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Research Article

Total Biomass Carbon Sequestration Ability under the Changing Climatic Condition by *Paulownia tomentosa* Steud

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Abstract
The concentration of carbon dioxide (CO_2) has risen continuously in atmosphere due to human induced activities, and has been considered the predominant cause of global climate change. *Paulowina tomentosa* Steud. (*P. tomentosa*), a multipurpose tree is popular around global market for its timber and its potential role in CO_2 sequestration. In this study, the total biomass carbon of five years old and newly planted *P. tomentosa* has been estimated. The results indicated that the average total biomass carbon of five years old plant was found to be 4.52±0.53Kg C Year^{-1} per tree i.e. 9.04±1.06-ton C ha^{-1} Year^{-1} (assuming 2000 plants per hector). Likewise, the average total biomass carbon of newly planted *P. tomentosa* within 4 months was found to be 6.07±0.38 Kg in remote village area in Nepal. The estimated biomass carbon in one year of newly planted plants was found to be 18.21±1.14 Kg Year^{-1} i.e. 0.36-ton C ha^{-1} Year^{-1}. These findings reveled that short rotational trees like *P. tomentosa* can be implemented in agroforestry system to reduce the green house emission in cities and emphasizes the carbon storage potential of agroforestry. *In vitro* micro propagation technique could be implemented to produce genetically uniform clone of *P. tomentosa* and can be applied in agroforestry system for the adaptation and to mitigate global climate change.

Keywords: Agroforestry; Climate change; *P. tomentosa*; CO_2 sequestration

Introduction
Most important greenhouse gas (GHG), carbon dioxide (CO_2) is essential for photosynthesis, which sustains the life of plants (Rogers *et al*., 1994). Human induced activities have escalated the concentration of CO_2 in atmosphere. Its concentration was 270 ppm before industrial revolution (Rogers *et al*., 1994) and according to data recorded by National Oceanic and Atmospheric Administration (NOAA) it has risen to 412.45 by May 14, 2018. Without additional effort to reduce GHGs emission, it is estimated to rise to more than 1300 ppm by 2100 (Edenhofer *et al.*, 2014). Atmospheric carbon is accumulating in earth's atmosphere at the rate of 3.5 billion tons per annum (Paustian *et al*., 2000), the largest portion of which resulting

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from fossil fuels combustion is 34% by sector (Edenhofer *et al.,* 2014). Kumar *et al.,* 2011 have suggested the positive effect of increased atmospheric CO_2 such as improvement of soil physical and chemical properties by soil organic matter build up and nutrient stocks in soil resulting plant productivity. However, increased of atmospheric CO_2 is considered the predominant cause of global climate change (Jose and Bardan, 2012).

Green trees and woodland play a vital role in the sequestration of carbon dioxide from the atmosphere. Trees utilize carbon dioxide and store as carbon in the trunk, branches, roots and leaves through the process of photosynthesis. CO_2 sequestration potential mainly depends upon the biological productivity, climatic condition, topography, management practices and varies from place to place on different regions on the basis of different species (House *et al.,* 2002). Altitude in Nepal ranges from 60 - 8,848 m height with diverse climatic and ecological zone. Geographically, it is divided into Himalaya region, Hilly region and Terai region. Government of Nepal have recognized Churia region (between Hilly and Terai regions) as vulnerable landscape.

One of the mitigating methods advocated by The Kyoto Protocol (Protocol, 1997) on reduction of carbon emission is to trade off carbon emission by sequestration in natural sink like trees (Sedjo and Sohagen, 2012). This strategy is relatively cost effective as it requires little new technology, readily themselves to local adoption and diffusion to the rural poor (Brown, 2002). Ever since, mitigation of increased atmospheric CO_2 by agroforestry sink strategy is being recognized widely. Many studies on agroforestry as a strategy for carbon sequestration have been carried out (Nair *et al*., 2009; Jose and Bardan, 2012). Others have studied potential soil organic carbon sequestration in agroforestry system (Lorenz and Lal, 2014). Nonetheless, limited details are available regarding carbon sequestration value and information about *P. tomentosa* and its implemented in agroforestry for climate change mitigation. Therefore, the main objective of this study was to measure the total biomass carbon storage potential of previously and newly planted *P. tomentosa* and to promote the plant as opportunity in agroforestry system to deal with CO_2 related mitigation option.

Agroforestry System and P. tomentosa

The awareness of agroforestry's potential for climate change adaptation and mitigation systems is growing worldwide (Cubbage *et al*.,2012 Nair et al., 2009; Schoeneberger *et al.,* 2012) offering the greatest CO_2 sequestration potential among different land use system by 2040 (Noble *et al.,* 2000). Agroforestry system combines trees and shrubs (perennial) with agronomic crops (annual or perennial). Therefore, they have both forest and grassland sequestration and storage patterns active (Schroeder *et al*., 1993). Globally, an estimated 700, 100, 300, 450, and 50-ton ha^{-1} of land are used for tree intercropping, multistrata systems, protective systems, silvopasture, and tree woodlots respectively (Nair *et al*., 2012). These practices have greater potential to increase carbon sequestration (Lee and Jose 2003; Nair *et al*., 2009; Schoeneberger *et al*., 2009; Morgan *et al*., 2010). Potentially accumulated carbon stored in above and belowground compartment of tree (Mosquera-Losada *et al*., 2011). Thus, management of agricultural systems to sequester carbon has been accepted as a partial solution to climate change (Morgan *et al*., 2010). Sustainably managing agroforestry system, carbon can be retained in these systems for centuries (Dixon, 1995). Additionally, agroforestry systems have been recommended to reduce soil erosion and improve water quality (WBCSD, 2010). It is also purposeful for a variety of benefits and services such as increasing crop yields, reducing food insecurity, enhancing environmental services, and resilience of agro-ecosystems (Ajayi *et al*., 2011).

Natural forest system is declining due to urbanization, expanding farm land and increasing the demand of timber (Chakravarty *et al*., 2011). The loss of these systems causes severe damage to regions ecosystem (Pimentel, 2006) . These alterations cascade through the ecosystem, resulting in increased temperature altered rainfall patterns and degraded soil profiles. Hence, apart from fossil fuel combustion, decimation of forest and its products could also be a factor that aids in changing global climate.

One of the ideal options to abate global climate change is implementing *Paulownia* trees in agroforestry system. It is fast growing multipurpose bio-energy tree which is readily sustainable and suitable for agroforestry system (Mosquera-Losada *et al*., 2011). Genus *Paulownia* belonging to family Paulowniaceae are divided into different species according to their flower and fruit morphology (HU, 1995). *Poulowina* is popular around global market for its timber due to its characteristics of rot resistance, dimensional stability and very high ignition point (Bergman and Whetten, 1998; Silvestere, 2005). Plantation of *Poulowina* can be done with about 2000 trees per hector and it can be harvested in 15 years for its valuable timber (Akyidis, 2010). Under natural conditions a 10-year-old *Paulownia* tree measures 0.3 – 0.4m in diameter at breast height (dbh), and yields timer volume of 0.3 - 0.5 m^3 (Flynn and Holder 2001).

Deep root system of tree in agroforestry system has been receiving increased attention for climate change adaptation and mitigation (Nair, 2012). *Paulownia* is deep rooted tree with a well-developed root system (El-showk & El-showk, 2003). Contrary to several others large, dichotomously branched roots growing downwards up to length of 8 meters (El-showk and El-showk, 2003), extensive root system of *Paulownia* grows deep in the earth and its crown develops a loose structure (Ayan, 2006) that significantly enhance the microclimate for growing crops (Wang and Shogen, 1992).Thus, *Paulownia* can be intercropped in crop field in agroforestry system. *Paulownia* intercropped with wheat enhanced the production rate when with no canopy (Zhao, 1986). Similarly, the production rate of maize and beans was decreased whereas the ginger production when intercropped with *Paulownia* increased greatly (Zhaohua, 1988). Nevertheless, *Paulownia* is intercropped mostly with winter crops and vegetables as trees have a period of rest during winter, meaning that there is no major competition for water and other nutrients at the period of rest (Wang and Shogren, 1992). However, the reason why a specific agroforestry practice contributed to carbon sequestration at a specific site where as another practices is not well understood (Jose and Bardhan 2012).

Natures of leaves of some species of *Paulowina* indicate border leaves of *P. tomentosa* among others (Rao 1986; Stankovic *et al*., 2009). Standard heart shaped leaves of *Paulowina* is large arranged in alternate pairs on steam ranging from 20.8 to 30.6 cm in longitudinal diameter (Kobayashi, 2008) can support CO_2 sequestration largely by effective photosynthetic activity. Leaves of *Paulownia* are good source of fat, sugar and protein and utilized as fodder for pigs, sheep and rabbits (Chaires, 2016). Furthermore, vegetation nitrogen concentration is linearly related with photosynthesis (Boegh *et al*., 2002). The nitrogen content (2.67% dry weight) in *P. tomentosa* leaves can be compared with some leguminous plants (Hui-jun and Ingestad, 1984). Photosynthetic rate increases substantially with increase CO_2 influx (Sigurdsson *et al*., 2002). Apart from these, the polyphenolic compounds produced by *Paulownia* shows high antioxidant property so research on antioxidant properties and medicinal value of secondary metabolites of *Paulownia* is gaining importance (Vaidhya *et al*, 2013).

P. tomentosa is mainly grown in hilly loess areas and in sandy, clay or salinized soil (Ipekci and Gozukirmizi, 2003). It can grow well without artificial irrigation as it has an ability to withstand drought (Xu *et al*., 2014). Furthermore, it exhibits strong transpiration rate and real tolerance to high metal concentration in both hydroponics and field (Doumett *et al*., 2010).

Propagation of *P. tomentosa* can be achieved through seed, cut steam and root and *in vitro* propagation technique (Burger *et al*., 1985). However, *in vitro* propagation technique is predominant than conventional methods while later is unreliable because of disease and pest problem, low germination (59%) and slow growth (Bergman and Moon, 1997). Different parts of plant can be used in *in vitro* propagation technique such as leaf, node, shoot tip (Song *et al*., 1989; Rahman *et al*., 2013) and *via* organogenesis (Corredoira *et al*., 2008). Our recent study on tissue culture of *P. tomentosa* (Magar *et al*., 2016) with hormone combination of BAP and NAA (1.0 mg/l BAP and 0.1 mg/l NAA) gave optimum results with disease free plants and well developed roots were found to be 80%. Thus, *in vitro* propagation, a powerful technique to generate lager number of healthy, genetically uniform plants can be applied in forest biotechnology and implement *P. tomentosa* as ideal species in agroforestry system.

Materials and Methods

Study Site

Study site was selected in previously planted *P. tomentosa* garden at Godavari Botanical Garden, Nepal. The site is located at 27.59ºN to 85.39ºE in elevation of 1500 meters above sea level. Garden lies 14 Kilometer southeast of Kathmandu in Lalitpur district of Nepal. Thirty plants (*P. tomentosa*) were planted on June, 2011 in a row without uniform morphology. Similarly, CO_2 sequestration was also measured for newly planted *P. tomentosa* (2 years old) in another site Bhimesthan-5, Sindhuli, Nepal located at 27.25ºN to 85.97ºE and elevation of 1077 meters above sea level. Plants were planted by individual farmer where 100 plants were taken for this study. Forest type in both sites includes moist coniferous evergreen and deciduous mixed forest. We also conducted field survey at other location including Ramechhap and Bhaktapur district of Nepal.

Above Ground Tree Biomass (AGTB) Estimation

Trees with Diameter at Brest Height (DBH) 5cm were considered for this study. DBH was measured at 1.3 m from ground level using diameter tape. Clinometer (Sunato, Japan PQ9) was used to measure the tangent angle of tree top from the observer's eye for estimation of tree height. Measuring tape was used to measure base distance from tree to the observer. Appropriate allometric equation was selected for estimation of above ground biomass.

Allometric Equation

The guideline published by ICIMOD suggested the allometric equation (modal) in estimating AGTB. It was developed by (Chave *et al.*, 2005) on the basis of climate and forest stand types. According to the guideline following equation was used to calculate AGTB (Above ground tree biomass). $\mathbf{AGTB = 0.0509 * \rho D^2 H}$, Where, $\boldsymbol{\rho}$= wood specific density ($gmcm^{-3}$), **D**= tree diameter at breast height (cm) and **H** = tree height (m)

Below Ground Biomass (BGB)

The relationship between root (below ground) to shoot (above ground) biomass is root to shoot ratio. (MacDicken, 1997) recommended that the root to shoot ratio is 1:5; that is, below ground biomass is estimated as 20% of above ground biomass.

$$Total\ Biomass\ = AGTB\ + BGB$$

Total Biomass Carbon

The biomass carbon is obtained by multiplying total biomass of tree with default value of carbon fraction 0.47 (Eggleston *et al*., 2006)

$$Total\ Biomass\ Carbon\ =\ Total\ biomass\ x\ 0.47$$

Results and Discussion

Observation of the plantation inside Godavari Botanical Garden revealed that there are number of other woody plant species including *P. tomentosa*, shrubs, grass and weeds. Some of the plants include *Cinnamomum camphora*, *Taxus mairei*, *Magnolia grandiflora*, *Cycas revoluta*, *Prunus cerasioiles*, *Rhododendron arboreum*, *Thuja orientalis* etc.

In this study total biomass carbon of previously planted *P. tomentosa* was estimated for a year (August 2015 to July 2016). The average biomass carbon within 12 months was found to be 135.68 ± 16.1 kg. The total biomass carbon for single tree per year was estimated to be 4.52 ± 0.53 Kg. Details carbon biomass for each month is mentioned on Table 1.

Similarly, 100 plants were planted by single farmer's crop field but, it was not intercropped with any crops. Average total biomass carbon within 4 months was found to be 6.07 ± 0.38 Kg. Estimated average total biomass carbon in one year was calculated as 18.21 ± 1.14 Kg i.e. 0.36-ton C ha^{-1} Year $^{-1}$. Detail carbon biomass for different months is indicated in Table 2.

Our field study in four districts found that plantation of *P. tomentosa* was done in hilly region of Nepal ranging from 700-2500 m. Our findings on total biomass carbon indicated that 5 years old *P. tomentosa* in Godavari sequestered 4.52 ± 0.53 Kg C $Year^{-1}$ per tree i.e. 9.04-ton C ha^{-1}. In contrast, lower carbon biomass was yield by newly planted plants in Sindhuli which showed 6.07 ± 0.38 Kg of total biomass carbon within 4 months. Estimated biomass carbon in a year of newly planted plants was found to be 18.21 ± 1.14 Kg $Year^{-1}$ i.e. 0.36-ton C ha^{-1} Year $^{-1}$. The reason for this is that the plants planted in Sindhuli were obtained through seed culture and early seedling growth by seed culture is slower than vegetative propagated plants from *in vitro* culture (Bergman and Moon, 1997). Site analysis in Sindhuli also indicates that early care to the plantation was neglected. Nevertheless, efficient growth, deep root system and large leaves of *P. tomentosa* contributes to generate large amount of C-rich biomass in above ground and below ground making it an ideal tree in agroforestry system.

Table 1: CO_2 sequestration ability of previously planted *P. tomentosa*

Months	**Tree age (years)**	**No. of trees**	**Above ground tree biomass (kg)**	**Below ground biomass (kg)**	**Total biomass (Kg)**	**Total biomass carbon ± SE (Kg)**
August, 2015	4	30	361.47	72.29	433.76	203.86 ± 36.76
December, 2015	5	30	548.24	109.64	657.88	309.20± 48.49
January, 2016	5	30	558.96	111.79	670.75	315.25 ± 52.99
March, 2016	5	30	583.26	116.65	699.91	328.95 ± 54.46
May, 2016	5	30	593.38	118.67	712.05	334.66 ± 55.58
July, 2016	5	30	602.02	120.40	722.42	339.54 ± 52.86
Difference within 12 months			135.68 ± 16.1			
Estimated total biomass carbon (single tree per year)			4.52 ± 0.53			

Table 2: CO_2 sequestration ability of newly planted *P.tomentosa*

Months	**No. of trees**	**Above ground tree biomass (kg)**	**Below ground biomass (kg)**	**Total biomass (Kg)**	**Total biomass carbon ± SE (Kg)**
March, 2016	100	2.43	0.48	2.91	1.37 ± 0.15
May, 2016	100	5.15	1.03	6.18	2.9± 0.28
July, 2016	100	13.2	2.64	15.84	7.44 ± 0.53
Difference within 4 months			6.07 ± 0.38		
Estimated total biomass carbon (per year)			18.21 ± 1.14		

Characteristic of root system is an important factor for success of agroforestry system as it contributes to maintain soil fertility and lowers the competition with crops (Schroth, 1995). Deep root system forms safety nets against nutrients leaching below the crop rooting zone (Van Noordwijk and Heinen, 1991) and it is a reasonable strategy for above ground tree functioning. In this study we have highlighted *P. tomentosa* a deep rooted woody tree (Ayan *et al.*, 2006) as a model plant which can be implemented in agroforestry system. Moreover, large leaves of *P. tomentosa* with efficient photosynthesis activity support CO_2 sequestration at greater amount. It could be alluded from (Zeng *et al.*,2013) that quantifying the carbon sequestration potential of the sampled four forest types, shrub, pine (*Pinus massoniana*) forest, pine and broadleaf mixed forest and evergreen broadleaf forest. Carbon storage in biomass increased significantly from the early succession stage shrubs (6.21-ton ha^{-1}) to the late stage broad leaf forest (134.87-ton ha^{-1}) this evidence support that the *P. tomentosa* with broad leaves can support CO_2 sequestration at greater rate. However, changes in the steam wood density in response to elevated CO_2 not only have clear consequence on carbon sequestration but also for wood quality for timber and paper production (Druart *et al.*, 2006). Furthermore, establishment of large scale short rotational woody crop plantation has been advocated as an effective method of CO_2 sequestration and mitigating increased CO_2 level (House *et al*., 2002).

Conclusion

Intercropping of *P. tomentosa*, a fast growing commercial woody plant in agroforestry system might be helpful in the context of GHGs mitigation strategy. The planted *P. tomentosa* have higher total biomass that might be highly supportive elements in carbon fixation and biomass production. Indeed, it is important to consider all the comportments of tree while determining accurate total carbon pool of tree. Further research is needed on forest trial to estimate realistic value of total carbon biomass of *P. tomentosa*.

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References

Ajayi OC, Place F, Akinnifesi FK and Sileshi GW (2011) Agricultural success from Africa: the case of fertilizer tree systems in southern Africa (Malawi, Tanzania, Mozambique, Zambia and Zimbabwe). *International journal of agricultural sustainability* **9**:(1): 129-136. DOI: 10.3763/ijas.2010.0554

Akyildiz MH and Kol Sahin H (2010) Some technological properties and uses of paulownia (*Paulownia tomentosa* Steud.) wood.

Ayan S, Sıvacıoğlu A and Bilir N (2006) Growth variation of Paulownia Sieb. and Zucc. species and origins at the nursery stage in Kastamonu-Turkey.

Banskota K, Karky B and Skutsch M (2007) *Reducing carbon emissions through community-managed forests in the Himalaya*: International Centre for Integrated Mountain Development (ICIMOD).

Bergmann B and Whetten R (1998) In vitro rooting and early greenhouse growth of micropropagated *Paulownia elongata* shoots. *New forests* **15**(2): 127-138. DOI: 10.1023/A:1006591704075

Bergmann BA and Moon H-K (1997) In vitro adventitious shoot production in Paulownia. *Plant cell reports* **16**(5): 315-319. DOI: 10.1007/BF01088288

Boegh E, Soegaard H, Broge N, Hasager C, Jensen N, Schelde K and Thomsen A (2002) Airborne multispectral data for quantifying leaf area index, nitrogen concentration, and photosynthetic efficiency in agriculture. *Remote sensing of Environment* **81**(2-3): 179-193. DOI: 10.1016/S0034-4257(01)00342-X

Brown S (2002) Measuring carbon in forests: current status and future challenges. *Environmental pollution* **116**(3): 363-372. DOI: 10.1016/S0269-7491(01)00212-3

Burger D, Liu L and Wu L (1985) Rapid micropropagation of *Paulownia tomentosa*. *HortScience* **20**(4): 760-761.

Chaires M (2016) *Functional analysis of salt stress induced genes from Paulownia elongata.* Dissertation, California State University, Northridge.

Chakravarty S, Ghosh S, Suresh C, Dey A and Shukla G (2011) Deforestation: Causes, Effects and Control Strategies. *Global Perspectives on Sustainable Forest Management* 3-21.

Chave Jr, Andalo C, Brown S, Cairns MA, Chambers J, Eamus D, Fölster H, Fromard F, Higuchi N and Kira T (2005) Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia* **145**(1): 87-99. DOI: 10.1007/s00442-005-0100-x

Corredoira E, Ballester A and Vieitez A (2008) Thidiazuron-induced high-frequency plant regeneration from leaf explants of *Paulownia tomentosa* mature trees. *Plant Cell, Tissue and Organ Culture* **95**(2): 197-208. DOI: 10.1007/s11240-008-9433-6

Cubbage F, Balmelli G, Bussoni A, Noellemeyer E, Pachas AN, Fassola H, Colcombet L, Rossner B, Frey G and Dube F (2012) Comparing silvopastoral systems and prospects in eight regions of the world. *Agroforestry Systems* **86**(3): 303-314. DOI: 10.1007/s10457-012-9482-z

Dixon R (1995) Agroforestry systems: sources of sinks of greenhouse gases? *Agroforestry Systems* **31**(2): 99-116.

DOI: 10.1007/BF00711719

Doumett S, Fibbi D, Azzarello E, Mancuso S, Mugnai S, Petruzzelli G and Del Bubba M (2010) Influence of the application renewal of glutamate and tartrate on Cd, Cu, Pb and Zn distribution between contaminated soil and Paulownia tomentosa in a pilot-scale assisted phytoremediation study. *International journal of phytoremediation* **13**(1): 1-17. DOI: 10.1080/15226510903567455

Druart N, Rodríguez-Buey M, Barron-Gafford G, Sjödin A, Bhalerao R and Hurry V (2006) Molecular targets of elevated [CO2] in leaves and stems of Populus deltoides: implications for future tree growth and carbon sequestration. *Functional Plant Biology* **33**(2): 121-131. DOI: 10.1071/FP05139

Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S, Seyboth K, Adler A, Baum I, Brunner S and Eickemeier P (2014) Summary for policymakers climate change 2014, mitigation of climate change. *IPCC 2014, Climate Change 2014: Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.

Eggleston S, Buendia L, Miwa K, Ngara T and Tanabe K (2006) *2006 IPCC guidelines for national greenhouse gas inventories* (Vol-5): Institute for Global Environmental Strategies Hayama, Japan.

El-Showk S and El-Showk N (2003) The Paulownia tree. *An alternative for sustainable forestry, Crop Development, Morocco*. 1-8.

Flynn JH and Holder CD (2001) *A guide to useful woods of the world. Madison.* 2nd edition. Forest Products Society.

House JI, Colin Prentice I and Le Quere C (2002) Maximum impacts of future reforestation or deforestation on atmospheric CO2. *Global Change Biology* **8**(11): 1047-1052. DOI: 10.1046/j.1365-2486.2002.00536.x

Hui-jun J and Ingestad T (1984) Nutrient requirements and stress response of Populus simonii and Paulownia tomentosa. *Physiologia Plantarum* **62**(2): 117-124. DOI: 10.1111/j.1399-3054.1984.tb00358.x

Ipekci Z and Gozukirmizi N (2003) Direct somatic embryogenesis and synthetic seed production from Paulownia elongata. *Plant cell reports* **22**(1): 16-24. DOI: 10.1007/s00299-003-0650-5

Jose S and Bardhan S (2012) Agroforestry for biomass production and carbon sequestration: an overview. *Agroforestry Systems**86***:(2). 105-111. DOI: 10.1007/s10457-012-9573-x

Jose S, Gold MA and Garrett HE (2012) The future of temperate agroforestry in the United States *Agroforestry-The Future of Global Land Use* (pp. 217-245): Springer. DOI: 10.1007/978-94-007-4676-3_14

Kobayashi S, Asai T, Fujimoto Y and Kohshima S (2008) Anti-herbivore structures of Paulownia tomentosa: morphology, distribution, chemical constituents and changes during shoot and leaf development. *Annals of Botany* **101**(7): 1035-1047. DOI: 10.1093/aob/mcn033

Kumar S and Lal R (2011) Mapping the organic carbon stocks of surface soils using local spatial interpolator. *Journal of Environmental Monitoring* **13**(11): 3128-3135. DOI: 10.1039/c1em10520e

Lee K-H and Jose S (2003) Soil respiration and microbial biomass in a pecan—cotton alley cropping system in Southern USA. *Agroforestry Systems* **58**(1): 45-54. DOI: 10.1023/A:1025404019211

Lorenz K and Lal R (2014) Soil organic carbon sequestration in agroforestry systems. A review. *Agronomy for Sustainable Development* **34**(2): 443-454. DOI: 10.1007/s13593-014-0212-y

MacDicken KG (1997) A guide to monitoring carbon storage in forestry and agroforestry projects.

Magar LB, Shrestha N, Khadka S, Joshi JR, Acharya J, Gyanwali GC, Marasini BP, Rajbahak S and Parajuli N (2016) Challenges and Opportunity of in vitro Propagation of *Paulownia tomentosa* Steud for Commercial Production in Nepal. *International Journal of Applied Sciences and Biotechnology* **4**(2): 155-160. DOI: 10.3126/ijasbt.v4i2.14752

Melorose J, Perroy R and Careas S (2015) No title no title. *Statewide Agricultural Land Use Baseline* **1**(2): 221-248.

Morgan JA, Follett RF, Allen LH, Del Grosso S, Derner JD, Dijkstra F, Franzluebbers A, Fry R, Paustian K and Schoeneberger MM (2010) Carbon sequestration in agricultural lands of the United States. *Journal of Soil and Water Conservation* **65**(1): 6A-13A. DOI: 10.2489/jswc.65.1.6A

Mosquera-Losada M, Freese D and Rigueiro-Rodríguez A (2011) Carbon sequestration in European agroforestry systems *Carbon sequestration potential of agroforestry systems* (pp. 43-59): Springer. DOI: 10.1007/978-94-007-1630-8_3

Nair P (2012) Carbon sequestration studies in agroforestry systems: a reality-check. *Agroforestry Systems**86***:(2). 243-253. DOI: 10.1007/s10457-011-9434-z

Nair PR, Nair VD, Kumar BM and Haile SG. (2009). Soil carbon sequestration in tropical agroforestry systems: a feasibility appraisal. *Environmental Science & Policy* **12**(8): 1099-1111. DOI: 10.1016/j.envsci.2009.01.010

Noble I, Bolin B, Ravindranath N, Verardo D and Dokken D (2000) *Land use, land use change, and forestry*: Cambridge University Press.

Paustian K, Collins HP and Paul EA (1997) *Management controls on soil carbon*: 1997a, CRC Press: Boca Raton, FL, USA. p.

Pimentel D (2006) Soil erosion: a food and environmental threat. *Environment, development and sustainability* **8**(1): 119-137. DOI: 10.1007/s10668-005-1262-8

Protocol K. (1997). United Nations framework convention on climate change. *Kyoto Protocol, Kyoto* **19**.

Rahman MA, Rahman F and Rahmatullah M (2013) In vitro regeneration of Paulownia tomentosa Steud. plants through the induction of adventitious shoots in explants derived from selected mature trees, by studying the effect of different plant growth regulators. *American-Eurasian Journal of Sustainable Agriculture* **7**(4): 259-268.

Rao A (1986) *Paulownia in China: cultivation and utilization*: Asian Network for Biological Sciences, Singapore, SG.

Rogers HH, Runion GB and Krupa SV (1994) Plant responses to atmospheric CO2 enrichment with emphasis on roots and the rhizosphere. *Environmental pollution* **83**(1-2): 155-189. DOI: 10.1016/0269-7491(94)90034-5

Schoeneberger M, Bentrup G, De Gooijer H, Soolanayakanahally R, Sauer T, Brandle J, Zhou X and Current D (2012) Branching out: Agroforestry as a climate change mitigation and adaptation tool for agriculture. *Journal of Soil and Water Conservation* **67**(5): 128A-136A. DOI: 10.2489/jswc.67.5.128A

Schoeneberger MM (2009) Agroforestry: working trees for sequestering carbon on agricultural lands. *Agroforestry Systems* **75**(1): 27-37. DOI: 10.1007/s10457-008-9123-8

Schroeder P (1993) Agroforestry systems: integrated land use to store and conserve carbon. *Climate Research* **3**(1): 53-60. DOI: 10.3354/cr003053

Schroth G (1995) Tree root characteristics as criteria for species selection and systems design in agroforestry *Agroforestry: Science, Policy and Practice* (pp. 125-143): Springer.

Sedjo R and Sohngen B (2012) Carbon sequestration in forests and soils. *Annu Rev Resour Econ* **4**(1): 127-144. DOI: 10.1146/annurev-resource-083110-115941

Sedjo RA and Sohngen B (2007) Carbon credits for avoided deforestation. *Washington, DC: Resources for the Future*. 07-47.

Sigurdsson BD, Roberntz P, Freeman M, Næss M, Saxe H, Thorgeirsson H and Linder S (2002) Impact studies on Nordic forests: effects of elevated CO2 and fertilization on gas exchange. *Canadian Journal of Forest Research* **32**(5): 779-788. DOI: 10.1139/x01-114

Silvestre AJ, Evtuguin DV, Sousa APM and Silva AM (2005) Lignans from a hybrid Paulownia wood. *Biochemical systematics and ecology* **12**(33): 1298-1302. DOI: 10.1016/j.bse.2005.07.004

SONG SL, SATO T, SAITO A and OHBA K (1989) Meristematic culture of seven Paulownia species. *Journal of the Japanese Forestry Society* **71**(11): 456-459.

Stankovic D, Nikolic M, Krstic B and Vilotic D (2009) Heavy metals in the leaves of tree species Paulownia elongata SY Hu in the region of the city of Belgrade. *Biotechnology & Biotechnological Equipment* **23**(3): 1330-1336. DOI: 10.1080/13102818.2009.10817664

Van Noordwijk M, Heinen M and Hairiah K (1991) Old tree root channels in acid soils in the humid tropics: important for crop root penetration, water infiltration and nitrogen management *Plant-Soil Interactions at Low pH* (pp. 423-430): Springer.

Wang Q and Shogren JF (1992) Characteristics of the crop-Paulownia system in China. *Agriculture, ecosystems & environment* **39**(3-4): 145-152. DOI: 10.1016/0167-8809(92)90050-L

WBCSD V (2010) 2050 The new agenda for business. *World Business Council for Sustainable Development, Geneva*.

Xu E, Fan G, Niu S, Zhao Z, Deng M and Dong Y (2014) Transcriptome-wide profiling and expression analysis of diploid and autotetraploid Paulownia tomentosa× Paulownia fortunei under drought stress. *PloS one* **9**(11): e113313. DOI: 10.1371/journal.pone.0113313

Zeng Z-Q, Wang S-L, Zhang C-M, Gong C and Hu Q (2013) Carbon storage in evergreen broad-leaf forests in mid-subtropical region of China at four succession stages. *Journal of forestry research* ***24***(4): 677-682. DOI: 10.1007/s11676-013-0404-3

Zhao J, Xiong G, Yao K and Li H (1986) *An economic analysis of the crop-paulownia system in western Henan Province.* Paper presented at the Submitted to the symposium of agroforestry systems in China. Nanjing Forestry University, Nanjing (in Chinese).

Zhaohua Z (1988) *A New Farming System--Crop/Paulownia Intercropping.* Paper presented at the Multipurpose Tree Species for Small-farm Use: Proceedings of an International Workshop Held November 2-5, 1987, in Pattaya, Thailand.

Zhu Z, Chao C, Lu X and Xiong Y (1988) Paulownia in China cultivation and utilization. Asian Network for Biol. *Sci. and Inter. Dev. Res. Centre, Singapore*.