figure 4: Dry matter yield (dt ha^{-1}) of barley, pea, false flax and blue lupine with and without herbicide application at site Aholfing in 2006. Shown are arithmetic means with $n = 4$ and the respective standard errors

The weed dominance was significantly lower ($\alpha = 5$ %) for most of the tested mixed stands compared to the single stands. The only mixed stand showing a very low weed suppression was blue lupine + safflower in the tested summer crops.

4 DISCUSSION

4.1 Biomass yield

Diverging from the assumption that mixed cropping can produce higher yields than single stands, we did not find a mixed stand having a higher yield than the more productive mixture partner alone.

It is easier to optimise the crop management for a single stand than to do so for mixed croppings in which the partner species have different demands concerning supply with nutrients, water and light. Especially the harvest time point, which was thought to be rather flexible in mixed stands, is difficult to determine in terms of maximising biomass amount and quality. In most mixed stands, the chosen harvest time point is suboptimal for at least one mixture partner, so that the theoretically possible yield and quality generally cannot be achieved.

The unfavourable high dry matter contents of some variants were caused by the unusually long aridness in May and June 2006 that led to an accelerated maturation of the crops.

4.2 Biogas production

The theoretical possible production of biogas is highly depending on the amount of biomass produced. Some mixed stands had slightly higher biogas output values, indicating higher amounts of energy-rich plant contents, but only for the mixed stand barley + false flax this increased biomass quality could compensate the lower yield. Fermenter batch tests will be necessary to test for synergistic effects between the plant contents, the calculation of theoretical biogas production alone is not sufficient.

4.3 Herbicide treatment and general weed suppression

We can conclude that the ability to suppress weed is generally higher in the mixed stands, as these crops have mostly higher plant densities than single stands, with all according effects on plant growth and habitus.

The application of herbicides in some more productive single stands has shown definite yield depressions. It is possible that the use of herbicides in mixed stands might damage one or more partners more severely than a tolerable weed occurrence could.

5 FUTURE PROSPECTS

As safflower showed relatively promising biomass yield results as single stand, but insufficient weed suppression in mixture with blue lupine, it is planned to test it in mixture with barley.

It is not possible to detect positive complementation of plant contents, that could increase the biogas output, by calculation alone. Fermenter batch tests will be needed to check if such synergistic effects exist, as these would increase the value of mixed cropping biomass enormously.

6 CONCLUSIONS

We have shown that mixed stands might be used to reduce the risk of losing the whole crop, as one species can substitute another under unfavourable circumstances. However, the crop management for mixtures is always suboptimal, leading to generally less biomass production than with single stands under optimised crop management.

Higher theoretical biogas and methane production was found in only one mixed stand, summer barley + false flax, as higher biomass qualities could not make up for reduced biomass yields compared to single stands.

It is possible that some plant species could have synergistic effects when fermented together, if their contents complement perfectly in regard to the needs of the fermenter bacteria population. These effects could only be shown by batch fermenter tests, and not by calculations of the theoretical biogas production or output alone.

7 ACKNOWLEDGEMENTS

We thank the field technicians Nicol Klinnert, Markus Krinner and Stefan Wiesent for their excellent work and endless motivation. Also thanks to the cooperating farmers who assisted us with the field work.

This work is part of the cooperative project "Development and comparison of optimised cropping systems for agricultural production of energy crops under different site conditions in Germany". We would like to thank the Agency of Renewable Resources (FNR) and the Ministry of Food, Agriculture and Consumer Protection (BMELV) for the financial support.

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