Journal of Arid Environments 132 (2016) 1–14

Contents lists available at ScienceDirect

Journal of Arid Environments

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

Review

The magnitude and spatial extent of influence of *Faidherbia albida* trees on soil properties and primary productivity in drylands

Gudeta W. Sileshi [1]

World Agroforestry Centre (ICRAF), Southern Africa Programme, Chitedze Agricultural Research Station, P.O. Box 30798, Lilongwe, Malawi

ARTICLE INFO

Article history:
Received 5 July 2013
Received in revised form
14 January 2016
Accepted 11 March 2016
Available online 27 April 2016

Keywords:
Bayesian analysis
Distance–decay
Ecological field theory
Meta-analysis

ABSTRACT

Faidherbia (*Faidherbia albida*) is being promoted widely in interventions for combating desertification, regreening of the Sahel and agroforestry projects in dry lands. Some scientists have questioned the wisdom of its wider promotion without clear evidence of its impacts. This review provides novel analyses of the magnitude and spatial extent of its influence on soil properties and primary productivity. A meta-analysis provided evidence for significant increases in soil organic carbon (SOC) (by 46%), total nitrogen (50%), phosphorus (21%), potassium (32%), and yields of maize (150%) and sorghum (73%) under the tree canopy compared to the open area. However, larger increases in SOC and nutrients occurred on inherently nutrient-poor sites than on nutrient-rich sites. Similarly, large increases in crop yields occurred in suboptimal conditions for crop productivity than in optimal conditions. The tree created predictable patterns in soil nutrients and crop yields consistent with distance–decay models of spatial interaction. Its growth and canopy development appear to explain the size dependence of the spatial extent of its influence, with a marked influence observed under large trees than small trees. The review also identified enormous variability in study design and statistical rigor, which appear to mask the expected patterns. Study designs and inferential statistics in current use neither address the intrinsic causality of patterns nor do they offer a mechanistic insight into the observed patterns. The major concerns and their implications are discussed and improvements for future research on single-tree influences on ecosystem properties in dry lands are suggested.

Contents

E-mail address: sileshigw@gmail.com.
[1] Current address: 1244 Ibex Hill, Lusaka, Zambia.

http://dx.doi.org/10.1016/j.jaridenv.2016.03.002
0140-1963/

1. Introduction

Faidherbia (*Faidherbia albida*) is widely distributed throughout the dry zones of Africa and the Middle East including Israel, Lebanon, Oman, Palestine, Saudi Arabia, Syria and Yemen (Barnes and Fagg, 2003; Boffa, 1999). It is adapted to a wide range of soils and altitudes ranging from 270 m below sea level in Palestine to over 2000 m in the Sudan (Barnes and Fagg, 2003) and Ethiopia (Hadgu et al., 2009). Unlike other trees, it remains leafless during the wet season and in leaf during the dry season, a phenomenon termed 'reverse phenology'. Its presence in the crop fields has been widely reported to increase soil fertility and crop yields, termed the 'albida effect' (Barnes and Fagg, 2003; Boffa, 1999). This has been recognized in the Sahel and East and Southern Africa for several centuries, and Faidherbia has been effectively managed in agroforestry parklands (Boffa, 1999; Kho et al., 2001). Faidherbia is also being increasingly promoted in various development projects such as combating desertification (Kirmse and Norton, 1984) and regreening of the Sahel (Reij et al., 2009). Some authors (Phombeya et al., 2005) have even proposed nationwide campaigns for planting Faidherbia in areas where this tree does not grow. With the advent of climate change, Faidherbia has also gained prominence in climate-smart agriculture. At the Durban Climate Change Convention in December 2011, the late Prime Minister of Ethiopia announced that a government initiative will establish 100 million Faidherbia trees on smallholder cereal croplands across the country. A large-scale effort in Eastern Zambia by a small landholder cooperative of 19,000 farmers is also promoting planting of the trees in conservation agriculture fields (Bosco, 2012).

Although over five decades of research has been conducted, there is no consensus on the distribution of yields in the canopy of Faidherbia (Boffa, 1999). Enormous variability also exists in study design, details of studies, and statistical rigor making it difficult to compare the results and draw widely applicable conclusions. Many of these studies do not evidently state about the status of the soil nutrients and yields beyond the influence of the tree canopy. The magnitude of the tree influence is variable and this appears to be determined by a complex interaction of factors including tree size, soil, water regimes and tree/crop management (Barnes and Fagg, 2003; Boffa, 1999). The relative contribution of each of these factors has not been quantified and the following questions still remain unanswered (Barnes and Fagg, 2003): (1) Does the tree's root system mine the soil beyond the reach of its crown? (2) Is Faidherbia any more effective in increasing soil fertility than other tree species in the ecosystem? (3) Is there any consistent increase in the soil nutrient pools and crop yields due to Faidherbia trees and how large is the effect size? (4) What is the spatial extent of the tree influence? Although there has been an increase in plot-level studies recently (Adamu, 2012; Bosco, 2012; Hadgu et al., 2009; Kho et al., 2001; Umar et al., 2013; Yengwe, 2011), we still lack a mechanistic understanding of the magnitude and extent of its influence on soils. In many studies, the differences between observations under the canopy and open area have been reported as nonsignificant (Table 1). Lack of statistical significance could be attributed to the high spatial variability, for example, in crop yields in dry lands (e.g. Buerkert et al., 1996). Lack of significance could also be an artefact resulting from inappropriate choice of sampling units, plot location and low statistical power of tests. The frequency of non-significant results has led some scientists to question the wisdom of its promotion in development projects.

Development of evidence-based policies and practice for scaling up Faidherbia will require a mechanistic understanding of its impacts at the individual tree and plot levels so that such information could be quantitatively scaled up to whole farm and landscape levels. A key element in this endeavour is a good knowledge of the area that a single tree is able to influence and how this relates to tree size and structure. This is important because the structure of individual trees determines the properties at the level of populations and spatial organization of vegetation (Enquist et al., 2009; West et al., 2009). For example, the scaling relationships between tree crown and root play an essential part in ecosystems stability in desert conditions and soil resource limitation in dry lands (Lefever et al., 2009). Unlike most tree species, Faidherbia is characterized by high variability in growth, anomalous crown development and peculiar phenological rhythms (Ismail, 1986; Werger and Ellenbroek, 1982). Information is virtually lacking on how its growth and crown development affect its influence on soil and primary productivity. Therefore, the objective of this paper is to (1) establish the magnitude and spatial extent of Faidherbia influence; (2) provide mechanistic explanations for observed patterns through inferences from theory; and (3) point out areas of concern in research design and application of inferential statistics.

2. Methods

2.1. Data collection

Secondary data on soil nutrients, plant productivity and tree growth variables were assembled by searching the literature in both published and unpublished sources.

2.1.1. Soil and plant data

Soil and plant data were assembled from several studies in order to estimate the magnitude of tree influence through meta-analysis. The selection and inclusion of studies were based on strict criteria to satisfy the requirements of meta-analysis. For a study to be included in the analysis, it must (1) have been published in a refereed journal, book chapter or peer-reviewed proceeding or any other report; (2) have soil or crop yield measurements 'under canopy' and a corresponding measurement 'outside canopy' to be treated as a well-defined control; (3) have reported the mean as numerical or graphical data; and (4) reported soil properties for each soil depth separately.

From the studies thus selected, pairs of observations (under canopy and corresponding values in the open area) on soil organic matter (SOM) and/or soil organic carbon (SOC), total nitrogen (N), extractable phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and pH, and crop yields or plant dry matter were extracted. The number of studies that qualified for inclusion in the meta-analysis is summarized in Table 1. As SOM consists of C, H, O, N, P and S, it is difficult to actually measure. Therefore, most analytical methods determine the SOC, which can be readily measured, and estimate SOM through a conversion factor. Conventionally, the Bemmelen factor (1.724) has been widely used