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CARBON STOCKS OF NEEM TREE (Azadirachta indica A. Juss.) IN DIFFERENT URBAN LAND USE AND LAND COVER TYPES IN NIAMEY CITY, NIGER, WEST AFRICA

Soulé Moussa*, Boateng Kyereh‡, Abasse Amadou Tougiani§, Mahamane Saadou¶

1. West African Science Centre on Climate Change and Adapted Land Use (WASCAL), Department of Civil Engineering, College of Engineering, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. Email: smoussa@st.knust.edu.gh

Telephone: +227 96801125 +233 501589424

2. Department of Silviculture and Forest Management, Faculty of Renewable Natural Resources, Kwame Nkrumah University of Science & Technology, Kumasi, Ghana.


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ABSTRACT
Urban trees play a crucial role in carbon offset. Nevertheless, much attention has been focused on natural trees role in atmospheric carbon reduction. Specifically, in Niger, the estimation of carbon stock of urban trees remains unexplored areas for climate change mitigation. The objective of the paper was to estimate carbon stock of Azadirachta indica in Niamey. We assessed the structure and carbon stocks of neem trees across urban land use and land cover types using non-destructive method. We measured 853 (DBH ≥ 5 cm) stems within 102 plots over 19.41 ha. The mean and standard error of neem structural characteristics were density 48±9.06 stems/ha, basal area was 5.23±0.93 m²/ha, tree cover was 26.84±4.48%. Neem tree structural characteristics varied significantly across land use and land cover types (P = 000.1). Big stems (40 > cm) contributed about 72% to the total aboveground biomass. The mean carbon density was 24.17±3.50 t/ha. While the highest carbon stock was observed in commercial areas (67.05±27.49 t/ha), the second lowest carbon stock was in administrative areas (14.04±2.71 t/ha). Neem trees should be accounted for in urban land use planning and national biomass carbon inventory. These results complement the international tree carbon dataset and reference level from Sahel city for climate change mitigation.

Keywords:
Sahel, urban forest, climate change mitigation

1. Introduction
Climate change is a worldwide environmental problem, with threats to socioeconomic and ecological systems (Intergovernmental Panel on Climate Change (IPCC), 2014). Urban areas are expanding rapidly (Grimm et al., 2008). About 55 % of the world’s population is in cities, and this figure is projected to reach
68% by 2050 with an increase of 90% occurring in Africa (United Nations, 2018). Urban areas are extremely important for global carbon accounting as 75% of carbon emissions come from cities (UN, 2017). Although urban areas constitute a major source greenhouse gases emissions mainly carbon dioxide (CO₂) (Seto et al., 2014), urban areas are vulnerable to climate change (Bulkeley & Betsill, 2006). Despite that urban areas are source of CO₂ emission, several studies in America, China and Europe (Nowak & Crane, 2002; Ning et al., 2015) and more recently in Ghana (Nero, Callo-Concha, Anning, & Denich, 2017) have demonstrated that urban trees remove considerable CO₂ from the atmosphere through carbon sequestration. Indirectly urban woody species also reduce building energy consumption, as they are natural air conditions, thereby reducing CO₂ emission from urban energy consumption (McPherson & Simpson, 2003). For instance, (Davies et al., 2011) pointed out that urban trees store a substantial quantity of carbon which accounts for more than 95% of the total carbon pool estimated in urban vegetation in Leicester, United Kingdom. (McHale et al., 2009). In addition to that some studied have shown that urban forests store more carbon than natural forest (Davies et al., 2011; Hutyra et al., 2011; Raciti et al., 2012) mostly in dry region where urbanization leads to carbon stock enhancement (Golubiewski, 2015). Recently (Mathias, 2018) has stated that urban trees can store as much carbon as tropical forest. However, urban trees can be a source of carbon dioxide during urban forest maintenance or due to natural factors. Therefore sustainable management of urban trees which requires information on its structure (Nowak et al., 2016).

Urban trees have an important carbon sequestration potential (Nowak et al., 2013; Zhao et al., 2016; Ning et al., 2015). However, much research focus has been given to natural woody species (Henry et al., 2013; Kuyah et al., 2014), little research has been done on urban trees carbon uptake which has led to a knowledge gap about the role of urban woody species in carbon capture (Weissert et al., 2014). For instance, few urban forest studies were done in West Africa with zero urban forestry studies in Niger (Hosek, 2014). For instance urban trees carbon sequestration studies remain unexplored domain for Intended Nationally Determined Contribution (INDC) of Niger (Conseil National de l’Environnement pour un Développement Durable, 2016). Further, a literature search revealed no information regarding urban trees carbon capture in Niger. There is a general lack of information on Niger’s urban forestry such as the role of urban trees in climate change mitigation in the international literature. This is due to a limited number of studies investigating the structure of urban trees in the Sahelian region. Studies conducted in the region have focused on urban trees in Kumasi (Nero et al., 2017a), in Lomé (Raoufou et al., 2011) and Ibadan (Agbelade et al., 2016) and none of them investigated the carbon stocks of urban trees mostly city dominant tree species as neem tree in Niamey (Illiaissou et al., 2016). However, the rapidly urbanized metropolis of Niamey has not been investigated, and their status is not well known regarding urban trees planation. A knowledge gap exists about the role of urban trees in carbon sequestration in Niger; whether or not urbanization has enhanced the carbon stocks across the different land use and land cover types in Niamey. Assessment of the carbon stock of neem tree in Niamey can provide data that fills this gap, and yield information that enhances our understanding of the role of urban trees and ensure effective planning and management of the urban landscape mostly urban trees aid in local climate change mitigation (Nowak & Crane, 2002). It was hypothesized that neem tree structure and carbon density are sensitive to land use and land cover types (LULC).

2. Materials and Methods

2.1 Study area

The study was conducted in Niamey in Niger. Niamey is situated in the Sahel Zone, where annual mean rainfall varies from 150 mm to 350 mm (Conseil National de l’Environnement pour un Développement...
Niamey is the political capital and largest city in Niger with an extended area of over 552.27 km², an urbanized area of 297.46 km² and a population of 1,026,848 people (INS, 2017). Niamey is located at latitude 13°20'-13°35'N and longitude 2°00'-2°15'E in western Niger (Fig. 1). The average yearly temperature in Niamey is 29.2°C.

Figure 1. Map of the study area

Source: Soulé Moussa (2018)

2.2 Neem plantations in Niamey city

Desertification constitutes a great environmental problem in Niger. This has led the Niger authorities to introduce *Azadirachta indica* in 1916 and 1963 in Niger in order to fight against desertification (Yacouba, 1999). But the massive plantation was though the creation of a green belt of Niamey with neem tree as major specie vast of 2500 hectares and long of 25 km in 1965 (Ministère de l’Environnement du Niger, 2010) to protect Niamey against desertification and other calamities. Neem tree has been widely planted in Niamey as avenues trees, public green spaces such as the United Nations bosquet (Yacouba, 1999) and private plantation for diverse uses. In addition to that, the Independence Day of Niger is commemorated on August 3, since 1975, it is instituted as Arbor Day to plant trees across the nation to help combat desertification and neem tree has been used for public urban afforestation in Niamey.

Neem tree plantations found within and at the periphery of Niamey was the study population. *Azadirachta indica* belongs to the botanical family of Meliaceae, is one of the most widely distributed and multipurpose
tree species used for urban plantation in Niger. Neem is used for several benefits such as medicinal (Ravva & Korn, 2015), firewood and land restoration in West Africa (Raj & Sahu, 2013) and shading in Niamey (Illiassou et al., 2016). Neem tree is the most dominant tree species in Niamey (Yacouba, 1999).

From field observation and discussion in Niamey, neem tree is used for shading purposes in urban settings in Niamey such as in Schools (Photo a), in the market (photo b) and roadside tree (photo c) and firewood (photo d). From field discussions, neem is used in Niamey for timber production in schools for making schools wood material (wood pillar for building classrooms) and in the mosque for burial material.

a. Neem used school shading  
b. Neem used for market shading  
c. Roadside neem trees  
d. Neem trees in the green belt

2.3 Data collection
2.2.1 Sampling design
A stratified random sampling approach was used for *Azadirachta indica* tree inventory as used in (Nero et al., 2017a) to study urban forests in Kumasi. We defined six urban land use and land cover (LULC) strata that are:

i. **Commercial**: market, shops, restaurant and garage;

ii. **Roads**: main streets and boulevards;

iii. **Residential**: Mosque, church and houses;

iv. **Schools**: primary schools, secondary schools, universities, polytechnics, training colleges etc. The schools were private as well as public;
v. **Administrative areas**: public and private services;
vi. **Urban-forested areas**: public green spaces (green belt of Niamey, bosquet of United Nations etc.), agroforestry systems, and wetlands, irrigated farmlands and botanical gardens.

The LULC types were randomly selected from five communes in Niamey (Figure 1). A random list for sampling was selected from an inventory of schools, administrative posts, urban green spaces, roads, markets and residential compounds obtained from directorates of education, environment, urban equipment and habitat and quartiers of the communes in Niamey. Neem trees structure was assessed through a survey of plants in plots of 50 m x 50 m, consistent with guidelines for inventories in the Sahel (Thiombiano et al., 2016). The plot size varied in some cases and was less than 0.25 ha if a randomly selected point could not allow a plot of a 2500 m$^2$ to be laid without getting into another LULC type. One of limitations was the inaccessibility to some urban land use and land cover types such as embassies, barracks and presidential residence.

### 2.2.2 Dendrometric measurement

All neem trees with diameter at breast height (DBH) and total height within a plot were measured. The minimum DBH of 5 cm is recommended for the Sahel region (Thiombiano et al., 2016). DBH was measured at 1.30 m from the ground using a diameter tape. Neems with forks before 1.3 m were considered as multi-stemmed; their stems were measured separately. The crown diameter (Largest and perpendicular) was measured using a tape meter.

### 2.3 Data analysis

#### 2.3.1 Structure of neem tree in Niamey city

The overall diameter for the multi stems diameters was determined as the square root of the sum of squares of individual stems (Kuyah et al., 2014). Neem tree DBH data were grouped into five DBH classes 5-10, and 10-20, 20-30, 30-40 and above 40 cm to provide the number of stems in each diameter class LULC in two cities. The mean diameter and height were calculated across land use and land cover types. The structure of neem trees population was assessed through the following parameters using the formulas as described in (Thiombiano et al., 2016). We calculated the basal area of *Azadirachta indica* in the six defined urban land use and land cover types using this formula:

\[
\text{Basal area (m}^2\text{): } D^2 \times \frac{\pi}{4}, \quad \text{with } \pi = 3.14. \text{ The total basal (m}^2/\text{ha}) \text{ was the sum of stems over areas.}
\]

**Stem density** (N/ha): Neem tree density is the number of individuals of each per unit area. Only the individuals with DBH ≥ 5 cm were used for the stem density calculation.

**Neem tree cover** (%): 
\[
\text{crown cover (m}^2\text{) / (area (m}^2\text{))100}
\]

with crown cover (m$^2$) = $R_1R_2\pi$ where $R_1$ = (perpendicular crown diameter)/2 and $R_2$ = (largest crown diameter)/2 as described in (Jennings, Brown, & Sheil, 1999).

#### 2.3.2 Assessment of biomass and carbon stock

Estimation of the aboveground and below ground biomass of each plant species was not feasible due to the lack of specie-specific model or suitable model for a given region or vegetation types in the literature (Henry et al., 2013). However, (Chave et al., 2014) developed generalized above ground biomass (AGB) model for different vegetation types and, which are used by authors when destructive methods are not allowed (Henry et al., 2013) mostly in the urban ecosystems where destructive methods cannot be allowed. The allometric model has been widely used to estimate the biomass of urban trees (Nero et al., 2017b; ...
Nowak et al., 2013; Stoffberg et al., 2010; Ning et al., 2015). Therefore, through a critical review of the literature allometric equation potentially suitable for estimating neem AGB in Niger was identified. The pantropical model developed by (Chave et al., 2014) for tropical forest, subtropical forests and woodland savannah were identified useful because the model performed well across forest types and bioclimatic conditions (Chave et al., 2014) (Table1). This model was used to estimate AGB biomass of trees in urban areas (Nero et al., 2017b) and in semi-natural vegetation (Dayamba et al., 2016). Allometric equations for tree roots are relatively rare in the literature (Cairns et al., 1997). Thus, belowground biomass (BGB) was quantified as a proportion of AGB biomass using root-shoot ratio developed by (Cairns et al., 1997) for tropical vegetation (Table 1).

### Table 1. Allometric models used for estimating neem tree biomass

<table>
<thead>
<tr>
<th>Source</th>
<th>Allometric models</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Chave et al., 2014)</td>
<td>$\text{AGB (kg)} = 0.0673 \times (\rho D^2 H)^{0.976}$</td>
</tr>
<tr>
<td>(Cairns et al., 1997)</td>
<td>$\text{BGB (kg)} = \text{AGB} \times 0.25$</td>
</tr>
</tbody>
</table>

Where: $\rho = \text{wood density (gcm}^3\text{)}, D = \text{diameter at breast height (1.3 m) (Cm)}, H = \text{total tree height (m)}, \text{AGB} = \text{aboveground biomass in kg}. The wood density was obtained from the (Intergovernmental Panel on Climate Change (IPCC), 2006) database. The total neem biomass was obtained by summing up the AGB and BGB, which were converted to carbon stocks using the default IPCC carbon fraction value of 0.47 (IPCC, 2006).

2.3.3 Statistical analysis

Before the statistical analysis, the Ryan-Joiner test and Levene ’test were used to check the normality and homogeneity of the data. An ANOVA test was used to examine the effect of land use and land cover types on neem trees structural characteristics (diameter, height, basal area, density and tree cover) at alpha 0.05 level of significance. We calculated the effect size with ANOVA between groups; we used $\eta^2$ (Eta squared) which is the sum of squares between groups over total sum of squares as described by (Vacha-haase and Thompson, 2004). We also tested the relationship between, DHB, Height, basal area, density, tree cover and AGB across LULC. As the carbon data was not normal, therefore Kruskal-Wallis Test (H) was used to test the effect on land use and land cover types on neem carbon density.

3 RESULTS

3.1 Structure of neem tree in Niamey city

We measured 853 (DBH ≥ 5 cm) stems of neem within 102 plots over 19.41ha. There was a significant effect of urban land use and land cover types on neem tree structural characteristics (density, basal area and tree cover) (F-stats = 22.36, P-values = 0.0002. DF= 2) with effect size ($\eta^2$) = 0.64 in Niamey. Neem tree density varied cross LULC (Table 2) in Niamey with a mean of 48±9.06 (SE) stems/ha. Neem average basal area was 5.23 ± 0.93 m²/ha and mean tree cover was 26.84 ± 4.48 %. Road and residential areas had the highest neem tree cover (Table 2). While road had the highest density and school had the highest basal area (Table 2). The lowest neem density was observed in the administrative and commercial areas. There were a strong positive correlation ($r = 0.94$) between neem tree cover and density and weak positive correlation between basal area and density ($r = 0.29$) and basal area and tree cover ($r = 0.19$). There were strong positive ($r = 0.92$) correlation between basal area and DBH across LULC. There were also a strong positive correlation between AGB and basal areas across LULC.

### Table 2 Structural characteristics of neem. The overall present total, mean, and standard error (SE).

<table>
<thead>
<tr>
<th>LULC</th>
<th>Area (ha)</th>
<th>Number</th>
<th>Density (ha)</th>
<th>basal area (m²/ha)</th>
<th>Tree cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administrative</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>School</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>LULC</th>
<th>Mean DBH (cm)</th>
<th>Mean Height (m)</th>
<th>Mean AGB (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administrative areas</td>
<td>34.52 ± 4.46</td>
<td>9.7 ± 0.57</td>
<td>23.93 ± 6.17</td>
</tr>
<tr>
<td>Commercial areas</td>
<td>37.87 ± 2.56</td>
<td>10.31 ± 0.36</td>
<td>114.10 ± 54</td>
</tr>
<tr>
<td>Forested areas</td>
<td>33.07 ± 0.91</td>
<td>7.55 ± 0.18</td>
<td>22.78 ± 5.13</td>
</tr>
<tr>
<td>Residential areas</td>
<td>36.56 ± 1.90</td>
<td>9.42 ± 0.30</td>
<td>50.80 ± 17</td>
</tr>
<tr>
<td>Road</td>
<td>30.57 ± 1.29</td>
<td>10.40 ± 0.25</td>
<td>54 ± 11.60</td>
</tr>
<tr>
<td>School</td>
<td>39.13 ± 1.53</td>
<td>9.17 ± 0.12</td>
<td>42.40 ± 18.60</td>
</tr>
<tr>
<td>Overall</td>
<td>35 ± 0.68</td>
<td>8.98 ± 0.09</td>
<td>41.14 ± 5.95</td>
</tr>
</tbody>
</table>

Source: Soulé Moussa (2018)

3.2 Dendrometric characteristics and biomass of neem tree

There was no significant effect of urban land use and land cover types on neem tree (DBH, H and AGB) (F-stats = 7.38 P-values = 0.011, DF= 2) with effect size (η²) = 0.48 in Niamey. The mean DBH of neem was 35 ± 0.68 cm; mean height was 8.98 ± 0.09 cm and mean AGB was 41.14 ± 5.95 t/ha. The commercial area had the highest AGB, and the lowest AGB density was observed in forested areas (Table 3).

Table 3. The values are mean ± standard error of DBH, height and AGB

3.3 Diameter classes contribution to the neem AGB

Table 4 shows the number of neem stems per diameters classes. The stems with large diameter > 40 cm are leading classes both regarding a number of stems and contribution to the AGB in Niamey city. The diameter classes < 10 cm least class regarding contribution even though it had the smallest number of stems.

Table 4 Diameter classes and its contribution to AGB

<table>
<thead>
<tr>
<th>DBH classes</th>
<th>Number of stems</th>
<th>AGB (kg)</th>
<th>Contribution to the AGB (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10 cm</td>
<td>37</td>
<td>502.07</td>
<td>0.10</td>
</tr>
<tr>
<td>[10-20]</td>
<td>127</td>
<td>8052.84</td>
<td>1.63</td>
</tr>
<tr>
<td>[20-30]</td>
<td>203</td>
<td>42741.99</td>
<td>8.65</td>
</tr>
<tr>
<td>[30-40]</td>
<td>234</td>
<td>87844.99</td>
<td>17.77</td>
</tr>
<tr>
<td>&gt; 40 cm</td>
<td>252</td>
<td>355258.05</td>
<td>71.86</td>
</tr>
</tbody>
</table>

Source: Soulé Moussa (2018)

3.4 Neem tree carbon stock density

Neem plantation carbon density also varied the LULC even though there was no significant effect of land use and land cover types on neem carbon density in Niamey (H= 8.35, DF =5, P = 0.14). The average neem carbon density in Niamey was 24.17±3.50 t/ha. While commercial areas had the highest neem carbon density (67.05±12±27.49 t/ha) followed by roads (31.72±6.79 t/ha), the lowest mean carbon density was observed in administrative areas (14.04±2.71t/ha) and forested areas (13.38±3.02 t/ha) (table 4).

Table 5. Neem mean carbon density ±standard error

<table>
<thead>
<tr>
<th>LULC</th>
<th>Number of stems</th>
<th>AGB (kg)</th>
<th>Contribution to the AGB (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administrative areas</td>
<td>37</td>
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<th>LULC</th>
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</tr>
<tr>
<td>Forested areas</td>
<td>13.38±3.02</td>
</tr>
<tr>
<td>Residential areas</td>
<td>29.87±9.97</td>
</tr>
<tr>
<td>Roads</td>
<td>31.72±6.79</td>
</tr>
<tr>
<td>Schools</td>
<td>24.93±10.94</td>
</tr>
<tr>
<td>Overall</td>
<td>24.17±3.50</td>
</tr>
</tbody>
</table>

Source: Soule Moussa (2018)

4. Discussion

Comprehensive information on urban trees in Niamey is lacking. Our results show high values of the neem tree structure in Niamey which can aid in urban forest management and urban land use planning. Our neem structure values (basal area, diameter and height) match previous studies that neem tree is a good accumulator of biomass (Bohre et al., 2016) even though in our study neem tree had the highest mean diameter at breast (DBH) and height (H). One possible reason is that (Bohre et al., 2016) assessed the average DBH and H according to age (2-18 age) of the plantation on mined areas in India. This could also be due to this study looked at neem structure across urban land use, and land cover gradient as LULC is the driver of urban trees structure (Nowak et al., 1996).

But our study concurs with the findings of (Bohre et al., 2016) who found a strong positive correlation between neem basal area and DBH in degraded mined areas. The strong correlation found between basal area and AGB explains that basal area can be a good predictor of AGB which as revealed by (Chiba, 1998). (Nero et al., 2017b) found that urban trees mean DBH in Kumasi city varied significantly among urban green spaces types which was contradicted by our results. This could be due to (Nero et al., 2017b) mean DBH was a combination of several urban tree species even though neem was one of them. Our results show that land use and land cover types constitute a driver of a neem tree structure which confirmed, for instance, the findings of who (Nowak et al., 1996) pointed out that land use is a driver of urban trees cover. The urban tree structure is important to the ecosystem services. For instance, roadside trees structure are an important role in carbon reduction, air pollution, runoff reduction and beauty of city (Wang et al., 2018). Research has shown urban tree shade has an impact on building energy use (Akbari, 2002) thus the high values of neem tree cover in Niamey across the land use and land cover types could be of great importance to cut the energy use by cooling the air as climate change mitigation.

Our study shows that big neem trees (DBH > 40 cm) are dominant class regarding AGB contribution. This matches the findings of (Kuyah et al., 2014) who found out that the trees with the large diameter trees dominated the AGB pool though they are few in stems of stems number in natural forest. In this study, the large trees are also dominant regarding stems number even though there was a weak positive correlation between AGB and stem density. This result demonstrates the importance of neem tree size in AGB carbon conservation in Niamey city. This could be an asset for urban trees biomass conservation as its lifespan is about 150-200 years (Ragit et al., 2011). Our study shows that neem tree stores a considerable amount of carbon in different urban areas even though the carbon density values are smaller than the findings of (Bohre et al., 2016). One of the possible reasons could be due to (Bohre et al., 2016) used destructive sampling approach based on the age of the plantation to estimate the neem carbon density in the mined area which is also different from our study area that analyzed carbon density along the urban LULC gradient. Our neem means carbon density values are greater than six-aged plantation and inferior to 7 to 8 aged plantation of (Bohre et al., 2016). In short neem tree carbon density found in Niamey is greater than
the average values found by (Pradesh, 2017) in urban areas in India even though our approach and number of sampled neem trees. Our results indicate that *Azadirachta indica* is a good carbon sequester in all LULC in Niamey City, which can be used by municipality authorities for urban afforestation in the contest of climate change mitigation.

4 Conclusions

Neem tree is used for urban forestry in Niamey with variable structure and carbon stocks as highlighted by this study. Neem is a biomass accumulator and carbon sink in the urban landscape based on the indirect approach. This study recommends further studies that quantify the urban forests biomass in Niger cities for promoting urban trees plantation for climate change mitigation. Therefore, this study recommends sustainable management of neem tree plantations in Niamey for carbon conservation. Neem should be accounted for in urban land use planning and in national biomass carbon inventory in Niamey.

5 Acknowledgements

Our sincere appreciation goes to the Federal Ministry of Education and Research (BMBF) and West African Science Centre on Climate Change and Adapted Land Use (WASCAL) for providing the scholarship and financial support for this program. Soulé Moussa thanks Institut National de la Recherche Agronomique (INRAN) du Niger, for providing the nice working space in Niamey city. Big thanks also the people of Niamey city for their cooperation.

6 References


