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Impact of *Acacia tortilis ssp. raddiana* tree on wheat and barley yield in the south of Tunisia

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ABSTRACT

In the past, *Acacia tortilis ssp. raddiana* (Savi) Brenan colonised thousands of hectares in central and southern Tunisia. Nowadays, the geographical distribution of *A. tortilis ssp. raddiana* is restricted to the National Park of Bou-Hedma (central Tunisia). The *Acacia* is of considerable interest for local populations and may be considered as a "foundation species" under arid climate. This study examines the effects of *Acacia* canopy on soil fertility and cereal productivity. The improvement in soil fertility and microclimate provided by *A. tortilis ssp. raddiana* is known to facilitate the establishment of new species, but little is known about the interaction between the tree species and the cereals cultivated by local farmers. We studied the effect of *A. tortilis ssp. raddiana* canopy on the yield of three cereals crops (*Hordeum vulgare* L., *Triticum sativum* L. and *Triticum aestivum* L.). We seeded 168 plots (15 × 15 m) under the tree canopy and in open areas on four different landform types (glacis, plain, wadis, and jessours) and measured cereal yield over two contrasting years (wet and dry). We found that: (1) precipitation and geomorphology are more important in determining cereal yield than canopy cover, (2) these effects on water availability are species-specific with no effect on the stress-tolerant barley. We finally discuss the potential negative effects of *Acacia* trees which may have balanced the positive effects found for nutrient in our study.

1. Introduction

The overall effect of trees on understory vegetation depends on the balance between their positive (facilitation) and negative (competition) effects (Callaway and Walker, 1997). The net result of this balance is mostly dependent on the tree species, tree density, and the nature of the associated species and environmental factors (Gea-Izquierdo et al., 2009).

Positive effects are often expected in arid areas, where trees improve seed trapping, nutrient and moisture availability, and protection from browsing or trampling (Flores and Jurado, 2003).

Trees can also reduce soil erosion (with their strong root system) and prevent desertification in arid zones (Young, 1989). Furthermore, they create subhabitats which differ from the surrounding vegetation and exert different influences on the herbaceous layer (Belsky, 1990). Legume tree species, such as *Acacia* species, are also known to improve soil nutrient availability (Gedda, 2003), which is firstly due to their ability to fix atmospheric nitrogen and thus improve soil fertility (increasing potentiality to produce); and secondly to their improvement of soil water availability by reduction of actual evapotranspiration (Munzbergova and Ward, 2002). Considerable research has been conducted on the effects of trees on understory crop yields in Africa. For example, in semi-arid areas of South Africa, *Faidherbia albida* has been shown to frequently raise yields of millets, maize and sorghum and is widely cultivated by farmers in parts of the Sahel and in southern Africa. Reasons for yield effect include higher nitrogen and phosphorus availability, moisture conservation and lower soil temperatures beneath canopies (Payne et al. 1998). A key feature of the "*albida system*" (Vandenbeldt, 1992) is that the understory cereals are not shaded since leaf fall takes place before cereal cropping and the tree canopy fills late or after cropping (Kho et al. 2001).

Other studies have demonstrated that the impact of trees on the understory vegetation could be negative (Belsky, 1990). For example, the roots compete for water and nutrients with understory vegetation. A reduction of soil water availability under

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savannah trees is often due to a high tree water uptake (Anderson et al., 2001). The role played by competition from tree roots is likely to be influential in the reduction of available soil moisture and hence in the reduction of plant growth (Moreno, 2008). Trees can also reduce light availability (Vetaas, 1992), which can also limit plant production (Anderson et al., 2001). Moreover, Rafiqul-Hoque et al. (2003) have shown that certain trees contain higher levels of bioactive chemicals, suggesting a large inhibitory potential (Barnes et al., 1996). Allelopathic interactions involve the production and release of chemical substances which can inhibit the growth and the development of the understory vegetation (Shaukat et al., 2003).

Agroforestry has drawn considerable attention because of its potential to maintain or increase biological productivity in areas characterised by large-scale extensive agriculture (Kidd and Pimentel, 1992). It is often assumed that appropriate agroforestry systems can provide the essential ecological functions needed to ensure sustainability and maintain favourable microclimatic influences. Such benefits may outweigh their greater use of water in areas of limited water availability. Cannell et al. (1996) argued that agroforestry may increase productivity because trees can capture resources which are underused by crops. Ovalle and Avendano (1987) reported that trees increase understory herbaceous productivity.

In many ecosystems of the world, the genus *Acacia* is widely distributed (Ross, 1981) and is economically important. Under arid and Saharan climates, *A. tortilis ssp. raddiana* plays a key role in ecosystem functioning and stability. This species may be considered as a foundation species (i.e. species that structure a community by creating locally stable conditions for other species, and by modulating and stabilising fundamental ecosystem processes, Ellison et al. 2005). For instance, in the African Saharan region, *A. tortilis ssp. raddiana* provides food and shelter to many desert animals, while the species is also a major source of fuel, fodder and remedies for local Bedouin people and their livestock (Ashkenazi, 1995).

The present study aims to assess the effect of *A. tortilis ssp. raddiana* (Mimosaceae) on cereal production. In southern Tunisia's arid ecosystems, the traditional *Acacia* agroforestry system, practiced for many decades, can be seen as a complex and dynamic resilient system reacting to a wide variety of long-term external changes and short-term disturbances related to climate, topography, soil texture and gemorphological variability.

In the Bled Talah region, agroforestry systems are based on cereal growing in association with native plantations of *Acacia* trees. Farmers commonly grow cereals under *Acacia* trees.

The most important cereals are barley (*Hordeum vulgare* L.), softwheat (*Triticum sativum* L.) and hardwheat (*Triticum aestivum* L.), and cereal production plays an important role in the family economy in South Tunisia.

Our main hypothesis was that *A. tortilis ssp. raddiana* could facilitate the growth of crops under an arid climate by improving ecological conditions under its canopy. In particular, *A. tortilis ssp. raddiana* was expected to enhance soil nutrient content and improve soil structure by adding organic matter to the soil. Moreover, the tree reduces water loss by soil evaporation, mainly in spring, when cereals are in a maximum growth period. Thus, we hypothesized that an improvement in the performance of seedlings growing under the *A. tortilis ssp. raddiana* canopy would indicate the prevalence of facilitation over competitive interactions.

Also, the objectives of this study were to determine whether *Acacia* trees modified the availability of certain resources (nutrients, water) to the point of promoting cereal yield and how this capacity is affected by site conditions (geomorphology, rainfall, type of cereal species).

2. Materials and methods

2.1. Study area and habitats

The study area is located in the Governorate of Sidi Bouzid, in central and southern Tunisia in the region of the Bou-Hedma National Park (33°30′N and 9°38′E). Following Emberger's classification (Emberger, 1955), the climate is Mediterranean arid with temperate winters. The average annual rainfall varies from 150 mm in the plain (a. s. l. 100 m) to 300 mm on the highest peak of the mountain range (a. s. l. 800 m). However, like in other arid Mediterranean climates, inter-annual variability in precipitation is high (151 mm $\pm$ 21 between the years 1996 and 2008). Mean minimum temperature of the coldest month (January) is 3.9 °C and mean maximum temperature of the warmest month (August) is 36.2 °C. *A.tortilis spp. raddiana* is a native tree species in the study area. According to Le Houérou (1969), the *A. tortilis* population is considered as a pseudo-savannah, with scattered tree or shrub individuals of *A. tortilis* associated with several species of grasses, shrubs and ligneous chamaephytes.

In the study area, according to the geomorphological structure, four habitats were identified (glacis, plain, wadis and jessours) where strong differences in soil water availability were observed. The glacis corresponds to an extension of the pediment composed of villafranchian calcareous crust and covered by shallow loamy soils. It receives water draining from the adjacent mountains. The plain is a large area with a gentle slope that does not receive streaming water. The wadis corresponds to wide depressions, accumulating water by flowing and streaming. The jessours is a man-made contour bank of earth with or without a wide spillway group of stones and earth walls that collect and retain soil washed down hillsides by torrential rains (Alaya et al., 1993).

Unpublished data (Abdallah et al., 2010) in the plain showed that the light (expressed in Lux) is significantly weaker ($F = 785.11$, $P < 0.0001$) beneath canopies (45.93 $\pm$ 1.13 Lux) than beyond tree canopies (135.13 $\pm$ 2.98 Lux). Light transmission is only 35% below the *Acacia*. Moreover, the soil water content is significantly higher ($F = 16.44$, $P < 0.001$) under the trees (1.78 $\pm$ 0.16 ml of water per 100 ml of soil) as compared to uncanopied areas (1.08 $\pm$ 0.007 ml of water per 100 ml of soil).

In order to verify soil water availability in the four habitats, soil moisture (volumetric soil water content) was measured in each habitat at a depth of 10 cm with an FDR probe (ThetaProbe ML2x, Delta T, Cambridge, UK). Ten measurements were made at random points per habitat type at different times. The first measures were made during the dry period (before rainfall), whereas the others were sampled after a 30-mm rain event, at the intervals of 2 and 4 days after the rain.

2.2. Cereal species

Three species of cereals were used for experiments: barley (*H. vulgare* L.), softwheat (*T. sativum* L.) and hardwheat (*T. aestivum* L.). The selection of these species was made in accordance with the characteristics of the agroforestry system in the Bled Talah region. The cereal crops are naturally grown in all four habitats. In arid Tunisia, cereals are annual species sown in October or November (Fig. 1). The height of the seedlings remains very low during the first part of the winter period. The growing season begins during the second part of the winter and ends quickly in the spring. Generally, the number of stems per plant is relatively low (five or six stems per plant). According to Floret and Pontanier (1982), a yield of 500–1000 kg ha^{-1} can only be observed once every 5 years. These low yields are due to a quick heading (in March) and a premature maturation (mid-April) induced by water stress which