Title: The potential for *Acacia saligna* Agroforestry farming systems in Tigray Ethiopia.

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Abstract:

The dryland regions of Tigray in Ethiopia are in great need of environmental restoration and innovations to improve food security. This paper outlines progress with the domestication and multi-purpose development of *A. saligna* for use in Agroforestry farming systems such as farm borders, small farm enclosures, compounds and community enclosures. The naturalised *A. saligna* in Tigray is highly outcrossing and genetically diverse with high potential for rapid improvement. *A. saligna* is easy to establish, drought tolerant, nitrogen fixing, coppices, produces valuable fodder for livestock, fuelwood and timber and seed for poultry and potentially human food. Trial results show good progress in the selection and development of multi-purpose and pole types. *A. saligna* and *A. glaucocaesia* were the most promising species at a lower rainfall site. Further research and development is required to quantify the economic and environmental benefits of *A. saligna* in agroforestry applications and to develop optimal silvicultural management practices to facilitate adoption and uptake by smallholder farmers. The principles and practice of the Farmer Managed Agroforestry Farming System are suggest as a vehicle for rapid Agroforestry scale up on farms in various agro-ecological zones of Tigray and other regions of Ethiopia.

Introduction

The Tigray region is one of the most degraded and food insecure regions of Ethiopia. There has been extreme environmental degradation evidenced by the loss of trees, grasses and general biodiversity. Low and declining soil fertility with high soil erosion rates, climate change, crop pests and diseases, high population growth, limited arable lands and lack of land ownership are all challenges that contribute to food insecurity. (Rinaudo and Admasu, 2010). In spite of the many challenges to food insecurity, there have also been significant efforts at environmental restoration which is a key foundation to sustainable and productive agriculture. The creation of vegetation enclosures covering at least 1.2 million hectares of mostly hilly land has been significant in recent decades. One of the main tree species planted in these enclosures is *Acacia saligna*. Although generally known as a conservation species, the recently completed project *"Acacia species for Food security and Environmental rehabilitation is the dryland areas of Northern Ethiopia"* (2010- 2014) has identified the valuable multi-purpose benefits of this species including, animal and bee fodder, sustainable fuelwood and timber, improved soil fertility and high protein seed for poultry and potentially human food (Anon, 2014) This paper outlines the type(s) of *A. saligna* naturalised in Tigray, current and future uses, together with progress in domestication, development and the significant potential for various agroforestry applications.

A.saligna **in Tigray**

A. saligna was first introduced into Tigray in 1972 and has shown outstanding performance in the rehabilitation of degraded lands due to its rapid establishment and growth, drought tolerance and nitrogen fixation (Rinaudo and Admasu, 2010). Most of the *A. saligna* in Tigray is found in enclosed areas and in household compounds where large mature trees provide shade. The naturalised type of *A. saligna* in Tigray is highly variable for a range of phenotypic characters and there are no records of what types of *A. saligna* were introduced (Cunningham, 2011). An important starting point in any domestication and development program is to identify the genetic makeup of the localised type(s). There are no formal taxonomic descriptions of the genetic entities present in the *A. saligna* species complex, but geographic descriptors have been assigned to informal subspecies names and at a broad level comprise subspecies *stolonifera, saligna* and *lindleyi.* At a finer level the *saligna* subspecies has also been divided into subspecies *stolonifera*, the Western *saligna* and Eastern *saligna* entities, the Northern *lindleyi* entity and the remaining populations of the subspecies *lindleyi*. (Millar et al. 2011). More recent taxonomic research indicates that the variation in *A. saligna* is best accommodated by four subspecies- *saligna, pruinescens, lindleyi* and *stolonifera* which have consistent differences in bud morphology. (Maslin et al., 2011)

In order to determine the genetic entities and levels of diversity in the localised *A. saligna* in Tigray, phylode samples were taken from individual trees (12) in four diverse enclosures (1. Adishehu; 2. Abreha Atsbeta; 3. Haikimeshal; 4. Bizert) and from trees (10) in the TARI compound in October 2011. These samples were then processed by the Department of Environment and Conservation in Western Australia for genomic DNA and genotypes obtained using five diagnostic microsatellite loci (Millar and Byrne, 2007) to differentiate the genetic structure of *A. saligna*. The results showed that in general there was a high degree of genetic diversity and heterozygosity within enclosure populations. On a broad level, most of the *A. saligna* individuals were identified as the informal subsp. *lindleyi* with some individuals from subsp. *saligna* and others with mixed co ancestry for two or more of the broad genetic entities. At a finer level, most of the *A. saligna* individuals were assigned to the Northern and general *lindleyi* entities, with other individuals assigned to Western and Eastern *saligna* and *stolonifera* entities and others with mixed co ancestry (see Figure 1. Millar and Byrne, 2012). These results indicate that there is good potential for rapid progress for the selection of suitable *A. saligna* types from within the localised populations of *A. saligna* for various end uses (e.g. fodder, timber, multi-purpose, and seed). When this material is also combined with the range of *A. saligna* provenances available from Western Australia, there is a high likelihood of success for the rapid development of improved *A. saligna*. It should also be noted that *A. saligna* is a highly outcrossing with random mating and pollen dispersal within the stand (Millar, 2008). Provenance Resource Stands (PRS) and seed orchards should therefore be kept separate to avoid contamination.

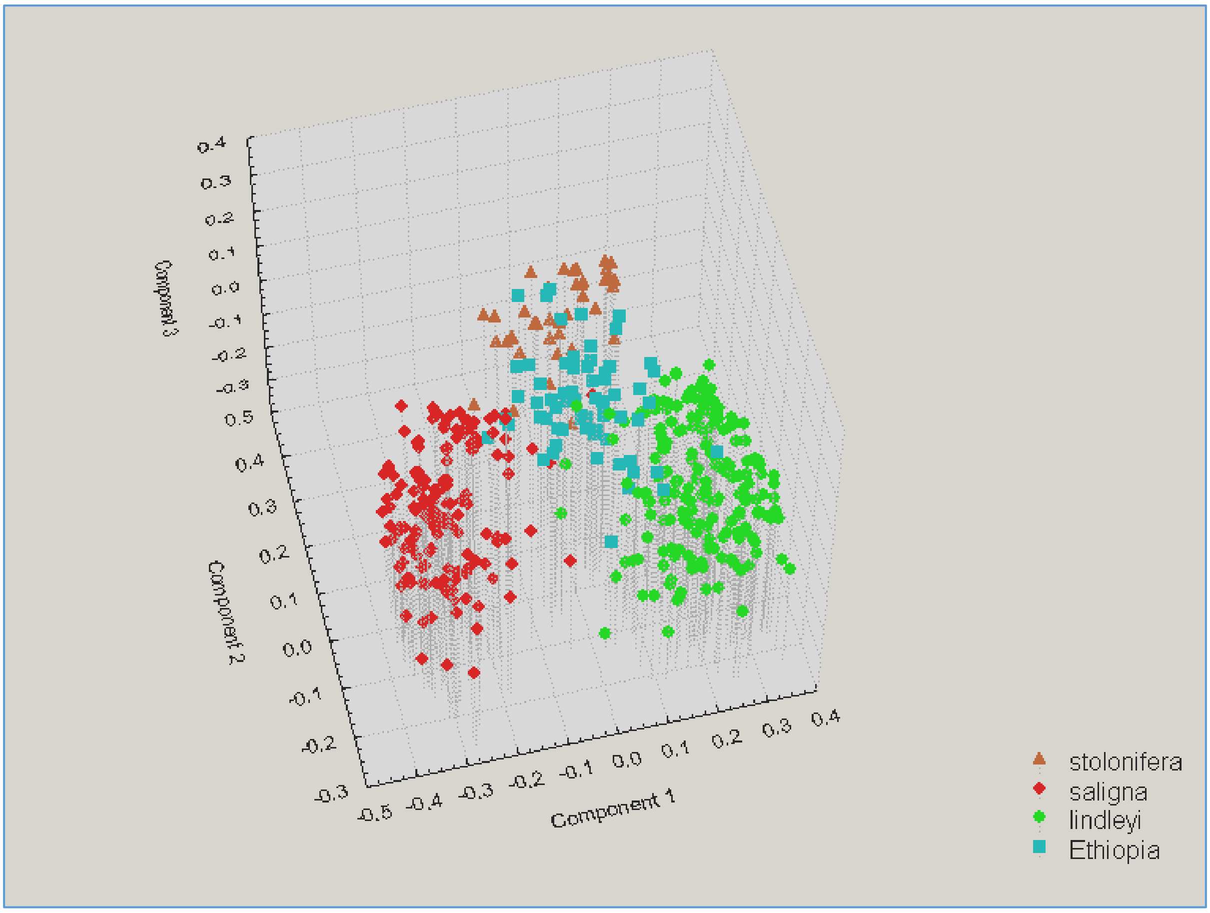

Fig 1. Principal coordinates analysis of *Acacia saligna* 'populations' from Ethiopia and populations of three genetic entities across the native range in Western Australia. (Millar and Byrne, 2012)

Uses of *A. saligna*

The first phase of the *"Acacia species for Food security and Environmental rehabilitation is the dryland areas of Northern Ethiopia"* project has clearly identified the valuable multi-purpose uses for *A. saligna*. Its ease of establishment, rapid growth in low fertility and degraded soils, drought tolerance, good biomass production and nitrogen fixing ability all contribute to its ability to diminish wind and water erosion and hence have high value for land restoration. In addition to these attributes, *A. saligna* foliage provide valuable fodder for small ruminants (Shumuye and Yayneshet, 2011; Gebre, 2011) and its pollen is a valuable source of bee fodder for hive health and enhanced honey production. The wide range of phenotypic forms also give potential to select types for building poles, particle board manufacture, farm tools and sustainable fuelwood via multi-branching types with good coppicing ability. Annual production of high protein seed has potential for poultry production (Anon, 2014).

The Acacia project also demonstrated how *A. saligna* could be successfully used in four Agroforestry farming systems: 1. Farm borders, 1. Small farm enclosures, 3. House compounds and 4, Community enclosures. (Figs. 2-5). Pruning demonstrations on *A. saligna* trees ranging from 3-8 years of age with three farmers research groups (FRG's) in the above four Agroforestry farming systems were completed in May 2014 (Cunningham, 2014 a). These demonstrations with the FRG groups were well received by the communities as trees provided valuable fodder (foliage) at a time of year when fodder was in demand, branches and larger wood that could be used for fuelwood. An example of a five year old *A. saligna* tree is given in Fig 6. A follow up visit to these FRG groups in December 2014 (7 months later) showed excellent recovery and regrowth after pruning for all ages of trees (Cunningham, 2014 b). Regrowth of the same tree given in Fig 6 to given in Fig 7.

Fig 2. *A. saligna* farm border (3 yrs) **Fig 3.** *A. saligna* in small farm enclosure

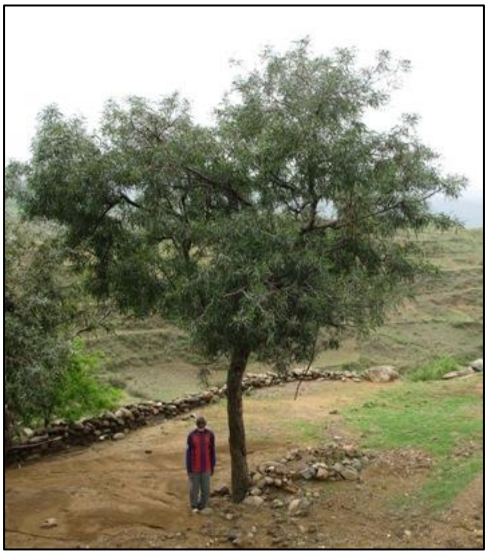

Fig 4. *A. saligna* house compound (6 yrs). **Fig 5**. *A. saligna* in community enclosure (Bizert)

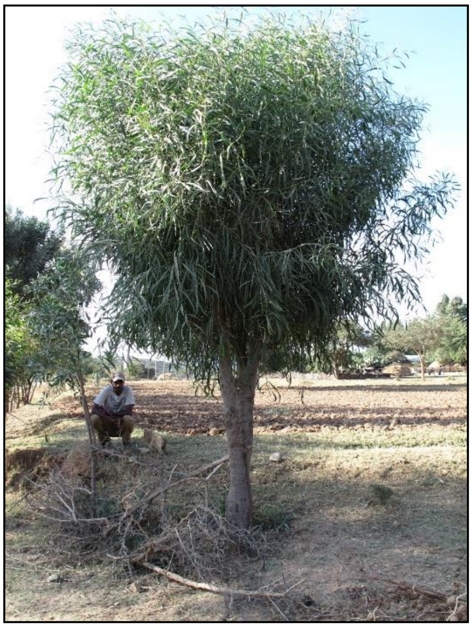

Fig 6. FRG at Abreha Atsbeta with *A. saligna* products. (Foliage, branches, wood). May 2014.

Fig 7. Regrowth after 7 months

Domestication and development of *A. saligna*

There are important principles and practices required for the domestication and development of improved tree types form wild tree types such as *A. saligna*. These include: 1. Deciding on what products and services are required from the trees; 2. A knowledge of the target environment; 3. Selection of appropriate germplasm with a broad genetic base; 4. A knowledge of its breeding system; 5. Conducting appropriate field trials with tree measurements of key selection criteria and 6. Establishing Provenance Resource Stands (PRS) where only elite trees are retained to produce seed orchards of the improved types.

The project team at the Tigray Agricultural Research Institute (TARI) decided that two improved *A. saligna* types for the mid-high (1500-3000m) agro-ecological zones in Tigray would be a useful starting point. 1. Multi-purpose for biomass (fodder), wood and seed; 2. Tall type for poles/wood. A rapid method to develop these *A. saligna* cultivars was applied by selecting the best 20-40 trees in four diverse enclosures (1. Adishehu; 2. Abreha Atsbeta; 3. Haikimeshal; 4. Bizert). Each tree was labelled and seed collected in December 2012, then bulked for each enclosure. In one of the enclosures, Adishehu, tall tree forms were identified and seed collected from 12 trees and bulked. PRS's of spaced trees (e.g. 3x4m), of each of these two localised bulks 1. Bulk of 4 enclosures (234 trees); 2. Tall type- Adishehu (100 trees) were established at TARI in August 2012. Data (tree characterisation) was then recorded for individual trees based on Key Selection Criteria (KSC) such as: adaptability (survival rate), growth rate (tree height/width), growth habit, seed production, coppicing ability, fodder quality and biomass/wood production for at least three years. The best 20-40 trees based on the KSC for each type would then be retained (other trees eliminated) and allowed to inter-pollinate to produce a uniform and improved type. These trees then become the improved seed orchard.

A complementary approach to produce the improved *A. saligna* types was also initiated with the introduction of *A. saligna* provenances from Western Australia. A comprehensive provenance trial (3 replicates of 20 trees) with 10 introduced provenances, two localised bulks and other control species was established at TARI in August 2012 (Table 1.).
A further PRS was also established with the best bet *A. saligna* subsp. Bambun road provenance (252 trees). This has been the most productive *A. saligna* provenance for biomass and seed production in Western Australia (Richard Mazanec, *pers. comm*).

Some results of the *A. saligna* provenance trial are presented in Table 2.
<u>Seedling vigour</u> in the tree nursery was generally good for *A. saligna* provenances with the exception of subsp. pruinescens and all the other comparison acacias species had poor seedling vigour. A growth habit score (May 2014) on the whole trial clearly showed that the Parkeyeering and Muntagin provenances were the most erect types with good potential for the development of pole types. Some trees in these provenances were clearly identified as pole types, reaching 8-10 metres in height after 2 years and 9 months of growth (Fig 8).
<u>Seed production</u> was observed when trees were two years and nine months of age, but was highly variable between replicates. In replicate one, a heavy clay loan soil, 39% of trees has seed, but there was no seed production in replicate two and only 6% of trees has seed in replicate three. All trees in both replicates two and three had much slower growth rates, primarily due to the lower fertility sandy loam soil. Seed production was therefore only estimated in replicate one. All trees were assigned a score (1-9), then a number of trees for each score were randomly selected across the trial and harvested for seed. Regression analysis of score vs actual see weight is in progress. There was significant variation between trees within and between provenances. The standout provenance for seed production was Murchison River with a mean tree score of **8.05** (Table 2). All trees (20) in this provenance were heavily laden

with seed which was uniform in maturity, but approximately 2 weeks later than other provenances.

Table 1. Acacia species and provenances established at TARI, Tigray 2012.

Treatment No.	Species	Subsp.	Provenance
1.	*A. saligna*	lindleyi	Arrowsmith River
2.	*A. saligna*	lindleyi	Mingenew
3.	*A. saligna*	lindleyi	Murchison River
4.	*A. saligna*	lindleyi	Parkeyeering
5.	*A. saligna*	lindleyi	Muntagin
6.	*A. saligna*	saligna	Bambun Rd
7.	*A. saligna*	saligna	Flynn Drive
8.	*A. saligna*	saligna	Lake Coolengup
9.	*A. saligna*	pruinescens	Palmer Block
10.	*A. saligna*	stolonifera	Pruinescens
11.	*A. saligna*	lindleyi	Bulk of 4 enclosures
12.	*A. saligna*	lindleyi	Tall Seln Adishehu enclosure
13.	*A. daphnifolia*		Coorow
14.	*A. microbotrya*		Tincurrin
15.	*A. microbotrya*	Tall form	Dandaragan
16.	*A. baileyana*		Stawell 2011
17.	*A. pycnantha*		Stawell 2011
18.	*A. microbotrya*		Stawell 2011

Biomass was also estimated for all trees in replicate one in late April, 2015. All trees were assigned a score (1-9), then a number of trees for each score were randomly selected across the trial and harvested at 1 m above ground level for Biomass. Biomass was divided into three parts- leaves, small branches and larger wood (Fig 9.). Both fresh and dry weights for each sample were/will be recorded for all tree harvests and regression analysis of score vs actual biomass component weights determined. The Murchison River, Bambun Rd and Lake Coolengup provenances had the highest biomass scores (Table 2).

Table 2. Results of *A. saligna* provenance trial (Rep 1) at TARI, 2012-14**.**

Species	**Subsp.**	**Provenance**	**Seedling vigour score[1]**	**Growth habit score[2]**	**Seed prodn score[3]**	**Biomass score[4]**
A. saligna	lindleyi	Arrowsmith River	7	4.84	3.36	4.8
A. saligna	lindleyi	Mingenew	5	4.78	2.5	3.7
A. saligna	lindleyi	Murchison River	**8**	5.0	**8.05**	**5.7**
A. saligna	lindleyi	Parkeyeering	6	**6.65**	5.0	3.26
A. saligna	lindleyi	Muntagin	6	**6.24**	1.0	3.95
A. saligna	saligna	Bambun Rd	**9**	5.3	2.71	**5.2**
A. saligna	saligna	Flynn Drive	**8**	4.59	1.0	2.0
A. saligna	saligna	Lake Coolengup	**9**	4.8	2.67	**5.1**
A. saligna	pruinescens	Palmer Block	4	5.44	0	4.25
A. saligna	stolonifera	Pruinescens	6	4.72	4.0	2.6
A. saligna	lindleyi	Bulk of 4 enclosures	**8**	5.53	3.69	3.89
A. saligna	lindleyi	Tall Seln Adishehu enclosure	**7**	5.53	2.87	2.88
A. daphnifolia		Coorow	2	5.05	2.0	1.0
A. microbotrya		Tincurrin	2	5.69	0	1.33
A. microbotrya	Tall form	Dandaragan	1	-	-	-
A. baileyana		Stawell 2011	1	5.61	1.0	-
A. pycnantha		Stawell 2011	1	-	-	-
A. microbotrya		Stawell 2011	2	5.4	-	-

1. Seedling vigour score: 1= poor, 9 = excellent.
2. Growth habit score: 1= prostrate, 9 = erect. 6/5/2014. Mean for reps 1-3.
3. Seed production score: 1 = low, 9 = high. Rep 1 only.15/12/2014. *A. microbotrya*- Stawell. Seeded in May 2015.
4. Biomass score: 1= low, 9 = high. Rep 1 only. 29-30/5/2015.

Fig 8. *A. saligna* pole type >10m.

(2 yrs, 9 months)

Fig 9. *A. saligna* Biomass (leaves, branches, wood)

(Tree biomass score = 9).

Data was also collected on the Bulk of enclosures and Adishehu *A. saligna* PRS's.

Seed production was recorded on 28.3 % of the Bulk enclosures trees and on 61.2% of the Adishehu enclosure trees in December 2014. A seed production score (1-9) was also assigned to all trees in these PRS's for comparison. An improved seed bulk (approx. 1 kg) was taken by sampling the best 20 trees (out of 116) that had high biomass and seed production scores of 7-9.

Biomass was also estimated for all trees in both PRS's by assigning a score (1-9).

There was a total of 285 trees in both PRS's. Based on both biomass, seed production and general appearance, a total of 113 trees were retained and pruned to 1 m in height for further evaluation and selection. All other trees (172) were eliminated from the trial.

Acacia development for low rainfall regions of Tigray

There has been considerable interest to evaluate a range of semi-arid edible Australian Acacia species in hot dry infertile regions of Tigray. An Acacia species elimination trial was established at Koraro in July 2013. The site was lower in elevation with approx. 450 mm annual rainfall, a generally hotter climate Than Mekelle and with deep infertile red sandy soils. Thirteen species and 22 seed lots were established in a replicated trial (Table 3). A trial evaluation after 10 months showed that growth and survival of most species was generally poor (37.5 % overall survival rate) with the exception of *A. saligna*. (80-85% survival). In addition to challenges in the tree nursery, a combination of small seedling size at planting, lack of nodulation, rodent damage, weeds, deep sandy soil and lack of adaptation may have all been contributing factors to this result (Cunningham, 2014a). A further trial evaluation after 22 months indicated that *A. saligna* had the best growth and survival (75-80%). *A. glaucocaesia* (50% survival) known for good fodder production had good vigour and was the only Acacia producing seed (Figs. 10, 11). *A. glaucocaesia* also displayed considerable phenotypic variation and is worthy of further testing. There were also isolated examples of *A. victoriae, A. pachyacra, A. adsurgens, A. tumida, A. melleodora* and *A. anuera* with good vigour, probably due to good nodulation? (Cunningham, 2014b).

Table 3. Survival of Australian Acacia species at Koraro (22 months)

Acacia species	**Seed lot type/No.**	**Survival % (22 months)**
A.saligna	Bulk of enclosures	75
A.saligna	Bambun Rd	80
A.micobotrya	Tincurrin	55
A.pycnantha	Stawell 2011	25
A.colei var. colei	WV11-006	50
A.colei var. colei	WV12-09	5
A.colei var. colei	WV12-033	15
A.colei var. ileocarpa	WV12-021	10
A.colei var. ileocarpa	ATSC 18813	5
A.colei var. ileocarpa	ATSC 18817	5
A.tumida var. pilbarensis	WV12-011	40
A.elachantha	WV11-003	25
A.adsurgens	WV11-012	25
A.melleodora	WV12-008	15
A.anuera var. tenuis	WV11-011	25
A.anuera var. tenuis	WV11-016	55
A.steedmanii	WV12-028	40
A.victoriae	WV12-052	25
A.victoriae	WV12-053	25
A.victoriae	WV12-054	20
A.pachyacra	WV12-039	15
A.glaucocaesia	WV12-017	50

ATSC = Australian Tree Seed Centre

Fig. 10. ***A. glaucocaesia*** **(22 months)** **Fig 11.** ***A. glaucocaesia*** **seed production**

Agroforestry farming systems.

There are vast areas of arable and non-arable land in Tigray where Agroforestry farming systems with *A. saligna* could bring underutilized land into production (e.g. Hillsides), help to restore degraded farm land and improve the livelihoods of small scale farmers through sustainable wood production, improved crop production and build farm resilience to climate change. The first phase of the *"Acacia species for Food security and Environmental rehabilitation is the dryland areas of Northern Ethiopia"* project demonstrated how *A. saligna* could be successfully used in four Agroforestry farming systems: 1. Farm borders, 1. Small farm enclosures, 3. House compounds and 4, Community enclosures. (Figs 2-5).

Preliminary pruning demonstrations of *A. saligna* trees within all these Agroforestry farming systems (Cunningham 2014 a, b) with three FRG's showed the potential for sustainable harvest of fuelwood, poles, and fodder. There is now great opportunity to revisit these farming systems to quantify the outputs and multiple benefits of *A. saligna* where trees are in situ. These demonstrations could also be used to determine the best silvicultural practices for maximum outputs from *A. saligna* trees (Fig 12).

Fig 12. Agroforestry farming with *A. saligna* (3 yrs.) on field borders. Mariamagamat.

Whilst improved *A. saligna* types can be grown in small farm enclosures (20-30 trees) and in household compounds, the greatest benefits can be expected from the development of *A. saligna* in integrated farming systems on farmland and enclosure areas. The main agroforestry principles and practices of the Farmer Managed Agroforestry Farming System (FMAFS) (Rinaudo and Cunningham, 2008; Cunningham, 2010) could be followed where Farmer Managed Natural Regeneration (FMNR) (Rinaudo, 2007) is enriched with *A. saligna*, other valuable trees, crops and livestock in an integrated system. There appears to be vast plain and valley areas of Tigray that have been cropped continuously for centuries and that are devoid of trees stumps or seed reserves so FMNR would have limited potential. These areas will require targeted planting and management of various tree species. There is also an estimated 1.2 million hectares of land in protected enclosure areas which are poorly managed (Rinaudo and Admasu, 2010). Many of these enclosure areas have mature *A. saligna* tress which could be pruned and sustainably harvested for fuelwood, fodder and seed.

A significant paradigm shift in land use policy, attitude change to include trees on farmland and field borders and the opening up of enclosures to community management and utilization is required. We estimate that community managed enclosure areas could provide significant amounts of *A. saligna* fodder, and fuelwood. This would enhance livestock production removing the pressure from degraded grazing lands and remove the need to exploit local forests for fuelwood and provide income generation from wood sales.

Conclusions

The foundation for sustainable and productive agriculture in Tigray is a healthy and functioning environment. Whilst much progress has been made through the creation of vegetation enclosures (Hillsides), tree planting and soil and water conservation activities, much more needs to be done to reverse land degradation and improve soil fertility on cropping land. Appropriate management and utilization practices need to be developed for *A. saligna* and the benefits of existing *A. saligna* in enclosure areas quantified. Utilization of *A. saligna* from these areas would provide direct benefits such as fodder, fuel and building timber and encourage the development of integrated Agroforestry farming systems with *A. saligna* on farmlands.

Our preliminary results indicate good progress in the domestication and development of improved *A. saligna* types for Agroforestry applications. Further selections and assessment of

A. saligna provenance trials are still required to ensure the best genetic resources are identified and PRS's can be established to produce orchards of improved types for seed production and wide dissemination to smallholder farmers. This ongoing development together with the quantification of the economic and environmental benefits of *A. saligna* in various Agroforestry farm demonstrations, refinement of silvicultural requirements and management should provide confidence for wide scale up and out. Where possible, the vast and now treeless Tigrinyian farming landscapes could be transformed with FMNR and fast growing *A. saligna* in integrated Agroforestry farming systems using FMAFS principles and practice. There would also be significant potential for adaptation of these farming systems to a range of agro-ecological zones in Tigray and other regions of Ethiopia.

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Annex 1. The Farmer Managed Agroforestry Farming System (FMAFS).

The Farmer Managed Agroforestry Farming System (FMAFS) (Fig 1.) is an Integrated Agroforestry farming systems developed in Niger as a whole farm system to overcome the main limitations to farming in the fragile Sahelian climate. It represents an incremental gradation into a more complex farming system, offering more benefits than Farmer Managed Natural Regeneration (FMNR) for enhanced food security and reduced vulnerability to famine. The FMAFS builds on the strengths of FMNR and is an alley cropping, agro-pastoral forestry system which incorporates a wide range of annual and perennial, indigenous and exotic plant species and livestock. The diversity in its design makes it flexible enough to meet individual farmer's varying needs and priorities.

Figure 1. A typical FMAFS in Niger with Acacias, FMNR and annual crops.

In the FMAFS, farmers determine the density and layout of tree plantings and annual crops and the types of indigenous and exotic trees. The foundations laid by FMNR are complemented by the introduction of other species including a range of fast growing multi-purpose Australian Acacias which produce wood and seed. The Acacias are planted along farm borders and in rows within the farm, providing human and animal food, firewood, timber, mulch, environmental restoration and crop protection. (Fig. 2.) Australian Acacias have high tolerance to drought and low susceptibility to most African crop pests and diseases.
Other valuable agroforestry species are used in FMAFS such as Pomme du Sahel (*Ziziphus mauritania*), Tamarind (*Tamarindus indica*), Boabab (*Adansonia digitata*) and Moringa.
Annual cash crops such as millet, sorghum, cowpeas, peanuts, hibiscus, sesame and cassava are planted in rotation between the tree rows, providing food and fodder and income. Crop residues are used as mulch for soil improvement and protection.

The FMAFS provides significantly increased farm income compared to traditional millet farming or to FMNR alone, and more diversity in income sources. Farm labour inputs and income are also spread much more evenly across the year instead of being concentrated within a four month period. As with FMNR, the biomass produced by the trees counters the impact of low soil fertility and water stress by providing mulch and soil organic matter as well as protection from winds and fuel for firewood Implementation of FMAFS results in greater insurance against total crop loss during adverse events such as drought, insect attack or storms because not all species and products will be equally disadvantaged by the same event in a particular year. This biologically diverse farming system also tends to offer a range of habitats for beneficial predators of crop pests. Hence the FMAFS assures a minimum income every year, even when annual crops fail.

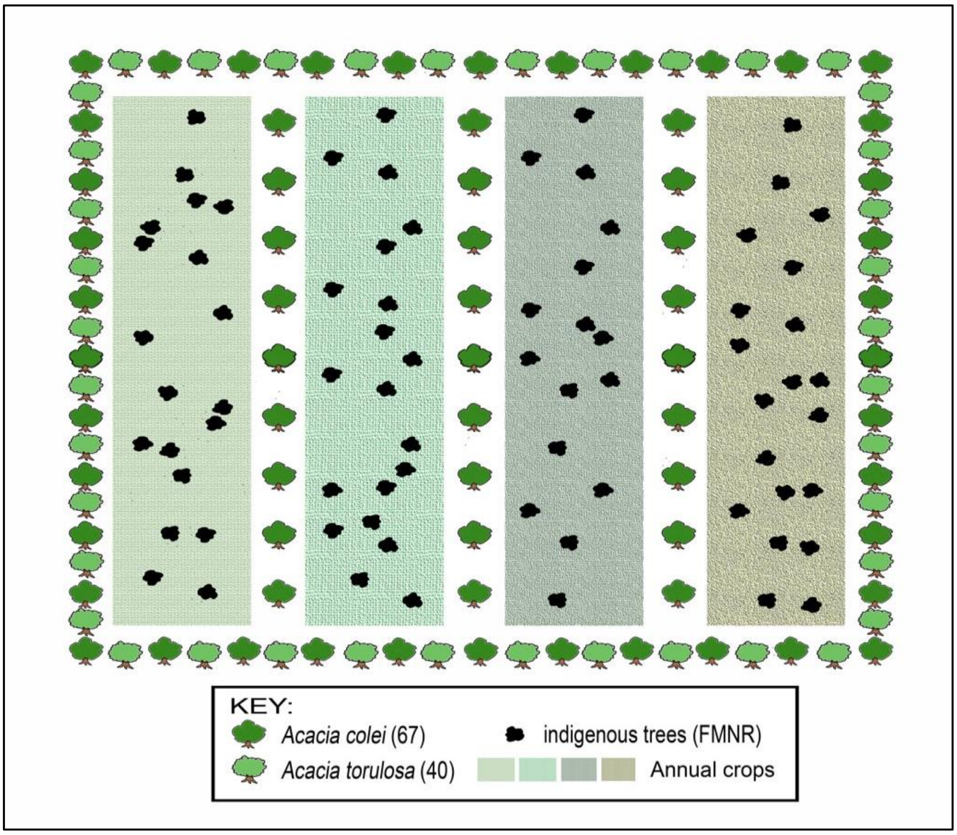

Figure 2. The Farmer Managed Agro-forestry Farming System, one hectare model. Trees on the boundary are spaced 5 m apart. Trees inside the borders are planted 10 m apart in rows with 25 m between rows. The rows of trees are oriented across the prevailing wind direction. Total number of acacia trees =107 per ha. Shaded area: FMNR with 40 to 120 trees per ha and annual/perennial crops in rotation.