Potential of *Tephrosia candida* for Restoration of Degraded Lands and Fuel Wood Production in Western Ethiopia

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Abstract
The challenges in restoration projects are to find potential and compatible tree and shrub species to start and scale up them in a way that will have a clear effect at the landscape level while these species can help to achieve climate-smart agriculture's "triple wins" of increasing rural incomes and biomass energy supply. This study aimed to examine the potential of Tephrosia candida as a species for degraded farmland restoration thereby to evaluate its biomass for fuel wood and local energy source. There are 3 locations where each location has 6 plots. Each plot contains 25 plants with 2m*2m spacing. Composite soil sample, plant height, DBH, survival rate, dry weight, crown cover, number of branches and time of seed collection were collected. Growth performance of Tephrosia candida was very fast which showed about 15cm height and 0.26cm diameter increment monthly, and its survival was 100% at all sites. Averagely 1.5 branches/Month recorded while crown cover increased accordingly, and on average 25 main branches and 38 secondary branches, and each shrub weigh 22.22kg on average when dried. Each Tephrosia's crown cover was 16.25m2 on average. Analysis of composite soil sample and after 3 years of implementation soil pH increment observed in all locations, accordingly, soil pH at Diga improved from 4.89 (before) to 5.22 (3 years after implementation). We recommend Tephrosia candida for fast restoration purposes and farmland fuel wood producing species to cover the increasing fuel wood demand due to its high potential of both restoration and high biomass production.

Keywords: Biomass energy, fuel wood, restoration, Shrub species *Tephrosia candida*

1. Introduction
1.1 Restoration and its limitations
In most developing and developed countries, the issues of energy, food and shelter demands and supplies are mainly depended directly or indirectly on natural resources, specially, on forest and land resources which is especially true for poor and vulnerable rural communities where land is often the most important asset, and land itself and other natural resources are under risk of degradations (IPBES, 2018; FAO and UNCCD 2022) [25, 12]. On the other hand, rapidly increasing population, deforestation, growing food waste and declining soil fertility are posing serious challenges to humanity for future food security where the land degradation must be solved (Gupta, 2019) [18]. As a result, currently, degradation of the Earth's land surface through human activities is negatively impacting the well-being of at least 3.2 billion people, loss of biodiversity and ecosystem services (FAO 2021, IPBES 2018) [25]. Achieving restoration of degraded lands can provide multiple benefits in terms of improving livelihoods, increasing bioenergy sources, empowering women and youth, and enhancing both biodiversity conservation and climate change mitigation and adaptation (FAO and UNCCD 2022, FAO 2018) [12].

The challenges in restoration projects are to find potential and compatible tree and shrub species to start and scale up them in a way that will have a clear effect at the landscape level while these species can help to achieve climate-smart agriculture's "triple wins" of increasing rural incomes, biomass energy supply, making agricultural products more resilient in the face of climate extremes, and making agriculture a solution to the climate change problem rather than part of the problem (Dewees *et al*., 2011) [8].

Africa is one of the most vulnerable continents in the world. It has over 700 million ha of its land already degraded, and degradation still occurs at an alarming rate of 3% annually. This offers tremendous opportunity for restoration. In the last two centuries, humans have converted or modified 70% of the world's grasslands, 50% of the savannah, 45% of the temperate deciduous forest, and 27% of the tropical forest biome primarily for farming and grazing activities (FAO 2021). In twenty years (1985-2005), the world's croplands and pastures expanded by 154 million hectares (Ray *et al*., 2012) [39]. This expansion has dramatically increased food production (Mansourian *et al*. 2015) [43, 34], but at the expense of many life-supporting ecosystem services on which our wellbeing, and that of future generations, depend (Duguma *et al* 2019) [35]. Agriculture and fuel wood are estimated to be the proximate driver for more than 80% of deforestation and land degradation worldwide (Kissinger and Desy, 2012) [30], which are likely to continue in order to meet the projected increases in demand for food, energy and water in the next decades (FAO 2021, FAO 2018). In 2016, Ethiopia faced the worst drought in fifty years that affected more than 10 million people (FAO, 2018). Although some articles discusses that over the last 20 years, the scale of restoration of degraded land through soil and land conservation and tree planting in Ethiopia is noteworthy, there are still tremendous land degradation continues in most parts of the country in general, and specifically in western parts of Ethiopia.

Tephrosia is a genus of leguminous shrubby plants and herbs mostly found in tropical countries (Blommaert, 1950). The plant is established easily from seeds (Barnes and Freyre, 1969) [1]. The foliage is often ashy-pubescent, hence the name *Tephrosia* (Gadzirayi *et al*. 2009) [16]. Tephrosia can be grown to improve soil fertility, for firewood, as an insecticide against storage pests and mites on plants. It is best species in open grazing areas, because goats and other animals usually do not like to browse the trees, and it is also quite resistant to termites (Garrity *et al*. 2010; Munthali *et al*. 2014) [17, 36].

1.2. Biomass energy demands and natural resources management

In sub-Saharan Africa countries, over two-thirds of the households use wood as their main fuel for cooking, heating and water boiling. In Africa, demand for wood is likely to continue where in Sub Saharan Africa, fuel wood dominates the use of wood, as it is the most important energy source (FAO 2017, De Miranda *et al*. 2013) [6], and the fuel wood consumption in Africa is predicted to increase in the consecutive decades from 2000 (FAO 2017; Sepp *et al*. 2014; Hoffmann *et al*. 2016; Sander *et al*. 2011; Dewees *et al*., 2011) [8, 42, 22, 41].

Whatever lands are chosen, bioenergy can strengthen the economic case for restoration (IRENA 2017) [27] while the worldwide use of bioenergy has been increasing greatly in recent years (IEA Bioenergy, 2016; IRENA, 2016) [24, 26], which was mainly driven by an increase in demand for low-carbon energy. For this purpose, there are different potential fuel wood plants, native and nonnative, which are acquired from the forest reserve or from people's homes and farmlands (Kaburi and Medley 2011) [29], while these plants differ by their material uses, attributes as a fuelwood, and ease of propagation (Fischer et al., 2012) [14]. Therefore, in our study, an on-farm experiment was established in 2020 in western Oromia, Ethiopia to examine the potential of *Tephrosia candida* as a species for degraded farmland restoration thereby to evaluate its biomass for fuel wood and local energy source as it can minimize burdens on natural forest resources in the 3 locations of the study area.

2. Materials and Methods

An on-farm experiment was established in 2020 in western Oromia, Ethiopia, and the three locations were Bako, Diga and Wayu Tuqa districts of western Oromia. The selected locations are where soil acidity is very high and land degradation is very severe. From different species of Tephrosia, *Tephrosia candida* was used here. We planted 150 Tephrosia plants in each location where there were 6 plots on each. Each plot contains 25 plants with 2m * 2m spacing.

All data including initial composite soil sample, growth parameters (height, DBH, survival rate), dry weight, morphological expressions (crown cover, number of branches) were collected, and an average data from each location were taken for further analysis.

3. Results and Discussion

3.1. Growth performance, dry weight and crown cover of *Tephrosia candida*

Data collection and measurement of its growth performances starting from germination were carefully conducted. The growth performance of *Tephrosia candida* was very fast which showed about 15cm height and 0.26cm diameter increment monthly, and its survival was 100% at all sites. Emergences of branches were averagely 1.5 branches per Month while crown cover increased accordingly. This performance of the tephrosia shrub will make it very potential for fuel wood and fast facilitation of restoration which also agree with Mafongoya and his colleagues finding, which says, at three months after planting, tephrosia exhibited good initial growth with the fastest growth with 138 cm, and wood biomass yield produced after nine months of growth was highest among other shrub species for *Tephrosia candida* (Mafongoya *et al*., 2003) [31]. Due to its fast growing and many branches bearing in short duration of time, tephrosia is preferably recommended for the purposes of restoration and bioenergy production at farmers level in which it can be used as an improved fallow agroforestry practices. This issue was briefly discussed in Christersson *et al*., (2006) [5], and in their finding they pointed that high biomass production, which could be influenced by man, include the choice of tree species, provenances and clones, together with good resistance to insects, fungus, virus and browsing animals and hardiness to frost and drought, where it is important to use trees species, proveniences and clones that have the potential for a rapid and dense canopy development where a design of the plantation is of great importance, and we recommend for such demands to use the *Tephrosia candida* shrub. Additionally, its fast growing habit is better than other leguminous and nitrogen fixing shrubs that it is also concluded better than *Leucaena leucocephala* and *Gliricidia sepium* species in Odedire and Babayemi (2007) [38] and

Makumba and Phiri (2008) [32] studies respectively.

A data collected after 3 years of planting showed that *Tephrosia* could bear on average 25 main branches and 38 secondary branches, and each Tephrosia shrub can weigh 22.22kg on average when dried. And also, each *Tephrosia's* crown biomass can cover the area of 16.25m2 on average (Tab. 1). In line with different studies and findings of many researchers, because of high demand and high consumption degrees of fuel wood in Africa, especially, in the sub-Saharan Africa countries, and also to fulfill the need of fast and high biomass bearing tree and/or shrub species, using tephrosia species is highly recommended by the current finding. This result can also contribute to Van Loon 2017 [46], IUCN 2016 and the Bonn Challenge findings and worries, which were highly described that the degraded lands are challenging and economically unattractive for food crop cultivation, biomass plantations with high-yielding wood or grass species can allow bioenergy and also can help to restore and reclaim such lands to be extracted without conflicting with food production thereby improve carbon storage. Additionally, growing wood on degraded land can further serve to curb unsustainable wood extraction from local forest resources (Van Loon, 2017) [46]. The best initiative of the Bonn Challenge, for example, provides a great opportunity to unlock the potential of degraded land which put its goal to a global endeavor to restore a total of 350 million hectares (Mha) by 2030, where 150 Mha projected by 2020, and another 200 Mha by 2030. Accordingly, 18 sub-Sahara African countries have pledged to restore some 75 Mha through AFR100, where the African Forest Restoration initiative aiming to regenerate 100 Mha (http://www.bonnchallenge.org/, Van Loon, 2017, IUCN 2016) [46].

Table 1: Morphological Expression of *Tephrosia candida*

Location	Plot No	Dry weight (kg)	Crown cover			Branch No	
			Radius(m)	R2(r*r)	Area(m2)=3.14* R2	Main	2ndary
Bako	1	22	2.3	5.29	16.61	26	37
Bako	2	21	2.2	4.84	15.20	25	38
Bako	3	24	2.5	6.25	19.63	27	38
Bako	4	23	2.3	5.29	16.61	24	36
Bako	5	22	2.3	5.29	16.61	26	39
Bako	6	21.5	2.1	4.41	13.85	25	37
Average		**22.3**	**2.3**	**5.2**	**16.4**	**25.5**	**37.5**
Diga	1	21	2.1	4.41	13.85	23	35
Diga	2	22.5	2.3	5.29	16.61	22	36
Diga	3	21	2.1	4.41	13.85	25	38
Diga	4	20	2.1	4.41	13.85	24	35
Diga	5	21	2	4	12.56	22	36
Diga	6	19	2.2	4.84	15.20	23	34
Average		**20.75**	**2.13**	**4.56**	**14.32**	**23.17**	**35.67**
Wayu Tuqa	1	19.5	2.5	6.25	19.63	24	37
Wayu Tuqa	2	21	2.35	5.5225	17.34	26	36
Wayu Tuqa	3	20	2.3	5.29	16.61	26	37
Wayu Tuqa	4	23	2.4	5.76	18.09	24	35
Wayu Tuqa	5	21	2.3	5.29	16.61	25	37
Wayu Tuqa	6	20.5	2.1	4.41	13.85	24	38
Average		**20.83**	**2.33**	**5.42**	**17.02**	**24.83**	**36.67**

3.2. Comparison of Growth Performance at the 3 Locations

Tephrosia candida shows well performance and 100% survival at all locations. There were no significant difference among dry weight biomass, crown cover, and sprouting of main and secondary branches (Fig. 1).

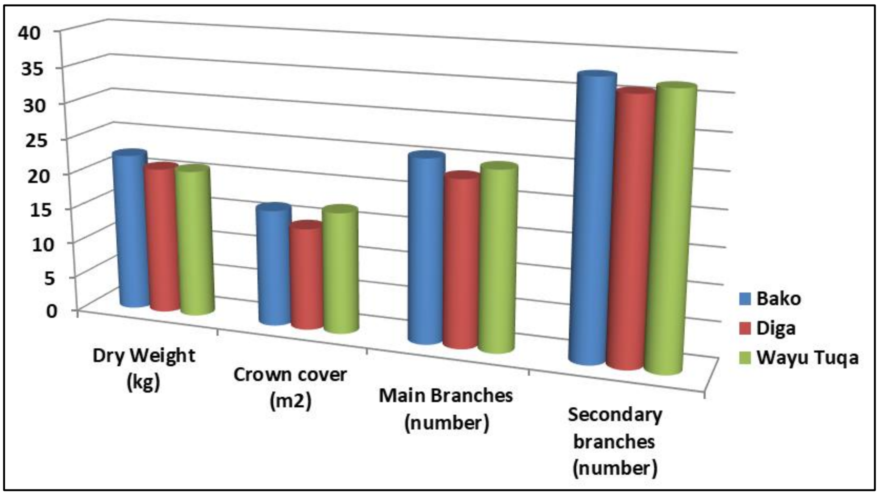

Fig 1: Graph of growth performances in all the 3 locations

From this graph, we can conclude that tephrosia can be well grown uniformly in different acidic and structurally different soil type areas, because these locations have different soil structures, fertility status and soil acidity levels.

3.3. Soil acidity improvement

Tephrosia candida is a shrub species with crowded crown and a shallow root which has very fast potential or ability to soften a compacted soil. Soil features under old tephrosia shrub is very soft, composted and looks better for production (Fig. 2). Composite soil sample (before tephrosia planting) was taken and pH values were analyzed. We also collected and analyze soil sample after 3 years of implementation, and its result shows that there is soil pH increment in all locations, for example, soil pH at Diga improved from 4.89 (before) to 5.22 (3 years after implementation) (Tab. 2). This result agrees with the findings of many studies who were explaining that tephrosia can be grown to improve soil fertility, for firewood, as an insecticide against storage pests and mites on plants, and it is also quite resistant to termites (Garrity *et al*. 2010; Munthali *et al*. 2014) [17, 36].

Table 2: Soil pH values before and after tephrosia plantation

Location	Soil pH before implementation	Soil pH after 3 years
Bako	5.11	5.47
Diga	4.89	5.22
Wayu Tuqa	5.16	5.51

From the table, we can understand that restoring degraded and acidic soil with tephrosia shrubs, and using them as an improved fallow can improve soil acidity problems thereby can improve vegetation survival even on the highly acidic soils within short period of improved fallow times. This was also discussed in the findings of Garrity *et al*. (2010) [17] and Munthali *et al*. (2014) [36] that tephrosia roots, leaves and seeds contain high amounts of nutrients, especially nitrogen, which is necessary for good plant development, and when the trees are cut and the leaves worked into the soil, these nutrients can be used by the plants that are grown after Tephrosia in the field.

Fig 2: Photo of old and failed *Tephrosia candida*, taken by the first author

From the picture, we can observe that whatever the soil from the beginning, tephrosia will soften the soil after few years and might be left the land for other agricultural activities so that it will be failed and used as a fuel wood.

3.4. Seed Collection and Handling

Tephrosia can in many ways be used just like pigeon pea, and seed harvest, storage and sowing are done in the same way. After collection of brown pods and threshing it, it is better to dry the seeds for at least 3 to 4 days under shade. In western Oromia, peak seed production is between November and February. However, it can bear to produce smaller quantities of seed throughout the rest of the year.

4. Conclusion and Recommendations

Over the last 20 years, the scale of restoration of degraded land through soil and land conservation and tree planting in Ethiopia is remarkable, however, there are still tremendous land degradation continues in most parts of the country in general, and specifically in western parts of Ethiopia. Potential species selection for restoration and multifunctional purposes is still challenging in most cases and many restoration projects are facing low survival rate of seedlings after planting. *Tephrosia candida* is a shrub species with crowded crown and a shallow root which has very fast potential or ability to soften a compacted soil even in acidity soils and high above ground biomass production. Restoring degraded and acidic soil with tephrosia shrubs, and using the shrub species as an improved fallow could also improve soil acidity problems and also can improve vegetation survival even on highly acidic soils within short period of times. Tephrosia is seen quite better in growth performance, survival rate, reclaiming soil acidity, dry biomass provision and softening compacted soils than other shrub species. Additionally, since it is not as palatable as other forage shrubs which attract goat, sheep, cattle and other browsing wild animals it is very potential for restoration activities, especially in open grazing countries like Ethiopia. Its seed can be collected and handled simply and it has seen that there is no germination problem for further production. Its fast growing performance and its short life cycle which support the shrub to rotate a farmland where it had been grown to any other crop production magnifies its demands. Therefore, this finding recommends *Tephrosia candida* shrub species for restoration of farmlands, and fuel wood production purposes within short period of time.

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