Review

Positioning fruit trees into climate change/variability scenarios: Opportunities and constraints in the placement of fruit tree species in payment for environmental services

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Extreme environmental conditions due to climate change or variability are a threat to crop production, productivity and livelihoods. Thus, providing alternative livelihoods to communities, especially the rural masses remain an important catalyst in reducing poverty, food insecurity and deforestation in the development of climate change/variability scenarios. This is critical in southern Africa where poverty, deforestation rate and food insecurity are high. These are challenges that rural development programs abating impacts of climate change/variability must address. Planting trees including those outside the forest has been a possible climate change mitigation or adaptation measure. Surprisingly, planting fruit trees have been given little attention and have always aligned to food security, but not their contribution to carbon sequestration and payment for environmental services (PES). There have been limited research studies quantifying carbon sequestration capacities in diverse fruit tree species. This contributes to low profile of fruit tree species in carbon trading. While the emphasis has been on forest trees, those trees outside the forest have also a role to play, especially with proper fruit orchard management systems and propagation protocols that maximize carbon reservoirs. This paper reviews the role of fruit trees in the context of carbon quantities sequestered and the reasons they should be considered in PES or better still carbon trading. It is envisaged that proper fruit tree orchard management practices and propagation protocols can be designed to increase carbon sequestration, while gaining some socio-economic benefits. We hypothesize that proper management of fruit trees offers an opportunity to extend and maximize fruit productivity and carbon storage over a long period. This provides a diverse development option within the framework of climate change/variability mitigation/adaptation. Planting fruit tree species presents many opportunities, but there are still limited documented research studies and piloted projects on any form of PES, especially carbon trading. It is clear that many research studies are warranted to quantify carbon storage within diverse fruit orchards and under different management systems.

Key words: Carbon storage, climate variability, dwarfing, grafting, tree biomass.

INTRODUCTION

The reality of climate change and variability has become evident as the livelihoods of many communities are being adversely affected, especially its negative impact on agriculture and natural resources in Africa (Eriksen et al., 2008). Increasing high temperatures, frequent droughts and floods in the tropics have become severe and disastrous. These natural disasters have negative impacts on water supplies and food availability. Extreme climatic conditions and associated crop diseases have negatively affected food supplies in the tropics (IPCC,
1996). Luckily, some countries or regions have indigenous plant resources and also a few well adapted exotic tree species which could be harnessed to address the impact of climate change/variability and meet the needs of local people in terms of food and income sources. Such plant resources include fruit trees.

Fruit trees, which are 'trees outside the forest', have been given little attention in climate change- a potential for carbon sink. There are management options which could be designed to increase carbon reservoirs in tree biomass and soil within a fruit orchard setting. In the meantime, carbon trading and other forms of payment for environmental services (PES) mainly focus on forest trees. The potential of fruit trees in carbon sequestration and environmental services remain unexploited. This could be partially attributed to limited research studies on carbon storage in diverse woody fruit trees, effects of different propagation protocols on amount of carbon stored within a fruit orchard and different management systems. Fruit orchards can positively contribute to a sustainable development under climate change scenario in the tropics considering the current expansion of agriculture and high level of poverty (FAO, 2010) which continue to shrink forest resources. It is almost certain that agriculture and human settlement expansions and high wood biomass (charcoal production) demand will continue despite the efforts of governments and other organizations threatening to stop them.

**Literature review**

We reviewed a number of publications on carbon storage by fruit tree species and other livelihood benefits derived from them. Our literature search included online published articles comprising journal papers, book chapters, online newsletters and websites. At least 20 publications were reviewed. Since there has been limitation in publications on carbon sequestration with respect to fruit tree species and based on propagation protocols, tree spacing, and tree age among other factors, we also calculated tree biomass of a few fruit trees using Brown (1997) method to elucidate our argument.

**LIVELIHOODS FOR SOUTHERN AFRICA**

Many countries of southern Africa have less technical, institutional and financial capacities to adapt to climate change (IPCC, 2002), and hence it is unlikely that the region can cope with extreme environmental conditions unless there are better climate change mitigation and/or adaptation strategies. It is predicted that production of maize, a staple food for many countries of southern Africa will decline by 10% (Jones and Thornton, 2003). Over the past 25 years, the population of food-insecure people in eastern and southern Africa has increased by 80%, while per-capita cropped area has declined by 33% (Funk et al., 2008). Worse still, many countries of southern Africa have little capacity to irrigate crops and their relatively high human population growth rate increases food shortages (Malawi Government, 2009). This requires a better strategy to ensure food sufficiency. Governments and other organizations often explore measures to mitigate/adapt to climate change/variability amidst some indigenous strategies that might address the impacts of climate change/variability. One main focus has been tree-based technologies that maximize carbon sink. Carbon dioxide (CO₂) has been singled out as a main culprit in climate change issues. Excess CO₂ in atmosphere spells catastrophes for the earth, especially in the tropical and subtropical areas where climate change/variability is expected to be detrimental to crop productivity. Temperatures are expected to be either too hot or low for optimal crop productivity, and hence many countries are unlikely to cope with such extreme temperatures (IPCC, 1996). Furthermore, variability in temperatures and rainfall from one year to the next makes adaptation difficult (Funk et al., 2008). It will be an added advantage if nutrition, food security and income from such tree based technologies are realized.

**LAND-USE SYSTEMS AND TENURE**

Fruit trees are becoming abundant on cultivated fields and around people’s homes. They form a great proportion of trees on homesteads in many rural and urban dwelling places. Fruit orchards occupy 54% of homesteads in Nigeria although such homesteads are usually less than a hectare (Degrande et al., 2006). They further reported that farmers plant many fruit trees to increase the density on their farms in response to a decrease in availability of tree products off-farm. According to Lars (2005), almost every household in Malawi owns some exotic fruit trees which are on homesteads and cultivated fields. In Zimbabwe, about 20% of total woodland resources used by rural households are wild fruit trees (Campbell et al., 1997). Collectively, these small and fragmented fruit orchards occupy a bigger land area. Thus, individual smallholder farmer tree planting system accumulates small amounts of carbon, but on a per area basis store significant amounts of carbon. Again, their abundance on homesteads and cultivated fields could reduce pressure on forest resources. Planting trees has remained the cheapest, most effective and valuable way of CO₂ removal from atmosphere (The World Bank, 2002; www.coloradotrees.org), but food insecurity and low income in southern Africa have led to a high deforestation rate (Roy et al., 1996; The World Bank, 2004).

To our knowledge, research studies to establish the potential of diverse fruit trees as mitigation/adaptation
measure to climate change/variability are limited, especially in the tropical and subtropical regions where trees have a great potential as carbon sinks (www.coloradotrees.org). As food insecurity still remains a challenge, tree-based technologies for climate change mitigation/adaptation have also to address this problem. This is where fruit trees may play a vital role in both food security and carbon sink.

CLIMATE CHANGE AND FOOD SECURITY

Inclusion of fruit trees into agricultural lands and homesteads can increase carbon sink just like other trees. Other countries, especially southern Africa have set aside national tree planting day and inclusion of fruit tree species in such tree planting programs could increase community participation in such tree planting programs. Apart from diversified livelihoods, fruit trees also provide environmental protection and increased biodiversity of cultivated plants despite a little attention from researchers (FAO, 2000).

As fruits are valuable sources of food and income in many rural communities, people are motivated to plant them around homesteads and cultivated fields. However, there have been a few studies to establish the capacity of fruit tree species in CO₂ sequestration and the best way to include them into PES. Furthermore, the trade-offs between the value of fruits for food security and sale, and the potential value of carbon needs thorough research studies. A farmer can benefit from food and income, and also from carbon credits. It is critical to exploit diverse and feasible mitigation and/or adaptation options that do not impinge on food production and fruit orchards provide that option. Henry et al. (2009) reported that increasing on-farm C stocks in areas with high population density can impinge on food security unless those increases are targeted in home gardens where fruit trees are often planted. In this case, woody fruit tree species can play a vital role in carbon storage.

Fruit trees remove CO₂ from atmosphere and assimilate it into their cellulose, reducing accumulation in the atmosphere through photosynthesis just like any other tree. Diverse fruit trees and adaptable species and cultivars to harsh environmental conditions can be selected to exploit their capacity in carbon sequestration.

DEFORESTATION

High deforestation rates contribute to CO₂ concentration into atmosphere. About 33,000 ha of forest cover have been lost between 2000 and 2010 in Malawi and 444,800 ha per annum of forest cover were lost in 2006 in Zambia (Stringer et al., 2012). Generally, farmers consume more wood than they plant and this significantly contributes to dwindling of forest resources. The presence of fruit trees on homesteads and cultivated lands offers some benefits towards tree biomass demand. Pruning fruit trees could provide farmers with wood biomass energy, considering that fruit trees in homesteads are larger than those in commercial fruit orchards as they are not pruned or trained. Again, there has been inadequate knowledge to manage them as horticultural crops on homesteads and this practice leads to an increase in tree biomass with time. This can be ideal as there is an expanded carbon sink and such projects may be marketed under a voluntary carbon market, supported by the commercial sector as a method of demonstrating corporate social responsibility. It is expected that many fruit trees derived from seedlings are vigorous in growth stature, and this requires pruning of unnecessary branches. However, not all trees derived from seedlings have high biomass compared to other types of propagules. Thus, a choice has to be made based on propagation protocol.

FRUIT TREE CULTIVATION

Amidst the huge demand for forest products and services, many farmers in southern Africa retain important fruit trees as they prepare land for farming (Packham, 1993; Shackleton, 2004; Leakey, 2005; Mng'omba et al., 2007). This practice and a deliberate fruit tree planting around homesteads can contribute to increased number of trees. This presents an opportunity to exploit fruit trees on cultivated fields and homesteads as coping measure for the impact of climate change/variability.

There is a potential in the tropics and subtropical to utilize fruit trees to offset some levels of CO₂ emissions. To improve our understanding, there is need for research studies. For instance, on tree morphology, propagation methods and physiology (growth rate) to establish carbon sequestration capacity over time and optimal tree management practices for effective fruit productivity and expansion of carbon sink. Obviously, propagation protocols influence tree growth and structure and hence needs evaluation as they influence the total tree biomass which has a bearing on carbon quantities sequestered.

CARBON STORAGE

Carbon in trees can be stored in trunks, branches, leaves, flowers, fruits and roots. Schaffer et al. (1999) reported that exposure of tropical and subtropical fruit trees (avocado, banana, mangosteen, citrus and mango) to elevated concentration of CO₂ significantly increased the rate of photosynthesis and consequently an increase in tree biomass. Photosynthesis in mangosteen increased by 40 to 60% when exposed to 800 ppm for one year compared to when exposed to ambient CO₂ concentration (Schaffer et al., 1999). They also reported
that elevated CO$_2$ either increased fruit yield and weight in some trees or increased carbon allocation to roots. This indicates that fruit trees could play a vital role in removal of CO$_2$ from atmosphere. Prolific flowering and fruiting abilities of trees increase carbon removal from atmosphere and store substantial amount of carbon as cellulose (Bickford, 2007).

Krishnamurthy and Indumathi (2009) calculated carbon storage in a citrus-banana orchard mixture. Based on 45% biomass estimation, a maximum total of 2.16 tons of carbon per hectare was stored in orchard mixture of citrus and banana from 2001 to 2003. Although the study did not indicate the contribution of each fruit tree species, it is unlikely that banana can sequester more than citrus, a woody tree. Some fruit tree species producing a lot of biomass (e.g. mango and avocado) can sequester more carbon than citrus, especially considering tree biomass accumulation and life span. Mango and avocado are widely grown in eastern and southern Africa. From 1999 to 2008, southern Africa annually produced slightly more than 75,000 tons of mango and avocado fruits (FAOSTAT, 2009). During the same period, eastern Africa had an average annual production of 157,000 and 958,000 tons of avocado and mango fruits, respectively. These figures indicate large production area of mango and avocado. Carbon sequestration schemes can be considered in such large fruit orchards. Further research studies are justified to quantify carbon amount sequestered by different fruit tree species.

Generally, a mature mango tree produces millions of flowers annually, but many drop to the ground (http://gears.tucson.ars.ag.gov/book/chap5/mango.html). According to Bickford (2007), plants expand their CO$_2$ sink capacity by producing many flowers and fruits, especially under high CO$_2$ concentration. In this case, woody fruit tree species with prolific flowering and fruiting capacity could be ideal in reducing substantial CO$_2$ concentration from atmosphere. Although trees expand their carbon sink by producing more flowers and fruits, the least amount of carbon is stored in fruits, and hence insignificant net carbon storage. The small quantity of carbon fixed in the fruits is released back into atmosphere through respiration by humans or animals if they feed on the fruits (Bickford, 2007). Carbon stored in leaves, flowers and pruning materials (unwanted branches) may contribute to C storage since this CO$_2$ can be converted into soil organic carbon (SOC) which might not be mobilized (Bickford, 2007). Deciduous fruit trees drop leaves annually, and hence the leaves contribute to soil organic carbon. Also, pruned tree branches left in the orchard enables carbon from tree cellulose to be converted to soil organic carbon. However, the proportion is another research gap to be addressed.

Cultivation practices influence storage of soil organic carbon and practices which include low or no till, the use of cover crops, and also fertilization often promote SOC storage (Bickford, 2007). The actual amount of carbon stored in the soil depends on mineralization processes. A net CO$_2$ storage, however, may depend more upon the woody biomass component of the tree itself than on soil carbon.

**PROPAGATION PROTOCOLS**

Fruit trees can grow and continue to sequester carbon as they accumulate biomass for years. Apart from tree management practices, propagation protocols can also influence efficacy of carbon sequestration. Asaah (2012) found differences in *Dacryodes edulis* biomass among the 10 year-old trees derived from three different propagules (seedlings, marcots and cuttings). There was a significant difference in carbon content. He found more biomass for those derived from marcots and cuttings than those derived from seedlings. Low tree biomass obtained from *D. edulis* trees derived from seedlings could be attributed to the fact that both marcots and cuttings are always true to type (resemble the mother plants unlike those derived from seedlings). It is possible that some dwarfing traits could be present in trees derived from seedlings as they receive pollen from different male trees. It is possible to have lower tree biomass for trees derived from marcots and cuttings if their stock plants had dwarfing traits.

Grafted fruit trees are another interesting dimension in carbon storage. The use of grafted/budded plants has become popular as they present a number of benefits such as avoiding soil-borne diseases, nematodes (avoids use of methyl bromide) and termites attack (Bally, 2006). Prolific accumulation of biomass in grafts may depend on rootstock. Trees derived from seedlings can accumulate more biomass than grafts so long as they do not have dwarfing traits. However, vigorously growing grafts can match those derived from seedlings. Thus, propagation techniques have significant influence on tree growth and biomass (Mng'o'mba et al., 2008; Asaah, 2012) and it is expected that grafts with slow growing rootstocks (dwarfing traits) have low biomass. According to Lockard and Schneider (1981), specific rootstocks significantly influence vegetative growth.

With respect to maximizing tree biomass to increase carbon sequestration, propagation methods are critical to maximize carbon sequestration. Vigorously growing trees can be efficient in sequestering CO$_2$ as they are able to accumulate a lot of biomass, and hence removing substantial amount of CO$_2$ from atmosphere. If grafting fruit trees is a preferred propagation technique to solve soil-borne diseases and achieve fruiting precocity, it will be critical to select vigorously growing rootstocks for high tree biomass. Also, grafted trees have shown tolerance to extreme soil temperatures (Bally, 2006) and this is an opportunity under the current threat of climate change/variability as the use of grafted trees could be a good adaptation measure to the high temperatures in the
We estimated carbon storage in grafted and un-grafted *Mangifera indica* (mango) and *U. kirkiana* trees using Brown (1997) method. We found more CO$_2$ sequestered in un-grafted *U. kirkiana* than grafted ones when comparing trees of the same age (Table 1). However, a model for a specific tree species may be needed. Carbon storage in grafted mango trees at six years of age was similar to un-grafted *U. kirkiana* trees which were ten years old (Table 2). This shows differences in growth; mango trees flowered and fruited earlier than *U. kirkiana* and this had a bearing on biomass accumulation. Thus, there is need to select rootstocks which maximize tree biomass to increase carbon storage.

**TREE SPACING**

Tree spacing is another factor that may influence tree biomass per unit area. Differences in tree spacing between grafted and un-grafted trees affect the potential carbon value. Generally, dwarf grafts need closer spacing than the vigorously growing grafted trees. This means more trees per unit area for dwarf grafts, but this close spacing may not increase carbon value per unit area. For instance, grafted mango trees with a mean diameter at breast height (DBH) of 10 cm (dwarf), valued at $0.23 each (EcosystemMarketplace, 2010), spaced at 4 × 4 m would have a value of $144 per hectare. Un-grafted mango with a mean DBH of 29 cm (vigorous growing grafts), valued at $2.77 each, spaced at 8 × 8 m would have a value of $432 per hectare. In this case, the carbon value of un-grafted trees is higher than grafted ones despite the wide tree spacing. Data in Table 2 show that differences in tree size (DBH) has huge differences in value as an indication of high biomass development in un-grafted trees.

**CARBON MARKETS**

There are a number of carbon markets including the voluntary markets that trade carbon stored in trees. To our knowledge, there have been limited piloted projects targeting trees outside the forest (including fruit trees) for carbon trading. Fruit trees are solely considered for food security and nutrition, but their potential in carbon sequestration has been given little attention. We believe fruit trees can effectively sequester carbon under a specific management practice. If carbon trading is based on woody tree biomass, then fruit orchards should be considered and specified management systems should be given attention as tree management has significant effect on tree biomass development. Obviously, some woody fruit tree species may be worthy carbon credits. Inclusion of fruit trees in carbon trading will benefit many farmers and could be an effective way of increasing tree numbers on farmland and securing farmers’ nutrition and health. In southern Africa, community forest tree programs may not be easy to implement due to small and fragmented landholding sizes and to some extent, the limited interest from smallholder farmers as such programs are long-term investments and do not meet their immediate demands. In view of this, our assumption is that inclusion of fruit trees in such programs can boost the adoption of community forest tree programs and make a positive impact on food security and carbon sequestration. It has been reported that increased crop

### Table 1. Carbon sequestered in *Mangifera indica* (mango) and *Uapaca kirkiana* trees.

<table>
<thead>
<tr>
<th>Species</th>
<th>Type</th>
<th>Age (years)</th>
<th>DBH class(cm)</th>
<th>Mean DBH (cm)</th>
<th>CO$_2$*(kg tree$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Uapaca kirkiana</em></td>
<td>Un-grafted</td>
<td>4</td>
<td>&lt;10</td>
<td>2.76</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>Grafted</td>
<td>4</td>
<td>&lt;10</td>
<td>2.29</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>Un-grafted</td>
<td>8</td>
<td>&lt;10</td>
<td>6.98</td>
<td>22.6</td>
</tr>
<tr>
<td></td>
<td>Grafted</td>
<td>8</td>
<td>&lt;10</td>
<td>5.79</td>
<td>14.6</td>
</tr>
<tr>
<td><em>Mangifera indica</em></td>
<td>Grafted</td>
<td>6</td>
<td>&lt;10</td>
<td>9.2</td>
<td>22</td>
</tr>
</tbody>
</table>

DBH = diameter at breast height; *Biomass calculations are after Brown (1997), carbon content is assumed to be 50% of dry biomass.

### Table 2. Carbon sequestered in *Mangifera indica* (mango) and *Uapaca kirkiana*.

<table>
<thead>
<tr>
<th>Species</th>
<th>Type</th>
<th>Age (years)</th>
<th>DBH class(cm)</th>
<th>Mean DBH (cm)</th>
<th>CO$_2$***(kg ha$^{-1}$)</th>
<th>Value*($ ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Mangifera indica</em></td>
<td>Grafted</td>
<td>6</td>
<td>&lt;10</td>
<td>9.2</td>
<td>107,500</td>
<td>475</td>
</tr>
<tr>
<td><em>Uapaca kirkiana</em></td>
<td>Un-grafted</td>
<td>8</td>
<td>&lt;10</td>
<td>6.98</td>
<td>56,500</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>Grafted</td>
<td>8</td>
<td>&lt;10</td>
<td>5.79</td>
<td>36,500</td>
<td>175</td>
</tr>
</tbody>
</table>

DBH = diameter at breast height; *Calculated at $4.50 per ton of CO$_2$ (Ecosystem Marketplace, 2010); **Biomass calculations are after Brown (1997), carbon content is assumed to be 50% of dry biomass.
and forest stands on farmland will increase CO₂ sink (World Bank, 2002; Seppala, 2009), and hence this opportunity must be utilized by inclusion of fruit trees in PES and carbon trading.

CONCLUSIONS

Fruit tree species provide an alternative livelihood to many smallholder farmers. They present a potential mitigation/adaptation measure. The new thinking should be to develop and identify suitable propagation protocols, management systems and suitable species to maximize carbon storage and to optimize fruit productivity. The use of woody fruit trees on homesteads and cultivated fields can offer a cheaper payment for environmental services including carbon credits if piloted. However, more research studies are needed to quantify CO₂ sequestration potential in diverse fruit trees including indigenous fruit tree species to local communities.

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