Weed species structural and functional composition of okra fields and field periphery under different management intensities along the rural-urban gradient of two West African cities

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ABSTRACT

In urban and peri-urban agricultural production systems of Sub-Saharan African cities, diverse and functional complex weed communities may help to maintain biodiversity and ecosystem services and therefore indirectly support crop performance. However, effects of agricultural intensification and urbanisation on important weed diversity in the West African region had received so far little attention, although in Burkina Faso and Ghana up to 90 per cent of the population depends on agriculture as a main source of income generation. Hence, our research focussed on the analysis of changes in weed assemblages' structure and function of okra fields that were cultivated under different management intensities and were embedded into the rural, peri-urban and urban environment of two West African cities: Ouagadougou (Burkina Faso) and Tamale (Ghana). We found a strong relationship between gender and market orientation of okra cultivation. Market orientation of okra farmers was also a major driver in shaping weed species assemblages and led to the development of a distinct weed assemblage in urban areas that even showed higher diversity in weeds' function. Morphological plant traits (life form, seed properties) were most affected by agricultural practises; distribution pattern of ecological traits (seed dispersal mode, pollination vector) seemed to be influenced additionally by environmental characteristics with less entomophilous but more ornithochorous weed species on okra fields within urban areas. Our results revealed that the management of okra was highly variable and that this variation was influenced by farmers' socioeconomic background leading to changes in soil properties. These in turn may alter the functional diversity of beneficial weed communities beyond changes in species richness by potentially harming the provisioning of ecosystem services such as pest control and pollination.

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1. Introduction

Urban and *peri*-urban agriculture (UPA) refers to a range of market-oriented agricultural production systems within and around cities among which cultivation of vegetables and fruits generally represents the major component (Zezza and Tasciotti, 2010). As such it is a typical feature of many West African cities by providing opportunities to effectively strengthen poor people's livelihood strategies and enhance their food sovereignty (Buerkert and Schlecht, 2013; Dossa et al., 2011). Urban agricultural systems can exhibit high levels of biodiversity and both provide and rely on ecosystem services (Garbach et al., 2014; Goddard et al., 2010; Lin et al., 2015). Weed communities constitute an important component of agroecosystems and although they often pose major constraints to resource-efficient crop production, diverse weed communities can support crop performance directly or indirectly by providing shelter and food resources for beneficial insect, spider and bird species and can therefore affect ecosystem functions and services (Isbell et al., 2011; Kohler et al., 2011; Marshall et al., 2003) such as reducing soil erosion and nitrogen leaching (Carlesi et al., 2013), pest control (Donald, 2004; Russell, 1989) and pollination (Kremen et al., 2002). Within West African UPA systems, numerous

and in part exotic vegetables and fruits, such as cucumber (*Cucumis sativus* L.), strawberry (*Fragaria* spec. L.), tomato (*Solanum lycopersicum* L.), spinach (*Spinacia oleracea* L.) and okra (*Abelmoschus esculentus* L. Moench) are cultivated whose fruit and seed production either rely or benefit from a diverse pollinator community (Klein et al., 2007). Okra has its origin in the African continent and has been grown as a crop for centuries. Meanwhile okra is cultivated intensively throughout the year within urban and peri-urban areas of Ouagadougou and Tamale. Studies showed that okra production can benefit significantly from cross-pollination through insects (Al-Ghzawi et al., 2003; Azo'o et al., 2011) whose abundance and diversity, however, is strongly related to certain weed species within and around crop fields that provide alternative food resources and refuge (Nicholls and Altieri, 2013).

Weed communities constitute a highly dynamic group adapted to frequently disturbed habitats (Roschewitz et al., 2005) with a species composition that is shaped by local factors (soil properties and management intensity), landscape complexity (urbanisation) and socio-economic conditions (ethnicity, farmers' market orientation; Bernholt et al., 2009; Godefroid and Koedam, 2007; Hope et al., 2003; Tscharntke et al., 2005). Agricultural intensification and urbanisation are strongly linked within West African countries, as local urbanisation gradients from rural to urban environments also constitute a steep gradient of management intensification (Drechsel and Keraita, 2014). Here urban vegetable production systems receive nutrient application far beyond optimum rates (up to 800 kg N ha^{-1}; Sangare et al., 2012) often combined with high doses of pesticides. Rural systems with poorly developed transportation systems and limited access to regional markets can be seen as the counterpart to urban agricultural systems with low agricultural performance. This may be attributed to a wide array of production-limiting constraints that include depleted soils and limited use of fertilizer and soil amendments (either organic or inorganic), unreliable rainfall and lack of irrigation capacity, limited access to improved varieties and seed distribution systems.

The rural-urban gradient around West African cities therefore facilitates spatially varying agroecosystems characterised by urbanisation (habitat degradation, fragmentation, impervious surfaces, anthropogenic impact) and local agricultural intensification (decreasing crop diversity, increasing input of mineral fertilizers and pesticides). Both processes are known to trigger losses in beneficial arable weeds leading to a homogenization of species communities affecting ecosystem functioning (Chamorro et al., 2016; Flohre et al., 2011; Flynn et al., 2009; McKinney, 2006). Analyses about the functional composition of weed communities, meaning the presence and dominance of certain plant traits, and functional diversity, rather than plant species richness alone, have been found to better predict the effects of landscape change or land use intensification on ecosystem processes and vulnerability (Dı́az and Cabido, 2001; Díaz et al., 2007; Knapp et al., 2010; Knapp and Kühn, 2012; Lavorel and Garnier, 2002; Van der Walt et al., 2015).

However, so far, in West Africa few studies address the effects of agricultural intensification and urbanisation on biodiversity losses, although agrobiodiversity plays an important role in making farming systems more stable and sustainable particularly within vulnerable areas. It also can enhance resource use efficiency, increase productivity and improve food security and sovereignty.

Hence our research objective focussed on the analysis of changes in weed assemblages' structure and function of okra fields and field periphery that were cultivated under different management intensities and were embedded into the rural, peri-urban and urban environment of two West African cities: Ouagadougou (Burkina Faso) and Tamale (Ghana). Through extracting the effects of agricultural intensification described by okra field soil properties, farmers' management strategies and farmers' socio-economic

aspect on weed species assemblages, this study also aimed at determining the contribution of urbanisation to changes in weeds' structural and functional composition.

2. Materials and methods

2.1. Study area

The study was conducted in 24 agricultural-used sites along an urbanisation gradient of the two West African cities Ouagadougou, Burkina Faso and Tamale, Ghana (Fig. 1). At the time of this study the Ouagadougou metropolitan area had a total population of 2,532,300 and was estimated at a size of 2800 km^2 (2015) whereas the urban population of the Tamale metropolitan area reached 371,400 and comprised 750 km^2 (2014). The dominant soil types along the rural-urban gradient of both Ouagadougou and Tamale were Plinthosols, Lixisols, Gleysols, Cambisols and Arenosols (classified after IUSS Working Group WRB, 2007; Bellwood-Howard et al., 2015). Ouagadougou is part of the West African Sudan Savanna and Tamale of the Southern Guinea Savanna. With increasing annual precipitation and a prolongation of the rainy season towards the South, the vegetation of this West African region is dominated by Poaceae, Fabaceae, Cyperaceae and Asteraceae, and characterised hence by a high proportion of therophytes (Thombiano et al., 2010). The predominance of Poaceae is explained by the metabolic advantages of C_4 plants, which are well adapted to hot and dry climates regarding their water and nitrogen economics (Guinko, 1984; Linder, 2001).

In and around both cities, four study sites each were selected in the rural, peri-urban and urban area. In each study site we established three spatially independent 200 × 200 m plots with an okra field at its centre (in total 36 plots per city). The urbanisation gradient was determined for both cities separately through the calculation of an Urban-Rural Index (URI; after Schlesinger, 2013) that is based on building density and travel time to the city centre with major markets. Building density was determined on the basis of high resolution aerial photographs that were taken for each of the 72 research plots in September 2014 with a scale of 300 × 300 m using a self-built multi-copter as a flying camera platform (hardware from HiSystems GmbH, Germany). The data set of building density (number of buildings per hectare) was normalized on a scale of 0–1. Travel time from the city centre to the particular research plot was calculated using ArcGIS Network Analyst (ESRI) by incorporating network data sets from OpenStreetMap (OSM). The data set of travel time was inverted and normalized on a scale of 0–1. The formula 0.4 x Building density + 0.6 x Travel time (Schlesinger, 2013) was used to calculate an individual URI value for each of the 72 research plots that lied between 0 (least urban) and 1 (most urban). Research plots located in the rural area of Ouagadougou had an average URI of 0.01 (n = 12), in the peri-urban area of 0.38 (n = 12), in the urban area of 0.69 (n = 12; ANOVA, $F_{2,8}$ = 19, $p \leq 0.001$) and were situated at an average linear distance of 55 km, 19 km and 6 km, respectively, from the geographical city centre. Research plots located in the rural area of Tamale had an average URI of 0.05 (n = 12), in the peri-urban area of 0.26 (n = 12), in the urban area of 0.7 (n = 12; ANOVA, $F_{2,9}$ = 95, $p \leq 0.001$) and were situated at an average linear distance of 33 km, 9 km and 5 km, respectively, from the geographical city centre.

2.2. Environmental data

For each of the 72 okra fields, environmental data were collected comprising soil properties, farmers' management strategies and socio-economic aspects of the household concerned. Soil characteristics (topsoil 0–20 cm) included organic carbon