South African Journal of Botany 113 (2017) 308–317

Contents lists available at ScienceDirect

South African Journal of Botany

journal homepage: www.elsevier.com/locate/sajb

Plant functional types differ between the grassland and savanna biomes along an agro-ecosystem disturbance gradient in South Africa

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ARTICLE INFO

Article history:
Received 10 May 2017
Received in revised form 28 August 2017
Accepted 5 September 2017
Available online xxxx

Edited by K Balkwill

Keywords:
Agricultural disturbance
Agro-ecosystems
Functional groups
Grassland
Savanna
Trait diversity
Vegetation composition

ABSTRACT

Intensive, large-scale cultivation of food crops has led to major biodiversity loss worldwide due to fragmentation and degradation of remnant semi-natural habitat within agro-ecosystems. The response of vegetation to these disturbances is often measured in terms of taxonomic diversity loss. However, some plant groups may have more pronounced negative reactions to agricultural disturbance than others, which may not necessarily be expressed in the overall species diversity of the community. It is now widely accepted that the responses of plant taxa to environmental disturbances may be more directly linked to characteristics or traits that enable or hinder their persistence in disturbed environments. This highlights the need to assess the impacts of agricultural disturbance on the abundance patterns and diversity of specific plant traits and functional types. Maize agriculture is a common land-use feature in the grassy biomes of South Africa, but the effect that crop production has on surrounding semi-natural vegetation is still relatively unknown. In this study, we describe the specific functional trait patterns of plant communities associated with maize agro-ecosystems in six localities situated within the Grassland and Savanna biomes of South Africa. Although functional diversity was severely decreased in maize fields, marginal vegetation (30–100 m from crop field edges) displayed no indication of functional diversity loss or major changes in trait composition. Chamaephytic and hemicryptophytic (perennial) life forms, nitrogen-fixing ability and spinescence were trait attributes that were most frequently found in semi-natural vegetation but were lost in the crop field environment. Inside the maize fields, these trait attributes were replaced by annual, low-growing individuals with clonal parts and long-range dispersal mechanisms that can establish in the ephemeral crop field environment. Observed patterns were different for grassland and savanna maize fields, indicating that maize fields situated in the Grassland and Savanna biomes favoured different plant trait assemblages.

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1. Introduction

The large-scale transformation of natural vegetation into agro-ecosystems has detrimental effects on environments worldwide (Sala et al., 2000; Wessels et al., 2003) and affects plant diversity and composition not only within crop fields but also in adjacent semi-natural vegetation (De Snoo and Van der Poll, 1999; Marshall and Moonen, 2002). Since plants represent the basis of most terrestrial food chains, changes in plant diversity or species composition may in turn affect consumer populations (Schellhorn and Sork, 1997; Siemann, 1998; Schaffers et al., 2008; Caballero-López et al., 2010). To regulate the management of diverse and functional ecosystems within an expanding agricultural landscape and to promote sustainable and balanced use of ecosystems and the services they provide, it has become increasingly important to understand the effect of anthropogenic activities on plant communities.

In sub-Saharan Africa, where rapid population increases and high direct dependence on natural resources coincide, biodiversity loss due to land-use change is of particular concern (Sanderson et al., 2002). Approximately 11 million hectares (9%) of land in South Africa are currently utilised for commercial pivot (irrigated) and non-pivot (dryland) annual crops and a further estimated 2 million hectares (2%) have been transformed for subsistence crop cultivation (DEA, 2016). South Africa's grassy biomes (grassland and savanna) have been classified as one of the most transformed and critically endangered biomes due to the degree of habitat loss, fragmentation and estimated future threats (Reyers et al., 2001). It is estimated that 23% has been transformed for cultivation and only 2% is currently protected (Fairbanks et al., 2000). Most of the savanna vegetation types in South Africa are used as grazing pastures for livestock or game (Cousins, 1999), although crop cultivation causes the greatest loss of savanna habitats in South Africa (Mucina and Rutherford, 2006). An estimated 11% of South Africa's savannas are

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Abbreviations: PFT, plant functional type; MZ, maize field; MV, marginal vegetation; RA, rangeland.

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http://dx.doi.org/10.1016/j.sajb.2017.09.008
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transformed for crop cultivation and only about 5% are formally protected (Fairbanks et al., 2000). With grassland and savanna being two of the most agriculturally productive biomes in South Africa, stock-grazing and dryland crop agriculture are two prominent and growing land-uses in the country (Neke and Du Plessis, 2004; Nazare, 2005; Mucina and Rutherford, 2006). Due to this rapid expansion of agricultural lands, a larger proportion of South Africa's diversity is currently found on farmland than in conservation areas (Wessels et al., 2003).

The response of biota to disturbance is often measured in terms of taxonomic diversity loss (O'Connor, 2005; Siebert, 2011). However, the responses of plant taxa to environmental disturbances may be more directly linked to characteristics or functional traits that enable or hinder their persistence in disturbed environments (Lavorel and Garnier, 2002; Deckers et al., 2004; Lososová et al., 2006). This realisation resulted in the increased popularity of functional trait analyses (Pakeman, 2011b; Zhang et al., 2014). Plants may be defined in terms of functional groups or types, which may be used as an alternative to taxonomic species, and are based on sets of similar traits and, theoretically, similar responses to, or effects on, their environment (Lavorel et al., 1997). When considering the ecosystem functions that species perform, the loss of some species may have a much more pronounced effect on the ecosystem than others, depending on how many functionally similar species are left to perform the function of the lost species (Petchey et al., 2009). Therefore, the loss of any particular species will always decrease taxonomic species numbers, but not necessarily functional traits. Accordingly, the impact of crop and rangeland agriculture on plant communities is often assessed by describing variation and response patterns in the abundance (number of individuals) of major functional groups, e.g. grasses or forbs (Fuhlendorf et al., 2001; Liira et al., 2008; Rutherford et al., 2012). It is also useful to assess responses of functional diversity to agricultural disturbance (i.e. the diversity of plant traits or functions present in a community) to determine impacts to ecosystem functioning since it is widely accepted that functional diversity promotes ecosystem stability and functioning (Petchey and Gaston, 2006; Flynn et al., 2009; Ma and Herzon, 2014). Among the multiple techniques used to measure functional diversity, functional type richness remains one of the most popular (Cadotte et al., 2011; Pakeman, 2011a). This technique involves the analysis of the richness (number) of functional types represented by species in an assemblage.

Considering the rapid transformation and degradation of South Africa's grassy biomes into croplands, there is a need to develop and refine conservation strategies for remaining semi-natural habitats. However, this realisation has not been accompanied by a considerable effort to understand the effects of these agricultural disturbances on species or functional diversity (Neke and Du Plessis, 2004). Information is available on the impact of livestock grazing on plant diversity and trait composition of natural and semi-natural grassland and pasture in South Africa (e.g. Uys, 2006; Geldenhuys, 2011; Rutherford et al., 2012), but similar research in crop agro-ecosystems is scarce, which reflects the overall tendency for plant ecologists to avoid highly disturbed agricultural areas (Robertson, 2000). Some studies have focused on the effect of crop agriculture on species diversity and composition (Wessels et al., 2003; O'Connor, 2005; Walters et al., 2006; Siebert, 2011), but very few studies to date have sought to test the effects of crop agriculture on plant traits and functional diversity (e.g Kemper et al., 1999).

Addressing the related knowledge gap in African maize-agro-ecosystems, this study contributes towards a basis for in-depth studies into the potential consequences of plant functional diversity loss for changes in ecosystem functions and the provisioning of ecosystem services due to land-use change and habitat transformation, respectively. Specifically, this study describes plant traits and major PFTs commonly associated with disturbance in agricultural landscapes of two biomes in Africa. The following research questions were asked: How are plant functional types and individual plant traits distributed along a disturbance gradient from low-disturbance semi-natural rangelands into high-disturbance maize fields across the two major grassy biomes? How does the agricultural disturbance intensity influence functional trait diversity? Do these patterns differ between the savanna and grassland biomes?

2. Material and methods

2.1. Experimental layout

Surveys were conducted from November 2009 to March 2012 in the six provinces of South Africa with the highest maize production (Hannon, 2012), namely the Eastern Cape, Free State, KwaZulu-Natal, Limpopo, Mpumalanga and North-West (a map of the study areas and sampling point layout is given in (Botha et al., 2016). Three representative localities were chosen for each of the two biomes, with one locality per province. The six survey localities had to fulfil pre-selected criteria. Firstly, the maize fields had to border on rangeland that remained unfragmented for approximately 5 km in the direction the transects were laid out. Therefore, the rangelands bordering the fields could not include old fields, strips between two fields, or between fields and tarred roads or buildings. Secondly, fields had to have clearly defined field margins with anthropogenic features such as fences, tracks, farm roads and headlands. Thirdly, fields were only sampled when the maize plants were at the flowering stage of development (specific to each province). The environmental variables and management regimes including biome, vegetation unit, altitude, farming type (commercial/subsistence), presence or absence of irrigation and width between rows of maize for the six sampling sites are given in Appendix, Descriptive data, Table 1. At each of the six localities, four sites (each comprising a maize field bordering on rangeland), were selected approximately 5 km apart. Six sampling points were established per site, resulting in twenty-four points at each locality and therefore 144 in total. Sampling points were placed along a 500 m maize field-field margin gradient, never less than 50 m or more than 100 m apart.

2.2. Land-use intensity classification of sampling points

The six sampling points of each site were classified into three classes based on their distance from the actively cultivated area, namely maize field, marginal vegetation and rangeland with two sampling points in each. This amounted to a total of 48 points per distance class for the entire survey. The maize field points (between 100 m and 30 m from maize field edge) were considered high land-use intensity (and therefore high-disturbance) sites subjected to ploughing and agrochemical (herbicide/pesticide/fertilizer) application, and which have been completely transformed for maize production. Marginal vegetation (30–50 m from maize fields) were medium land-use intensity, medium disturbance uncultivated areas characterised by transformed natural vegetation, but also indirectly influenced by agricultural activities associated with the directly adjacent maize fields. These areas typically included features such as farm tracks, ditches or fences that accompany the field boundary vegetation (Summary of the general habitat information is given in Appendix, Descriptive data, Table 1). Rangeland (100–400 m from maize fields) were low-intensity, low disturbance uncultivated semi-natural vegetation used almost exclusively for livestock grazing. These were classified as low disturbance areas, since there were relatively low stocking rates on all the farms, all of which were predominantly maize production systems.

2.3. Vegetation sampling and trait selection

At each sampling point, a fixed-width (2 m) line transect approach was used (Hill, 2005), including ten parallel transects of 20 m each, spaced approximately 2 m apart. One plant species for every major growth form (grass, herb, shrub and tree) was recorded at 1 m intervals along each transect. In this case, the nearest individual of each major group to the point was recorded. To be recorded a species had to touch

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