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Review

Effect of forests practices on local climate

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For decades, forest researchers have known that planting trees on cropland or pastures (that is, afforestation) can lower the surface albedo and that landscapes with low albedo absorb more solar radiation than more reflective surfaces. Consequently, afforestation will typically darken the Earth's surface (when compared to grasslands or deserts). In spite of this knowledge, many believe that afforestation will cool the Earth's atmosphere since wood is composed of carbon molecules. Therefore, there are two schools of thought on how afforestation affects global climate. The "CO_2 School" believes that afforestation will have a cooling effect, regardless of the location of the planted trees. In contrast, the "Holistic School" believes the climate is a complex system affected by numerous variables, including clouds and the surface albedo. Many from this School say that afforestation in boreal zones could warm the Earth. This paper reviews some papers from the "Holistic School" and asks the question: will afforestation in temperate zones warm the Earth?

Key words: Albedo, boreal, deforestation, carbon sequestration, climate change, climate policy, tropical.

INTRODUCTION

The debate on the effect of forests on local climate is very old. As far back as the 15th century, some noted a decrease in rainfall after deforestation in the Azores and Canary Islands (von Homboldt, 1866). Although the theory that deforestation decreases rainfall was strongly held by some foresters (Fernow, 1888), others were more skeptical. For example, Mark Harrington, chief of the Weather Bureau, concluded from surveys conducted in Europe that data suggested no significant influence on the rainfall amounts (Kutzleb, 1971).

Now the debate has evolved to how forests affect global temperature. Currently, there are two schools of thought regarding forestry practices that might "mitigate" the effects of climate change. The "CO_2 School" believes that sequestering 60 gigatonnes of carbon by afforestation will have the same effect on the Earth's temperature as reducing atmospheric emissions by 60 gigatonnes of carbon (for example, Stinson and Freedman, 2001; Kirschbaum, 2003; Pacala and Socolow, 2007; Canadell and Raupach, 2008). They believe the primary role of forests in affecting atmospheric temperature is either as a carbon sink (for example, afforestation) or as a carbon source (for example, deforestation) . Some say that afforestation is "one of the most widely recognized forestry practices for the mitigation of climate change" (Malmsheimer et al., 2008).

In contrast, the "Holistic School" says global climate is a complex system affected by various factors including surface albedo, clouds, water vapor, etc. Consequently, they say that the results from sequestering carbon dioxide by tree planting are not the same as those obtained from reducing emissions from carbon dioxide (Marland et al., 2003). In fact, afforestation in some places might have unintended climate consequences (Jackson et al., 2008). Some from this school say that afforestation might warm the Earth and deforestation

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could cool the Earth (for example, Betts, 2000; Gibbard et al., 2005; Bala et al., 2007). This paper reviews some of the literature from the "Holistic School" of thought and examines some potential costs associated with large-scale afforestation.

LOCAL VERSUS GLOBAL EFFECTS

The "local" and "global" effects may differ in opposite directions which explain some of the confusion regarding the effects of forests on atmospheric temperature. Some papers discuss only the "local" effects while others discuss the "global" effects. For example, the effects of establishing a conifer plantation on a pasture can have a "local" cooling effect on the soil surface while simultaneously having a warming effect on the Earth's global atmosphere. This is analogous to the effect that air conditioning (AC) units have on temperature. The amount of heat produced by an AC unit is greater than the amount of cooling provided in the building. Therefore, the AC has a "local" cooling effect while it simultaneously increases the temperature of the atmosphere outside the building.

Albedo is defined as the ratio of reflected solar radiation from the surface to incident radiation upon it. Basically, it is a measure of the reflectiveness of an object. An albedo of 1 indicates a perfect mirror while a perfect black-body (which absorbs all light falling on it) would have an albedo of zero. Understanding albedo is critical to understanding why forests can produce a global warming effect, even when the local temperature of the forest floor is cooler than the surface of a pasture.

The albedo of mature conifer forests can be 0.07 to 0.08 (Brown, 1972; Betts and Ball, 1997) to 0.14 (Hollinger et al., 2010). The albedo of hardwood forests is typically higher than that of pine and may range from 0.12 to 0.19 (Hollinger et al., 2010). About four decades ago, forest researchers demonstrated the albedo of deciduous forests increased when snow covered the forest floor (Hornbeck, 1970; Federer, 1971; DeWalle and McGuire, 1973). Although the albedo of pine forests changes somewhat with season, the range in monthly albedo values is greater for deciduous hardwoods (Hollinger et al., 2010). Typically the values are lowest when leaves are on the ground and highest when leaves are on the trees. In comparison, the albedo of bare soil might be 0.17 and green grass might be 0.25 (Hollinger et al., 2010).

Some claim that forests will increase evapo-transpiration (compared to adjacent non-forested areas) and this will have an additional cooling effect. This again is a "local" effect, it is important to remember that the energy absorbed during evaporation is the same as the energy released during condensation (that is, 2257 kJ/kg). Therefore, evaporation of a kilogram of water in a conifer plantation will have a local cooling effect, but the condensation of water as dew is 100 km from the plantation will have a warming effect on the atmosphere. Therefore, although increased evaporation will have a localized cooling effect, it really has no long-term effect on the global temperature. It should be pointed out that some modelers report only one side of this equation.

AFFORESTATION

Boreal zone

Several researchers (Thompson et al., 2009; Swann et al., 2010; Bernier et al., 2011) agree that afforestation in boreal zones could warm the Earth. Swann et al. (2010) used a complex computer model to estimate the effects of afforestation on warming the Arctic. They suggest that 300 million ha of broadleaf afforestation (>60° N latitude) would increase transpiration rates, lower surface albedo, and warm the Arctic. They report that warming would be due to both a decrease in average surface albedo, reduced amount of sea ice, and more water vapor in the Arctic atmosphere. Their computer model was used to estimate a warming effect in the Arctic region that ranged from +0.2 to +1°C.

Another computer modeling approach involves "deforesting" all boreal forests to guess how that might affect the global temperature. Bala et al. (2007) estimate that removal of all trees (>50° N) would release 80 gigatonnes of carbon into the atmosphere but the virtual Earth was cooled by -0.8°C. On a regional basis, they estimate that deforesting the Arctic zone would cool the land in that region by -3.8°C. This suggests that forestation in boreal zones since the last ice age has contributed to warming the Earth despite the sequestration of 80 gigatonnes of carbon. The sequestration rates of some management systems for aspen might be only 0.7 tonnes of C/ha/year (Stinson and Freedman, 2001) and this rate would be lower as light intensities decline.

These models suggest that in the boreal zone, the change in albedo (due to afforestation) and/or the change in atmospheric moisture levels are more powerful than the change in atmospheric CO_2 due to sequestration.

Tropical zone

Most climate modelers agree that deforesting all tree cover in the tropics would warm the Earth's atmosphere. Complete deforestation of tropical forests (20° S to 20° N) might warm the Earth by an estimated 0.7°C (Bala et al., 2007). The reason for this predicted warming involves both a carbon dioxide effect (due to a release of about

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422 gigatonnes of carbon) plus a reduction in the formation of clouds (Baumgartner, 1984; van der Molen et al., 2011). The predicted decrease in cloud formation (from deforestation) would result in reflecting less radiation from the atmosphere. In contrast, if afforestation in tropical zones produced more clouds, this might cool the Earth. Therefore, on a per-hectare basis, some say the effect of afforestation (on global temperature) in the tropical zone is three times greater than afforestation in temperate zones (Arora and Montenegro, 2010).

Temperate zone

Some argue that afforestation in temperate zones will cool the Earth (Montenegro et al., 2009) whereas others suggest it might warm the Earth (Feddema et al., 2005; Barnes and Roy, 2008; South, 2008). Others say the effect is not clear (Bonan, 2008) or is not statistically different from zero (Arora and Montenegro, 2010; Fall et al., 2010). Some say the result would depend on both growth rate of the plantations and the amount of change in the albedo of the Earth's surface. Afforestation with slow-growing conifers in high-altitude zones (for example, the Pyrenees) may not sequester much carbon by 2050 but it would have a relatively large effect on the albedo. In contrast, afforestation with exotic conifers in New Zealand would sequester more carbon and would have a minimal affect on surface albedo (Kirschbaum et al., 2011). In some arid zones, some say it may take five to eight decades before the "carbon sequestration" effect will equal the warming effect from darkening the Earth's surface (Rotenberg and Yakir, 2010) whereas others disagree (Lee, 2010).

The following is from an IPCC report (Forster et al., 2007) . "Since the dominant aspect of land cover change since 1750 has been deforestation in temperate regions, the overall effect of anthropogenic land cover change on global temperature will depend largely on the relative importance of increased surface albedo in winter and spring (exerting a cooling) and reduced evaporation in summer and in the tropics (exerting a warming) (Bounoua et al., 2002). Estimates of global temperature responses from past deforestation vary from 0.01°C (Zhao et al., 2001) to -0.25°C (Govindasamy et al., 2001; Brovkin et al., 2006)." This report suggests that deforestation (that is, converting forests to cropland and pastureland) has increased the albedo of the temperate zone, and likely resulted in a global cooling effect. When compared to an estimate of natural vegetation (without human influence), increases of cropland/pasture land might result in a radiative forcing of -0.4 W m^{-2}, with half of this occurring since 1750 (Forster et al., 2007). In temperate zones, it seems logical that if croplands and pastureland (once forested) were replanted to trees (to an extent equal to the amount of deforestation since 1750), the radiative force would be equal to +0.2 W m^{-2}.

These estimates illustrate why those from the "Holistic School" are not certain that afforestation in high-altitude, temperate zones would result in cooling the Earth. Therefore, we do not really know if funding temperate-zone afforestation to sequester carbon would actually result in cooling the Earth. For example, complete deforestation of temperate forests might release about 316 gigatonnes of carbon into the atmosphere but this might cool the land by an estimated -0.2 C (Bala et al., 2007) . Overall, the cooling effect on the entire globe might be only -0.04 C. Using this logic, one might assume that afforestation that removed about 63 gigatonnes of carbon from the atmosphere might have one fifth of the effect of adding 316 gigatonnes. This effort might warm the landbase by +0.04 C.

It is generally assumed that when cultivation of soil ceases and trees are established on cropland, the soil carbon levels will increase in time (Vesterdal et al., 2002). However, this relationship might not hold when native grasslands are converted to plantations. Some temperate grasslands contain more carbon/ha (to a soil depth of 1 m) than the average temperate forest (House et al., 2002). For example, a 40 year-old pine plantation might contain 230 tonnes of carbon/ha (total) with perhaps 70 tonnes of that amount in the top meter of soil (Malmsheimer et al., 2008). In contrast, one hectare of temperate grassland may contain 236 tonnes of carbon (C) in the top meter of soil (for example, 2.3% soil organic matter) with an additional 7 tonnes of grass (House et al., 2002). A question that needs to be addressed is: In the long-run, will afforestation reduce the amount of soil carbon?

COSTS

One factor that we consider is the cost of climate mitigation with afforestation. According to the "CO_2 School," sequestering 60 gigatonnes of carbon (at 250 kg C/ m^3, this would equal 240 billion cubic meters of wood), might reduce the amount of carbon dioxide in the atmosphere by 17 to 21 ppmv (House et al., 2002). This might result in an 8.5 to 10.5 year delay in reaching a carbon dioxide level of 600 ppmv. As a comparison, if the price of a tonne of carbon was set at $183, landowners in the USA might sequester 0.35 gigatonnes of carbon/year with afforestation (Maness, 2009). This would require annual transfer of payments of more than 64 billion dollars and might result in a reduction in atmospheric CO_2 by 0.1 ppmv (equivalent to a delay of about 18 days). Ten years of investments (that is, 640 billion dollars) might be enough to delay the rise by 0.5 year. What is typical of such calculations is a lack of information on the effects of

Table 1. Estimated temperature effects from afforestation and deforestation. Estimated costs are not associated with deforestation since short-term profits are typically obtained with the sale of wood products.

Region	Change (ha)	Estimated cost (US$)	Temperature effect	Reference
		Afforestation		
Arctic	+0.3 billion	$300 billion	Arctic warmed +1 ëC	Swann et al., 2010
Arctic	+0.1 billion	$100 billion	Globe cooled -0.015 ëC	Arora and Montenegro, 2011
Temperate	+1 billion*	$1 trillion	?	House et al., 2002
Temperate	+0.1 billion	$100 billion	Globe cooled -0.017 ëC	Arora and Montenegro, 2011
Tropical	+0.1 billion	$100 billion	Globe cooled -0.07 ëC	Arora and Montenegro, 2011
		Deforestation		
Arctic	-1.37 billion	--	Arctic cooled -3.3 ëC	Bala et al., 2007
Temperate	-1.04 billion	--	Land in NH cooled -0.7 ëC	Bala et al., 2007
Temperate	-1.04 billion	--	Globe cooled -0.04 ëC	Bala et al., 2007
Tropical	-1.76 billion	--	Globe warmed +0.7 ëC	Bala et al., 2007
Globe	-6.2 billion	--	Globe cooled -3 ëC	Renssen et al., 2003
Globe	-4.1 billion	--	Globe cooled -1 ëC	Davin and Ducoudré, 2010

*Assumes temperate forests can sequester 200 tonnes C/ha

spending 0.64 trillion dollars on global temperatures. In some cases, over 100 billion dollars could be spent on afforestation in temperate zones without achieving a measurable effect on global temperature (Table 1).

In contrast to the investment of expanding the rate of afforestation, there might be both financial and climate benefits from harvesting 20 gigatonnes of carbon from boreal conifer forests. Converting boreal conifers to lumber and wood pellets would not only have an economic benefit to loggers and mill workers, but if the harvested land were converted to more reflective landscapes, it might also have a cooling effect. If prescribed burning were used to convert harvested areas to boreal lichen woodlands, this would increase the surface albedo (Bernier et al., 2011) . The overall cooling effect from deforesting one quarter of boreal forests is estimated to be at least -0.2°C (Bala et al., 2007). Estimates of global temperature responses from past deforestation (primarily in temperate zones) vary from 0.01°C (Zhao et al., 2001) to –0.25°C (Govindasamy et al., 2001; Brovkin et al., 2006) . During this period of land-use change, many houses were built using wood harvested from land that was converted to row-crops and pastureland.

Jackson et al. (2008) said that “Policies for climate mitigation on land rarely acknowledge biophysical factors, such as reflectivity, evaporation, and surface roughness. Yet such factors can alter temperatures much more than carbon sequestration does, and often in a conflicting way. Ignoring biophysical interactions could result in millions of dollars being invested in some mitigation projects that provide little climate benefit, or are worsely counter-productive.” In some cases, afforestation may cost $1,000 per ha but it might cost twice that amount (Plantinga and Mauldin, 2001; McKenney et al., 2004). A large- scale afforestation effort to mitigate climate change might cost $100 billion or more (Table 1). Depending on the latitude, this effort may have no measurable effect on the climate, especially since “most data sets of global temperature are in fact not global in extent or systematic in quantity measured” (Christy, 2005).

CONCLUSIONS

The climate is not a simple system and therefore, there is no simple answer to the question “will afforestation in temperate zones warm the Earth?” The answer will vary depending on the model used and if the answer is related to “global effects” or just “local effects.” Some modelers have suggested that afforestation in the Tropics would cool the Earth while boreal afforestation would warm the Earth. We claim we do not know if afforestation in temperate zones will have any statistically significant effect on the global temperature. To date, the climate models used in the modeling have not been verified and this makes speculations about “global” effects questionable. We have a low level of confidence that the predictions from these models are accurate down to the first decimal place (that is, 0.1°C) . In the absence of data, we doubt that afforestation in temperate zones is an effective practice for the mitigation of climate change.

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