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Is crop yield related to weed species diversity and biomass in coconut and banana fields of northeastern Brazil?

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ABSTRACT

The ability to accommodate crop production for an ever-growing human population and achieve conservation of rapidly declining biodiversity remains a challenging task worldwide. In agroecosystems, weed diversity and biomass are frequently assumed to be negatively related to crop yield and biomass. However, positive effects of weed species (pollinator and parasitoid attraction) and different resource acquisition strategies may reduce the competitive character of weeds—a potential that can be exploited within land-sharing approaches (i.e., biodiversity conservation and agriculture on the same site). This study aimed at analyzing the relationships of weed diversity and biomass to crop yield and biomass in coconut and banana fields within an irrigation farming scheme established in former Caatinga seasonal dry forest ecosystems around the Itaparica Reservoir, Pernambuco, Brazil. Within each of 21 selected crop fields, we collected weed diversity and biomass data in the fields' center and edge along with general information on crop yield and the use of fertilizers and other agrochemical inputs. We found no evidence for a negative relationship of crop yield or biomass and weed diversity. On the contrary, crop yield and weed alpha diversity were significantly positively correlated (Shannon and Simpson indices, evenness). In contrast, weed biomass showed a significant negative correlation to crop yield. The use of organic fertilizer had a significant positive effect on crop yield, whereas no impact of herbicides or insecticides was detected. In addition, the field edge provided habitat for more weed species than the field center. Overall, our data show that in perennial tropical crop fields high yield is not opposed to high weed diversity. Moreover, the data suggest that organic farming in the area will likely not lead to yield losses. Nevertheless, the related weed assemblages inhabited only a few typical species of the native dry forest vegetation which makes their contribution to biodiversity conservation at the landscape scale debatable.

1. Introduction

More than 30% of the ice-free area of the earth is currently directly used for agriculture (Hurtt et al., 2011). At the same time, the world is facing an accelerated extinction rate of species and a dramatic loss of biodiversity in all biomes (Millennium Ecosystem Assessment, 2005). As land must be used to provide food for earth's continuously growing population, the success of biodiversity conservation is tightly linked to our ability to integrate conservation efforts into human-driven landscapes (Fahrig et al., 2011).

Two main strategies known as land sparing and land sharing have been proposed to protect biodiversity (Phalan et al., 2011). Land sparing refers to the practice of intensifying agriculture on productive soils to gain areas for efficient species conservation in other places, whereas land sharing aims at integrating conservation and crop production on the same site (also described as wildlife-friendly farming; Green et al., 2005). Up to now, neither of these strategies seems appropriate to achieve all conservation goals and for all land-use systems (Grau et al., 2013). In particular, land sharing seems to be the more appropriate option in agroforestry and in livestock systems, whereas land sparing has been shown to be efficient in cash crop production schemes such as oil seeds, wheat, and sugar cane (Clough et al., 2011; Grau et al., 2013). In both options, agrarian habitats will play a pivotal role in biodiversity conservation due to their wide distribution and huge area they cover.

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Crop yield and weed biomass have commonly been assumed to be negatively related (Zimdahl, 2007). There may also be a negative correlation between crop yield and weed diversity (Clough et al., 2011; Syswerda and Robertson, 2014). However, weed–crop competition is expected to be less pronounced when the species are characterized by high functional diversity in terms of resource acquisition traits (Smith et al., 2009). In fact, there is growing empirical evidence that diverse crop and weed communities may show no (Epperlein et al., 2014) or even a positive relationship of crop and weed biomass (Smith et al., 2009). Accordingly, weed diversity and crop yield may be unrelated (Pollnac et al., 2009) or positively related (Hooper et al., 2005). Moreover, the combination of functionally different crop species such as cocoa and banana has been shown to lead to higher yield overall and per crop plant (Deheuvels et al., 2012).

Such positive weed–crop relationships can be expected to rely on beneficial plant–plant interactions (see Wardle et al., 1998) which may derive, for example, from functional complementarity in terms of root and canopy architecture of the plants involved (Brooker et al., 2015). Complementarity enables resource sharing, mitigation of severe environmental effects, or the supply of resources from one species to the other (Nakamura, 2008). Consequently, positive plant–plant interactions and the resulting biodiversity impacts are often more obvious under cases of resource limitation (Mulder et al., 2001; Brooker et al., 2008; Nakamura, 2008). The beneficial interaction among species may be direct, as in the case of the community's exploitation of limited resources (e.g., phosphorous; see Karanika et al., 2007; Oelmann et al., 2011), or indirect through a more diverse and abundant community of soil organisms (Zak et al., 2003; Chung et al., 2007; Hol et al., 2013), pollinators (Bennett and Isaacs, 2014), or herbivore predators (Gosme et al., 2012; Puech et al., 2014).

However, agroecosystems do not necessarily yield more biomass when only a few species are present (Coulis et al., 2014). Positive biodiversity effects have more often been reported in species-rich communities such as grasslands (Bullock et al., 2001; Karanika et al., 2007; Tilman et al., 2012), prairies (Bonin and Tracy, 2012), or artificial moss communities (Mulder et al., 2001). In such ecosystems, complementarity of species seems to play a more pronounced role for positive biodiversity effects (complementarity effect) rather than selection effects, i.e. the beneficial impact of individual species with particular traits occurring randomly in species-rich communities (Cardinale et al., 2007; Fargione et al., 2014). In biodiversity experiments, also the duration of plant–plant interactions increased the probability of positive biodiversity effects (Cardinale et al., 2007; Fargione et al., 2014). Whether such findings also apply to crop production systems is still discussed (Schöb et al., 2015).

In tropical latitudes, natural ecosystems, including tropical dry forests (Bianchi and Haig, 2013), are continuously being transformed to pastures and agricultural land (Pan et al., 2011), leading to severe losses of biodiversity. The Caatinga of northeastern Brazil is the largest seasonal dry forest region in South America. Approximately 50% of the area supporting native vegetation in the past has been either completely converted or heavily modified by land use (Menezes et al., 2012). Overuse together with the presumed impact of regional climate change is accelerating desertification (Oyama and Nobre, 2003), although recent surveys indicate a slight increase in forest cover during the last decade (e.g., Menezes et al., 2012). Different agroecosystems such as coconut (*Cocos nucifera* L.) and banana (*Musa* × *paradisiaca* L.) fields cover about 10% of the area (Menezes et al., 2012) and may contribute to biodiversity conservation. However, only a few studies have addressed the link between biodiversity and crop yield in such ecosystems (Aguiar et al., 2013). We hypothesize that complementarity of weeds and crops in terms of belowground and light resources is particularly pronounced in perennial crop fields due to the different plant functional types involved and to the long interaction time, which increases the probability of positive biodiversity effects.

This study aims at determining the relationship between the biomass and diversity of weeds and the yield and biomass of coconut and banana crops in irrigated areas within former Caatinga dry forest areas around the Itaparica Reservoir, Pernambuco, Brazil. Coconut and banana are the most frequently grown crops in the area (Silva et al., 2007). In particular, we analyzed the following questions: (1) Are crop yield and crop plant biomass correlated with weed diversity and biomass, and if so, positively or negatively? (2) Which environmental and management variables influence crop yield, weed diversity, and biomass of crop plants and weeds? (3) Are there differences between the crop–weed relationships of coconut and banana fields? Based on these data, we draw conclusions on a diversity-optimized crop production in tropical dry forest ecosystems.

Table 1
The use of fertilizers, insecticides, and herbicides, as well irrigation technique and grazing on the studied banana and coconut fields.

Crop species	Field no.	Fertilizer	Insecticide	Herbicide	Irrigation technique	Grazing
Banana	1	Organic	Yes	No	Spray	No
	2	Organic + chemical	No	Yes	Micro-spray	No
	3	No	No	No	No	No
	4	Organic + chemical	Yes	Yes	Micro-spray	No
	5	Organic + chemical	No	Yes	Spray	No
	6	Organic + chemical	No	Yes	Micro-spray	No
	7	Organic + chemical	Yes	Yes	Micro-spray	No
	8	No	No	No	No	No
	9	Organic + chemical	No	Yes	Micro-spray	No
Coconut	10	Organic	Yes	No	Spray	No
	11	Organic + chemical	Yes	Yes	Micro-spray	No
	12	Organic + chemical	Yes	No	Spray	Yes
	13	No	No	No	Spray	No
	14	Organic	No	No	Spray	No
	15	Organic + chemical	Yes	Yes	Micro-spray	No
	16	Organic + chemical	Yes	Yes	Drip	No
	17	Organic	No	No	Spray	Yes
	18	Organic + chemical	Yes	Yes	Spray	No
	19	Organic + chemical	Yes	Yes	Spray	No
	20	Organic + chemical	Yes	Yes	Drip	No
	21	Chemical	Yes	Yes	Spray	Yes