Responses of drylands woody vegetation to elevated CO2: review of consequences and research needs.

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Abstract

Global changes such as elevated carbon dioxide [eCO2] and warming have been described as the most serious environmental threats to our planet. Elevated CO2 may have important consequences on forested ecosystems. Although, the impact is worse in dryland ecosystems as atmospheric changes increase aridity and change soil fertility, but it remains unknown. The study aiming at understanding the effects of eCO2 and its consequences on Hashab (Acacia senegal) as a dryland C3 tree species with substantial ecological and economic roles. We quantitatively reviewed and discussed over 50 papers on the literature about CO2 elevation (eCO2) effects on C3 plant and ecosystems to understand how eCO2 will affect dryland C3 species of sub-Saharan Africa. We found in the literature that, for C3 species generally eCO2 increases photosynthesis rate and reduces stomatal conductance but with increased plant leaves' area leading to release water. Water loss due to stomatal conductance is unavoidable in dryland ecosystems. More seeds can be produced in eCO2 but with mostly correlated seed low quality which may limit seedling recruitment. Seedlings, as the most responsive stage to eCO2, may respond by enhancing growth and biomass production or experience photosynthesis down regulation and/or photorespiration. The results suggested that A. senegal, as a C3 and leguminous species will respond to eCO2 by two scenarios; 1) positively through enhancing growth and biomass or; 2) a negative photosynthetic acclimation that could be due to physiological dysfunction that resulted in metabolic compulsions. The responses need to be further investigated under different ecological conditions to feedback the global changes and ecosystem monitoring including changes of species composition is recommended.

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Abstract:

Global changes such as elevated carbon dioxide [eCO_2] and warming have been described as the most serious environmental threats to our planet. Elevated CO_2 may have important consequences on forested ecosystems. Although, the impact is worse in dryland ecosystems as atmospheric changes increase aridity and change soil fertility, but it remains unknown. The study aiming at understanding the effects of eCO_2 and its consequences on Hashab (*Acacia senegal*) as a dryland C_3 tree species with substantial ecological and economic roles. We quantitatively reviewed and discussed over 50 papers on the literature about CO_2 elevation (eCO_2) effects on C_3 plant and ecosystems to understand how eCO_2 will affect dryland C_3 species of sub-Saharan Africa. We found in the literature that, for C_3 species generally eCO_2 increases photosynthesis rate and reduces stomatal conductance but with increased plant leaves' area leading to release water. Water loss due to stomatal conductance is unavoidable in dryland ecosystems. More seeds can be produced in eCO_2 but with mostly correlated seed low quality which may limit seedling recruitment. Seedlings, as the most responsive stage to eCO_2, may respond by enhancing growth and biomass production or experience photosynthesis down regulation and/or photorespiration. The results suggested that *A. senegal*, as a C_3 and leguminous species will respond to

eCO_2 by two scenarios; 1) positively through enhancing growth and biomass or; 2) a negative photosynthetic acclimation that could be due to physiological dysfunction that resulted in metabolic compulsions. The responses need to be further investigated under different ecological conditions to feedback the global changes and ecosystem monitoring including changes of species composition is recommended.

Keywords:

Acacia senegal, climate change, drylands, elevated CO_2 , Savanna, Sudan, Africa

1. Introduction:

Global climatic changes have been described as the most serious environmental threat to our planet due to massive anthropogenic activities (IPCC, 2014). Human activities are significant causing factor for increasing atmospheric pollution and concentrations of greenhouse gases (GHGs) that are considered a crucial indicator for climate change (Reynolds-Henn et al. 2010; IPCC, 2014).

Since the industrial era, CO_2, nitrous oxide and methane emissions have been raising up along with concomitant increasing in global mean temperature. Nowadays, CO_2 is at the highest levels worldwide (IEA, 2022). The level has increased by about 40% since the industrial era to reach 390.5 ppm in 2011 and expected to rise up to 985 ppm during the upcoming 100 years (IPCC, 2013 and 2014). Despite the pandemic and its associated large scale & wide lockdown, it increased from 412 ppm in 2020 to reach 419 ppm in 2021 and additional increases (4.9%) are predicted in 2022, almost returning back to pre-pandemic level (during pandemic the decrease was 5.4%). These persistent increases are due to substantial rise in consumption of fossil fuel (Le Page, 2019).

The increase in CO_2 concentration of earth's atmosphere associated with predictions of global warming (IPCC, 2013) and water scarcity (ESCWA,

2011) have stimulated excellent reviews and growing body of knowledge about the consequences of high concentration of CO_2 on biodiversity in general and woody vegetation diversity in particular (Yeboah et al., 2016). However, impacts are worse in dryland ecosystems, particularly sub-Saharan Africa (IPCC 2014; Niang et al. 2014).

For instance, recent studies have reported that impacts of climate change will have profound effect on vegetation composition and structure (e.g. Díaz et al., 2019) and ecosystem functions (e.g. USGCRP, 2018). Moreover, CO_2 concentrations on the atmosphere are likely to stimulate plant-microbes competition and increase soil fertility (Karhu et al., 2014). Globally, the above mentioned effect will increase C&N fixation rate in both above ground and below ground vegetations and by time will result in inefficient N in ecosystems (Luo et al., 2004). The enhanced vegetation accrual of N can explain the reduction in soil organic N (Gill *et al.*, 2006). According to Karhu et al. (2014), the consequences of elevated CO_2 will depend on the soil moisture and soil nutrient content, therefore the impact will be worse in dry areas of sub-Saharan and savannah regions due to severe drought and land degradation (Delgado-Baquerizo et al., 2014). Hu et al. (2016) reported that generally under elevated CO_2 interaction of woody vegetation and soil microbes are predicted to play a fundamental role in availing more nutrients, although under limited nutrient conditions tree-microbes struggling for nutrients will bear out the overall biomass dimensions.

Accounting for about 40% of the earth's area, dry lands are considered to be most vulnerable spots for impacts of CO_2 concentrations accompanied with global temperature increases (Stanley et al., 2000 and Cherlet et al., 2018). According to White et al. (2002) about 50% of the world's countries are completely or partially characterized by features of dry ecosystems. For instance, in Africa as reported by Ffolliott et al. (2002), IUFRO (2004), Yang et al. (2005) and Zeng and Yoon, (2009) dry ecosystems are spreading out in 36 countries which is about 43% of the continental area. Even though, the dry region is a habitat of near two fifth of the world's resident citizens and it is inclined to enlarge because of population outgrowth and dry land natural extension (Yang et al., 2005; Zeng and Yoon, 2009).

Hashab (*Acacia senegal)* is an important example of dryland forest tree, it is a dry land's woody plant legume with substantial ecological and economic roles for Africa's community livelihoods. Interconnecting Forests, Science and People (IUFRO, 2004) has reported that the established intercropping *A. senegal* resilient system that has been in Sub-Saharan Africa for handed years, is to be exposed to many anthropogenic and ecological hazards.

Nevertheless, the tree is one of the most priority forest types in Sudan. It produces gum Arabic. Contributing to over 90% of global production, gum Arabic is of great socio-economic impacts. Agroforestry opportunity, animals' feed, shelter for shade, high quality charcoal, lumber and medicines are the other purposes of the tree (Fagg and Allison, 2004; Fadl and El Sheikh, 2010; Sprent et al., 2010; FAO, 2017).

Acacia senegal is a C_3 species (Sibret, 2018) hence, it may have physiological adaptations to CO_2 concentration on growth parameters, biomass accumulation and fitness. However our understanding to the mechanisms and magnitude of these effects is limited. Moreover, a better understanding of impacts of high CO_2 concentrations on the essential *A. senegal* is crucial (Sleen et al., 2015). On the other hand, many recent reports (e.g. Siddig, 2019; UNEP, 2020) have warned from ecological data-deficiency and information gap in Africa including impacts of CO_2 elevation on dryland woody vegetation. Accordingly, this study aims at exploring the impact of CO_2 raise on *A. senegal* and its consequences on dryland ecosystems' patterns by reviewing and discussing the responses of woody vegetation to CO_2 concentration. Finally, we also point out some needed research directions in this topic and recommended measurements.

2. Methodology:

This study focused on literature analysis and considering search of papers published in notable journals with focus on consequences that will face the dryland environments. In particular, a simple internet search have been begun by which keywords like drylands vegetation, acacia trees, global change, C_3 species, CO_2 increases based on searching procedure explained above plus looking at the titles, about fifty articles have been identified as relevant for further assessment. Therefore, in each article we looked at the title, abstract, keywords as well as skimming throughout the papers' results and discussions for collecting detailed evidences about the consequences that the drylands may face up to under elevated CO_2 and generally C_3 species responses and adaptation.

Specific information searched for were growth (e.g. photosynthesis, stomatal conductance, respiration, drought, soil, microbial activities, nutrition, seed production and seedling performance) and development (e.g. biomass production, dry weight) parameters.

3. Responses of woody vegetation to elevated CO_2:

Impact of increased CO_2 concentrations on plants is a long-standing research topic for plant ecologists. In particular, the responses of photosynthesis, stomatal conductance and respiration & transpiration, to elevated CO_2 as well as their subsequent effects on plants' growth & health indicators, seed production and seedling performance are among the many research areas of recent works (Steinger et al., 2000; Katul, 2010). The literature of woody vegetation responses to elevated CO_2 have been well addressed (e.g. Yeboah, 2016). Considerable attention is growing on mechanisms and amount of carbon sequestration (Yeboah, 2016) and due to their extensive coverage, nearly one third of earth's surface and two thirds of gross biomass production, there are a growing interest in the consequences of CO_2 concentration on woody vegetation (Wisniewski and Neil, 2012; Bhargava et al., 2016) and in the following paragraphs we are discussing some of these responses.

3.1. Photosynthesis

Generally woody vegetations respond to CO_2 concentration by accelerating photosynthetic metabolic reactions and increasing allometry and biomass productivity with enhancement in litter quality and quantity and rhizodeposition as well (e.g. Knapp et al., 1996; Ainsworth and Long, 2005; Albert et al., 2011; de Graaff *et al.*, 2011). Accordingly, more detritus and root exudates with easy digested carbon are expected to be added into soil (Jones et al., 2009; Larsen et al., 2011).

According to Reddy et al. (2010), elevated CO_2 enhances photosynthesis system and biomass production for many plant species, assuming that growth limiting factors are available. It has long been known that, when C_3 tree species exposure to CO_2 for short term, this can intensify photosynthetic process and ameliorate growth provided other resources are not seriously limited (Haverd, 2019; Ainsworth and Rogers, 2007), whereas, for long time the intensification usually counterbalanced by reduction in metabolic synthesis (Long et al., 2004).

For the increase in relative growth rate and net assimilation rate that accompanied with a decrease in specific leaf area that typically happens under CO_2 concentration, the averages across the slow and fast-growing *Acacia* species were increases of relative growth rate and net assimilation rate with a decrease in foliage area per unit foliage dry mass (Poorter *et al*., 1996). The greater enhancement of net assimilation rate by elevated CO_2 in Acacia species, was offset by an equally large reduction of foliage area per unit foliage mass. This can be attributed to *Acacia species* from semi-arid environments which are inherently slower growing than those characteristic of mesic environments (Atkin *et al*., 1998). Slow growth in the semi-arid species is not associated with lower net assimilation rate or less plant mass allocated to foliage. Rather, their slow growth is associated with a smaller foliage area per unit foliage mass compared to their faster-growing counterparts. Phyllode production reduces the relative growth rate because phyllodes have a smaller area per unit foliage mass than leaves (Atkin *et al*., 1998). Not surprisingly, phyllode production is dominant in inherently slow-growing acacia species from semi-arid environments, with exclusive or dominant leaf production mainly occurring in faster-growing species from mesic environments (Atkin *et al*., 1998).

3.2. Stomatal conductance:

Many studies (e.g. Gedney et al., 2006 and Betts et al., 2007) indicated that high CO_2 makes stomata to open less minimizing water loss resulting in greater surface running water. By this means and for instance in drylands, decreasing lost water may be prolonged growth period (Volk et al., 2000). However, this effect can be counteracted by leaves' area that enlarged by CO_2 making no matter for water use efficiency (Ziska et al., 1991). Nevertheless, stomata lesser opening releases the amount of CO_2 that would have absorbed by plant, into atmosphere (Shiren, 2013).

A possible beneficial effect of this increase in water use efficiency is a reduction in the rate of water consumption per unit leaf area, but the simultaneous increase in total leaf area as a result of CO_2 increase may partly offset this increase in WUE. Increase in WUE as a result of increasing

CO_2 concentration has been observed in a number of tropical pioneer and climax tree species including *Acacia mangium* (Oberbauer *et al.*, 1985, Reekie and Bazzaz, 1989; Ziska *et al.*, 1991).

Investigations of stomatal response to ecological changes has a dual approaching models, the first one is depending on the effects of environmental changes on stomatal through semi-empirical experiments and photosynthetic performance (Jarvis, 1976; Leuning, 1995).

The other one, alternatively, depends on the plant- water requirements and points out to organizing performance of stomata, consistent with these approaches, when stoma opens to get carbon it concurrently releases water, this evaporated water is respected as at expensive of plant water balance (Makela et al., 1996). This water loss due to stomatal conductance is even more costly and unavoidable in dry land ecosystems.

***3.3. Respiration*:**

Short-term elevation of CO_2 increases assimilation rate and decreases transpiration rate in C_3 plants (Shiren et al., 2013). Seemingly, elevated CO_2 has a retrogressive fitness to ecosystem transpiration, when CO_2 increases transpiration rate entirely decreases (Ziska and Bunce, 1994; Gonzalez-Meler, 2004). The mechanisms that reduced transpiration can be attributed to increased rate of light independent reactions of carboxylation that stabilize CO_2 (Gonzalez-Meler, 2004).

Transpiration per unit leaf area of *Acacia farnesiana* (L.) Willd. plants grown at ambient CO_2 (concentration of 385 ppm) was about twice that of plants grown at elevated CO_2 (980 ppm). However, when plants grown for more than a year at elevated CO_2 were exposed to ambient CO_2 for 9 days, they transpired at half the rate of those had been grown at ambient CO_2. Similarly, plants grown at ambient CO_2, when exposed to elevated CO_2, transpired at twice the rate of those grown at elevated CO_2 (Dugas *et al.*, 2001).

Concentration of CO_2 can improve plant growth and biomass production by 27% without changing in respiration rate, while in ambient the improvement may reach 20% but associated with increases in whole plant community respiration rate (Miquel et al., 2004; Hamilton et al., 2002).

More often than not, high CO_2 decreases leaves' transpiration rate and increases plant leaves' area leading to release water. The water released is balancing of that would be saved in low transpiration rate (Heath and Kerstiens, 1997).

3.4. Drought:

World-wide and for upcoming hundred years, temperature is foreseeing to increase by 2 to 4.5^{o}C on average, as a consequence of elevated CO_2, leading to change rainfall fluctuation pattern and increasing aridity (IPCC, 2013). The ecological changes alters biotic and abiotic factors that can change ecosystems composition and function (Beier, 2004; Santoyo, 2017). These anticipated climatic changes will have important consequences on ecosystem water availability (i.e. drought) specially in drylands of Africa (Ľubica et al., 2010).

Many studies (e.g. Gessler et al., 2017; Escós et al., 2000; Blodner et al., 2005) reported that drought may decrease photo-assimilates by restricting stomatal opening, metabolic reactions and photosynthesis rate causing a substantial lack in biomass production and thus success in seedling establishment and plant competitiveness. Combined of increased aridity periods and temperature will amplify the consequences of drought by paced evaporation, minimized plant detritus and exudates, controlled soil microbes and fertility (Sowerby et al., 2008; van Meeteren et al., 2008; Selsted et al. 2012).

On the other hand, when soil moisture is not affected, increased temperature, at globe scale, will reversibly enhance soil microbes, nutrient minerals availability and soil fertility and so, enhance vegetation growth and productivity (Jonasson et al., 2006; van Meeteren et al., 2007; Selsted et al., 2012).

3.4. Soil:

According to Keeling et al., (1995) and throughout the last ten years, there are two assumptions to describe the link between soil fertility and plant growth in the era of increasing CO_2 as the issue is of great consideration. Earliest for short-period, the increasing of soil fertility and microbes activity under carbon concentrations is continuous or whether for long-period, the fertilization enhancement will not continue because of reduction in nutrients of soil mainly N (Diaz et al., 1993).

The latest, plant soil interaction under CO_2 concentration will change soil C&N cycle that lead to either increases or decreases CO_2 emissions (Smith et al., 2000). The two assumptions are dealing with the changing in soil carbon & nitrogen and microbial activity because soil C&N cycle entirely correlates to microbial activity.

Large-scale pool of soil organic matter decomposition or synthesis reactions will result in considerable changes in the rate of CO_2 emission. Several investigations have concerned with this topic (e.g. Lichter et al., 2005 and 2008; Hoosbeek et al., 2006; Langley et al., 2009; Hoosbeek et al., 2006) as at large-scale pools, soil carbon responses to CO_2 concentration by two variant approaches enhancement or detraction. Soil organic matter C&N can increase or decrease under CO_2 concentrations, these two induced processes are crucial and connected with pool C&N dynamics. In one hand, what let researchers to suggest that CO_2 concentration will increase SOM is due to raising plant exudates, detritus, soil microbial activity (Pritchard et al., 2008).

On the other hand and according to Finzi et al. (2007) and Gill et al. (2006) plan tissue gains more nutrient elements under CO_2 concentration making litter is rich in N and detritus as well. However, such process is demonstrating the changes in nitrogen content as it is lesser in tested soil than control.

3.6. Microbial activity:

Under CO_2 concentration 'priming effect' is one procedure that, probably, affects soil carbon accumulation to increase this enhances soil microbial activity and makes both original and newly added organic matter to soil available for microbes to enlarge their mass and to improve their activity (Kuzyakov et al., 2000; Fontaine et al., 2007; Patterson, 2009; Langley et al., 2009). Nevertheless, the improvement of availing SOM seems to be not sustainable, as some studies (e.g. Langley et al., 2009) concluded that calculations of carbon added and depleted from soil result in reduction in carbon.

'Mine' procedure is another method under CO_2 concentration in which soil microbes have to search for more N from old organic matter, but the "mined" N usually removed by under stories growth making no enhancement in microbial biomass because of N inefficiency. Nonetheless, the new added organic matter can liberate CO_2 to atmosphere by amplified oxidation (Kuzyakov et al., 2000).

Estimation of such N increases is complicated due to need to understand why under CO_2 concentrations, plant demand more N that in the same amount of the decline one in the N cycle process (Reich et al., 2006). Nonetheless, the estimation of net N flows under CO_2 concentration in the environment at large is the key answer for the knowledge of N limitation in era of climatic changes (Sharon et al., 2010).

3.7. *Nutrition*

The increased demand of mineral nutrients in ecosystems often under elevated CO_2 may not be compensated because of limited mineral nitrogen supply. Nitrogen mineral supply is limited factor for potential growth of the individual plant and the community level under elevated CO_2 (Eamus & Jarvis, 1989). However, N_2-fixing species can compensate the shortages of nitrogen and plant in nitrogen-limited conditions may depend on them for nitrogen balances in the ecosystems (Hartwig et al., 2000; Soussana & Hartwig, 1996).

Legumes can enhance their symbiotic nitrogen fixation under elevated atmospheric CO_2. A higher biomass investment in tissues (e.g. nodules) is one mechanism and the other is increasing nitrogenase activity (a greater amount of N_2 fixed per unit nodule mass and time), but these mechanisms can be additive, or cancel each other out. (Schortemeyer et al. 2002; Thomas et al., 2000).

Rastetter et al. (1997) suggested that nutritional imbalances may limit effects of CO_2 on plant due to changes in above-ground (C) and/or below-ground required nutrients. Accordingly, decline in below-ground N constrains effects of CO_2 elevation on woody vegetations (Poorter and Pérez-Soba, 2001). Furthermore, under CO_2 concentration soil poor in N content produced N-limited leaves that resulted in reduced photosynthetic reactions (Curtis et al., 2000).

According to Saxe et al. (1998) nitrogen limitation is often observed in high CO_2 though, enhancement in woody vegetation growth could be reserved merely with sustainable supply of nitrogen. Plant with ability of N_2-fixing is proofed to enhance soil mineral N content in elevated CO_2, hence other existing non-fixing species can assimilate more carbon as well. This interaction effect is considered as a 'positive effects' (Schortemeyer et al., 2002).

3.8. Seed production:

In era of high CO_2, reproductive traits such as flowering and seed production are vital features of the plant communities' future dynamics (Ibanez et al., 2006). Elevated CO_2 can alter tree population dynamics and ecosystem composition by affecting quality of seed bulks and then establishment of seedling (Caspersen and Saprunoff, 2005).

For instance, elevated CO_2 can increase seed production quantities (Jablonski et al., 2002) but are likely associated with decreasing features such as seed C/N, germination and biomass (He et al., 2005). Rather, leguminous tree can avoid reducing seed quality in high CO_2 by its N_2-fixing ability, provided that the compensated nutrients are balancing the gained carbon that being available at CO_2 elevation (He et al., 2005; Miyagi et al., 2007).

In response to elevated CO_2 seed nitrogen reduced by 14% on average for 179 studied species while, there were significant variations between legumes and non-legume species; legumes were not affected while in non-legume species nitrogen was reduced (Jablonski *et al*., 2002). When more N available at elevated CO_2 concentrations seed biomass will increase without reduction in seed quality. But even in N-reduction system, legume species can invest more carbon that being available at elevated CO_2 for increasing the N_2- fixation process (Allen *et al*., 2000 and Hikosaka *et al*., 2011). Therefore under CO_2 concentration, legumes can increase their seed mass without decreasing in seed N concentration while non-legumes can increase their seed mass but with reduction in seed N concentration which may result in seed quality and seedling future development (Fenner, 1991; Andalo *et al*. 1996).

3.9. Seedling's performance:

Many studies (e.g. Radford & Cousens, 2000; Edwards et al., 2001; Nguyen et al., 2017) reported that successful germination and well establishment of new plantations are determining ecosystem's future composition and services. Elevated CO_2 can increase relative growth rate of many species as earlier stage of plant is more responsive to CO_2 (during a couple of days or weeks) leading to advantage plant future growth (Norby et al., 1996).

Ainsworth & Long (2005) and Ainsworth & Rogers (2007) in FACE experimental studies of seedlings reported that soil N content is determining the photosynthesis rate, as the rate in N-limited soil is lower than that of rich N. Since the limited growth factors rather than C seems to be limited or even decline under CO_2 lead to down-regulate growth enhancement. Soil fertility will play a vital role in establishing seedlings for community new generations.

The effect of elevated CO_2 on C_3 species' seedlings is transiently stimulated the Relative Growth Rate (RGR, increase in mass per unit mass per day) and likely the effect depends on the inherent RGR of the species. Environmental conditions often determine this characteristics as unfavorable conditions have the species of low RGR (Chapin, 1980; Lambers and Poorter, 1992; Poorter, 1993; Lambers et al., 1998). In woody plant species, characteristics of RGR are often robustly associated with a lower foliage area per unit foliage dry mass and lower N concentrations (Atkin and Lambers 1998; Atkin et al. 1998).

4. Conclusions and future directions:

Despite the increase in atmospheric CO_2 concentrations at the global scale, elevation of CO_2 in temperate forests, thought to stimulate plant growth and eventually NPP. In contrary, drylands of Africa such as Savanna woodlands are reported to be most vulnerable and highly sensitive to impacts of associated climate changes at the local scale. Examples of serious impacts of climatic changes in Savanna ecosystems can be on soil moisture availability and soil microbial communities those of critical roles in nutrient cycling and plant growth in dryland ecosystems, respectively. Consequently, these changes in such important processes may directly influence fauna and flora diversity and distribution as well as their associated ecosystem services which eventually affect human livelihoods in these ecologically fragile regions.

Nevertheless, impacts of climatic changes on woody vegetation are still limited and many questions are yet to be answered. For instance, understanding and predicting the effects of climate change on specific important Savanna trees species and consequently their ecosystem services is crucial and much needed research direction. Moreover, the responses and adaptations of the most important C_3 tree species in dryland of Sudan like *Acacias (e.g. A. senegal, A. nilotica, A. seyal* ...etc) to CO_2 elevation need to be evaluated for short and long-term periods to draw a holistic picture of their ecosystem dynamics. Nonetheless, other interacting factors with CO_2 such as water limitation, thermal stress, and nutrient deficiency should be investigated for better understanding responses of plants to climatic changes.

On the other hand, for a proper adaptation planning for drylands vegetation in the face of climatic changes there are few management interventions that have to be in place. These measures may include;

1) Following suitable rain water harvesting practices.

2) Developing vegetation assessment and vulnerability mapping following remote sensing technology, for example.

3) Given the predicted impacts on seed production, soil-plant-nutrition, and seedlings' performance, some attention has to be devoted to vegetation rehabilitation programs.

4) Adoption of a long-term ecosystem monitoring including changes of species composition and diversity as well as net photosynthesis and stomatal responses (i.e. Ecosystem productivity). Important values for a such proposed monitoring will not only provides ability to detect changes in CO_2 concentrations at the ecosystem level or allow better understanding of relation between CO_2 elevation and up-regulation or down-regulation of photosynthesis but also show plants stomatal response to elevated CO_2 and under which conditions this occurs.

Overall, an impact of CO_2 elevation is expected to be worse in tropical dryland ecosystems and particularly in sub-Saharan Africa. Accordingly, much attention should be devoted to understanding how elevated CO_2 will affect dryland woody vegetations and subsequent ecological functions and services in sub-Saharan Africa.

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