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Perennial wild plant mixtures for biomass production: Impact of species composition dynamics on yield performance over a five-year cultivation period in southwest Germany

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ABSTRACT

Wild plant mixtures (WPMs) are a promising perennial cultivation system for biogas production with numerous ecological benefits. However, to date, there is little information on their long-term development. To investigate this, two different WPMs (S1, Rieger-Hofmann GmbH, 2016; S2, Saaten-Zeller GmbH, 2016) of up to 27 native, mainly wild species with a combination of annual, biennial and perennial life cycles were established at three sites in southwest Germany in 2011. At Hohenheim (HOH), fertilization was varied (0, 50, 100 kg ha^{-1} nitrogen) and a split plot design with three replications was used. At Renningen (REN) and Sankt Johann (SJO) single plots were used and fertilized with 50 kg ha^{-1}. Harvest and sample analysis were conducted each year over a five-year cultivation period. The development of dry matter yield (DMY), dry matter content (DMC) and species composition dynamics of the WPMs were investigated.

The DMYs varied strongly between the mixtures, sites and years, ranging from 2.9–22.5 Mg ha^{-1} yr^{-1}. Significant effects of mixture ($P < 0.001$) and site x age interactions ($P < 0.05$) were found. On average, S2 had about 55% higher yield than S1 over the five years (S2 accumulated DMY: 50.2–74.2 Mg ha^{-1} s). For both mixtures, a high number (up to 19) of WPM species were recorded, but this declined over the cultivation period at all sites. The DMYs at REN and SJO increased with time, whereas at HOH the high weed pressure from the grassland pre-crop resulted in decreasing yields. Here, the nitrogen mineralization of the grassland residues was high enough to mask fertilization effects. A good substrate quality for ensilaging (DMC >28%) was achieved at all sites every year except 2011. From these findings, we can recommend the WPM concept based on the S2 mixture as a feasible cultivation system with potentially high ecological benefits, in particular for marginal sites.

1. Introduction

The use of plant species mixtures in agriculture is seen as a promising way of combating the disadvantages that have accompanied the intensification of farming with its reliance on monocultures (Robinson and Sutherland, 2002; Tilman et al., 2014). These include susceptibility to pests and diseases, and loss of biodiversity (German Council of Environmental Advisors, 2007). Through a wider genetic base, species mixtures can provide more diverse and resilient crop production systems (Sanderson et al., 2007; Weigelt et al., 2009). The differences in eco-physiological requirements of the individual species allow the mixture as a whole to cope better with differences in site and climatic conditions (Baumgärtner, 2007; Finger and Buchmann, 2015; Haddad et al., 2011). Mechanisms that benefit plant mixtures compared to monocultures include the complementary use of available resources and the counterbalancing of susceptibility to disease between the various species (Li et al., 2014). The optimal use of resources can be achieved through the spatial arrangement of leaves (optimal exploitation of light) and roots (optimal uptake of water and mineral nutrients) (Frankow-Lindberg and Wrage-Mönnig, 2015) and the extension of the growing season (Pembleton et al., 2015).

In energy crop cultivation, species mixtures are seen as an opportunity to overcome the risks associated with mono-cropping while at the same time contributing to an increase in biodiversity. Crop-based biogas-substrate production is a particular focus of criticism due to the dominance of maize. For this reason, the concept of using wild plant mixtures (WPMs) as a biogas-substrate has recently been developed in Germany by the Bavarian State Research Centre for Viticulture and Horticulture (LWG) and the breeding company Saaten Zeller (Vollrath et al., 2012). The idea

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behind the concept is that a perennial biomass production system is established by sowing a mixture of annual, biennial and perennial species together (Vollrath et al., 2012). In the first year, when yields in mono-cropped perennial systems such as cup plant (*Silphium perfoliatum* L.) (Gansberger et al., 2015) and Sida (*Sida hermaphrodita* L.) (Jablonowski et al., 2016) are generally low, the WPM yield is comparably high. This is because the yield is provided by annual species (e.g. sunflower (*Helianthus annuus* L.), Chinese mallow (*Malva verticilliata* L.), amaranth (*Amaranthus cruentus* L.)) while the perennial crops are establishing (Vollrath et al., 2012). From the second year onwards the yield is derived from the biennial and perennial species (e.g. glastum (*Isatis tinctoria* L.), common mallow (*Malva sylvestris* L.), red clover (*Trifolium pratense* L.), mugwort (*Artemesia vulgaris* L.), tansy (*Tanacetum vulgare* L.)) (Vollrath et al., 2012). This system enables cultivation with low soil disturbance, as tillage is only necessary in the year of establishment, but without loss of yield in the first year (Vollrath et al., 2012).The WPMs developed by the above-mentioned groups comprise various native wild and cultivated plant species with different life cycles (Kuhn et al., 2014; Vollrath et al., 2016, 2012). Preselected plant species were screened for their dry matter yield (DMY), specific methane yield, adaptability to environmental conditions and ecological value for above-ground and soil fauna (Vollrath et al., 2016, 2012). Combinations of species were then composed, which allow a high number of species to be present in the stands in each year of cultivation. The result was a new biomass cultivation system for biogas production designed to provide yield for a period of up to five years (Vollrath et al., 2012). It is based on a WPM of over 25 annual, biennial and perennial predominantly native wild plant species, which is intended to generate a higher ecological value than maize-dominated crop rotation systems in combination with acceptable yields, especially on marginal sites or sites close to natural habitats (Vollrath et al., 2012).

The main ecological advantages are considered to stem from:

- high diversity: long flowering periods with different species in bloom, attracting insects at different times and providing food to a large number of species (Vollrath et al., 2016) comparable to wildflower strips (Hatt et al., 2015);
- the permanent soil coverage from the second year onwards, which is expected to provide food and shelter for above-ground and soil fauna (Emmerling, 2014; Felten and Emmerling, 2011),
- the late harvest, providing habitat, food and shelter to various species, such as partridge, hoofed game, common hamster etc. (Fischer and Wagner, 2016; Vollrath et al., 2012),
- the undemanding nature of the WPM species in terms of low agrochemical input and high stress tolerance and potential adaptability to marginal site conditions (Friedrichs, 2013).

The use of species mixtures may however also hold disadvantages. These include competition between the different species, which can lead to lower overall yields, and more complex management systems which cannot be optimized for all species. Lack of homogeneous ripening makes the timing of the harvest difficult and can lead to variation in biomass composition. And finally, the ecological advantages of WPMs will only take effect if the conceptual approach – i.e. the interplay of annual, biennial and perennial species – can be successfully implemented.

There have so far been no long-term investigations into the use of wild plant mixtures as bioenergy crops and, as such, there is little information available on their establishment, yield and quality over a cultivation period of at least five years. The objective of this study was therefore to assess the development of two wild plant mixtures at three sites with different climatic conditions over a five-year cultivation period to examine (i) the development of biomass yield and dry matter content and (ii) the dynamics of species composition within the cultivation system.

2. Methods

In 2011, field trials were established at three different sites near Stuttgart, southwest Germany: at Hohenheim (abbreviated to HOH), Renningen (REN) and Sankt Johann (SJO). Two wild plant mixtures (WPMs) were planted at each site. These are referred to as S1 and S2. The soil and climatic conditions of the sites and the management of the field trials are described in the following sections.

2.1. Soil and climatic conditions

The site at SJO has long-term conditions approximately 1 °C warmer with approximately 150 mm less annual precipitation than the sites at HOH and REN, due to its higher altitude (Table 1). The soil properties of the three sites are comparable (Table 1), but there was a difference in pre-crops grown prior to the WPM establishment: at SJO winter wheat, at HOH grassland and at REN fallow. All three sites were characterized by a humid temperate climate over the whole WPM cultivation period (Fig. A1), but with differences between sites and years. The average annual temperature mainly coincided with the long-term data at each site with the following exceptions: (i) the winter 2011/2012 was approximately 3 °C colder; (ii) the winter 2013/2014 was approximately 3 °C warmer; and (iii) the average annual air temperature was approximately

Table 1
Geographic conditions of the sites.

	Site[a]		
Parameter	HOH	REN	SJO
Position			
Latitude (DD[b])	48.71504	48.7402	48.4716
Longitude (DD)	9.2113	8.930	9.3026
Altitude (m)	400	470	710
Soil properties			
Soil type	Luvisol	Pelosol-Pseudogley	Brown earth
Soil texture	Clayey loam	Silty clay	Humous clayey silt
Pre crop	Grassland	Fallow	Winter wheat

[a] HOH, Hohenheim; REN, Renningen; SJO, Sankt Johann.
[b] DD, decimal degrees.

Table 2
Annual precipitation totals and average annual temperatures of the sites during the cultivation period 2011–2015. The deviations from the long-term values are given in brackets.

	Site[a]		
	HOH[b]	REN[c]	SJO[c]
Annual precipitation (mm)			
2011	548(−150)	555(−133)	942(−8)
2012	700(+2)	681(−7)	816(−134)
2013	775(+77)	852(+164)	963(+13)
2014	747(+49)	732(+44)	1115(+165)
2015	488(−210)	511(−177)	708(−242)
Average annual temperature (°C)			
2011	10.7(+1.9)	9.6(+1.3)	8.2(+0.9)
2012	10.1(+1.3)	9.0(+0.7)	7.6(+0.3)
2013	9.5(+0.7)	8.4(+0.1)	7.4(+0.1)
2014	11.2(+2.4)	10.1(+1.8)	9.5(+2.2)
2015	10.9(+2.2)	9.8(+1.5)	8.3(+1.0)

[a] HOH, Hohenheim; REN, Renningen; SJO, Sankt Johann.
[b] Data supplied by University of Hohenheim (Inst. for Physics and Meteorology, Germany, 2015).
[c] Data supplied by WebWerdis (DWD, Germany, 2015).