THE AGROECOLOGY OF *FAIDHERBIA ALBIDA* ON THE TONGA PLATEAU OF SOUTHERN ZAMBIA

by

Carl Trent Wahl

A thesis submitted in partial fulfillment of

the requirements for the degree of:

Master of Science

(Agroecology)

at the

UNIVERSITY OF WISCONSIN-MADISON

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ADVISOR APPROVAL PAGE

William L. Bland

21 July 2010

William L. Bland

Date

Chair, Department of Soil Science

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Dedication

To the people of rural Zambia who in over six years have never failed to surprise me with their kindness, their gentleness, and their knowledge:

Twalumba kapati.

"Blessed are the meek: for they shall inherit the earth."

- *Matthew 5:5*

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School of Agricultural Sciences

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- Dr. Benson Chishala   Senior Lecturer, Department of Soil Science
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Table of Contents

List of Tables

Chapter Four

List of Figures

Chapter Four

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General Introduction

The Green Revolution ushered in the modern era of industrialized agriculture across much of the developing world, but is largely considered a failure in sub-Saharan Africa. A number of reasons have been proposed for this failure, particularly the prohibitively high importation and transportation costs of chemical fertilizer (Collier & Gunning, 1999). In light of the increasing consumption of maize (*Zea mays*) across the entire region, especially in Eastern and Southern Africa, maize production has steadily increased (McCann, 2005). Without chemical fertilizers, small-scale farmers are induced to clear and cultivate progressively previously unused land in a continual search for fertile soil (Chidumayo, 1987). In areas where the land frontier is closed, farmers are unable to practice traditional fallowing periods, and the continual cropping of maize leads to degradation in soil quality that results in poor production (Chidumayo, 1987; Lal, 1988).

Over the last thirty years, there has been increasing attention paid to low external input agricultural (LEIA) technologies as an answer to the challenges facing small-scale farmers in sub-Saharan Africa. A large portion of these activities involves the intentional use of trees on farms in a system of methodologies collectively known as agroforestry (Rocheleau et al., 1988; Nair, 1989). These methodologies are especially notable for their ability to conserve and partially restore soil fertility in lieu of fertilizer inputs, at a considerably lower financial cost. However, these practices do entail a considerable amount of farmer training in new methodologies and tree species, as well as significant investments in land, labor, and time. Small-scale farmers operate on a fixed budget of labor, land, and time to produce annual crops for both consumption and revenue; dedicating a portion of these resources for trees that do not provide immediate utility to the household can serve as a powerful disincentive to adoption of these technologies. Additionally, non-indigenous species such as *Leucaena leucocephala*, *Gliricidia sepium*, or *Sesbania macarantha*, though popular in agroforestry circles, are often little known to farmers outside of research or project demonstration plots.

One tree species in particular, *Faidherbia albida*, has been touted as an appropriate solution to many of the disincentives to agroforestry adoption. Though slow growing relative to other agroforestry species, *F. albida* is indigenous to semi-arid regions of sub-Saharan Africa; furthermore, it has a unique deciduous cycle in which it sheds its entire leaf biomass prior to the advent of the rains, minimizing light and rainfall interception for crops sown under its canopy (Wickens, 1969; Fagg, 1995). *F. albida* also fixes nitrogen, and through its leaf fall distributes a flush of readily mineralized nitrogen to the topsoil that is beneficial to grain crops, particularly maize (Rhoades, 1995).

At first glance, the use of *F. albida* would appear an elegant fit for the agricultural contexts of Zambia. As a nation, Zambia leads the world in direct consumption of maize per capita (McCann, 2005). Small-scale farmers produce the lion's share of this maize; however, their productivity is stagnant at about 1.6 metric tones per hectare and use of chemical fertilizers is less than half of optimal recommendations (Heisey & Mwangi, 1996). Preliminary trials by the Conservation Farming Unit (CFU) of the Zambia National Farmers Union (ZNFU) have shown that maize yields under *F. albida* canopies are 70 to 300% higher than that of yields outside of the canopies (Aagard, 2004).

Despite the proven benefits of *F. albida* to maize production and its social promotion by NGOs, adoption (e.g. the spontaneous planting) of *F. albida* by small-scale farmers in most areas of rural Zambia remains limited. One can assume in most cases that simple causal relationships prevent widespread uptake of *F. albida*; e.g. it is not endemic in much of the settled areas of Zambia and therefore it takes time for farmers to adopt the new technology. However, on the Tonga Plateau in southern Zambia this explanation falls short; Tonga farmers retain young *F. albida* that are dispersed by grazing cattle, but they do not plant the species. Furthermore, the Tonga people have long experience with *F. albida* in their agropastoral practices that suggests a highly developed institutional knowledge of the species (Allan et. al, 1946; Trapnell & Clothier, 1957; Sturmheit, 1990; Olsen, 1992; Olsen, 1995). Utilizing this institutional knowledge in the context of the agropastoral livelihoods of the Tonga presents an opportunity to inform interventions that promote *F. albida* on the Tonga Plateau.

This research represents our efforts to capitalize on that knowledge. We start in chapter one by developing an agroecological analysis of the ecology of contexts that shape Tonga farm holons, and how these holons have recently begun to marshal *F. albida* in response to changes in the ecology of contexts (Bland & Bell, 2007). The second chapter explores tensions within these holons based on customary gender roles that influence both the perception and propagation of *F. albida*. The third chapter synthesizes these findings in order to suggest different approaches for expanding the contributions of *F. albida* on the Tonga Plateau that are cognizant of both the ecology of contexts and the internal tensions that guide Tonga farm holons with respect to the species.

Concurrent to developing a social narrative of *F. albida* on the Tonga Plateau, I also performed preliminary research on physical properties of soils under *F. albida*. Hitherto, the trees' effect on these properties has received little attention in comparison to chemical characteristics of the soils under *F. albida* (Barnes, 2003). Therefore, I conducted a series of soil infiltration tests to determine whether or not *F. albida* influences the saturated hydraulic conductivity (K_{fs}) of soil under its canopy relative to soil immediately outside its canopy. In chapter four, I report the results of those tests and make suggestions for improving the testing procedure in light of the research conducted.

This thesis is composed in a style that deserves further explanation. The first three chapters, which describe the narrative of F. albida on the Tonga Plateau, are meant to stand alone as separate articles that will later be submitted for publication. As such, certain materials, such as methodology, are repeated in each of the first three chapters. I have also written these chapters in the first person plural, as opposed to the first person singular more commonly used in a master's thesis. Furthermore, rather than writing a single literature review for the entire thesis, I have integrated literature reviews into each of the four chapters. Consequently, each chapter includes a bibliography for references used within that chapter.

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Chapter One - Use of *Faidherbia albida* on the Tonga Plateau of Southern Zambia: An Agroecological Analysis

Carl T. Wahl[1], William L. Bland[2]

Abstract

Faidherbia albida is a tree species indigenous to semi-arid regions of Africa that substantially increases maize (Zea mays) yields in its immediate vicinity. In southern Zambia, F. albida is widely used in indigenous maize farming systems and this has apparently increased over the past two decades. Using a combination of interviews, group meetings, and observations, this study developed a holon agroecological analysis of the contexts that have shaped past and current uses of F. albida by farmers on the Tonga Plateau: cattle, land tenure, maize, soil, and government agricultural policy. We observed a bimodal age distribution of the trees in agricultural fields and posit that the missing cohorts were removed as weeds as a result of evolving notions of what constituted modern farming practices in the emerging maize economy. With subsequent research and social promotion of the beneficial effects of F. albida, farmers are now being encouraged to allow the trees to grow in their fields. This advice took root in farmer knowledge contexts because of positive regard for F. albida and timeless injunctions against cutting mature specimens. This case study illustrates the use of holon agroecology to develop a rich appreciation of how evolving contexts have shaped farmers' behavior in southern Zambia.

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[1] M.S. Agroecology, University of Wisconsin, Madison, Wisconsin, U.S.A.

[2] Professor, Dept. of Soil Science, University of Wisconsin, Madison, Wisconsin, U.S.A.

1. Introduction

Agroforestry - the simultaneous cultivation of farm crops and trees to enhance soil fertility - is proposed as an alternative to expensive chemical fertilizers, particularly in small-holder farms of sub-Saharan Africa (Rocheleau et al., 1988). Extensive literature demonstrates the ability of at least 12 exotic and indigenous species (*Cajunus cajun; Tephrosia vogelli; Sesbania* sp., *Leucaena leucocephala, Gliricidia sepium, Flemingia macrophylla, Calliandra calothyrsus, Senna* sp., *Azadirachta indica; Casuarina* sp., *Melia azedarach*, black wattle) of trees to fix nitrogen, suppress weeds, mulch soils, reduce wind and water erosion, provide cattle fodder, and so forth (Rocheleau et al., 1988; Nair, 1993). The potential for positive agronomic effects using agroforestry practices in farming systems throughout sub-Saharan Africa are undisputed.

The use of *Faidherbia albida* as an intercrop with cereals in sub-Saharan Africa is extensively documented in agricultural and ecological literature (Barnes, 2003). The tree is most noted for its uncommon phenology in which it sheds all its leaves prior to the beginning of the rainy season (Wickens, 1969; Fagg, 1995). This annual litterfall under mature trees adds significant amounts of nitrogen to the topsoil right at the start of the growing season; furthermore, light and rainfall interception is minimized thanks to the open canopy (Rhoades, 1995). These conditions are ideal for maize cultivation under the tree, and studies have shown that maize production is doubled when intercropped with *F. albida* (Aagard, personal communication). At the end of the rainy season, the leaf canopy returns and shades the underlying soil throughout the dry season (Wickens, 1969). *F. albida* also provides benefits to livestock through the provision of shade and fodder; in the case of the latter, the trees drop seedpods that are highly palatable to livestock late in the dry season when other fodder sources are minimal (Fagg, 1995; Ibrahim and Tibin, 2003; Bwire et al., 2004).

Despite the enormous agronomic potential of agroforestry species and methodologies, including *F. albida*, adoption in sub-Saharan Africa remains low (Kiptot et al., 2007). In four years of working in rural agriculture and food security development in rural areas across Zambia, we knew from everyday interactions and observations that farmers had dismal yields and that chemical fertilizers, though highly desired, were financially accessible to but a few farmers. Despite repeated exposure to low external input agricultural practices such as agroforestry through non-governmental organizations (NGOs), we rarely observed farmers adopting these methodologies.

In eastern Zambia, researchers characterize adoption of agroforestry practices as a function of socio-economic factors such as wealth, gender, labor availability, or farm size (Franzel et al., 2002; Phiri et al., 2002, Ajayi et al., 2003). Institutional structures such as enforcement of grazing bylaws are also considered influential, e.g., where browsing or trampling by free ranging cattle can destroy young trees, or the proximity of the village to areas where pilot projects were taking place (Franzel et al., 2002, Ajayi and Kwesiga, 2003). Factors such as these are used to assess adoption potential of these practices and iteratively make adaptations to the practices, in the hope of to aiding dissemination of agroforestry technologies (Franzel et. al, 2001). Retrospective study sometimes reveals barriers to adoption that reveal a paucity of understanding regarding local agricultural practices or institutions that shape those practices. The example of cattle grazing pigeon pea (*Cajunus cajun*) in research sites, or traditional and historical implications of land tenure and food security that impact cattle grazing and seasonal burning suggest that a deeper understanding of small-scale farming endeavors might positively influence agroforestry intervention design (Franzel et. al, 2002; Ajayi and Kwesiga, 2003).

Agroforestry researchers in eastern Zambia and sub-Saharan Africa have recognized the need for developing a more robust, inclusive language that would qualitatively evaluate the adoption of agroforestry technologies (Ajayi et al., 2006; Ojiem et al., 2006; Kiptot et al., 2007; Giller et al., 2009). This paper describes the use of *holon agroecology* (Bland and Bell, 2007; 2009) as a qualitative framework for developing a farmer-centric understanding of both traditional and contemporary uses of *F. albida* by farm households on the Tonga Plateau in southern Zambia. The physical constituents of the farm holon are the human actors, animals, equipment, etc. involved directly in the agricultural endeavor. These humans marshal themselves and the other physical entities towards accomplishing some vision of an agricultural ambition that arises from the intentions of one or more of the involved humans. These intentions and the resources (human and otherwise) pulled into service to satisfy them are envisioned as constituting the farm holon (Bland and Bell, 2007).

A farm holon possesses capacity for self-governed action, e.g., how soil is tilled, what fields are planted to what crops, how much grain will be sold, etc. At the same time, the farm holon is embedded in many contexts, e.g., a community, a land tenure system, farming traditions, a farmers' cooperative, a biome, a nation. These contexts and their interactions create an ecosystem—an *ecology of contexts* of which the farm holon simultaneously is a part and helps constitute (Bland and Bell, 2007). The farm holon's range of self-governed action, however, is largely circumscribed by these contexts, e.g., climate, knowledge, and markets often limit the species that can be economically cultivated by a farmer. Within its ecology of contexts there are many *configurations* that a farm holon can assume and be viable—the configuration of a farm holon arises as the sum total of choices made by human actors and the resulting behaviors of everything else in the holon. The ecology of contexts is dynamic, e.g., market opportunities change with government policy, and so the farm holon may need to change its configuration in order to persist. It is the genius of farmer that discovers and rediscovers configurations that are viable in his or her ecology of contexts to persist in the face of change, or to increase labor and resource productivity.

Some contexts must be taken as given, e.g., climate, while the farm holon may possess some capacity to shape others, e.g., farmer knowledge or soil fertility. In this paper we explore the application of holon agroecology to understanding adoption of particular practices by farmers and exogenous interventions to encourage specific practices. Some practices are, intentionally or otherwise, brought about by macro policy changes, e.g., maize price supports, and this is readily seen as a contextual change to which the holon might react by altering its configuration. In the case of agricultural development through technological innovation, in contrast, targeted research, demonstration, and training programs seek to induce farm holons to incorporate a practice or technology into their way of interacting with the world.

Our objective was to understand the present state of farmer interactions with *F. albida*, ultimately to inform agricultural development involving the species. Specifically, there is one question that motivates our study: what is the nature of the relationship of farmers to *F. albida*, and how has this relationship evolved? Holon agroecological analysis directs our attention to contexts that have shaped Tonga farming endeavors over the past century, particularly cattle-rearing, customary land tenure, maize cultivation, and government agricultural policy. These contexts are historically contingent. Appreciating their evolution helps us understand how and why farm holons may have changed configurations through time, and the potential for capability of the holon to, in turn, influence (or not) one or more contexts. Utilizing the evolution of those contexts, we reincorporate *F. albida* and how its utilization in Tonga farm holons was enhanced by realignments in these contexts that concurred with increased social promotion of the species. In light of those contexts, we summarize how the use of *F. albida* represents an expansion in Tonga farm holons' capability and the implications of that expansion in social promotion of the species on the Tonga Plateau.

2. Data gathering and theoretical framework

The analysis presented here derives from 13 weeks of agroecological field research in western Monze District, Zambia, beginning in May 2009 and lasting through August of the same year. We have also utilized extensive historical research of ecological and ethnographic data regarding the Tonga Plateau and the Tonga people. The agroecological data were collected through an assortment of channels: participant observations while living as a member of a household; 30 semi-structured interviews with individual heads-of-households and two semi-structured group interviews with 15 married women, which were conducted with the aid of a local research assistant; ten semi-structured field visits; the excavation and inspection of 40 shallow soil profile pits; and three non-consecutive days of trailing cattle herds throughout the landscape. Yields, land area, and monetary wealth are best estimates, as farmers describe these terms only vaguely in non-standard measures because of reticence to reveal their wealth.

In this study, we consider the household the basic unit of the farm holon. On the Tonga Plateau, a household is an autonomous unit composed of the nuclear family (husband, one or more wives, and children) as well as any dependents residing with the family, i.e., grandchildren, nieces/nephews, grown unmarried children, etc. The head-of-household is the dominant member of the household and makes the ultimate decisions over how land is used, what crops are grown, where labor will be allocated, how land is tilled, and so forth (Colson, 1958). Most of the heads-of-households interviewed were male; only in cases where women were widowed or had divorced their husbands were they the head of the household. We observed no differences between gender on the autonomy of decision-making by heads-of-households.

3. Results

During our research study, we noted that trees on the agricultural landscape were limited to field boundaries or roadside edges. None of these trees had been intentionally planted, but were rather the result of farmers not cultivating these edges out of respect for adjacent property. Within the actual fields, most of the trees had been removed, with the notable exceptions of *F. albida*, *Kigelia africana*, and *Adansonia digitata.* Of these trees, only *F. albida* was observed to have a bimodal age distribution, whereas only mature specimens of the other two species were observed. The bimodal age distribution of *F. albida* trees in fields suggested that there had been a hiatus in recruitment or the loss of established trees. In the following sections, we discuss how this phenomenon reflects the changing relationship of farmers to *F. albida* in their farming endeavors.

3.1 The Lost Generation of Faidherbia albida

Observations made during multiple visits to farmers' fields did not show a wide variety of age distribution of *F. albida* in fields used for annual crops. Instead, there were large numbers of young *F. albida*, ranging from the clustered groups of seedlings up to trees of heights between seven to fifteen meters with fastigiate shaped crowns. Interspersed across the landscape both in fields and along borders were isolated mature trees with expansive, tilted canopies reaching heights of over 20 meters. However, there were very few instances of *F. albida* trees with semi-fastigiate or rounded crowns that indicate middle-age, i.e., 20 to 60 years old (Barnes, 2003). The few middle-aged *F. albida* trees were confined to field boundaries, roadside edges, old kraal sites, or areas that had previously not been cultivated, such as those close to riparian areas.

The observed bimodal age distribution of *F. albida* seemed at odds with farmer depictions of the trees. Injunctions against cutting *F. albida* appeared to have been followed throughout living memory; for example, different households in one village could recall only one incident where three mature trees had been cut down and sold for dugout canoe construction by a farmer who had lost all his cattle to the dreaded *Corridor* (*Theileriosis*), a tick-borne bovine disease that ravaged the Plateau in the early 1980's and remains endemic in the area (Nambota et al., 1994; Merck, 2008). Furthermore, we were unable to detect any evidence of mature trees having been cut, such as stumps or the emergence of new trees from lateral roots of trees that had been felled (Olsen, 1992; Barnes, 2003). Possible explanations were that recruitment of the species through cattle dispersal had stopped or slowed, or that a disease had struck a number of the trees for a period of time. Though recruitment would have undoubtedly slowed during as a result of the *Corridor* outbreak in the early 1980s, there were few *F. albida* of ages that corresponded to the period before the outbreak. Furthermore, there was no mention in household narratives or observable evidence of abnormal mortality of *F. albida* due to pathological causes, which was born out by the presence of middle-aged trees in uncultivated areas.

3.2 Farmer perceptions of Faidherbia albida in western Monze District

Farmers characterized their retention of *F. albida* in fields as primarily a response to both poor soil fertility and consequently, poor maize harvests. Every head-of-household interviewed commented that the tree provided "manure" (organic fertilizer equivalent to animal droppings) to the soil surface due to its annual litterfall. Some of the beneficial effects were also consigned to manure from cattle that clustered under the trees to browse seedpods that fall in mid-to-late October; however, farmers clearly indicated that the leaf litter had a far greater effect on soil fertility. Participants were also unanimous in describing the trees' effects on maize as very positive, claiming that the stalks were "greener" and cob size was larger under the tree. Overall, informants' perception of the tree was that it improved the soil to the benefit of maize crops.

Participants also discussed management of *F. albida* in some detail. Recruitment of the species occurs as a result of cattle dispersing the seed through their manure after browsing seedpods late in the dry season. *F. albida* seedlings that germinate in fields are not weeded in the first year of establishment, and consequently, seedlings appear in clusters of three to five trees. In subsequent seasons, farmers plow around these clusters; once the clusters become wide enough to interfere with plowing, they are culled to a single tree. As that tree grows larger, low-lying branches are cut to allow oxen to pass near the trunk. The plowing around the base of young trees prevents lateral roots from spreading outward, and precludes subsequent root interference with either plows or crop roots. Farmers asserted the early plowing forces roots to grow downwards into the soil, but had little noticeable effect on the tree.

Informants reported that despite the large numbers of cattle, goats, and sheep that graze many fields the trees are little affected by those animals. Animals are herded away from fields during the growing season, and consequently, there was no browsing pressure on newly germinated *F. albida*. This allows the young trees to develop sharp thorns that later deter extensive browsing by livestock.

Narratives about local knowledge of *F. albida* were exemplified by one farmer's description: "We have always known musangu [*F. albida*] is a good tree." When asked the origin of this knowledge, farmers invariably responded that their parents, particularly their fathers, had told them *musangu [F. albida]* trees were good and should never be cut. Many also described their knowledge of *F. albida* as supplemented by radio programs and periodic training visits from NGOs in recent years.

Given the considerable observational knowledge of *F. albida* and injunctions against removing standing trees, a remaining plausible reason for the hiatus in recruitment of the trees was that farmers had for a period of time (from approximately the mid-1950's to the early 1990s) removed emerging seedlings from crop fields. In light of the extensive benefits to the farm holon provided by *F. albida*, why was recruitment thwarted? To understand this phenomenon, we must first understand the ecology of contexts that have shaped and continue to shape Tonga farm holons, and how that ecology at first prevented and later allowed *F. albida* to be marshaled by those holons.

3.3 Key contexts in which Tonga plateau farm holons perform

Holon agroecology emphasizes contexts and intentions as central to developing understanding of farming endeavors. There are innumerable contexts that arguably shape a farm holon, and identifying and researching the most relevant is the task of the agroecological analyst. Following are historical perspectives on what we assert are the contexts that have in the past and remain central to understanding the evolving relationship of Tonga plateau farm holons to *F. albida*: cattle, land tenure, maize, soil, and government agricultural policy.

Cattle

Cattle are ubiquitous on the landscape of western Monze District, and are highly valued for their provision of draught power, milk, and manure. Interviewees that owned cattle reported herd sizes ranging from a single cow or a span (two) of oxen to over 20 animals. These herds are closely managed in communal grazing areas throughout the rainy season (November to April) to prevent damage by trampling or browsing in other households' fields. In late May, the cattle are brought back to homesteads and are allowed to forage in harvested fields, but are closely watched to prevent damage to standing crops. By early June, after fields have been entirely harvested, cattle are allowed to roam freely across the landscape, but are returned to kraals at night for security and to concentrate their droppings for later applications to maize fields. With the advent of the hot, dry season in mid-August, cattle are rarely herded to prevent undue stress; the cattle shade under mature stands of *F. albida* through the heat of the day and browse throughout the evening and early morning hours. The only intentional movement in this period is attributed to weekly trips to local dip tanks to prevent mortality from *Corridor* disease. In late October, when fodder sources are depleted, cattle cluster under mature *F. albida* to consume the seedpods that drop from the tree in mid to late October.

One-third of the heads-of-households interviewed did not own cattle, but still utilized them for draught power on their farms. Most of these households borrowed cattle from relatives or in exchange for work performed in the dry season. For example, three heads-of-households we interviewed that did not own cattle were loaned spans of oxen in return for tending others' cattle herds. However, in the case where oxen were borrowed from relatives, households often had to wait for the cattle owner to till his or her fields before tilling their own. Households that cannot borrow oxen are compelled to rent oxen to till their fields. These interviewees reported that though oxen are readily available for rental, tillage is often delayed until the household can amass sufficient cash to pay for the tillage of their fields.

Our interviewees expressed no concern about others' cattle grazing crop residues in their fields after harvesting was completed. Participants suggested that this beneficial to soil fertility, as the cattle were deposit manure while browsing. One female head-of-household even suggested that planting *F. albida* would be further enhance soil fertility, because "cattle eating the cow-biscuits [*F. albida* seedpods] would drop more manure on the fields." This value of grazing cattle dropping manure had also recently shifted perceptions of burning crop residues in the surrounding area; informants explained that households had for the past five years ceased burning fields so that cows would continue to graze and deposit manure.

Informants described cattle ownership as more prevalent in past, but a widespread outbreak of *Corridor* disease in the early 1980s had wiped out a substantial number of herds. As one farmer described it, "one fell in the morning, then another in the afternoon, until they were all gone." Though cattle are still considered a measure of wealth and status in western

Monze, interviewees expressed doubts over possessing large herds of cattle. The primary reason given was the lack of ample rainy season pasturage due to a constriction of communal grazing lands. Other households also described the cost of providing preventative treatment such as inoculation and dipping as prohibitive for large herds. Consequently, informants were specific about desired herd sizes ranging from 10 to 25 animals, considered adequate to providing draught power, manure, milk for the household, while having the reproductive capacity to maintain the herd's numbers.

Land Tenure

Heads-of-households have exclusive rights to their land, including its allocation to others and use of resources on that land such as trees. It was especially notable in that interviewees would refer to their land resources using definitive possessives such as "my land" and "my trees." Male heads-of-households dictated usage of these resources by other family members, particularly wives growing crops for household commodities such as groundnuts or sweet potatoes. They also were adamant about their ownership of the trees; in order for someone within or outside of the household to cut a tree for firewood or timber, they must first ask permission from the head of household. However, permission to cut a tree was rarely denied; one interviewee who derived part of his income from woodcarving described the exceptions to this rule: "you cannot cut mbuyu [*Adansonia digitata*], muzungula [*K. africana*], and musangu [*F. albida*]; others are no problem".

How various heads-of-households had received their land and how they allocated it to offspring followed a patriarchal pattern for male-headed households. When describing the history of their farms, many of these heads-of-households explained they had asked their fathers for land when they desired to marry and start a new homestead. In many cases, fraternal brothers we interviewed owned adjoining fields that had been allocated to them at different times by their fathers. Fields were split up and allocated according to soil quality, so a son requesting rights to land receives equal shares of non-contiguous fields. As this process continues with other sons who are starting their own households, land holdings become more spatially fragmented. Almost every head-of-household interviewed had rights to two or three distinct pieces of land that were separated in some cases by one or two kilometers. The continual subdivision of the land indicated that no unclaimed land remained, which informants would often point to a reason for not expanding their hectarage, or to explain why people had migrated away from the village to less populated districts further north, such as Mumbwa, Chibombo, Kabwe, or Kapiri Mposhi.

Maize

The main staple food and cash crop for all households is maize (*Zea mays*). Maize is directly consumed as *musoja* (grits) for breakfast or lunch; otherwise, kernels are ground and cooked into a thick porridge known as *nsima* and serves as the base for most meals. Households often grew a specific landrace of flint maize called *kahamba* to use for making *musoja*, based on specific taste and processing preferences. Informants indicated that households were less selective about maize ground for *nsima*; farmers grew both open-pollinated dent varieties (OPVs) such as Hickory King (*gaankata)* or Obatampa, and multiple hybrid varieties of dent maize. The only commonality among maize used for *nsima* flour was that they were all white dent varieties.

Maize cultivation in southern Zambia predates written records by almost four centuries (Miracle, 1966). Elderly farmers described their parents as pursuing a more pastoral lifestyle in which cultivation was done almost exclusively by hand and largely controlled by women. In these systems, Tonga farmers grew a wide variety of maize landraces that were a supplement to sorghum and millet cultivation; these landraces were mostly flint varieties that were favored for their taste and their ease of processing (McCann, 2005). The multi-colored *kahamba* variety used for *musoja* is a modern day remnant of these flints.

The advent of colonial rule at the turn of the 20th century led to sweeping changes in the agricultural systems in southern Zambia. First, the suppression of Barotse raids on Tonga livestock freed the herds to grow unabated on the Tonga Plateau (Vickery, 1986). Second, the introduction of the oxen-drawn plow by Jesuit missionaries in 1905 increased the utility of cattle as draught animals, irrevocably setting the Tonga on the path to agropastoralism (Carmody, 1992; Vickery, 1986; Murphy, 2003). Third, the completion of the Livingstone-Elisabethville railroad in 1905 gave Tonga farmers access to the market for maize grain in the mining regions of the Belgian Congo (Allan, 1970; Colson, 1970; Vickery, 1986). Though large areas of fertile land along the line-of-rail were allocated to white settlers, the relative plentitude of land and the access to maize markets through the line-of-rail led to a gradual expansion of maize as a cash crop (Colson, 1970; Vickery 1986).

Maize itself underwent a number of changes in this period. The introduction of higher yielding OPV dent varieties such as Salisbury White and Hickory King, and colonial mandates for maize grain quality shifted the maize preferences from the harder, variable colored flint varieties to more uniform white dents (Vickery, 1986; McCann, 2005). Though flint varieties continued to be cultivated for home consumption, maize grown for the market became increasingly standardized to meet market constraints, as white dents were considered more suitable for mechanized milling (Kumar, 1994; McCann, 2005). After Independence in 1964, government seed breeding programs developed an array of hybrid white dent varieties for smallholder farms (Lombard and Tweedie, 1972; McCann, 2005). This process was continued after the liberalization of the Zambian economy in the early 1990s by both privatized parastatal institutions (e.g. Maize Research Institute and Zamseed) and private seed companies (McCann, 2005).

Currently, white dent maize makes up the vast majority of crops grown in western Monze District. In fields we visited, at least 75% of the tilled area had been cropped to maize. Interviewees preferred hybrid maize seeds to landraces and local OPVs, explaining that hybrids had a higher yield advantage. However, not all farmers purchased hybrid seeds because of their high cost, and instead used seeds saved from their previous season's crops. Farmers who did purchase seeds rarely purchased chemical fertilizers, which were ubiquitously described as prohibitively expensive. An informal survey of agro-dealers in town affirmed this characterization, as the 400kg of basal and top dressing fertilizers recommended for one hectare of maize cost approximately 2,000,000ZMK ($400 USD), an almost incomprehensible sum of money for a rural Zambian household. Farmers complained that the inaccessibility of seed and fertilizer inputs were the biggest hindrances to realizing better yields.

According to informants, the dominant reason for growing maize is to the large market supported by government price supports. While crops such as sweet potatoes, groundnuts, *mbwiila* [*Vigna subterreanea*], or cowpeas can only be sold on the open ("town") market, maize grain can potentially be sold to the Food Reserve Agency (FRA) at a guaranteed floor price (65,000ZMK per 50kg bag) that was much higher than town market prices (25,000-35,000ZMK per 50kg bag). Unfortunately, in seasons with ideal rainfall conditions, such as 2008-2009, the FRA will impose purchase quotas on each depot. Many of the heads-of-households interviewed were unable to sell to the FRA because of this quota, and were instead forced to sell on the town market at lower prices. In addition, transport costs to the town market were reported to be 3,000 to 5,000 ZMK per 50 kg bag of maize, further eroding revenues.

The second reason maize is almost exclusively grown is its dominant role in household food consumption. Informants described maize in superlatives such as "the best food," or "good food," implying that maize was the food of choice. It also delineates a social identity, which one gentleman summarized by saying "Tonga people eat maize because it is *our* food." Furthermore, maize is a social medium of exchange; a large surplus of maize that can be shared with neighbors or family in return for future assistance is a valuable asset that maintains social networks. For instance, one area headman kept an oversupply of maize in order to feed other households in his area that had poor maize harvests, which he described as his obligation as a leader and through which he maintained respect in his community.

Finally, the predominance of maize on the landscape revolves around the social definition of a good farmer. Interviewees typified a good farmer as one who produced a good surplus of maize using modern farming practices. These practices revolved exclusively around maize and included conventional tillage utilizing plows and oxen, purchase and use of seeds and chemical fertilizers, and continuous weeding. The focus on maize is to such an extant that farmers rarely consider other cultivated plants such as sweet potatoes as intrinsically crops. As one male head-of-household directly stated: "You cannot be a good farmer without growing maize."

Soil

Narratives about soil quality were unqualifiedly lachrymose; “tired,” “worn-out,” “burned,” “exhausted,” and “used-up” were terms repeatedly applied to local soils. Field surveys we conducted confirmed most of these descriptions; topsoil had almost no organic matter, and soil structure appeared to be massive with little aggregation. During my fieldwork, which was early in the dry season, the soil surface in maize fields had dried down and formed an often-impenetrable crust. The topsoil in many cases had been thinned from continuous annual plowing and seasonal erosion; in other areas where the topsoil was deeper, the repeated plowings had created a impervious plow pan 20 cm (the depth of the plow share) under the soil surface, which impeded water infiltration and root growth deeper into the soil. Though we did not sample soil chemical characteristics, household narratives about yields indicated that soil nutrition was also bereft. Farmers claimed that in many soils, realizing any marketable maize harvest was categorically impossible without using prohibitively expensive chemical fertilizers.

In lieu of fertilizer, farmers with cattle would apply manure selectively to their soils; manure is distributed on soils that are judged to be of a higher quality in order to maintain their productivity. Farmers also practiced crop rotation with groundnuts, which was perceived as “restoring the soil.” In a few cases, farmers also utilized household residues (ash and manure from small livestock), or cover cropped with velvet beans (*Mucuna pruriens*). As previously indicated, *F. albida* trees were allowed to naturally recruit wherever they germinated, thanks to farmer perceptions of the tree as improving soil quality and thereby boosting maize yields.

Though the nutritional poverty of the soil was well understood by informants, the degraded physical structure of the soil was either not considered or underestimated by participants. For example, though we saw marked evidence of sheet erosion, farmers did not disclose this as a problem affecting their soils. Also, farmers were unaware of the existence of plow pans that were evident in many sites. However, farmers did remark that once the rainy season began, plowing could not begin until the soils had absorbed enough moisture to be friable. They also noted that in seasons exhibiting high rainfall, such as 2007-2008, soils became waterlogged for extensive periods. Though farmers saw both cases as problematic, they attributed the cause to rainfall and not the soil's physical characteristics.

Government Agricultural Policy

During the colonial era, state intervention in agriculture was largely focused on the small population of white settlers clustered on either side of the line-of-rail in southern Zambia. Having excluded native Africans from the choicest lands and designating the so-called "Native Reserves" for them, colonial authorities subsequently paid little attention to smallholder agriculture in the Reserves. However, colonial ecologists visiting the Reserves on the Tonga Plateau became progressively more worried about the concurrent expansion of cattle and maize cultivation, and their impacts on soil degradation (Trapnell, 1957; Allan, 1970; Vickery, 1986).

In response to concerns over soil degradation in the Native Reserves, the colonial government established the Kanchomba Agricultural Station south of Monze in 1936 (Dixon-Fyle, 1977). A methodology of crop rotation and manure application known as the "Kanchomba system" was promoted among local smallholder farms. This system was later incorporated into the Improved Farmer Scheme (IFS) in 1946, which in addition to crop rotation and manure application emphasized weed control and contour farming (Dixon-Fyle, 1977). The incentives for household adopting these systems were market-based; farmers who adhered to the strict standards of the system were paid a cash bonus for each bag of maize they sold. However, the rigidity of the IFS standards deterred many farmers from joining the scheme; also, improvement of soil quality was perceived by farmers as potentially leading to land acquisition by the colonial government (Dixon-Fyle, 1977). Consequently, adoption of the Kanchomba system was minimal (Dixon-Fyle, 1977; Wright, 1983; Vickery, 1986).

Despite the failure of the Kanchomba system and the IFS, a precedent was established for modern expectations of farming, particularly weed control, as integral to higher maize production. With the advent of Independence in 1964, the target of agricultural extension changed from the white commercial farming sector to smallholder farms. However, these farmers were encouraged to follow proscriptions of farming that emphasized maximizing maize production through utilization of hybrid seeds and chemical inputs that was predicated on timely planting and continuous cultivation to reduce weed pressure.

Initially, the Zambian government, flush with revenues from the state-owned copper mining industries, was able to realize this vision of modern agriculture through the parastatal National Marketing Board (NAMBoard). NAMBoard heavily subsidized the purchase of hybrid seeds and chemical inputs, making them widely accessible to rural farmers. It also acted as the single purchaser of maize grain from rural producers, paying a pan-territorial floor price for maize across Zambia. Furthermore, government agricultural research and extension efforts became fixated exclusively on maize production, even in areas not suited for its growth (Kumar, 1994).

The collapse of the copper market in 1973 did not end the government beneficence towards NAMBoard. The popularity of the subsidies with rural farmers who benefited from the overvalued floor prices, as well as urban consumers who were able to purchase maize meal at undervalued rates allowed the subsidies to persist for 18 years despite its enormously negative impacts on the Zambian economy (Chizuni, 1994; Hill and McPherson, 2004). NAMBoard's created contexts that profoundly influenced the holonic configuration of farms. Providing easy access to seeds and fertilizers allowed farmers to artificially maintain production despite a shrinking land base and degradation of the soil context. The biggest impact, however, was the expansion of the maize context; by subsidizing both maize production and consumption over nearly three decades, NAMBoard fostered an ethos surrounding both maize consumption and cultivation. Sitko (2007) referred both ethe as "fields of performance" in which notions of modernity have influenced perceptions of maize in southern Zambia.

4. Discussion

The contexts in which Tonga farm holons operate create an ecosystem - cattle, land tenure, maize, soil, and policy interact to create a performance space in which farmers pursue their agricultural ambitions. Farms share many similarities in crops and practices, suggesting a *resonant configuration*—a general way of seeking a livelihood from agriculture that is permitted, if not encouraged, by the extant ecology of contexts and which many farmers chose to pursue (Bland and Bell, 2009). The cattle context reflects a history of new market opportunities, new demand for draught power, and devastating disease. The end of open lands in the region has transformed tenure traditions, and markets for maize and agronomic characteristics have made this crop central to these holons. Finally, depletion of the soil and changing government policy ushered in notions of a "good farmer," and then made this a very challenging prospect. With this contextual knowledge and our interview and observational data in hand we return to our motivating questions: how has the relationship of farmers to *F. albida* evolved?

4.1 Why Faidherbia albida seedlings were removed

The social ethos of a good farmer that began in the colonial era and manifested itself after Independence was heavily influenced by perceptions of modernity surrounding agriculture (Sitko, 2007). In particular, the necessity of removing weeds in order to reduce competition for water, light, and nutrients with maize was emphasized by agricultural extension efforts in both periods. Presumably, what was designated as weeds extended to anything that was not maize, including young *F. albida.* This point was emphasized by a retired, 85-year-old agriculture extension officer who had worked for both the colonial and Zambian governments, who emphatically stated that "*musangu* [*F. albida*] trees do not belong in maize fields." Given the social and institutional definitions of modern farming, it is not surprising that the beginning of the lost generation of *F. albida*, i.e., those 20 – 60 years old, roughly corresponds with the advent of agricultural extension on the Tonga Plateau.

What is also notable in written histories of agriculture on the Tonga Plateau is that knowledge of *F. albida* was predicated around the trees as indicators of soil quality. Extensive ecological and agricultural surveys from the colonial area are rife with descriptions of soils associated with particular species, e.g. *Uupaca* soils, Mupane [*Colophospermum spp.*] soils, and *Acacia* (or Thorn) soils (Allan et al., 1948; Trapnell, 1957). Soils in the latter group were noted for their inherent quality, especially with regards to their ability to withstand repeated cultivation, and included species such as *Acacia albida [F. albida],* *Acacia woodii*, and Whitethorn Acacia (*Acacia constricta*) (Allan et al., 1948; Trapnell, 1957). With regards to *F. albida,* these surveys do not mention extensive recruitment of the species, any perceived benefits of the trees to the soil, or any particular affinity on behalf of farmers for the trees. Jesuit mission histories also ascribe cultivation around *F. albida* to inherent soil fertility, associating it with locations such as termite mounds and valleys (Murphy, 2003). Sturmheit (1990) reported that in very rare cases, farmers would even remove large trees under the assumption that the soil would remain fertile.

4.2 Evolved knowledge of Faidherbia albida

The relationship of farmer and tree has evolved subsequently as agronomic research regarding *F. albida* in both Zambia and southern Africa was undertaken. Wickens (1969) described agronomic research of the species as limited, and most of that was confined to West Africa. Bonkoungou (1992) specifically demarcated 1966 as the beginning of agronomic research into *F. albida.* A comprehensive bibliography of *F. albida* written by Barnes (2003) also points to an increasing trend in research involving the agronomic effects of *F. albida* beginning in the mid-1960s. Whether or not *F. albida* improves soil quality or performs its function as a result of opportune growth sites is still being determined (Vandenbelt, 1992; Geiger, 1994). However, current characterizations of *F. albida* often depict the tree as a "fertilizer factory" or a "fertilizer tree" (Marshall, 2009; CGIAR, 2010). These depictions favor the notion of *F. albida* as improving soil quality.

4.3 System shocks and the realignment of Tonga farm holons

In 1990, pressures to reform Zambia's government and economy lead to the dissolution of the one-party state and multiparty elections in 1991. The election of Dr. Fredrick Chiluba as president was followed quickly by structural readjustment policies denationalized many parastatals, including NAMBoard. Though the efficacy of NAMBoard had declined throughout the 1980s, the sudden loss of input subsidies and price supports under market liberalization stripped away certain aspects of the capacity of farm holons to react to contextual shifts in decreasing soil fertility, also in a context of land constraints. On the heels of the downfall of the one-party state came a severe drought in the 1991-1992 and 1994-1995 growing season. Rural maize production in southern Zambia was almost nonexistent, and Southern Province, once considered Zambia's breadbasket, required extensive shipments of maize to supply basic household needs (Cliggett, 2000).

The impact of these structural and ecological shocks, combined with increasing scarcity of land on the Tonga Plateau, engendered a variety of responses in Tonga farm holons. The most apparent was the migration of many households to districts in Central Province; interviews revealed that these migrations were spurred by a lack of both rainfall and fertile land. Families that remained on the Plateau took up a variety alternate income generating sources, such as rearing of small livestock, woodcarving, knitting, charcoal manufacturing, or increasing the cultivation of other cash crops, particularly cotton. In a number of cases, farmers constrained by the limited availability of cattle had modified either their plowing habits or their equipment in order to cultivate enough land to grow a usable supply of maize. One farmer in particular had revived a practice from the Kanchomba system, utilizing velvet beans (*Mucuna pruriens*) in his crop rotation to improve the soil quality.

4.4 The Emergence of Faidherbia albida

The abundance of young (e.g., less than 15 years old) *F. albida* observed in many fields suggests that some widespread phenomenon allowed recruitment of the trees in maize fields beginning in the mid-1990s. This was not the result of a collective epiphany, we propose, but rather realignments in the fields of performance surrounding maize cultivation, initiated by the social promotion of *F. albida* by non-governmental organizations (NGOs). Informants recounted training programs by NGOs such as World Vision, Cooperative League of the USA (CLUSA), and Zambia National Farmers Union (ZNFU) in which numerous agricultural topics—including the retention and planting of *F. albida*—were discussed. Other interviewees cited radio programs funded by NGOs such as the "Radio Farm" forum that encouraged propagation of *F. albida.* On the national level, the language of agroforestry has steadily entered government discourse; the Fifth National Development Plan includes language promoting agroforestry activities among farmers (GRZ, 2006). The barrage of information surrounding *F. albida* over the past two decades was instrumental in establishing the social acceptability of using the trees as a device for improving soil fertility, thus granting farmers expanded capability with respect to their soil context.

Why have Tonga farm holons expanded to incorporate *F. albida* into maize-dominated configuration in lieu of other agroforestry or agricultural methodologies? We posit that it is not for lack of promotion of other ideas; interviewees reported that they had been exposed to soil improvement methodologies such as contour farming, improved fallow cropping, and conservation agriculture over the same time period as they had heard about *F. albida.* However, during the research study we saw no other cases of farms adopting these other methodologies.

We propose that Tonga Plateau farmers have had long experience with *F. albida*, and so incorporating the tree into their holon configuration was, compared to other possible innovations, relatively comfortable. Holonic thinking would view this as the tree having a long-standing place in farmers' knowledge context. Informants often based their observation of improved maize production on isolated stands of mature trees that were scattered across the landscape away from the river valleys. One key aspect of the social promotion that enhanced recruitment of the species was the idea that *F. albida* could actually improve soil fertility rather than the older notion of it simply being an indicator of inherent soil quality. The augmentation of traditional knowledge through social promotion enables farmers to exert their choice to allow *F. albida* to spread naturally. Also, this long agricultural experience gives farmers the confidence to incorporate a tree that take some years to make a discernable improvement to soil quality (Okorio and Maghembe, 1994; Rhoades, 1995; Chamshama, 1998).

Allowing natural recruitment of *F. albida* also is readily accommodated by other contexts. The trees have observable impacts on soil quality that are beneficial to maize production, and so they expand farmer capability with respect to this crop context. Recruitment and management of the species does not interfere with the common agronomic practice surrounding maize. New trees appear from cattle droppings, and aside from periodic trimming to allow cultivation around the base of young trees, little maintenance is required that would alter seasonal labor patterns.

In the context of land, retaining *F. albida* trees becomes advantageous with the movement toward patrilineal allocation of land to sons. Allowing trees to grow represents an investment in land and soil quality that will ensure one or more male children's capability to provide for their father in his old age. The exclusive rights of heads-of-households over their land and traditional injunctions against cutting standing *F. albida* ensures the safety and permanence of these investments.

F. albida satisfies the context of cattle rearing and herding directly due to its provision of shade and fodder in the dry season. Even farmers who do not own cattle acknowledged benefiting from *F. albida* when animals owned by others that are shading or browsing under trees on their land deposit manure. Indirectly, early establishment of the tree is not hindered by grazing animals, which are herded away from croplands after the rains commence. The tree protects itself from browsing through its own thorny branches, sparing the need to enclose the tree and reducing labor requirements necessary to protect the species.

Lastly, institutional contexts within Zambia, specifically those surrounding agricultural policies, now support agroforestry methodologies. The Fifth National Development Plan includes language encouraging of spread of agroforestry technologies to smallholder farmers (GRZ, 2005). Non-governmental organizations working in agriculture, particularly ZNFU, have incorporated agroforestry within their respective program. In my discussions with local and district level agriculture extension officers, forestry officers, NGO workers, and research faculty at the University of Zambia, responses indicated that *F. albida* was an acceptable and desired species to promote in small-scale agriculture. The increased inclusion of agroforestry, especially *F. albida*, in the larger discourse of agriculture has expanded the capacity for Tonga farm holons to alter their configurations to accept *F. albida.*

We note that recent promotion of *F. albida* goes beyond letting seedlings disbursed by cattle grow; it includes active propagation of the trees through raising seedlings in nurseries and subsequent transplanting to the field. Our informants indicated that this practice is rare in the research area, and we did not observe any such activity. We explore this question in another paper (Wahl and Bland, 201x).

5. Conclusions

The contemporary use of *F. albida* represents an expansion of Tonga farm holons in response to evolution of critical contexts and is accommodated, if not fostered, but other contexts. We propose that the apparent success in changing behavior toward *F. albida* by active social promotion was rooted in prior knowledge of the tree. The widespread recruitment of the species observed in western Monze District suggests that this use is now part of the resonant configuration of farm holons in that portion of the Tonga Plateau. As such, further promotion of *F. albida* as a maize intercrop on the Tonga Plateau that recognizes and enhances local knowledge of the species would potentially increase the propagation of the trees (Wahl & Bland, 201x).

An agroecological analysis such as this one is place specific, necessarily so by the central role of context. Thus its application in the design of agroforestry interventions, is limited in extent to farm holons that share a similar resonant configuration and ecologies of context. Though this analysis can directly inform such interventions in portions of southern Zambia, it may not be applicable to other regions of Zambia. We offer this effort as a case study in holon agroecological analysis, drawing attention to the power of understanding diverse contexts and the essential act of patiently and humbly listening to those who are configuring and reconfiguring their farm holons in order to continue to derive a livelihood from agriculture. We hope that similar exercises will improve our design of other interventions to improve farmer capacity toward their contexts, toward a more resilient and efficient holonic configuration.

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Chapter Two - A Miracle for Whom? The Implications of planting *Faidherbia albida* on gender roles in Southern Zambia

Carl T. Wahl[1], William L. Bland[2]

Abstract

Faidherbia albida is a tree species in indigenous to semi-arid regions of Africa that benefits maize (Zea mays) growing in its vicinity, as well as contributing to livestock management through the provision of shade and fodder. As such, the trees are being promoted as a solution to chronic issues of food insecurity. In southern Zambia, F. albida is utilized extensively in indigenous farming systems, but on family farms, benefits of the trees appear to accrue mostly to male heads-of-households. Using a combination of semi-structured interviews, group meetings, and observations, this study explored the historical evolution of gendered divisions in agricultural endeavors in southern Zambia, and how these divisions both influence and are influenced by the propagation of F. albida. Results indicate that while women supply considerable labor for seeding and weeding the maize crop, its benefits accrue largely to men. Programs to propagate F. albida require labor that largely falls to women, yet the tree benefits maize and so firstly men. Traditional women's crops, groundnuts and sweet potatoes, do not benefit from F. albida. Thus, there are significant disincentives for women to participate in propagating F. albida. Gender divisions in farming endeavors of southern Zambia need to be considered in social promotion of F. albida so that efforts to propagate the trees do not exacerbate tensions within rural households.

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[1] Agroecology Master's candidate, University of Wisconsin, Madison, Wisconsin, U.S.A.

[2] Professor, Dept. of Soil Science, University of Wisconsin, Madison, Wisconsin, U.S.A.

1. Introduction

Modern narratives of small-scale farming in sub-Saharan Africa depict a region plagued by soil degradation, manifesting itself in poor harvests that contribute to food insecurity on both the household and national levels. Industrial agricultural technologies, particularly the intensive use of chemical fertilizers, have largely failed because households lack the financial resources to purchase these inputs (Collier & Gunning, 1999). In lieu of expensive manufactured fertilizers, a number of technologies involving the use of trees on farms, known collectively as agroforestry, have been developed as a solution to issues of soil degradation for small-scale farmers (Rocheleau et al, 1988; Nair, 1989).

Though agroforestry encompasses a broad range of tree species and methodologies, one in particular, *Faidherbia albida*, is heralded as potentially solving many of sub-Saharan Africa's chronic issues with food security. An indigenous species, *F. albida* is described as a replacement for chemical fertilizers, based on its capacity to boost grain yields, particularly that of maize (*Zea mays*) (CFU, 2007). In the Republic of Zambia, the Conservation Farming Unit (CFU) of the Zambia National Farmers Union (ZNFU) characterizes *F. albida* as "The ultimate solution for Small-scale Maize Production" (Aagard, 2004).

1.1 Faidherbia albida

These characterizations of *F. albida* as improving soil fertility are well documented in scientific literature (Barnes and Fagg, 2003). What is especially notable about *F. albida* is its uncommon phenology in which it sheds all its leaves prior to the beginning of the rainy season (Wickens, 1969; Fagg, 1995). The deposition of leaf litter under mature trees adds significant amounts of nitrogen to the topsoil at the beginning of the growing season (Rhodes, 1995). *F. albida* has also been shown to fix nitrogen, further benefiting soil fertility

(Rao et al., 1998). By shedding its leaves, competition for light and rainfall with crops planted under the *F. albida* trees are minimized (Fagg, 1995). Studies have shown that maize production is doubled when intercropped with *F. albida* (Aagard, personal communication, March 16, 2010). The leaf canopy flushes with the end of the rainy season, shading underlying soil throughout the dry season (Wickens, 1969).

Aside from benefiting soil fertility, *F. albida* contributes a number of other ecosystems services. *F. albida* trees drop seedpods that are highly palatable to livestock late in the dry season, when other fodder sources are exhausted (Fagg, 1995; Ibrahim and Tibin, 2003; Bwire et al., 2004). Livestock also benefit from the shade provided by *F. albida* (Hadgu et. al, 2008). Flowering *F. albida* provide an ample source of fodder for honeybees, and mature tree trunks are valued for dugout canoe construction (Wickens, 1969; Fagg, 1995).

The multifunctional benefits of *F. albida*, particularly those concerned with maize production, have led to extensive promotion of the species in Zambia. The ZNFU-CFU has conducted extensive research on *F. albida* at their Golden Valley Agricultural Research Trust (GART) in Chisamba as an integral part of Conservation Agriculture Programme (CAP). To that end, the CFU unit is working to have 120,000 small-scale farmers plant 260,000 hectares of *F. albida* at a stocking rate of 100 trees per hectare (Aagard, 2004).

Use of *F. albida* in Zambia is not without precedent in indigenous agricultural systems. Ecological surveys and mission histories from the colonial era recorded the cultivation of millet (*Pennisetum glaucum*) and sorghum (*Sorghum sp.*) under and near mature *F. albida* by the Plateau and Valley Tonga (Allan et al., 1945; Trapnell, 1957; Murphy, 2003). Surveys conducted in the post-Independence era have shown that usage of the tree now includes maize cropping systems that now predominate the Tonga Plateau (Sturmheit, 1990; Olsen, 1992). Furthermore, the natural recruitment of the species through cattle dispersal appears to be increasing as a response by Tonga households to changes in their agroecological contexts (Wahl and Bland, 201xa).

1.2 Faidherbia albida - A miracle for whom?

The benefits of *F. albida* to maize production in Zambia are indisputable. The effects of the tree on production of non-cereal crops are less clear. Evidence from field trials conducted with *F. albida* in Zambia suggests that the tree has little influence on the production of cotton (*Gossypium sp.*), groundnuts (*Arachis hypogaea*), and soybeans (*Glycine max*) (Aagard, personal communication, March 16, 2003). Furthermore, there is little or no evidence in the literature of the tree's impacts on other important Zambian food crops, particularly sweet potatoes (*Ipomoea batatas*). Studies of sweet potatoes production suggest that the root biomass declines in soils with high nitrogen levels, though aboveground biomass increases (Leonard, 1948; Hartemink et al., 2000). Given the high levels of nitrogen evident beneath mature stands of *F. albida,* it is plausible that sweet potato yields might be suppressed under the trees (Rhoades, 1995).

In the discourse of improving food security through the planting and utilization of *F. albida*, the assumption is that higher production of maize will inherently increase food security. The World Food Summit of 1996 defined food security as the condition "when all people at all time have access to sufficient, safe, nutritious food to maintain a healthy and active life" (WHO, 2010). The United States Agency for International Development (USAID) expands that definition to incorporate food availability (sufficient quantities of appropriate foods), accessibility (sufficient resources to purchase or barter for appropriate foods), and utilization and consumption (correct usage of foods) (USAID, 1992). However, the logic that *F. albida* trees positively impact maize yields will increase food security of smallholder farm households may, however, overlook important gendered divisions of land usage, labor, and expenditures.

In exploring the discourse of food security with respect to these divisions, we envision the agricultural endeavors of interest in terms of holon agroecology (Bland & Bell, 2007). In this framework, farmers seek to satisfy their agricultural ambitions (e.g., a livelihood) by organizing and manipulating other humans, animals, plants, land, and material goods. The farm holon consists of all these things as they are used in accordance with the farmer's intentions, but as constrained by the ecology of context in which the agriculture must be conducted. Holon agroecology posits that the human decision makers (e.g., male heads-of-household, a farm family, or a corporation) find ways to configure the farm holon to meet their goals, but these configurations are never free of internal tensions, and must always be open to revisions as contexts change. Holon agroecology proposes that agriculture innovations such as *F. albida* will be incorporated into the farm holon if that innovation relieves some internal tensions, or provides a new opportunity in light of evolving contexts.

In this paper, we explore the farm holons of southern Zambia, with particular attention to the division and attendant tension of labor and crop usage relates to gender and how those divisions impact household food security. In light of these divisions, we discuss their implications in current and future promotion of *F. albida*, and how those promotions impact household food security.

2. Methodology

The analysis presented in this paper derives from 13 weeks of field research in western Monze District, Zambia, beginning in May 2009 and lasting through August of the same year, as well as historical research of ethnographic data regarding the Tonga Plateau and the Tonga people (hereafter the Plateau Tonga). Narrative data were collected through an assortment of channels: participant observations while living as a member of a household; 30 semi-structured interviews with individual heads-of-households and two semi-structured group interviews with 15 married women, which were carried with the aid of a local research assistant. Furthermore, we have utilized the primary author's background experience as a rural agricultural extension volunteer with the U.S. Peace Corps in Zambia from 2004 to 2007.

In the context of southern Zambia, we define a household as the individual family unit, including the head-of-household, spouses, children, and dependants. Within this narrative, we also include the material and derived assets of the household, e.g., land holdings, draft animals, domestic livestock, labor, etc. that are marshaled in agricultural endeavors. For the purposes of this paper, consideration of the various actors and assets, and their interactions is centered on the male-headed households which dominated in the data set.

3. A gender history of agriculture on the Tonga Plateau

Prior to the arrival of Europeans to southern Zambia, the Plateau Tonga were a pastoral people who cultivated small fields of millet, sorghum, flint maize, groundnuts, and assorted vegetables to supply their food needs (Vickery, 1986). Early histories describe Tonga society as relatively egalitarian in comparison with other tribes in Zambia, due to their lack of regimented social authoritarian positions, such as chiefs or headmen (Colson, 1958; Colson, 1962). This egalitarian nature is attributed in large part to the Tonga being unfortunately located between more powerful kingdoms such as the Kokolo, the Lozi, and the Ndebele, each of whom frequently raided the Tonga Plateau for cattle and slaves (Vickery, 1986). Consequently, social groupings were small; though language and cultural affinities existed across the Plateau Tonga, social adherence was to small matrilineal kinship groups (Colson, 1962).

The primary unit of production and consumption prior to European arrival was the household, and apparently labor toward cultivation was shared equally by the sexes, though tasks of clearing new land fell to the men (Wright, 1983; Vickery, 1986). However, designation of land usage and agricultural production were specific to gender, which then influenced the utilization of foodstuffs. The household designated harvests from women's fields for household consumption, whereas men's harvests were set aside in case women's stores ran out. Men's grain stores could also be used to assist relatives or neighbors in duress, or exchanged for goods and services. Furthermore, the ownership of cattle also appeared to be gender-neutral. The task of herding animals was usually assigned to young boys, though both adult men and women would assist when the need arose (Vickery, 1986).

The allocation of wealth within and among households was largely based on complex traditions of bridewealth (*lobola*), e.g., payments of goods by a groom to a bride's relatives. If the payment was in goods, it was typically in movable goods (*lubono*), such as cattle, goats, or implements, as opposed to immovable assets such as fields or structures (Colson, 1958). In lieu of goods, the groom performed brideservice (labor) for the bride's family, particularly the mother (Wright, 1983).

3.1 The colonial era and transitions in gender roles

The arrival of European influence under the aegis of the British South Africa Company (BSAC) in the 1890's had immediate effects on the Plateau Tonga that resonate into the present. Raiding of cattle and households was suppressed, and consequently Tonga cattle grew relatively unabated (Colson, 1962). In 1905, Jesuit missionaries introduced the ox-drawn plow, expanding the utility of cattle as draught animals (Murphy, 2003). At the same time, a railroad connecting Livingstone and the British colonies further south to the mining regions in Katanga Province of the then-Belgian Congo was constructed through the middle of the Tonga Plateau. Almost overnight, a market was created for foodstuffs, particularly maize grain to supply the mining industry of Katanga Province, and later, the Copperbelt region of Northern Rhodesia (Vickery, 1986).

The marked increase in cattle numbers had an immediate effect on the institutions of bride payments. Brideservice as a form of payment declined as a result of the increased prosperity brought by larger herds, and was supplanted by bridewealth increasingly paid in cattle or the cash equivalent (Colson, 1958; Mizinga, 2000). This system of exchange was usually paid to the father of the bride; Colson (1962) only recorded two cases in which the mother of the bride received cattle as a portion of the bridewealth. Though women had access to cattle through matrilineal clan inheritance, e.g., the division of wealth following the death of a male relative, married women had little opportunity compared to their husbands in designating or allocating cattle to children or relatives (Colson, 1958; Colson, 1962).

The introduction of the plough to the Tonga Plateau and its subsequent promotion by Catholic and Seventh-Day Adventist missionaries served to deepen labor divisions within the household. Mission histories record promotion of the plow, as well as tasks such as training the oxen to the yoke, as carried out exclusively by men (Wright, 1983; Murphy, 2003). The introduction of plows which could be pulled by a single team of oxen in the late 1920's spread the adoption of the technology across the Tonga Plateau; though these plows could be operated by women, the tasks surrounding their use quickly became dominated by men (Colson, 1958; Vickery, 1986).

The increased market for maize grain via the line-of-rail dovetailed neatly with the expansion of cattle and their increased utility as draught animals. Maize harvests could be expanded through clearing and tilling of more land up to the household's labor and draught power capacity. The act of clearing and plowing fields, combined with possession of the land and the ownership of cattle and tillage, placed the surplus harvest firmly in possession of the men. Though women performed the tasks of planting, weeding, and harvesting the maize crop, as well as crops used for household consumption, they were not entitled to revenues from the surplus maize crop. Furthermore, women had little say over the use of the revenues realized from the maize crop, despite their contribution in labor to plant and weed the crop. Men also exerted their rights over women's crops, and could refuse to give consent for the women to sell those crops (Colson, 1958; Wright, 1983; Vickery, 1986).

Finally, agricultural education in the colonial era was geared overwhelmingly toward men. Initially, knowledge of western agricultural practices was gained directly from missions such as the Jesuit school at Chikuni, in which demonstration and promotion of the plow was oriented to men (Carmody, 1999; Murphy, 2003). These missions were slow to incorporate women into their programs, and tended to promote the notion of women as caretakers of the household (Carmody, 1993; Carmody, 1999; Mizinga, 2000). The colonial government initiated agricultural extension in the late 1930's using the "Kanchomba system," which was formulated around a rigorous schedule of crop rotation and manure application that treated a household's land as a single unit (Dixon-Fyle, 1977; Wright, 1983). This ignored the traditional gender separation of fields and led to men becoming the arbiters of how household lands would be managed (Wright, 1983). Also, these extension efforts excluded women from agricultural education; only men were allowed to learn these modern agricultural practices (Muntemba, 1982). Though the Kanchomba system and its later expansion into the Improved Farmer Scheme of 1946 were largely considered failures, they created a model that lived on in agricultural education and extension after Zambia's Independence in 1964.

3.2 Retrogression of women's status in the post-colonial era (1964-1990)

After Independence, the Zambian government established agricultural policies to ensure national food security through increased crop production by encouraging the cultivation of hybrid maize. The government provided subsidies in the form of loans for agricultural inputs (seeds, fertilizer, and equipment) and pan-territorial price supports for maize were established, utilizing revenues from Zambia's burgeoning copper mining sector. The state also subsidized consumer food prices in order to keep the cost of foodstuffs low for urban dwellers (Chizuni, 1994; McCann, 2005).

The independent government removed colonial-era restrictions that precluded women from agricultural education, but institutionalized perceptions of gender continued to constrain women's access to modern agricultural practices. Married women could not receive agricultural loans without their husbands agreeing to be guarantors, which was a rare occurrence (Muntemba, 1982). Agricultural extension officers were usually men, and cultural norms often precluded male officers speaking with married women during extension visits. In training sessions conducted by these officers, men and women were both welcome to attend, but men were usually given preferential treatment (Carr, 1991). Extension courses offered at farm institutions along the line- of-rail were also predicated on social norms; courses for women were often focused on household tasks, such as cooking, knitting, and sewing (Muntemba, 1982). Furthermore, husbands often forbade married women from attending these training sessions out a fear of potential infidelity (Mizinga, 2000).

Trends of wealth dispersal through bridewealth payments and inheritance that originated during the colonial era were strengthened after Independence and contributed to the increasing marginalization of married women. Bridewealth payments increased throughout the late colonial/early Independence era, and the higher payments were perceived as guaranteeing a husband's full rights to both his wife's and their offspring's labor. Though women could divorce onerous husbands, they would generally receive little recompense, in the form of land, equipment, or cattle, for their labor expenditures while in his household (Colson, 1958; Wright, 1983). Inheritance patterns also changed from the larger matrilineal kinship group to the patriarchal household; in the case of the former, a woman had more chance of receiving wealth, but in the latter wealth was often designated to male heirs. This trend away from the kinship group to the nuclear family was supported by the colonial courts, which allowed individuals a means of redress for property appropriated by his kinship group if he so desired (Colson, 1962).

With Independence in 1964, the new government absorbed colonial policies intact without addressing the allocation of wealth in rural Zambian communities. This was part of a tenet of the early Zambian government stressing non-interference in customary law regarding wealth disbursement. A prime example was the Lands Act of 1975, in which the government assumed control over all formally titled lands, but did not affect customary land ownership

(Smith, 2004). Later policies that directly addressed women's rights to land in customary land ownership were largely ineffectual; for example, the Intestate Succession Act of 1989, which directly guaranteed a widowed spouse 20% of her husband's wealth as well as arbitration over another 50% for the children of the deceased, was either unknown or blatantly ignored in rural areas of Zambia and garnered little advantage for married women (GRZ, 1989; Nsemiwe, 2006).

3.3 The agricultural landscape of rural southern Zambia

The collapse of the global price of copper in 1973 initiated a decline in the Zambian economy that eventually lead to the fall of the one-party state in 1991. Heavily indebted, the newly elected government under President Chiluba undertook structural adjustment programs to liberalize the economy (Hill & McPherson, 2004). The state subsidizes for agriculture such as input loans and price supports disappeared, and consequently, the cultivation of hybrid maize was significantly reduced (McCann, 2005:166).

The sudden decrease in the maize crop did not reflect a reduction in small-scale households' desire to grow it. Expectations of government support for maize cultivation that had built up over the first three decades of the independent state led to broad opposition to economic reforms by rural farmers, and in the mid-1990s, the Zambian government slowly began reinstituting subsidies to small-scale farmers as a matter of political expediency (Rakner, 2001:88). In 1996, the Food Reserve Agency (FRA) was founded with the intention of maintaining national food reserves by purchasing a small portion of the national maize production. However, by 2006 the mission of FRA had expanded to include direct control of the import and export of maize grain, standardization of maize quality, and a significantly larger purchase of national maize production to the extent that the FRA controlled the majority of the maize market in Zambia (Doresh et al., 2009:352).

The reemergence of state intervention in agriculture has created preferential economic incentives for rural maize production relative to other crops. The FRA sets a pan-territorial maize price that exceeds market prices, and purchases large volumes of maize at each depot. However, purchases of other crops, e.g., cassava, rice, soybeans, or groundnuts, are limited to a fraction of the maize crop. For example, in the 2007-08 season the FRA planned to purchase 400,000 metric tones of maize, versus a combined total of 6,000 metric tones of these other crops (FRA, 2010).

Rural maize production in southern Zambia is likewise driven by social expectations of modernity that maintain the production and consumption of maize. Sitko (2008) defines these expectations as "fields of performance" in which modernization of rural agriculture in southern Zambia has been symbolized by the adoption of technologies surrounding the cultivation of maize that have been promoted by successive governments in Zambia. These fields of performance create social definitions for "good farmers" that are predicated on specific practices:

> Farming demands growing extensive fields of maize, knowledge of types of hybrid seeds that are appropriate for different climates, rates of fertilizer application, and cattle. As one farmer stated, without the ability to use these inputs, "you are nothing … you are not fit to be in the village." (Sitko, 2008: 9)

4. Present exhibitions of gender roles in agriculture

The evolution of the fields of performance surrounding maize cultivation on the Tonga Plateau and the concurrent delineation of gender roles toward household agriculture endeavors serves as a historical backdrop for how these roles currently manifest themselves in western Monze District. In this section, we explain these manifestations with regards to land allocation, labor expectations, marketing of surplus produce, and expenditure of revenue from these surpluses, based on interviews and observation during my research study. We then discuss how these gender roles have played out in interventions involving *F. albida* on the Tonga Plateau.

4.1 Land allocation

Women are allocated land seasonally by their husbands, who designate a given area for the production of "women's crops" such as sweet potatoes, groundnuts, and flint maize (*kahamba*). This portion of land is significantly smaller than that designated for maize, and never composes more than a quarter of a household's land holdings. Men's contribution to these fields is limited to plowing; all subsequent planting, cultivation, and harvest activities are carried out by women. Following the harvest of these fields, control of the land reverts to the husband, who subsequently designates a new portion for women's crops in the following season. Male heads-of-households described this annual shifting of women's crops as part of a crop rotation designed to restore soil fertility for subsequent cropping of maize. During interviews, women expressed that though they have some say over which fields are selected for their use, the allocation is determined mostly by the demands for the maize crop.

4.2 Labor allocation

Men are responsible for clearing annual shrub growth from fields prior to the beginning of the rains in mid-November. Once the rains commence, men plow the fields to loosen the topsoil, and then make a second pass to open planting furrows. Women then plant crops in both their husband's fields and their own. Weeding of crops commences immediately after planting; again, men will use ox-drawn plows or cultivators to weed between the rows, whereas women chop the weeds growing between the plants using small hand-hoes. Maize and groundnuts are cultivated in this fashion at least once, until crop growth precludes the passage of oxen; subsequent weedings are then carried out entirely by hand if deemed necessary by the head-of-household.

The cultivation of sweet potatoes is the most labor-intensive of the crops grown on the part of women. After the fields are tilled, women use hoes to build small mounds approximately 50 cm apart in which individual vine cuttings are planted. These mounds prevent waterlogging of the roots, as well as easing their eventual harvesting. However, the spacing of the mounds precludes passage by oxen, and weeding must be accomplished entirely by hand.

The perceptions of these labor activities differed according to gender. Male heads-of-households claimed in all cases that labor was shared by virtue of their having tilled the fields. However, female informants characterized men's labor as limited to their work guiding the equipment behind oxen. Women also commented that their husband tended to rest their oxen and themselves in the afternoons; the male contribution to afternoon labor was half-jokingly described as "sitting in a chair and giving directions."

Harvest activities are also segregated according to gender. Men and women both participate in harvesting the maize crop, but women do most of the hand shelling or threshing of maize grain destined for market. Sweet potatoes and groundnuts are dug up and processed entirely by women. In the case of the former, women dig deep pits adjacent to the household in which the roots are layered between branches and dry sand to keep them cool and dry until they can be removed for sale or consumption.

It is worthwhile to recognize that these tasks are performed in addition to everyday household chores that are expected of women, which are in themselves considerable. These include hauling water, caring for infants, preparing meals, gathering firewood, cleaning the household, doing laundry, watering gardens, and so forth. In observations and prior experience in Zambia, rarely has the senior author seen a woman not preoccupied with some necessary task at any given time of the day.

4.3 Marketing of surplus produce

Unshelled maize cobs are brought in from the fields and placed in elevated, grass-roofed wicker structures (*butaala*) following the harvest. These structures come in different shapes and sizes, but are the basic measure for how much maize will be kept for consumption. Male informants would indicate that after filling one or two butaala for household use, the remaining surplus of maize would be bagged and sold. For heads-of-households who are cooperative members, maize can be sold at the nearby FRA depots at the national floor price (65,000 ZMK per 50 kg bag, 2009). Non-members could sell at the depot if that depot's quota had not been reached (4,400 x 50 kg bags in 2009). However, most non-members lacked this option and transported their maize to town to sell to the town market for a significantly lower price (25,000 – 30,000ZMK).

Sale of women's crops is far more nuanced, because they are usually lower in volume than maize, lack any form of guaranteed market, involve household consumption dynamics that are not as fixed as maize, and are more perishable. A wife must first decide what portion of her crops will be sold and what sort of opportunity cost the household will incur in the form of lost nutrition. If her husband approves of the sale, she must then acquire grain sacks to bag the crops, and then transport the crops to sell at the town market. In some cases, women can entrust this task to friends or family members who will organize the transport and sale of the produce; in other cases, women must themselves go to town and sell the produce. This also presents an opportunity cost; a woman must consider who will take care of the household while she is away. Often, women with small children or no grown daughters are unable to leave the household for the extended period of time necessary to sell crops in town.

In any case, selling crops on the town market is a daunting task for either men or women. Unlike the FRA, which provides a centralized market with uniform pricing over a period of months, the town markets are decentralized and subject to seasonal price fluctuations. Selling produce on the town market is a complex process of determining whom among multiple buyers will offer the highest price, or has the capacity to purchase large quantities of produce. If large-scale buyers are not present, the seller must then attempt to sell the produce piecemeal at the best rates he or she can find. This process can often take up significant amounts of time; household interviews and observations revealed that the minimum time for selling produce required at least an overnight stay and often two nights away from the household.

Marketing of sweet potatoes also presents a host of difficulties for women. Unlike maize or groundnuts, which can be stored for extended periods of time if kept dry and protected from insects, sweet potato roots degrade much more quickly. Desiccation occurs in roughly two to three months, even in cases where the roots are stored in pits, and markedly decreases the market value of the produce. Leaving sweet potatoes in the field is not an option, as cattle herds are allowed to graze crop fields by late June and there is a significant risk from cattle digging up and eating the roots. Therefore, immediately after harvest the market for sweet potatoes quickly becomes saturated, and prices correspondingly decrease.

Unless a woman has a large volume of sweet potatoes, it is usually not worth the cost and effort to sell them at the town market. One woman commented that these difficulties shape men's desire to grow maize, as "selling maize is easier than our crops."

4.4 Expenditure of crop revenues

Another important differentiation in gender roles is how revenues realized from marketed household surpluses are spent. When asked what they would buy with maize revenues, almost all men responded that maize seed, chemical fertilizers, equipment, equipment repair, and livestock, particularly oxen, were their top priorities for purchase. Men characterized their expenditures for improved seeds and fertilizers as a means of benefiting the subsequent season of maize cropping, which could eventually result in the future accrual of wealth in the form of equipment and cattle, thus satisfying the social requirements of being a "good farmer." Married women, on the other hand, expend their crop revenues in toward household expenditures. This can be in the form of cookware, dishes, secondhand clothes, shoes, school supplies (notebooks, pens, and uniforms), yarn, and alternate foodstuffs, such as soya pieces, beans, and small dried fish (*kapenta*).

Women's characterization of spending habits indicated that men have considerably more freedom in deciding how their expenditures are spent. One interviewee characterized men as sometimes "squandering money on girls and drinking [spirits]," whereas women "spent money more wisely than men," i.e., on items that benefited the household. Married women characterized their decision-making for expenditures as circumscribed by their husbands, who often "instructed" the women in what to buy; however, women did not profess any capacity to instruct men in their expenditures. It appeared that this had not always been the case; in the past, men and women had apparently shared more of the decisions for the utilization of the household budget. Women said that in the present day, men were taking less responsibility for the household. One wife described this as "jealousy over women's programs" that had been carried out by NGOs; exclusion from programs promoted to women alone apparently justified some men's decision to distance themselves from household responsibility.

The only shared expenditure that periodically arose from household interviews was support for children's education. A few male heads-of-households utilized their harvest as a means of directly supporting older children attending school away from the village; this support could be in the form of monies for paying the school and boarding fees, or directly supplying maize for the student's own consumption. Payment of school fees for young children attending the local basic school was also a shared responsibility for some households. However, the support of children's education was dependant on the success of the harvest; poor harvests usually resulted in households halting a child's schooling until adequate support could be mobilized in subsequent seasons.

4.5 Manifestations of gender in promotion of Faidherbia albida

Social promotion of planting *F. albida* in western Monze District is carried out through either radio programs or non-governmental organization (NGO) training sessions. These promotions uniformly recommend building, planting, and maintaining a tree nursery for *F. albida* in the latter half of the dry season and then planting the seedlings into the maize fields after the rains have begun in earnest. Specific instructions for households wanting to plant the tree are to first acquire seeds and polyethylene planting tubes from either a ZNFU agent or a local representative. They then are supposed to build an elevated nursery stand, fill the tubes with soil, scarify the seeds, plant the nursery, and then water the seedlings until the rains have started. The seedlings are then planted out in fields at a recommended spacing of 10 meters by 10 meters.

Household interviews described the implementation of these instructions as following clearly gendered. The construction of household structures is almost entirely accomplished by men, and therefore, they build the nurseries. However, the remainder of the duties are borne by women, including treating seeds, filling the tubes, planting the seeds, watering the seedlings, protecting them from roving animals, and planting the seedlings into the fields. It bears repeating that these activities take place in addition to women's everyday roles in household; furthermore, these activities correspond with the beginning of the rainy season, when demands for women's labor in the fields are particularly high.

Men and women in western Monze District have extensive knowledge of *F. albida* and its capacity to improve soil fertility and consequently, maize harvests; to that extent, households have allowed recruitment of trees through dispersal by cattle (Wahl and Bland, 201xa). However, interviews and conversations with both men and women revealed that systematic planting of *F. albida* occurred on a very limited basis, due to a lack of training and nursery inputs, such as seeds and polyethylene tubes (Wahl and Bland, 201xb). However, in interviews with married women, I was told that a few of them had maintained nurseries in prior years at the behest of their husbands, but had not planted the trees. They explained that they had not intentionally failed to plant the trees, but their reasons suggested neglect; e.g., they had forgotten to water the nurseries, goats had knocked over the stands, or they were simply too busy to plant the trees on time and the seedlings had died.

5. Fallen nurseries: Implications of planting *Faidherbia albida* on gender roles

While a lack of time on the part of women offers a simple explanation for the failure of *F. albida* nurseries, there are a number of disincentives women may have for planting the trees on a large scale. First, in the current system of customary land tenure, women have little control over either the use of or the allocation of land. When married women are allocated land, it is seasonal and at the discretion of their husband. Women are cognizant of long-term capacity of *F. albida* to improve soil fertility, and consequently, increase maize yields. However, the benefits of *F. albida* are perceived by both men and women as limited to maize, which is a crop controlled entirely by men. Strong cultural injunctions against cutting *F. albida* make the trees a permanent fixture on the landscape, and may therefore designate a field for long-term growth of maize. Juxtaposed on the increasing scarcity of available land on the Tonga Plateau means planting *F. albida* in household fields trees may reduce the overall land area that women can seasonally access for crops other than maize.

A second disincentive arises in women's lack of control over their labor rights toward maize cultivation. Interviewees described weed competition as higher under *F. albida* due to the enhanced soil fertility, and that additional cultivation was therefore required. Though men described the weeds under *F. albida* as spindly, shallow-rooted, and easy to remove, an additional cycle of cultivation, especially for women using small hand-hoes, represents a significant addition of women's labor to the maize crop. Having a fixed supply of labor over which they exert little control, additional labor requirements towards maize could deprive women's labor expenditures toward their crops or household chores.

Women's lack of rights over surplus maize harvests creates a third disincentive to planting *F. albida.* As mentioned previously, each household retains a specific amount of maize for household consumption, e.g., a specific number of bags or *butaala* of maize. Any maize produced beyond that set limit is used at the discretion of the male head of household. In most cases, these surpluses are used for expenditures that enhance men's fields of performance towards maize cultivation or for the accumulation of real wealth, particularly in the form of cattle. However, outside of support of older children attending secondary school, expenditures from a surplus of maize usually do not directly benefit the household.

Finally, *F. albida* trees are perceived as not beneficial to most women's crops; in particular, the trees may have a negative effect on the yield of sweet potato roots, which form a major portion of women's marketable produce (Leonard et al., 1948; Hartemink et al., 2000). The monies realized from these harvests are used directly to support the household with alternate foodstuffs, clothes, school supplies, clinic fees, and so forth. Reducing the capacity to produce these crops could have a direct impact on women's capacity to enhance household food security, as well as the health and education of children.

6. Summary: Making *Faidherbia albida* work for the household

The production of maize is vital to ensuring Zambia's overall food security situation, especially given the fact that Zambians directly derive over half of their caloric intake from the crop (McCann, 2005). Small-scale farmers' capacity to produce maize must be increased to ensure continued national food security. In light of increasing land scarcity in many parts of Zambia, particularly the Tonga Plateau, maize agriculture has shifted from extensive to intensive land use that requires high levels of soil fertility. In lieu of expensive and often inaccessible chemical fertilizers required to maintain soil fertility, *F. albida* provides a potentially inexpensive long-term solution to problems associated with the intensification of maize agriculture.

Treating rural households as socioeconomic units striving for a common end often ignores gendered divisions in land, labor, and expenditure allocation (Geisler, 1993). Holon agroecology suggests that such division may derive from un-unified intentions, and potentially create tensions with the farm holon (Bland & Bell, 2007). Though *F. albida* does have the potential to improve long-term production of maize by small-scale farming households, its permanence on the landscape and its exclusive benefits to maize production relative to women's crops suggest that it may deepen the disenfranchisement of women within household agricultural endeavors. This disunity exacerbates tensions within the farm holon, rather than increasing its options and resilience. Also, improved production of maize relative to other crops does not necessarily imply an improved standard of living for all members of the household; a decrease in the capacity of women to produce crops other than maize could reduce household food security, health, and education.

The object of this paper is not to decry planting of *F. albida* on the Tonga Plateau, but rather temper the social promotion of the species with respect to the internal gender dynamics of rural farming households. First, recommendations for propagating the trees should take into account labor constraints faced by women during the rainy season and provide options that would save considerable time and labor, such as direct seeding of *F. albida* rather than using tree nurseries (Wahl & Bland, 201xb). Second, the percentage of a household's land that should be planted to *F. albida* must take into account the amount of labor women will expend weeding that land, as well as providing adequate land that is not planted to *F. albida* to order to allow women to cultivate their crops. Rather than make a blanket recommendation for all households, agencies promoting *F. albida* should engage all household members in reflecting on the full implications of the trees when deciding how much land should be dedicated to planting the trees that takes into account women's activities. Third, agencies need to actively support interventions that increase the productivity of women's crops, such as sweet potatoes, groundnuts, and other marketable foodstuffs. A good example of this is ZNFU's promotion of a wide variety of grain legumes as an integral part of a conservation tillage regimen. Furthermore, these interventions need to provide appropriate training that would expand marketing opportunities for women selling those crops.

The extensive anthropological research of the Plateau and Valley Tonga of southern Zambia reveals families there to be remarkable and complex institutions (Colson, 1958; Colson, 1963; Sen, 1984; Cliggett, 2000). Though our discussion relates specifically to *F. albida*, it serves as an example for considering the implications of interventions intended to improve small-scale agriculture on the Tonga Plateau and across Zambia. In developing such interventions to improve food security and rural livelihoods, we must constantly query the farm holons as representative institutions to ensure those interventions are equitable throughout the household and reduce, rather than aggravate, tensions between household members as they pursue their farming endeavors.

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Chapter Three – Building on Farmer Knowledge to Expand the Intentional Propagation of Faidherbia albida on the Tonga Plateau of Southern Zambia

Carl T. Wahl[1], William L. Bland[2]

Abstract

Faidherbia albida is indigenous to semi-arid regions of Africa and has demonstrated great potential for increasing yields of maize (Zea mays) cultivated in its vicinity. As such, the trees are being promoted as a solution to chronic issues of soil infertility and food insecurity. In southern Zambia, F. albida are used extensively in indigenous farming systems, but propagation of the species appears limited to cattle dispersal, despite efforts to encourage propagation of the trees in nurseries. Using a combination of household interviews, group meetings, and field observations, these efforts were critically evaluated in light of farmer knowledge of F. albida, as well as methodologies and resources employed in propagation of the species. Results show that despite extensive knowledge of F. albida and its benefits, along with ample local seed resources, intentional propagation was limited because of perceptions that external resources such as potting tubes and seeds were required for success. Furthermore, labor requirements for tree nurseries fall during a period of intense labor demands for planting crops that can preclude transplanting of seedlings. Modified strategies for propagating F. albida using nurseries that could exploit local knowledge and material resources are discussed. However, it is suggested that direct seeding of F. albida be considered as a means of propagating the trees, given the relative abundance of seed-

[1] Agroecology Master's candidate, University of Wisconsin, Madison, Wisconsin, U.S.A.

[2] Professor, Dept. of Soil Science, University of Wisconsin, Madison, Wisconsin, U.S.A.

bearing trees in southern Zambia and the potential savings in labor. Presenting farmers with a variety of options for planting F. albida that utilize existing resources could potentially increase uptake of the species in southern Zambia.

1. Introduction

Degraded or declining soil fertility on small-scale farms has been identified as major impediment to the improving the productivity of small-scale agriculture in sub-Saharan Africa (Smaling et al., 1997). Synthetic fertilizers are financially inaccessible to many of these small-scale farmers, so a number of low external input agricultural (LEIA) systems have been developed in response to decreasing soil fertility. Integral to these systems is the integration of trees into farming systems in a variety of methods collectively known as agroforestry (Rocheleau et al., 1988; Nair, 1993).

One indigenous species in particular that holds a great deal of promise for agroforestry in sub-Saharan Africa is *Faidherbia albida*. Widespread throughout much of the semi-arid areas in the region, *F. albida* is most notable for its effects on grain production. The cause of this is the so-called "*albida* effect," in which the trees shed their leaf biomass prior to seasonal rains (Wickens, 1969; Fagg 1995). This minimizes light and rainfall interception by the canopy and allows crops to be grown directly under *F. albida*. Furthermore, this annual deposition of leaf matter provides a flush of available nitrogen to the topsoil directly beneath the trees' canopies (Rhoades, 1995). This leads to significantly higher yields of cereal grains, particularly maize, under *F. albida* canopies relative to outside their canopies (Bunderson, et al. 1990). Furthermore, the trees are deep-rooted and apparently do not interfere with crops grown (von Maydell, 1988).

Beyond its benefits to crop production, *F. albida* serves a number of other useful purposes, particularly in agropastoral systems. At the end of seasonal rains, the trees' redevelop leaves that provide shade throughout the dry season, and serve as a cool respite for livestock (von Maydell, 1988). *F. albida* also produces seed pods that drop late in the dry season that a valuable source of fodder for livestock when other feed sources are at a minimum (Wickens, 1969; Ibrahim & Tibin, 2003). The flowers are also a good source of forage for bees, and boles of mature trees are valued for making canoes (Wickens, 1969; Fagg, 1995).

In the Republic of Zambia, efforts to promote the planting of *F. albida* by small-scale farms have been increasing; these promotions are carried out by government agencies such as the Ministry of Agriculture and Cooperatives, as well as non-governmental organizations such as the Conservation Farming Unit of the Zambia National Farmers Union (ZNFU). The promotions are carried out in a variety of ways: field visits by farmers to demonstration farms, training of farmers by extension agents, and radio programs that air in both English and most of the predominant local languages of Zambia (ciBemba, ciLozi, chiNyanja, ciTonga, and kiKaonde).

The Tonga Plateau in southern Zambia provides an attractive setting for the promotion of *F. albida* because of the traditional use of the trees by small-scale farmers. Known to the Tonga people as *musangu* or *munga*, mature *F. albida* trees found in nearly pure stands along watercourses or in isolated stands of two or three trees in upland fields. These trees are valued for their provision of shade and fodder to cattle, as well as the perception by local farmers that the trees improve soil fertility. The retention of *F. albida* was originally due to patriarchal injunctions against cutting mature trees combined with long experience regarding the trees' effects on crop production (Strumheit, 1990; Wahl & Bland, 201xa). Recent promotion of the species and changes in the ecology of contexts that shape farmer decisions have altered social acceptability of *F. albida* such that seedlings resulting from cattle dispersal are not removed (Wahl & Bland, 201xa).

Despite the increased dispersal of *F. albida* trees on the Tonga landscape, local recognition of the trees' value in maize production, and promotion efforts by agencies such as ZNFU, virtually no farmers are intentionally planting the trees. In this paper, we address the reasons farmers do not plant *F. albida* in light of current training strategies and farmer perceptions of those strategies. We argue that the paucity of intentional propagation of *F. albida* is due to the externalization of knowledge and material resources surrounding the tree, as well as gendered divisions of labor surrounding nursery maintenance. We then propose alternative methods for planting *F. albida* better aligned with labor constraints and local resources, and make use of farmer knowledge of the tree species.

2. Methodology

The analysis presented in this paper derives from 13 weeks of field research in three contiguous villages of western Monze District, Zambia, beginning in May 2009 and lasting through August of the same year. Data was collected through an assortment of channels: participant observations while living as a member of a household; 30 semi-structured interviews with individual heads-of-households and two semi-structured group interviews with 15 married women, which were carried with the aid of a local research assistant; and personal observations made during guided and unguided visits to farmers' fields. We have also utilized the principal author's background experience as a rural agricultural extension volunteer with the U.S. Peace Corps in Zambia from 2004 to 2007.

When interviewing farmers regarding their use of *F. albida,* we sought to avoid phrasing questions in ways that might bias the answers. For example, farmers were not asked "Why don't you plant *F. albida* in your fields?", which might appear judgmental and cause farmers to prevaricate in their response. Rather, we posed open-ended queries such as "Tell me how these trees came to be in your field," or "Tell me how these trees are used by farmers," in order to allow farmers to relate their own stories surrounding the trees. When definitive questions were asked, they were focused on farmer observations of *F. albida*, such as "Do animals graze young trees?" or " When do leaves fall off the trees?" Combining the qualitative narratives with quantitative answers, we were able to create a realistic depiction of the issues directly affecting the planting of *F. albida*.

3. Current strategies for planting *Faidherbia albida* on the Tonga Plateau

The sample population of households interviewed during the course of this study was uniformly aware of the benefits of *F. albida* to maize production. Farmers attributed these benefits primarily to the annual deposition of leaves on the soil surface, which was enhanced in some cases by manure left by cattle shading or browsing under the tree canopy. Furthermore, with the exception of one 84-year old man, all heads-of-households expressed a desire to have more *F. albida* in their fields in order to increase the benefit to maize production. These heads-of-households also described that maintenance requirements for seedlings or young trees in the fields were minimal. Browsing pressure from livestock is reportedly limited because of thorns on *F. albida* branches, and apart from pruning low-lying branches to allow oxen to pass underneath, no additional labor was required for trees growing in cultivated fields.

Farmers' knowledge of *F. albida* diverged regarding the propagation of the trees on the landscape, based largely their exposure to formal training. The majority of farmers interviewed had received little training about *F. albida,* and regarded dispersal by cattle as the only means of planting the trees. Farmers that had received some formal training were aware of dispersal by cattle, but regarded prescriptive methods in training sessions as the lone alternative for planting the species. In the following sections, we discuss these findings and their manifestations in dispersal of *F. albida.*

3.1 Cattle dispersal

As mentioned previously, mature *F. albida* tend to be clustered along watercourses in nearly pure stands. Informants' narratives described cattle herds as frequenting these areas, especially in the latter half of the dry season, when temperatures begin to rise. Unlike the early portion of the dry season, when cattle are herded to prevent damage to unharvested fields, late season herding management appears to be more laissez-faire. With the exception of weekly dipping to prevent the spread of tick-borne diseases, cattle are left to graze on their own schedule. Apparently, the high temperatures induce the cattle to graze in the late evening and early morning hours; by mid-morning, the herds shade under the *F. albida* trees, where they rest throughout the heat of the day.

By the time mature *F. albida* begin shedding their seedpods, cattle excursions into upland fields to forage is limited to areas adjacent to watercourses. Consequently fields in these areas have a much higher density of young *F. albida* than fields further from the watercourses. Young trees were also clustered around areas where cattle were brought for watering, such as boreholes, shallow wells, and reservoirs. In areas where cattle traffic was minimal, few *F. albida* were found.

Changes in grazing pattern associated with the onset of the rains in mid-November also appeared to influence the spread of *F. albida* away from watercourses. With the exception of oxen, which are kept in homestead kraals for plowing fields, the herds are gathered and moved *en masse* along roads or trails to communal grazing areas, typically large *mupane* (*Coleosperma mopane*) woodlands that are considered unfit for farming. The herds are kept in these areas throughout the rainy season to prevent damage to crops, which precludes further dispersal of *F. albida.*

Not surprisingly, farmer attitudes towards planting the tree were heavily influenced by the relative distance of their fields from watercourses. Though every household expressed a desire to have more *F. albida* trees, households with fields adjacent to watercourses expressed a belief that dispersal through cattle would populate their fields with sufficient numbers. Conversely, farmers with less cattle traffic in their fields because of distance from watercourses expressed a stronger desire to learn how to plant *F. albida.*

3.2 Nursery methods

Agency recommendations for planting *F. albida* follow specific steps that are outlined in the ZNFU leaflet "How to Plant and Look After Musangu" (CFU, 2007). In summary, farmers are instructed to get *F. albida* seeds and black polyethylene tubes from ZNFU and construct small, elevated nurseries for the seedlings. In late October, the tubes are filled with rich topsoil, and scarified seeds are planted in the tubes, which are placed in the nurseries. The nursery is regularly watered for five weeks, after which the young trees are planted into maize fields at regular intervals of 10 meters by 10 meters, assuming the rains have started on time. Beginning in May, farmers are instructed to water the seedlings, and protect them from wandering animals by covering them with thorny branches.

Out of the 30 households interviewed, six had been exposed to trainings by either ZNFU agents or by a farmer representing ZNFU in the area. The heads of these households could recite the steps for planting *F. albida* by rote, and often produced copies of the aforementioned leaflet that had been distributed during trainings. However, these participants reported that actual planting had yet to occur, because of a lack of polyethylene tubes, seeds, or both. It is worthwhile to note that in three cases, farmers had received *F. albida* seeds from ZNFU agents in the past. When asked about the origin of the seeds, the farmers were unsure other than that the agents had brought the seeds with them.

Among all the households interviewed that had been exposed to some form of training regarding *F. albida*, there was an overarching impression that propagation of the trees had to closely follow the prescribed recommendations for planting, or it could not be successfully accomplished. The lack of external resources, such as seeds and planting tubes, had proscribed the planting of the trees because of the perceived necessity of following the recommended planting regimen.

Though none of the heads-of-households interviewed reported constructing nurseries or sowing trees, interviews with married women revealed that in three cases nurseries had been constructed for planting using seeds and tubes from ZNFU. However, none of the seedlings were planted out; women explained that they had been too busy with other tasks to maintain or plant out the seedlings, and as a result, the nurseries were knocked over by roving goats or the seedlings had dried up for lack of watering.

4. Why is propagation of *Faidherbia albida* not happening?

Based on our analysis, existing interventions that promote *F. albida* fall short in three ways: first, they do not build on local knowledge of natural tree propagation; second, they do not utilize local resources for planting the trees; and third, they disregard gender divisions of labor surrounding maintenance and planting of young trees.

4.1 Externalization of knowledge of Faidherbia albida

The long experience with *F. albida* and the evolution of its usage on the Tonga Plateau suggest that households' knowledge of the tree is both extensive and adaptable. The depth of observational knowledge was evident in highly nuanced descriptions of the trees' effects that arose in different interviews. For example, one farmer explained that water infiltration under mature *F. albida* was enhanced though hoof action by shading cattle that broke up the crusted soil surface, allowing early rains to infiltrate into the soil faster. Other farmers differentiated the effects of *F. albida* on various crops, saying that the tree was beneficial to maize yields, but suppressed yields of groundnuts (*Arachis hypogaea*) and sweet potatoes (*Ipomoea batatas*).

Also notable are farmers' recently evolved perceptions of the relationship between *F. albida* and the soil. Colonial era ecological surveys indicate that *F. albida* was considered an indicator of inherent soil fertility rather than a means of improving soil quality (Allan et al., 1946; Trapnell & Clothier, 1957). Also, soil fertility improvement was largely attributed to cattle manure rather than the deposition of leaf biomass (Sturmheit, 1990). Household interviews revealed a shift in both perceptions; *F.albida* was seen as the reason for the fertile soils under its canopy, and that the enhanced fertility was mostly due to leaf litter rather than cattle manure. Households indicated that social promotion of *F. albida*, particularly radio programs, had help shift these perceptions.

The key area in which farmer perceptions of the tree have not evolved according to their own observations is how *F. albida* is propagated. All households were knowledgeable about "natural" recruitment of the trees via cattle dispersal; however, the underlying processes that influence seed germination were largely unknown, e.g. scarification of seeds and killing of predatory bruchid (*Bruchidae*) beetles by passage through the gut, or the protection of undigested seeds from bruchid infestation within dung piles (Shayo & Uden, 1998). Farmers who had received formal training were aware of the need to scarify *F. albida* seed coats prior to planting in the nurseries, but there was no evidence of the association of this procedure with similar processes inherent in passage through the cattle digestive tract.

4.2 Underutilization of local resources

Training in propagation of *F. albida* is further divested from farmers by the perceived necessity of external resources to plant the tree, particularly the plastic planting tubes and tree seeds. In the case of the former, farmers were generally unaware of where to find the tubes, or said they were not available unless they were delivered from outside the village. This is not surprising given that the planting tubes are manufactured in Lusaka. Moreover, the perception that farmers had developed was that intentional planting of *F. albida* was predicated on the use of the tubes.

The provision of seeds also caused a more direct separation between local and external resources. Three households actually produced small, green-lidded jars of *F. albida* seeds with that they had been given by ZNFU agents. Though indistinguishable from seeds gleaned from numerous local trees, the act of receiving seeds had engendered a sense that the seeds delivered by agents were superior to local seed sources. This reaction is not surprising given associated household preferences for hybrid maize seed purchased in town to recycled seeds or local landrace varieties (Wahl & Bland, 201xa). Furthermore, households were largely unaware of the origin of these seeds; one farmer suggested that they might be from Chisamba, where ZNFU maintains small-scale research farms.

These seeds were delivered to an area with many healthy, mature trees in a variety of growing conditions. On visits to upland fields within the study area, particularly near to watercourses, we observed numerous seed-bearing *F. albida* of heights greater than 20 meters and average canopy radii of 12 to 15 meters growing in a variety soil conditions. Along the watercourses, there were even denser stands of mature *F. albida*, a few of which approached or equaled the maximum dimensions of the species (Storrs, 1979). Clearly there were large numbers of suitable trees from which to select seeds that could be used for propagation. Although out fieldwork period did not correspond to the time when seed pods drop, most mature trees exhibited pod development that suggested ample seed production; also, we were easily able to collect half a kilogram of seeds from desiccated pods leftover from the previous year that had not fallen to the ground.

4.3 Gendered divisions of labor

The third challenge for using nurseries to establish stands of *F. albida* arises from the extra burden it places on women based on clear gender divisions of labor in the region (Wahl & Bland, 201xb). Household narratives revealed that the beginning of the rainy season (November and December) feature high labor demand. Men are typically tasked with clearing fields of any brush immediately prior to the rains; once sufficient rain has fallen to allow tillage, they proceed to plow. Once the soil has been prepared, women plant both the maize crop and crops utilized for the household, such as groundnuts and sweet potatoes, which apparently starts in late November and continues into the first half of January. Immediately following planting, cultivation to remove weeds commences; men utilize plows or cultivators to weed between rows, and women weed between plants with small hand hoes. Discussions with married women described these tasks, particularly weeding, as occurring almost continuously from December through February. Women also described the demands for planting and weeding crops as taking up most of the day; the only respite from the fields appears to be when women return home to perform household chores.

It must be noted that women are still expected to carry out a considerable number of household tasks, such as drawing water, preparing food, cleaning the household, caring for children, and so forth. The labor demands for planting and weeding are significant enough that other food production tasks are abandoned throughout the rainy season; none of the households interviewed maintained gardens during the rainy season, relying instead on gathering traditional vegetables, such as amaranth (*Amaranthus* sp.), blackjack (*Bidens pilosa*) or cleome (*Cleome* sp.).

Set against the context of existing gendered labor roles, it is understandable how the labor requirements for nursery propagation of *F. albida* can become extraneous for women. Men's tasks appear to be limited to constructing the elevated nursery stands. From that point forward, the remainder of the tasks (scarring seeds, filling tubes, planting seeds, watering, and then planting seedlings) appears to be carried out entirely by women. In the two instances where nurseries had been constructed, women had expressed they had been too busy to look after them.

Another gender factor that may influence the use of nurseries to promote *F. albida* are the effects of the trees on crops that are predominantly grown by women. Though household narratives supported the positive benefits of *F. albida* on maize yields, they described the trees as suppressing the belowground yields of sweet potatoes and groundnuts. Both crops are used for either household consumption or sold to pay for household necessities, e.g. school fees, clothes, alternate foods, and other sundry items. On the other hand, benefits from surplus maize harvests typically accrue to the husband, and are utilized for purchasing livestock, equipment, or inputs for the subsequent year's maize crop that are controlled by the male head-of-household. Establishing stands of *F. albida* whose long-term benefits are perceived to be for maize, may be a disincentive for women to plant the trees (Wahl & Bland, 201xb).

5. Alternative strategies for promoting *Faidherbia albida* on the Tonga Plateau

In light of chronic degradation of soil quality, and the high cost of chemical fertilizer, the use of *F. albida* as an intercrop has enormous potential to boost maize production in a cost-effective manner. Indeed, efforts to promote the species over the past two decades has encouraged the recruitment of the species through cattle dispersal by altering the former practice of removing emerging *F. albida* seedlings (Wahl & Bland, 201xa). However, the current methodologies used to promote *F. albida* on the Tonga Plateau fail to utilize local knowledge of propagation of the trees, and predicates intentional planting on external resources. If this situation persists, recruitment of *F. albida* through natural dispersal will likely continue, though in a non-systematic pattern that will be slow and favor areas more heavily trafficked by cattle.

In order to expand the propagation of *F. albida* on the Tonga Plateau, we propose ideas for propagation strategies that would enhance farmer knowledge of *F. albida,* utilize local resources for planting the trees, and reduce labor requirements surrounding the propagation of the species. Given the desire expressed by numerous households to have more *F. albida* trees, these strategies could better enable households' capacity to propagate the trees, and potentially lead to increased intentional recruitment of *F. albida* on the Tonga Plateau.

5.1 Building farmer knowledge

An effective way of building farmer knowledge of tree propagation would be to relate how simple scarification of seeds emulates the action of cattle's digestive tracts. This could be accomplished by doing a side-by-side comparison of scarred and non-scarred seeds. For example, placing both sets seeds of seeds in a cup of water overnight and showing how treated seeds imbibe water and swell, whereas untreated seeds remain unaffected. Another example could be carried out through simple germination tests using treated and untreated seeds to show how treatment affects seed germination rates. Farmers could also be shown how to identify seeds that are more likely to be viable, i.e. those seeds that are mature and not infested by bruichid beetles.

Another avenue of enhancing farmer knowledge of the trees in areas with high densities of mature *F. albida* is to teach farmers how to identify specimens that could be utilized as local seed sources. Ideal candidates would be mature trees growing in fields removed from watercourses and exhibiting characteristics such as uniform crown development, good production of seedpods, and no apparent incidence of disease or rot.

5.2 Utilizing local resources

As mentioned previously, in areas with relatively high densities of *F. albida*, local seed sources should be identified and utilized for propagating the trees. Though this may require advance fieldwork by extension agents, identifying even a limited number of candidate trees could provide ample supplies of seed at no cost to households other than requesting permission from the landowner to collect the seeds.

Local alternatives are also available for the plastic tubes used in nursery stands. Cheap and widely available substitutes can be found in waxed or lined cardboard cartons used to hold beverages such as opaque beer (i.e. Chibuku, Timwenge, Lusaka Beer, etc.) or milk (i.e. Parmalat). These cartons, particularly those for opaque beer, are found in large quantities outside of taverns and present something of eyesore as they are typically left in ditches or rubbish heaps. Removing the bottom of these containers creates a facsimile of plastic tubes; however, slightly more soil is necessary to fill these tubes and they should treated with ash or motor oil to deter termites before placing them in the nursery.

5.3 Labor-saving alternatives to tree nurseries

The use of nurseries to ensure a higher survival rate of *F. albida* is important in cases where seed sources are limited and seeds must be brought from outside the local area. The use of nurseries can also give trees a head start on the growing season, particularly in areas subject to short-term droughts, such as the Tonga Plateau. However, in the areas where *F. albida* trees can be found in relative abundance, direct seeding could represent a significant savings of both labor and time (Ochsner, 2001). Though we were unable to locate literature comparing mortality rates of *F. albida* in Zambia that were raised in nurseries versus direct seeding, studies conducted in Senegal revealed that local provenances have lower mortality rates when directly sown (Samba, 1992).

A possible scenario for direct seeding would first require the collection and pretreatment of seeds from suitable parent trees. After the rains have commenced and planting of maize begins, the seeds would be soaked in water overnight, and any seeds that fail to imbibe water would be discarded. The imbibed seeds would then be planted at the recommended spacing of 10 meter by 10 meter at the same time maize crops are planted. To further ensure success, two or three seeds imbibed seeds would be planted in a single location; after the seeds have germinated, extraneous seedlings would be removed. As the seedlings growing in situ with maize crops, pressure from weeds would be reduced through standard cultivation. The young seedlings are protected from grazing pressure because of herding practices that keep livestock out of the fields during the growing season; once the fields are harvested and livestock are allowed into the fields, the seedlings will have developed enough thorns to preclude all but minimal browsing pressure.

5.4 Cautions on Planting Rates

Household interviews and personal observations suggest that once *F. albida* trees are established, strong patriarchal injunctions prevent the removal of these trees for any reason (Wahl & Bland, 201xa). Therefore, it is essential that social promotion of *F. albida* account for the trees' long-term effects on crops cultivated by women for household use, e.g. sweet potatoes and groundnuts. Though we do not suggest any target densities or patterns for *F. albida* plantings, we would caution that not all of a household's land should be intercropped with the trees in order to allow the continued cultivation of these crops within household farming endeavors.

6. Conclusions

Efforts to promote *F. albida* in rural Zambia are laudable in that the trees could potentially ameliorate deficiencies in soil quality detrimental to the production of maize by small-scale farmers. However, in areas where *F. albida* and local knowledge of the trees is endemic, such as the Tonga Plateau, these efforts should incorporate these knowledge and material resources, as well as recognizing labor constraints in farming activities and therefore influence propagation of the trees. Presenting farmers with a series of options for planting *F. albida* that builds on their knowledge and utilizes available resources could potentially increase the effectiveness of these interventions. Furthermore, freeing households from the perception that external resources are necessary to propagate the species would augment the potential for other households to emulate or adapt alternative methods for intentionally propagating *F. albida.*

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Chapter Four - Influence of *Faidherbia albida* on Saturated Hydraulic Conductivity (K_{sat}) of Soils in Southern Zambia

1. Introduction

In sub-Saharan Africa, small-scale farmers are increasingly cultivating hybrid maize (*Zea mays*) and find themselves faced with a wide array of challenges, especially with regards to improving or maintaining soil quality. Farmers who cannot afford chemical fertilizers are often forced to open new lands realize a harvest, contributing to rampant deforestation (JAICAF, 2008). In places where open land is unavailable, farmers cultivate the same lands annually; the majority of these farmers cannot afford chemical fertilizers to maintain soil fertility, and consequently, crop yields are diminished (Lungu, 1999). Also, the repeated monoculture of maize in the absence of traditional fallow periods has further contributed to the degradation of soil quality (Holden, 2001).

In light of the issues facing small-scale farmers in sub-Saharan Africa, the use of agroforestry has been actively promoted as a long-term remedy to soil degradation (Nair, 1989). Agroforestry is a method of agriculture based on the simultaneous cultivation of farm crops and trees; extensive literature derived from research in sub-Saharan Africa demonstrates the ability of many species of trees to fix nitrogen, suppress weeds, mulch soils, halt wind and water erosion, provide cattle fodder, and so on (Rocheleau et al 1988; Nair 1989).

The perceived agronomic benefits to small-scale farmers relative to their financial costs makes agroforestry an attractive idea for low external input agriculture (Holden, 1993). However, agroforestry does require considerable investments in education, labor, and social acceptability. There is a significant knowledge gap for many tree species and methodologies that require extensive farmer training and demonstration. Furthermore, most agroforestry technologies require inputs of time, space, and labor that detract from the cultivation of food or subsistence crops. Lastly, agroforestry technologies often require a shift in seasonal labor patterns that can be socially disruptive (Ajayi et al, 2006).

One agroforestry species, *Faidherbia albida* (Del.) A. Chev. (syn. *Acacia albida*), offers a number of features that support its use by small-scale African farmers. First, *F. albida* is indigenous to semi-arid regions of sub-Saharan Africa, notably Sahelian West Africa, along the Great Rift Valley, and along the Zambezi River valley; as such, there is considerable local knowledge of the tree in indigenous agroforestry systems (Wickens, 1969). Second, the trees shed their leaves just before the rainy season, minimizing light and rainfall interception for crops sown under their canopies. Furthermore, the annual deposition of leaf biomass provides a flush of organic nitrogen at the beginning of the growing season, which serves to significantly boost grain yields sown under the canopies relative to outside the canopies (Bunderson et al., 1991; Depommier et al., 1992; Rhoades, 1995). Third, the leaf canopies *F. albida* grow back immediately prior to the dry season, shading the soil surface underneath the tree and reducing the evaporation potential (PET) by perhaps 50%; this shade also provides a welcome respite for grazing cattle (Charreau & Nicou, 1971). The seedpods fall from the tree late in the dry season and provide a valuable fodder source for livestock at a time when other feedstocks are critically low (Ibrahim & Tibin, 2003; Bwire et al., 2004). The multiple benefits provided by *F. albida* and its ability to be planted in situ with crops for long term improvement of soil productivity make it an ideal agroforestry species for small-scale farmers (Fagg, 1995).

Though the impacts of *F. albida* on soil fertility have been extensively examined, the trees' effects on physical characteristics of soil under their canopies are less well known. Most studies limit this discussion to the improved microclimate creating a more welcoming environment for soil microbiota under the canopy due to dry season shading effects that significantly lowered soil temperatures and PET (Charreau & Nicou, 1971; Vandenbelt and Williams, 1992). Barnes and Fagg (2003) in their comprehensive monograph and bibliography of *F. albida* mention higher silt and clay fractions relative to sand fractions under tree canopies, but do not ascribe reasons for this increase.

Querying the influence of agroforestry species in general and *F. albida* in particular on the physical aspects of soil is becoming increasingly important in light of potential shifts in southern African climate induced by human carbon emissions (Bates et al, 2003). Understanding the influence of *F. albida* on soils' capacity to absorb and store water in light of precipitation extremes will inform the discussion of whether the trees can improve small-holder farmers resilience to these extremes. In this chapter, we explore these effects utilizing measured, anecdotal, and observed data collected during an agroecological survey of *F. albida* conducted between May and August of 2009 in western Monze District on the Tonga Plateau of southern Zambia.

This study primarily focuses on our efforts to determine the impact of *F. albida* on saturated hydraulic conductivity (K_{fs}), utilizing a single-ring infiltrometer, including the methodologies employed, preliminary results, and an analysis of those results. We also comment on other impacts of *F. albida* on soil structure gleaned from field observations and farmer interviews, particularly with regards to the influence of termites and cattle traction around the base of the tree. We then summarize these impacts and make suggestions for future research based on our findings.

2. Site description

The Tonga Plateau in the Southern Province of Zambia is a headland that encompasses a triangular-shaped area bounded by the Kafue National Park on the west, the Zambezi Escarpment to the southeast, and the floodplain of the Kafue River to the north (Vickery, 1986). The average elevation of the Plateau is 1000 meters above sea level; visually, the landscape is characterized by gentle undulating hills periodically interspersed with ephemeral streams. The climate is delineated into three distinct seasons: a cool, dry season from May to August; the hot, dry season from August to November; and the rainy season from November to April. Average rainfall during the rainy season is roughly 800 millimeters; however, rainfall exhibits extremes that range from 200 millimeters in 2004/05 to over 1000 millimeters in 2007/08.

In ecological surveys conducted during the colonial era, the landscape of the Tonga Plateau was described as containing a mixture of open-canopy woodlands dominated by species such as *Julbernardia*, *Isoberlinia*, *Coleosperma*, and *Acacia* (Allan, 1946; Trapnell & Clothier, 1957; Storrs, 1979). However, anthropogenic factors including extensive agriculture and cattle herding heavily influence the present ecology of the landscape. As such, most the fields have been cleared of large trees with the exception of isolated stands of *F. albida* or *Adansonia digitata*; land that is under fallow or unused is covered in dense thickets of *Dichrostachys cinerea*. The only place where large trees occur is along field boundaries or cart tracks, where isolated instances of *Poliostigma thonningii*, *Trichilia emetica*, and *Kigelia africana* can be found.

On the Tonga Plateau, soils are generally classified as Luvisols-Phaeozems or Acrisols (GRZ, 1986), which roughly correspond to the USDA classification of Ultisols (Acrisols), Alfisols (Luvisols) or Mollisols (Phaaeozems), exhibiting various levels of argilluviation and base saturation (Buol et al., 2003). These soils also exhibit significant anthropogenic influence because of agriculture; Tonga farmers utilize ox-drawn moldboard plows to annually turn over the soil to a depth of 20 centimeters. Increased land pressure has led to continuous cultivation of the soil with few or no fallow periods; consequently, the repeated plowing at the same depth has caused the formation of indurate layer known as a "plow pan." Furthermore, the repeated cultivation of the topsoil and the removal of crop residues through cattle grazing results in a poorly structured soil with little evidence of aggregation or visible signs of soil organic matter.

3. Theoretical framework and methodology

Saturated hydraulic conductivity or field-saturated hydraulic conductivity (hereafter denoted as K_{fs}) is a quantitative measure of a saturated soil's ability to transmit water when subjected to a hydraulic gradient (driving force for water movement). Alternately, it can be thought of as the ease with which pores of a saturated soil permit water movement based on the size and configuration of soil pores. Flow rate in a pore is proportional to the fourth power of its radius; therefore, larger pores tend to dominate water movement through soil. In general, soils with a higher sand fraction tend to have higher K_{fs} than silt or clay-dominated soils with fewer macropores (Hillel, 1980). However, other factors can also strongly influence K_{fs}; for example, macropores created by root channels, earthworms, or termites can increase K_{fs}, whereas anthropogenic factors such as compaction or tillage may reduce the number of macropores and consequently decrease K_{fs} (Hillel, 1980; Brady & Weil, 2004).

3.1 Measuring K_{fs} under Faidherbia albida

Past experience in rural Zambia dictated that any equipment used for scientific measurements has to be portable, durable, and easily repaired using local resources. For our research, the best fit for this description was the single-ring infiltrometer, from which a series of robust measurements may be derived. In order to determine K_{fs}, we utilized single- and double-ponded infiltration at a steady state flow through the ring at one or more fixed heights (hydraulic heads) above the soil surface (Reynolds and Elrick, 1990). For the majority of the measurements collected, the necessity of carrying water from distant pumps or streams caused us to use the single-ponded depth solution for calculating K_{fs}. However, when water was easily accessed from a nearby stream, we also carried out a single series of tests using the double-ponded depth solutions.

Ten *F. albida* trees were selected for measuring K_{fs} using the single-ring infiltrometer. The trees selected were chosen according to the following site characteristics under and around the tree: uniformity of tillage practices, uniformity of crops grown, and a level soil surface. Basic features of the trees and surrounding area were recorded including: location, height, canopy radius, diameter at breast height (DBH), tillage practices, and crops grown in the past season. For each tree selected, four locations were measured using the single-ring infiltrometer. These locations were measured from the trunk of the tree in fractions of a third of the tree's canopy radius; therefore two sites under the tree's canopy were at distances of one-third and two-thirds of the canopy radius from the trunk, whereas the two sites outside the tree's canopy were at distances of four-thirds and five-thirds the canopy radius from the trunk (Figure 1).

In the case of the single-ponded depth measurements, the following procedure was carried out for each location. First, excess surface debris (e.g. grass, maize stover, seeds) was initially cleared from the soil surface. The ring was pounded into the soil using a slide hammer, an iron plate, and a level to ensure the soil ring was inserted to a uniform depth of five centimeters. Bentonite clay was then lightly sprinkled around the inner edge of the ring to reduce infiltration adjacent to the cylinder walls. A small plate with three supporting legs was then placed within the ring on the soil surface. This plate prevents surface disturbance when adding water and holds the water ponding depth references. The legs were lightly pressed into the soil to ensure the plate surface was level at a height of 4 centimeters above the soil surface. Following the placement of the plate, 10 liters of water were applied to the ring to initially saturate the soil. Once the water in the ring fell to a height of 3.5 centimeters above the plate surface, a fixed volume of water (100, 250, or 500 milliliters) was poured into the ring and a timer was started. Once the water level dropped to the ponded height of 3.5 centimeters, the time was recorded and the same fixed volume of water was poured into the ring. This step was repeated until the flux of water (mL/s) through the ring had stabilized. Recorded data was later processed using the using the solution for a single-ponded depth proposed by Reynolds and Elrick (1990).

For double-ponded depths, a nearly identical process was used. However, once flux from the ring had stabilized at the 3.5 centimeter ponded depth, water was applied to the to bring the head 9.5 cm above the plate. Fixed volumes of water were to maintain that height were added and timed identical to the process outlined previously until flux from the ring at the higher ponding depth had stabilized. This recorded data was then processed using the two-ponding depth solution from Reynolds and Elrick (1990).

Measurements were conducted during the cool, dry season (June through August). During this period, there is little agricultural activity in the fields, as the maize harvest is usually completed by the first two weeks of June. Aside from continual cattle grazing that removed or knocked down crop and weed residues, there was no apparent change to the soil surface. Furthermore, this period corresponds to the flowering and fruiting stage in the phenology of *F. albida*; biomass deposition is limited to flowers being blown out of the trees' canopies following their dehiscence. Aside from shading effects under mature trees, direct impacts of the trees on the soil surface appeared to be minimal.

3.2 Observational Data and Farmer Narratives

Observational data was gathered during infiltration testing, visits to farmers' fields, and transects of the landscape conducted on days when interviews with farmers were not scheduled. In most cases, these transects consisted of walks paralleling the local watercourse, where *F. albida* were growing in a variety of conditions. Also included in transects were three non-consecutive days of following local cattle herds as they grazed across the landscape. Inspection of termite influence was carried out through visible observation and excavation of soil pits around the base of four trees.

Anecdotal evidence was gathered from individual interviews conducted with 30 individual households and two group interviews with 15 married women in the three adjoining villages that comprised the research area. These interviews were based off a semi-structured schedule of open-ended questions that queried the households' farming endeavors and their use of *F. albida*. These interviews were carried out with the assistance of a local translator who was conversant in both English and ciTonga.

4. Results and discussion of the influence of *Faidherbia albida* on K_{fs}

Use of either the single- or double-ponded measurements did not indicate clearly that presence or absence of the tree affected K_{fs} for the ten trees sampled (Table 1). Measured values for K_{fs} ranged from 2.25 x 10^{-5} m s^{-1} to 7.9 x 10^{-6} m s^{-1}, which are typical for moderately permeable, well-drained soils (Brady & Weil, 2004). No effect of *F. albida* on soil infiltration was captured by the measurements. In the following sections we discuss the factors that contributed to the inconclusive measurements of K_{fs}.

4.1 Site variability

In the field setting of western Monze District, the selection of test sites with uniform site characteristics was limited due to logistical constraints. Though a number of sites with similar features (e.g. tree and canopy dimensions, soil texture, tillage and cropping practices) were identified during the course of the research study, many of these proved difficult to test given their distance from readily available water supplies or from our base of operations during the research survey. Consequently, sites were selected based on logistical accessibility rather than on uniformity of characteristics such as soil, tree size, or the previous season's crop. This introduced a significant amount of variability between each of the selected sites.

Tree size and age was the most readily apparent difference among sites. Among the ten sites tested, two trees exhibited rounded crowns that suggested an age of greater than 20 years, and only one was a mature tree, exhibiting the tilted crown indicating advanced age (Fagg, 1995; Rhoades, 1995; Barnes & Fagg, 2003). The remainder of the trees tested were less than 20 years old and featured narrow fastigiate crown habits that cast transient shading on the soil surface, compared to the older trees that formed a complete shade canopy. The cumulative effects of shading of the younger trees on the underlying were less apparent than more mature trees. For example, mature trees were observed to have few perennial grasses or shrubs growing under their shade canopy, whereas young trees did not visually affect the growth of neighboring plants. Furthermore, we observed that mature trees had greater termite pedoturbation of the soil, particularly close to the tree trunks. This pedoturbation was readily evidenced by termite mounds arising from the base of these trees, and in the case of one mature tree, a pedon of surface soil with higher clay fractions (determined through hand texturing) in the midst of a field dominated by sandy soils. Excavation of soil profiles within pedon revealed multiple instances of termite activity, such as tunnels, galleries, and fungal nests.

Soil surface hardness also varied across sites, which limited our ability to drive the infiltrometer into the soil. Upland sites where maize had been cultivated frequently featured soils with a very hard Ap layer. Though a number of attempts were made to test these sites, they were abandoned because their high strength precluded driving in the infiltrometer ring. Consequently, the sites that were tested were those with less indurate surfaces layers that had either comparatively higher sand fractions in the Ap layer, or where the Ap layer had been broken to harvest sweet potatoes or groundnuts.

Tillage practices also exerted a strong influence on infiltration measurements. Out of the ten sites tested, seven had undergone continuous conventional tillage for at least 30 years with ox-drawn plows to a depth of 20 centimeters. In these sites, there was a distinct plow pan formed from the repeated scraping action of the plowshare. This pan often created infiltration patterns under the infiltrometer that were deformed; rather than water infiltrating downward, most of the water appeared to be moving laterally through the soil surface. At one site, the deformation was not caused by a plow pan, but rather by the abrupt transition from the cultivated topsoil (A_p layer) to the much denser subsoil (B layer). This layer was so dense that attempts to excavate it with hand tools failed. Wuest (2005) suggests that shallow infiltration measurements in dry soils with plow pans are affected by lateral flow of water rather than gravitational movement. Conversely, three sites were tested in a field where the landowner utilized a Magoye ripper to penetrate the plow pan. In these sites, excavation of test sites revealed less lateral flow and more gravitational movement of water (see Figure 2).

The most recent crop grown also likely influenced crop measurements. In three of the ten sites tested, groundnuts had been grown, whereas maize was grown in the other seven sites. Harvesting of groundnuts requires digging up the pods of the plant from the soil surface, whereas maize stalks and roots are left in situ on the soil surface. The disturbance of the soil surface caused by harvesting the groundnuts broke up the top eight to ten centimeters of the topsoil. This artificial disturbance above the plow pan also contributed to excessive lateral movement of water during infiltration tests, and likely affected measurements.

4.2 Equipment limitations

As mentioned previously, the single-ring infiltrometer is appropriate for testing infiltration in field setting given its durability and simplicity; however, its use is predicated on readily available water sources, as its usage requires significant volumes of water. Water constraints often influenced selection of testing sites, because the time spent transporting water by foot to otherwise ideal sites rendered them logistically impractical.

The difficulty accessing water also caused us to rely on the single-ponding depth solution rather that the double-ponded depth solution for calculating K_{fs}. The key difference between these solutions is that the former utilizes a shape factor based on the texture of the soil being tested to determine K_{fs}, whereas the latter solution derives K_{fs} independent of this shape factor. We were not able to accurately determine soil texture in the field, nor have we received the texture measurements of soil samples submitted to the University of Zambia. Therefore, we had to assume soil texture based off our observed data, which we lowered our confidence in the measurements of K_{fs}.

Another limitation of the single-ring infiltrometer was the design of the plate we employed. The massive structure of the topsoil often prevented the feet of the plate from penetrating the soil surface when setting up the equipment. However, once the soil surface had saturated, the plate often settled deeper when fixed volumes of water were added to the ring. This reduced the ponding depth, and introducing error into estimates of K_{fs}.

5. Observed and anecdotal influences of *Faidherbia albida* on soil physical characteristics

Observations carried out during infiltration testing and field visits, combined with farmer narratives of *F. albida*, suggest that there are multifaceted effects of trees due to termite pedoturbation and cattle congregating under the trees. In this section, we outline these affects and their possible implications on soil characteristics under and adjacent to *F. albida* tree canopies.

5.1 Termite pedoturbation

In the course of our observations, we noticed that a significant number of mature trees had termite mounds surrounding the base of the trees. Given the cooler soil and air temperatures because of shading effects under mature trees, termites appear to prefer these areas for mound construction. The formation of these mounds, and associated burrowing and gallerying by termites acts as a mechanism for pedoturbation of the soil profile through the translocation of clay particles to the soil surface (Young, 1998).

Macropores created by termite activity could drastically impact infiltration rates. In three separate test sites, we unknowingly placed our infiltrometer on these tunnels; consequently, any volume of water poured in into the rings drained away faster than could be measured. Previous research suggests that termite-induced change in soils increases infiltration, particularly in crusted soils (Mando et al., 1999; Abe et al., 2000). However, associations of *F. albida* with termites have not been extensively researched outside of growth characteristics of trees relative to their proximity to termite mounds (Geiger et al., 1994).

In light of short duration of our study, it was difficult to determine if mature trees with complete shade canopies create microsites that are preferred by termites, or if the trees preferred the same soil characteristics as termites. However, we noted that in many cases, small termite mounds were often located very near to or surrounding existing mature trees. Though we did could not determine whether the trees or the mounds had developed first, the close association of the small mounds near mature *F. albida* suggested some association between the two species.

An interesting manifestation of termite activity we observed that suggested the tree created ideal conditions for termites was the occurrence of fungal gardens directly beneath some mature *F. albida* trees. In typical settings, termites create relatively impermeable mounds over the fungal masses (Trapnell et al., 1976). However, we noted three cases where the fungal masses were located immediately beneath the soil surface next to the buttress of the trees' roots. In fields where cultivation has been continuous for long periods, repeated plowing around the base of the trees creates small, elevated islands of undisturbed soil that appear to emulate termite mounds in function by covering the fungal masses. The anthropogenic manipulation of soil around the trees appeared to create microsites that were ideal for termite nests.

Farmer narratives revealed that soil from termite mounds was perceived as being more fertile than adjacent soils. Two female heads-of-households described using these soils as a substitute for fertilizer; apparently, soil is removed from mounds and applied directly to small areas. However, no association of termites with *F. albida*, or their apparent effects on soil texture or infiltration under tree canopies was reported in any of the household interviews. This may have been a result of our interview schedule, which did not directly query these associations.

5.2 Cattle influences

A few farmers commented that in some cases, initial infiltration of early rainfall was improved under *F. albida* canopies relative to soils outside the canopy. The reasons for this improved infiltration were not elaborated upon by these farmers, with one exception: one head-of-household explained that cattle congregating under the trees in large numbers tend to loosen soil surface through their hoof action. He surmised that this breaking up of the surface allowed early rains to soak into the soil under *F. albida* canopies more readily than surrounding areas.

The trampling action of cattle is typically characterized in the literature as increasing the bulk density and lowering infiltration rates of soils because of hoof compaction (Warren et al., 1986; Abdel-Magid et al., 1987; Bettridge et al., 1999). However, these studies focus on managed and unmanaged rangelands that are continuously grazed. On the Tonga Plateau, cattle graze in fields only during the dry season, and are herded to communal grazing area at the beginning of the rains. Soils in fields were observed to be relatively massive, with poor structure. Thus it seems unlikely that cattle trampling could further increase bulk density through compaction; also, there is a strong possibility of surface infiltration being improved through hoof action that disturbs the otherwise massive soil surface.

5.3 Stemflow

Three farmers interviewed suggested that *F. albida* influenced soil moisture in two ways. They said that the trees' roots ameliorated dry spells by bringing water to the soil surface; conversely, they suggested that the tree root structure allowed excess water to drain downward, preventing the "drowning" of crops. Interestingly, these farmers had all received formal training on *F. albida* from a local Zambia National Farmers' Union agent, whereas other farmers who had not attended trainings did not mention these effects.

In the case of soil moisture, research conducted in Malawi shows that available water content is higher in the top 120 centimeters of soils under mature *F. albida* canopies relative to soils outside the canopies during the rainy season; however, the reason for this phenomenon has yet to be described (Rhoades, 1995). As for drainage, we could find no evidence in the literature of *F. albida* root channels influencing excess water movement.

6. Recommendations for future research

Our measurements of soil infiltration under *F. albida* canopies revealed a number of strengths and weaknesses of the single ring infiltrometer as a tool for measuring K_{fs}, given the significant variability among test sites, logistical constraints, and equipment limitations. Furthermore, observed and anecdotal evidence suggests that soil physical characteristics are highly influenced by factors such as termite activity and cattle herding. In this section, we recommend alterations to the testing regimen for single-ring infiltrometers in order to improve future measurements of K_{fs} under *F. albida* in field conditions. We also suggest avenues for future research that would better explain the effects of *F. albida* on soil physical properties.

6.1 Improvements in testing K_{fs} using the single-ring infiltrometer

Given our limited time and budget, logistical constraints had a major effect on both how many sites could be tested and how those sites were tested. Assuming a scenario where more time and resources were available, we would suggest that local assistants be hired to help transport water to sites. This would allow a wider array of sites to select from and also allow the use of the more accurate double-ponded depth solution to determine K_{fs}. Having more sites to gather infiltration would expand the dataset to include subsets of locations based on trees' characteristics (e.g. age and size), the previous season's crop, and tillage practices that would create a more nuanced view of *F. albida* trees' effects on infiltration.

Thorough pre-wetting of the soil surface and plow pan may make it possible to install the ring in sites where high soil strength precluded measurements. However, care must be exerted to avoid excessive disturbance of the soil surface that might influence infiltration measurements. Also, this would require an ample supply of water that would add to logistical overhead. Therefore, it might behoove researchers to investigate these sites during the rainy season, when soil might be more easily penetrated.

Measuring water movement through dry soils with an underlying plow pan could be further investigated in two ways. First, addition of soil dye to fixed volumes of infiltrating water could help visually determine how plow layers affect water movement (Wuest, 2005). The use of dyes would also help characterize preferential flow of water under ponded conditions, particularly in the case of termite macropores (Ghodrati & Jury, 1990). Second, in sites where plow pans are prevalent because of continuous cultivation, successive infiltration tests at progressively deeper ring depths would help determine how downward water movement affected by plow pans. Executing a series of test above, through, and below the plow pan might reveal differentiation between K_{fs} in successively deeper layers to clarify if low pans impede infiltration. We would recommend that the ring not simply be driven deeper into the soil profile due to possibly deforming the ring; instead, a fixed depth of soil would be excavated and the ring would be driven to the same depth for each test. Progressively deeper layers in a nearby site would then be excavated and successively tested (Figure 3).

Finally, the use of a plate which sits directly on the soil surface is subject to changes in height as soil becomes saturated should be replaced by a plate that is suspended from the upper rim of the ring. This would remove the possibility of head height changing in the course of infiltration testing. Furthermore, if the plate were suspended from the rim of the ring in a fixed position, ponded height measurements would be simplified (Figure 4).

6.2 Suggestions for future research

The evidence of termite activity observed under mature *F. albida* canopies points to significant modification of soil profiles by termite pedoturbation. Field studies conducted in west Africa revealed that termites increase infiltration and reduce bulk density of soils (Mando and Miedema, 1996; Mando et al., 1997). Furthermore, termite mound soils have been shown to have markedly different levels of soil fertility from adjacent soils, particularly with regards to cation exchange capacity, macronutrient availability, and carbon storage (Trapnell et al., 1976; Wood, 1988; Black & Okwakol, 1997; Jones, 2009). Further investigation of how termites interact with mature *F. albida* in field settings could provide insight into how the trees influence soil properties.

Another avenue of research would be a longitudinal study of Tonga cattle herding practices and their affect on soil infiltration under mature *F. albida*, particularly during the hot, dry season (August through November) and into the beginning of the rainy season (November and December). Observations and measurements to estimate cattle preference for certain trees or locations, cattle density under trees, and the impact of hoof trampling on soil surface characteristics would determine whether initial infiltration increases or decreases as a result of cattle interaction with the trees.

Finally, it must be noted that the research study took place at the beginning of the dry season (late May) and extended through the remainder of the cool, dry season (June through August). During this period, the *F. albida* trees are not used by cattle for shade or fodder, leaves remain on the trees, and little agricultural activity occurs that would influence soil properties. A study such as this conducted during a comparatively more active period in the annual cycle of the tree (October through December) could clarify interactions with cattle, leaf litter, and tillage. A long-term study incorporating infiltration measurements may show seasonal variation between soils under and adjacent to *F. albida* canopies that we were unable to capture during our research.

7. Conclusions

Given site variability, the limited number of test sites, and logistical and equipment limitations, we were unable to conclusively determine the influence of *F. albida* on soil hydraulic conductivity. As such, we have suggested a number of recommendations for future use of the single ring infiltrometer in field conditions typical of southern Zambia.

Though we were unable to specifically address the question of hydraulic conductivity, our research did yield a number of possible reasons for *F. albida* trees' influence over soil characteristics, particularly with regards to termite pedoturbation and the influence of cattle around mature trees. Future research into these aspects would help to further inform the long-term impacts of *F. albida* on soil properties and how those impacts affect the overall resilience of farmers who include the trees in their farming systems.

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Figures:

Figure 1. Infiltration testing setup.

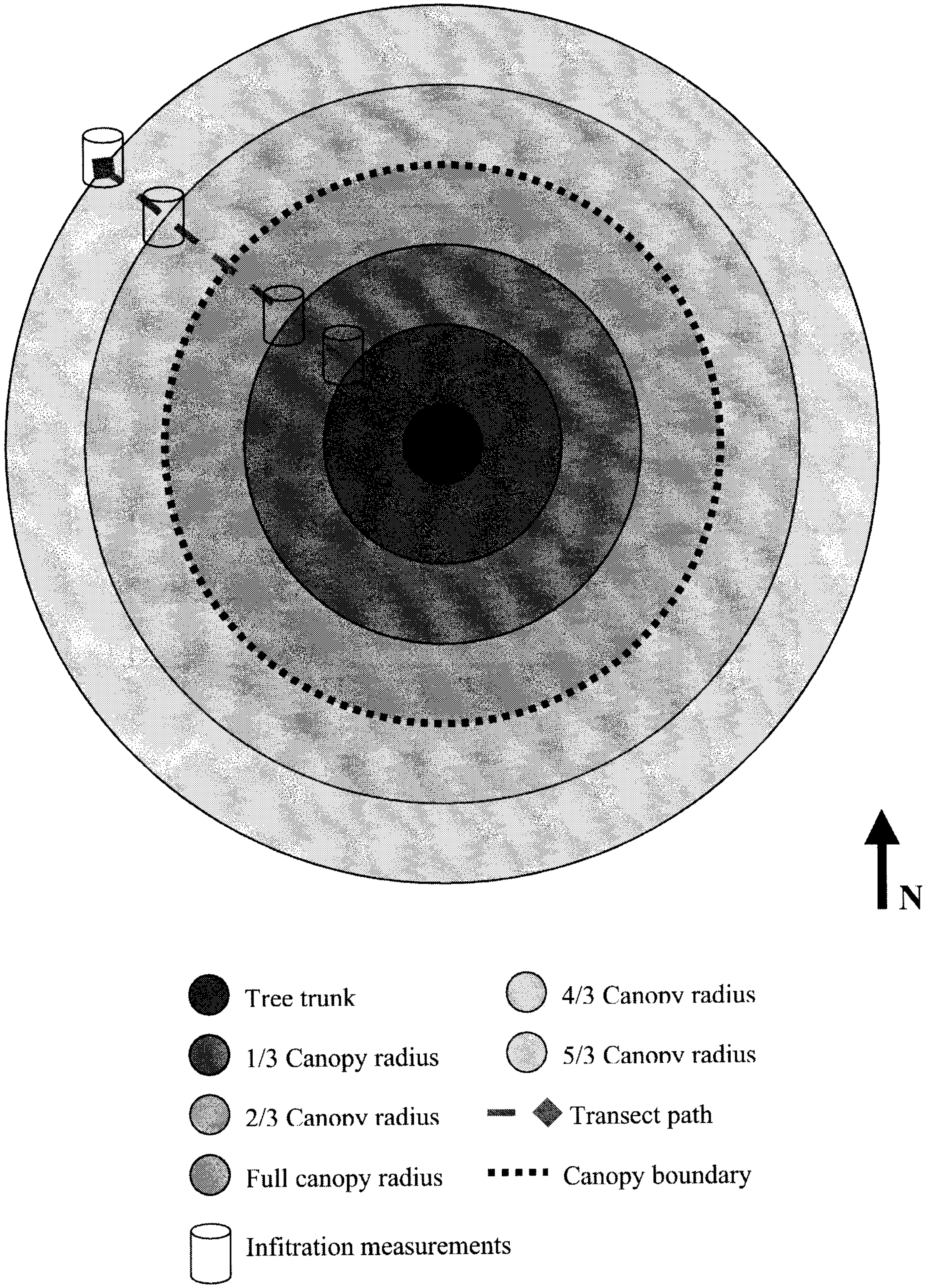


Table 1. Field saturated hydraulic conductivity (K_{fs}) as measured using one ponding depth; values in parenthesis are normalized values compared to average K_{fs} outside of tree canopies.

	1-3	2-3		4-3	5-3	
Tree #:	**Kfs (m/s)**	**Kfs (m/s)**	**Avg. K_{fs} (m/s) IN**	**Kfs (m/s)**	**Kfs (m/s)**	**Avg. K_{fs} (m/s) OUT**
1	3.50E-05 (0.76)	3.66E-05 (0.80)	3.58E-05 (0.78)	2.88E-05 (0.63)	6.32E-05 (1.37)	4.60E-05 (1.00)
2	7.21E-05 (1.27)	1.50E-05 (0.26)	4.35E-05 (0.77)	8.87E-05 (1.56)	2.48E-05 (0.44	5.68E-05 (1.00)
3	3.85E-05 (0.72)	3.20E-05 (0.60)	3.53E-05 (0.66)	5.49E-05 (1.02)	5.24E-05 (0.98)	5.37E-05 (1.00)
4	2.25E-05 N/A	2.39E-06 N/A	1.25E-05 N/A	N/A	N/A	N/A N/A
5	2.72E-06 (0.21)	3.94E-06 (0.30)	3.33E-06 (0.26)	1.89E-05 (1.46)	7.02E-06 (0.54)	1.30E-05 (1.00)
6	8.03E-06 (0.78)	7.78E-06 (0.75)	7.90E-06 (0.76)	1.04E-05 (1.00)	(0.00)	1.04E-05 (1.00)
7	2.25E-04 (3.74)	2.24E-04 (3.72)	2.25E-04 (3.73)	7.79E-05 (1.29)	4.25E-05 (0.71)	6.02E-05 (1.00)
8A	7.15E-05 (1.59)	6.51E-05 (1.45)	6.83E-05 (1.52)	6.51E-05 (1.45)	2.47E-05 (0.55)	4.49E-05 (1.00)
9A	2.98E-05 (0.98)	6.16E-06 (0.20)	1.80E-05 (0.59)	2.59E-05 (0.85)	3.51E-05 (1.15)	3.05E-05 (1.00)
10A (BN)	1.97E-05 (3.99)	7.17E-05 (14.56)	4.57E-05 (9.28)	3.07E-06 (0.62)	6.78E-06 (1.38)	4.93E-06 (1.00)
10B (BN)	1.44E-05 (0.56)	1.27E-05 (0.49)	1.36E-05 (0.52)	3.05E-05 (1.17)	2.15E-05 (0.83)	2.60E-05 (1.00)

Figure 2. Deformation patterns resulting from indurate layers underlying A_p layer of soil. Grey shaded oval bounded by dashed line represents approximation infiltration pattern in ripped soils; grey arrows reflect approximate water movement in plowed soils.

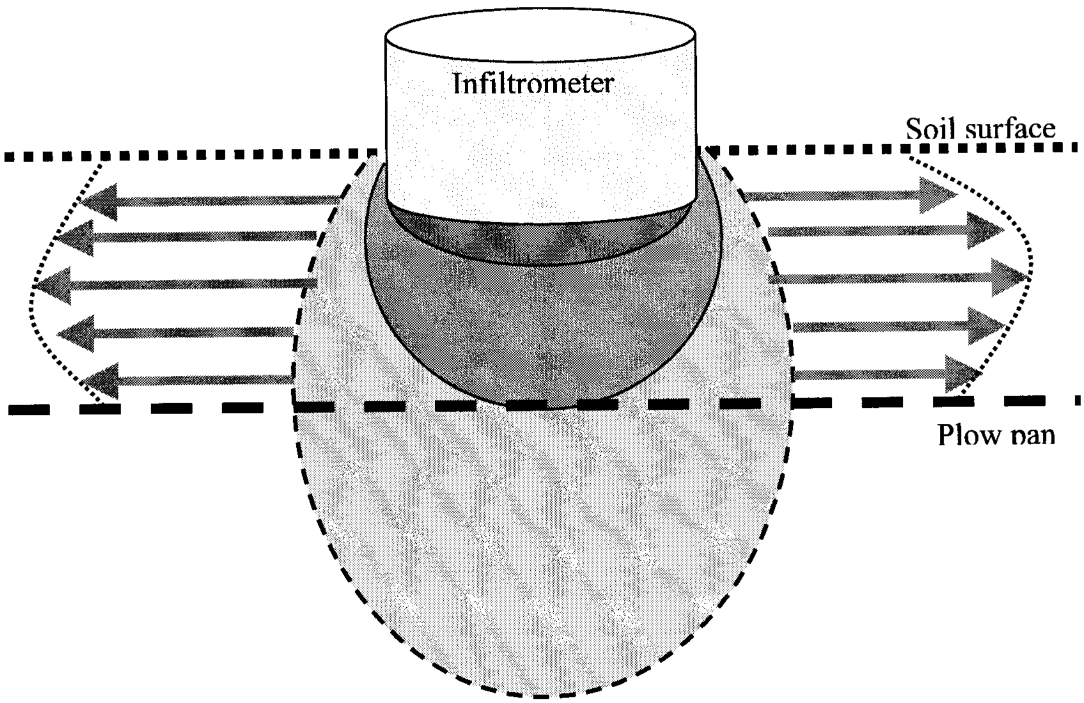
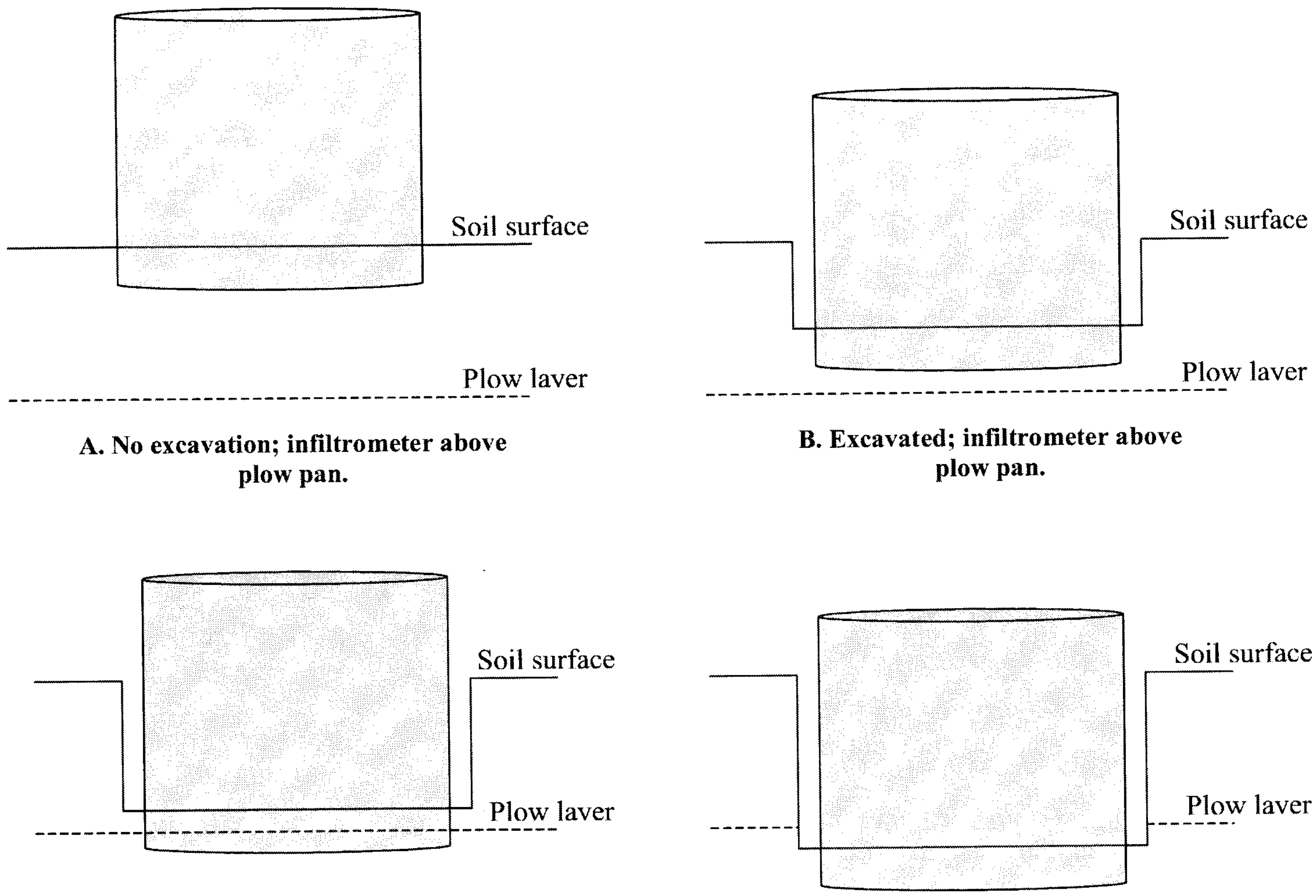


Figure 3. Testing of successively deeper soil layers relative to the plow pan.



A. No excavation; infiltrometer above plow pan.

B. Excavated; infiltrometer above plow pan.

C. Excavated; infiltrometer through plow pan.

D. Excavated; infiltrometer below plow pan.

Figure 4. Suggested modifications to existing plate structure. Existing plate structure with supporting "feet" (left); suggested modification by suspending plate from the infiltrometer rim and removing plate "feet" (right).