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PLANTATION FORESTRY IN BRAZIL: THE POTENTIAL IMPACTS OF CLIMATIC CHANGE

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ABSTRACT--Most climatic changes projected to occur in Brazil would reduce yields of silvicultural plantations, mainly through increased frequency and severity of droughts brought on by global warming and by reduction of water vapor sources in Amazonia caused by deforestation. Some additional negative effects could result from changes in temperature, and positive effects could result from CO_2 enrichment. The net effects would be negative, forcing the country to expand plantations onto less-productive land, requiring increased plantation area (and consequent economic losses) out of proportion to the climatic change itself. These impacts would affect carbon sequestration and storage consequences of any plans for subsidizing silviculture as a global warming mitigation option.

Climate change can be expected to increase the area of plantations needed to supply projected internal demand and exports from Brazil. June-July-August (dry season) precipitation reductions indicated by simulations reported by the Intergovernmental Panel on Climate Change (IPCC) correspond to rainfall declines in this critical season of approximately 34% in Amazonia, 39% in Southern Brazil and 61% in the Northeast. As an example, if rainfall in Brazilian plantation areas (most of which are now in Southern Brazil) were to decline by 50%, the area needed in 2050 would expand by an estimated 38% over the constant climate case, bringing the total plantation area to 4.5 times the 1991 area. These large areas of additional plantations imply substantial social and environmental impacts. Further addition of plantation area as a global warming response option would augment these impacts, indicating the need for caution in evaluating carbon sequestration proposals.

KEYWORDS--plantations; silviculture; eucalyptus; Brazil; global warming; climate change

1. INTRODUCTION

Brazil hopes to substantially expand its area of plantations in part through international sources of environmental funding for sequestering atmospheric carbon dioxide to reduce global warming. For example, the FLORAM proposal, put forward by the University of São Paulo, calls for installing an additional 20 X 10^6 ha of silviculture in Brazil over a period of 30 years as a global warming mitigation option[1].

Plantation forestry would be affected by climatic change, both from global warming and from other processes such as the reduction of evapotranspiration that results from converting Amazonian forests to cattle pasture. Most climatic changes would have negative impacts on plantation yields, thereby forcing the country to maintain larger areas of silviculture to supply the same flows of forest products (and substantially diminishing the profitability of doing so). Nevertheless, Brazil's abundant land resources place it in a privileged position in absorbing the costs imposed by climatic change, as well as in responding to the opportunities offered by proposed countermeasures in the plantation forestry sector.

The trends in Brazil's silviculture sector have been analyzed elsewhere as a reference scenario for assessing the impacts of climatic changes and of programs to combat global warming through subsidizing silvicultural expansion[2]. Plantation expansion can be expected to shift from Southern Brazil to the Northeast and Amazon regions. As plantations expand to meet growing domestic demand and to take advantage of export opportunities offered by international markets for products derived from wood, the marginal yield of new plantations can be expected to decrease as progressively less-productive sites are brought under silviculture[2]. The reference scenario projections assume a constant per-capita demand for wood products in Brazil and that Brazil's share of the market for supplying wood products to non-tropical countries remains constant (both conservative assumptions). Under this scenario, in which climate is assumed to be unchanged, plantations will expand through the year 2050 to occupy an area 3.2 times larger than the 7 X 10^6 ha of plantations Brazil had in 1991.

[Figure 1 here]

2. IMPACT OF CLIMATE-INDUCED CHANGES

2.1. Impacts on silviculture

Climatic change can be expected to reduce silvicultural yields to the extent that the climate becomes drier in major plantation states such as Minas Gerais, Espírito Santo, São Paulo, and Paraná as a result of global warming and/or reduced water vapor transport from Amazonia. (i.e., ref. 3). General circulation model (GCM) results for rainfall at low latitudes are sufficiently inconsistent that, pending the availability of better models, few researchers have ventured to calculate the potential impact of precipitation changes on agricultural production[4]. Nevertheless, it behooves us to examine the implications of results from existing climate models, while bearing in mind the degree of uncertainty attached to these findings. The general conclusion of drier, less-favorable conditions over much of the world is consistently found by the various modeling groups[5]. This general qualitative result appears unlikely to change as modeling and measurements improve, even though predictions for any particular point on the earth's surface are presently much more uncertain.

Reduced rainfall is the most likely form of climatic change to affect plantations. The influence of precipitation on plantation growth occurs through its effect on soil moisture, and GCM results are less varied for soil moisture than for rainfall. Although soil moisture would provide a more robust GCM output than precipitation itself, information is lacking to predict yield changes from soil moisture, making it necessary to rely on precipitation as the indicator of climatic change. The Intergovernmental Panel on Climate Change (IPCC) presents results for precipitation changes "around the time of a doubling of CO_2" in a simulation experiment in which CO_2 was increased by 1%/year in the United Kingdom Meteorological Office (UKMO) model[5]. Projected changes in the real atmosphere would result in doubling the atmospheric concentration of CO_2 gas, in relation to pre-industrial levels, in about 2070 according to the IPCC's "business as usual" scenario, while the combined effect of increases in CO_2 and trace gases would reach a level equivalent to doubling pre-industrial CO_2 in about 2025.

The IPCC presents results for two seasons: December-January-February and June-July-August. In June-July-August expected rainfall declines by 1 mm/day in virtually all of Brazil. In December-January-February it declines by 1 mm/day in Amazonia, increases by up to 2 mm/day in part of the Northeast, and stays unchanged in Southern Brazil. In almost all of Brazil (including all parts of the country where silviculture is a significant activity now or in the foreseeable future), June-July-August is the dry season while December-January-February is the rainy season. Dry season changes can be expected to have the greatest impact on silvicultural yields: water often limits growth during this part of the year under present conditions, yet there may be water to spare during the rainiest part of the year. In areas outside of Brazil's extreme south, the annual rings evident in the wood of plantation trees correspond to dry (as opposed to cold) seasons.

The impact of a given change in mm/day of rainfall would vary considerably, depending on how much rain a given area receives today. In the dry Northeast, a loss of 1 mm/day would represent a large percentage decline, while the relative impact would be lower in areas with more rainfall. A rough idea of the magnitude of impacts can be gained from 30-year averages of monthly rainfall reported by da Mota[6] for 28 weather stations (11 in Amazonia, 4 in the Northeast and 13 in Southern Brazil). The mean values are 2085 mm for Amazonia and 1489 mm for the Northeast and 1535 mm for Southern Brazil. Considering these means, the changes suggested by the simulation reported by the IPCC represent decreases of annual total precipitation of approximately 18% in Amazonia and 24% in Southern Brazil, and an increase of up to 12% in the Northeast. However, the June-July-August precipitation is believed to be most closely related to plantation yields. Considering only the precipitation in this season (269, 150 and 234 in Amazonia, the Northeast and Southern Brazil, respectively) the changes represent large decreases in all regions: by 34% in Amazonia, 61% in the Northeast, and 39% in Southern Brazil. Variability in precipitation may increase as a result of climate change, which would make the impacts on plantations more severe than that indicated by mean values.

Epaminondas S.B. Ferraz has developed a regression equation relating biomass increment in *Eucalyptus* to precipitation at three sites in the State of São Paulo[7]. The increments were determined by gamma-ray attenuation dendrometry applied to tree rings in wood samples covering the 1964-1991 period. The samples were from a mixture of species: *Eucalyptus grandis*, *E. propinqua*, *E. saligna* and *E. alba*. Over a range of precipitation from 40% below the mean to 50% above the mean, the percent increase in the annual biomass increment above the mean is given by the following equation ($n=39$, $r^2=0.49$):

$$B = -0.017 + 0.348\ P \qquad \text{Equation 1}$$

where:

B = the percent change in annual biomass increment above the mean

P = the percent deviation in annual precipitation above the mean

Considering the annual rainfall changes mentioned earlier for the three regions based on the UKMO model results reported by the IPCC, Equation 1 implies yield decreases of 6% in Amazonia and 8% in Southern Brazil, and an increase of 4% in the Northeast. Considering the June-July-August rainfall believed to be most critical, yields in this period would decrease by 12% in Amazonia, 14% in Southern Brazil and 21% in the Northeast. These results must be approached with caution, given the high uncertainty of both climatic change predictions and the magnitude of yield response to precipitation changes. In addition, use of Equation 1 assumes that single-year changes in growth increment (observed) would be the same as a change over many years. The longer-term changes would be influenced by accumulated stress and by changes in carbon allocation in individuals and ecosystems.

In practice, the relation of precipitation reduction to plantation yield will not be a straight line decline as implied by Equation 1. The yield of each tree species can be expected to follow a curve when related to precipitation, with a steep decline at low precipitation values, tapering to a plateau where precipitation is sufficient for the species. As climatic change progresses, firms can be expected to change the species planted in favor of more drought-resistant ones, such as _E. camaldulensis_. Losses may be greater than an ideal sequence of species changes would suggest if firms fail to switch species due to misjudgment and due to the rapidity and unpredictability of climatic changes. The composite of individual species curves would approximate a straight line with a shallower slope than the one describing the yield of any particular species (Fig. 2). The slope would necessarily be shallower than the average for individual species (independent of the sharpness of the response of each species) because of the horizontal displacement of the individual species curves along the axis representing annual rainfall (Fig. 2). Droughts can affect mortality, as well as yield: in 1993 a drought in a former _cerrado_ (Central Brazilian dry scrub savanna) area of Mato Grosso caused high mortality in stands of _E. urophylla_, _E. pellita_ and _E. cloeziana_ that had previously been highly productive, although stands of _E. camaldulensis_ maintained their more modest levels of productivity despite the drought[8].

[Figure 2 here]

The above discussion of precipitation decreases considers only the effect of global warming. Brazil is likely to suffer additional losses of precipitation due to reduction of evapotranspiration caused by deforestation in Amazonia. About half of the rainfall in Amazonia is water recycled through the forest as evapotranspiration[9]. Maintenance of forest vegetation in Amazonia is heavily dependent on this recycled water, which can be expected to decrease with continued replacement of forest by pasture[10, 11]. Some of the water vapor originating in Amazonia is transported to Southern Brazil[3, 12]. The rotation of the earth causes trade winds to follow a counter-clockwise semicircular path in the Southern Hemisphere, leading from Amazonia to Southern Brazil. Decreased water vapor supply to Southern Brazil, where most of the country's silviculture is located, would aggravate precipitation declines stemming from global warming.

The direct effects of rainfall reduction on yields are likely to underestimate the true effect of climate change. Synergistic effects with other factors could reduce yield substantially more. One is insect attack: trees under stress from droughts provoked by climatic change will be more vulnerable to attack by pests[13].

A drier climate in plantation areas could also be expected to lead to greater fire hazard. Fire is a problem in plantation silviculture even in the absence of climatic change, requiring a certain level of investment in fire control, and a certain level of losses when burns occur. Pine plantations in Paraná require continuous vigilance[14]. Eucalyptus is also fire prone because of the high content of volatile oils in the leaves and bark.

Temperature changes can also affect plantation yields. Temperature changes near the time of doubling CO_2 have been reported by the IPCC for various GCMs[5]. The Geophysical Fluid Dynamics Laboratory (GFDL) model indicates mean increases of 1-2°C in Amazonia, 1°C in Southern Brazil and 1°C in the Northeast. The Max-Planck Institute (MPI) model indicates 1°C increases in all regions of Brazil; the National Center for Atmospheric Research (NCAR) model indicates no change, and the UKMO model indicates 2°C changes virtually throughout the country. Other models with a more complete representation of plant physiological effects indicate up to 2.6°C average temperature increase in Amazonia resulting from the same increase in CO_2 [15]. The IPCC models in the Second Assessment Report (SAR) indicate a temperature increase between 2° and 3° in Amazonia[16].

Considering a hypothetical increase of 1.5°C by the year 2050 in Espírito Santo and Minas Gerais, Reis et al.[8] concluded that either the present plantation area would have to be moved to higher elevation (a shift considered impractical) or the genetic material would have to be completely replaced following the global strategy proposed by Ledig and Kitzmiller[17]. In addition to direct effects of temperature considered by Reis et al.[8], temperature increases have a synergistic effect with drought, the impact of dryness being worse at higher temperatures (lower elevations) due to higher water demands in plantations.

Some expected changes would be beneficial for plantations. Carbon dioxide enrichment increases the water-use efficiency of *Eucalyptus*[18]. Photosynthetic rate increased in these experiments from 96% (*E. urophylla*) to 134% (*E. grandis*). Growth of the different plant parts showed similar responses. Higher levels of CO_2 also stimulate nitrogen fixation, which could be expected to lower the fertilizer demands of plantations[19].

Considerable caution is necessary in interpreting the potential beneficial effects of CO_2 enrichment. One problem is frequent confusion, and occasional outright misrepresentation, of different measures of greenhouse gas increase: doubling [of present day] CO_2 concentrations, doubling of pre-industrial CO_2, and "2 X CO_2" (doubling of the CO_2-equivalent impact of all greenhouse gases as compared to the pre-industrial atmosphere) (see review in ref. 20). The 2 X CO_2 mark is expected to be reached around 2025, whereas doubling of the pre-industrial CO_2 concentration would occur around 2100, and doubled present day concentration after that. The benefits of CO_2 enrichment at doubled pre-industrial CO_2, or even of doubled present day CO_2, are often juxtaposed with the climatic impacts of 2 X CO_2, rather than with the greater impacts that would exist when the other CO_2 concentration landmarks (doubled pre-industrial CO_2 or doubled present day CO_2) are reached (see review in ref. 20). In order to have a valid calculation of *net* changes in yields, the timing of both benefits and impacts must be the same.

2.2 Impacts on areas of plantation

Possible impacts of climatic change on yields and areas of plantations can be roughly assessed by a series of simple assumptions, in order to arrive at a preliminary judgment as to whether this is a serious problem for Brazil. Despite uncertainties regarding the magnitude and rapidity of climatic changes, one can gain an idea of the range of potential impacts by constructing scenarios at different assumed percentages of reduction in precipitation. Here calculations are made assuming no climatic change, and assuming reductions of 5%, 10%, 25%, and 50% in precipitation by the year 2050. As explained earlier, precipitation results reported by the IPCC for "around the time of doubled CO_2" indicate that in Southern Brazil (where most of the country's plantations are located), annual total rainfall would decrease by 24% while rainfall in the dry season would decrease by 39%.

Considering the relationship of Ferraz[7] given earlier (Equation 1), reductions of 5%, 10%, 25%, and 50% in annual precipitation correspond to reductions in base yields of 1.7%, 4%, 9%, and 17%, respectively. Base yields refer to the yield from a given quality of land using 1990 technology. Because the rainy season precipitation that is included in the annual rainfall data on which the regression developed by Ferraz[7] is based may have less impact on eucalyptus yield than dry season precipitation, the above estimates for reductions in base yields may be conservative.

Climatic change would require larger areas of plantations (and consequent greater expense) to meet the same levels of demand. The percentage increase in areas required can be greater than percentage decline in per-hectare yields caused by climatic change because expansion of plantation area implies moving onto progressively poorer sites where productivity will be less.

Figure 3 provides a causal loop diagram of the relationships used to project plantation yields and areas. In diagrams of this type, the sign by each arrow indicates the direction of change in the quantity at the head of the arrow given an increase in the quantity at the tail of the arrow. Increasing areas planted are the combined result if declining marginal yields and increasing total demand for wood products. Marginal yields decline both as a result of reduced precipitation and expansion onto more marginal land (a consequence of using a greater fraction of the available land).

[Figure 3 here]

The effects of different climatic change scenarios on the average marginal yield (the yield of new areas of planting) are shown in Fig. 4-A, while the effects on cumulative yields (the average yields over all plantations maintained, including the earlier ones on the best land) are shown in Fig. 4-B.

[Figure 4 here]

As plantation yields decline, the consequent need to expand areas of silviculture forces planting onto less-productive land quality classes. Marginal yield are lower as planting moves onto poorer land, while cumulative yields also decline, but remain higher than the marginal yields. The area of short-rotation plantations under different climatic change scenarios is shown in Fig. 5-A. The short-rotation plantation expansion rate under different climatic change scenarios is given in Fig. 5-B. The response of yields and area of short-rotation plantations to the percent of precipitation decline from climatic change by the year 2050 is shown in Fig. 6-A in absolute amounts, and in Fig. 6-B as percent difference from the no climatic change scenario. Projections over the 1990-2050 period for a reference calculation with no change in climate (Fig. 5-B) are compared in Figs. 6-A and 6-B with the situation in the year 2050 assuming climatic change (precipitation reduction) ranging from 0-50%. The likely pattern of the effect of climatic change is apparent, with disproportionate increases in plantation areas needed to supply demand when yields decline due to climatic change.

[Figures 5 and 6 here]

Assuming no technological change, if there were a 10% drop in rainfall, a 3.5% drop in marginal yield would result, leading to a 5% increase in the area of short-rotation plantations required. A 50% drop in rainfall would produce a 17% drop in marginal yields and a 38% increase in short-rotation area requirements (Fig. 6-B). Conversely, any improvements, such as genetic breeding advances that increase yield by a given percentage, decrease area requirements by more than the same percentage.

It is important to realize that positive changes, such as technological advance in tree breeding, could be equal in magnitude to negative changes such as yield decline from climatic change, but that such a conclusion would not be a neutral in terms of its policy implications. This is because negative impacts such as climatic change should best be approached on the basis of the precautionary principle, whereas it is wisest not to count on future technological advances before they occur. Were technology to improve yields over the period by the same amount that climatic change reduces them (by 17% in the most extreme case calculated), the effect would be the same as the zero climatic change scenario.

It should be emphasized that the calculations in the current paper are <u>demand driven</u>. This is to say, they assume that the domestic population demand and projected export quantities will be met, and calculate <u>how</u> this would be done, rather than allowing these product flows to be reduced as climatic change renders them too expensive to maintain.

3. ADAPTATION AND COPING OPTIONS IN THE SILVICULTURE SECTOR

Actions in the silviculture sector have significant potential as response options to reduce global warming by maintaining or increasing carbon stocks in plantations and wood products and, in the case of charcoal used in Brazil's iron and steel industry, through fossil fuel substitution[21]. The potential of silviculture is more limited, however, for adaptation, or coping in the sense of getting along with climatic change, rather than as a means of fighting against it.

Societies can adapt to change by altering the productive activities they pursue to support their populations. If climatic change renders certain areas less appropriate for the agricultural or other use they formerly had and more appropriate, for example, for a silvicultural plantation, then a switch to forestry will be the likely outcome. Even if the climatic conditions at the site in question remain completely unchanged, climatic changes elsewhere may alter the relative prices of the different commodities that might be produced, leading to a decision to use land for forestry rather than, say, for pasture or annual crops. Climatic change, of course, may not be the only or even the principal cause of such shifts: markets for products of plantation forestry can be expected to increase in the future as a result of the continued human destruction of mature native forests in the tropical, temperate, and boreal zones.

Rapid tree growth, low land prices, and low labor and tax costs in tropical locations make them likely sites for plantation expansion, including plantations subsidized with funds from carbon-offset programs intended to avert climatic change elsewhere in the world. Conversion of land to plantations can deprive local populations of their means of support[22]. In the case of plantations for charcoal, the industry's competitiveness depends on maintaining most of the labor pool under conditions of extreme poverty. Expansion into drier areas, as in the Northeast, would be likely to favor drought-resistant species such as <u>E. camaldulensis</u> that are more suitable for charcoal than for pulp; any climatic change leading to drier conditions in the existing plantation area would favor the same species shifts and social consequences. Mechanisms are needed to insure that plantation establishment, especially when financed as a carbon offset, is only encouraged where it is beneficial[23].

Among the effects of subsidizing plantation expansion would be increasing supplies of wood products beyond the levels they would otherwise reach, with consequent lowering of prices in Brazil and in the countries to which Brazil exports. The macroeconomic impacts of this would be many. Unsubsidized competitors would clearly sustain losses. Any reduction in plantation and wood product pools elsewhere by the losers in this competition would reduce the net carbon benefits of the plantation subsidy program. Evaluation of these and other ramifications of carbon-offset proposals in silviculture are needed before major initiatives are undertaken.

The ultimate coping mechanism in tropical countries, as well as for the globe as a whole, will be to adjust human population and consumption levels to the carrying capacity of the land. Many climatic changes entail reduction of productive capacity and, on a global scale, will demand diversion of hundreds of billions of dollars in resources to activities intended merely to substitute for natural climate regulation mechanisms and keep the world's environment and human infrastructure at a state roughly equivalent to what we have today for free. Capital, land, and human resources allocated to response options, including forestry initiatives such as plantations motivated by carbon considerations, will not be available for producing food and other necessities. The carrying capacity of the world as a whole will be lower than it would be without climatic change; reductions will be greater in some countries than in others, and in a few instances countries may benefit from more favorable climate.

Human population numbers and levels of consumption must eventually come into balance with the carrying capacity of each country. Particularly in tropical forest countries, carrying capacities for human populations are lower than many have been led to believe[24]. The process of adjustment to carrying capacity limits is likely to be a painful one even without the added strictures imposed by climatic change. The challenges these adjustments pose must be faced with even greater speed in light of impending climatic changes: policies affecting population and consumption should be based on rational decisions.

Were subsidization of silviculture adopted as a major response option to global warming, the landscape in much of Brazil could be dramatically altered. Global warming response options in the silviculture sector have significant potential to cause social and environmental impacts. An urgent need exists for criteria to assess the impacts of global warming and of proposed response options, and mechanisms to avoid injustices in the way these are distributed. Safeguards are currently inadequate to ensure that major impacts do not result from efforts to avert global warming by promoting carbon sequestration in plantations.

4. CONCLUSIONS

Global circulation models used by the Intergovernmental Panel on Climate Change (IPCC) indicate precipitation declines in Brazil that can be expected to decrease the yields of silvicultural plantations. Simulated climate experiments reported by the IPCC with CO_2 gradually increased to "around the time of CO_2 doubling" produce June-July-August (dry season) precipitation reductions corresponding to approximately 34% in Amazonia, 39% in Southern Brazil, and 61% in the Northeast. Taking as examples rainfall reductions of 5%, 10%, 25% and 50%, plantation area requirements are calculated to increase up to 38% over those without climatic change, which would bring the total plantation area by 2050 to 4.5 times the 1991 area.

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FIGURE LEGENDS

Figure 1 -- Regions of Brazil and locations mentioned in the text. "Southern Brazil" refers to the portion that is neither Amazonian nor Northeastern.

Figure 2 -- General pattern expected for the relationship of yield to rainfall for different silvicultural species. The composite of individual species curves would approximate a straight line with a shallower slope than the one for any particular species.

Figure 3 -- Causal loop diagram of relationships for projecting plantation yields and areas. Signs by each arrow indicate the direction of change in the quantity at the head of the arrow given an increase in the quantity at the tail of the arrow.

Figure 4 -- Short-rotation plantation yields under different climatic change scenarios:

A.) Marginal yields.

B.) Cumulative yields.

Figure 5 -- Area and expansion rate of short-rotation plantations under different climatic change scenarios:

A.) Area maintained.

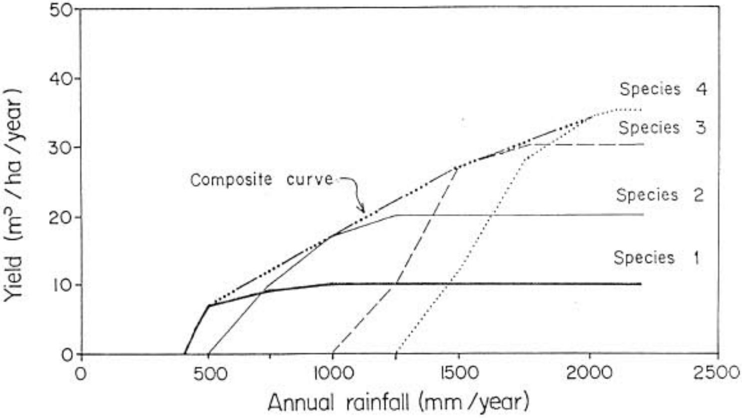
B.) Expansion rate.

Figure 6 -- Response of yields and area of short-rotation plantations to the percent of precipitation decline resulting from climatic change by the year 2050:

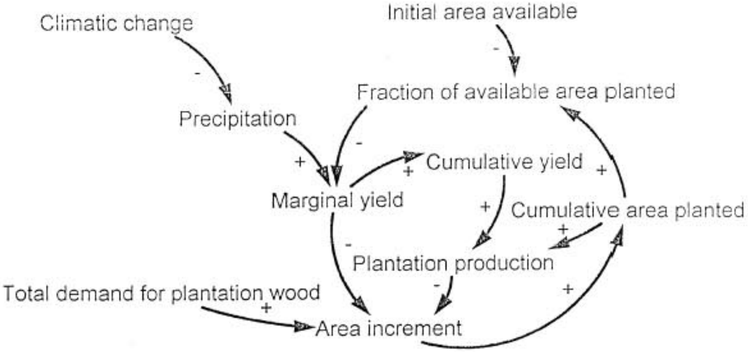
A.) Response expressed in absolute amounts.

B.) Response expressed as percentage deviation from the no climatic change scenario.

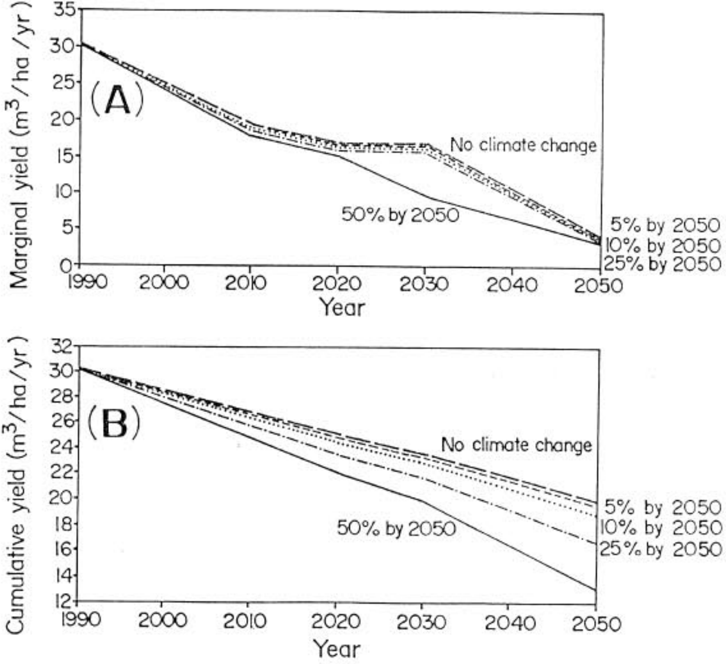

Roraima
Amapa
Amazonas
Para
Maranhao
Ceara
Rio Grande do Norte
Paraiba
Pernambuco
Piaui
Tocantins
Alagoas
Sergipe
Acre
Rondonia
Mato Grosso
Bahia
Goias
Minas Gerais
Espirito Santo
Mato Grosso do Sul
Sao Paulo
Rio de Janeiro
Parana
Santa Catarina
Rio Grande do Sul
km 0 200 400 600
STATE BOUNDARIES
LEGAL AMAZON
NORTH-EAST
SOUTHERN BRAZIL



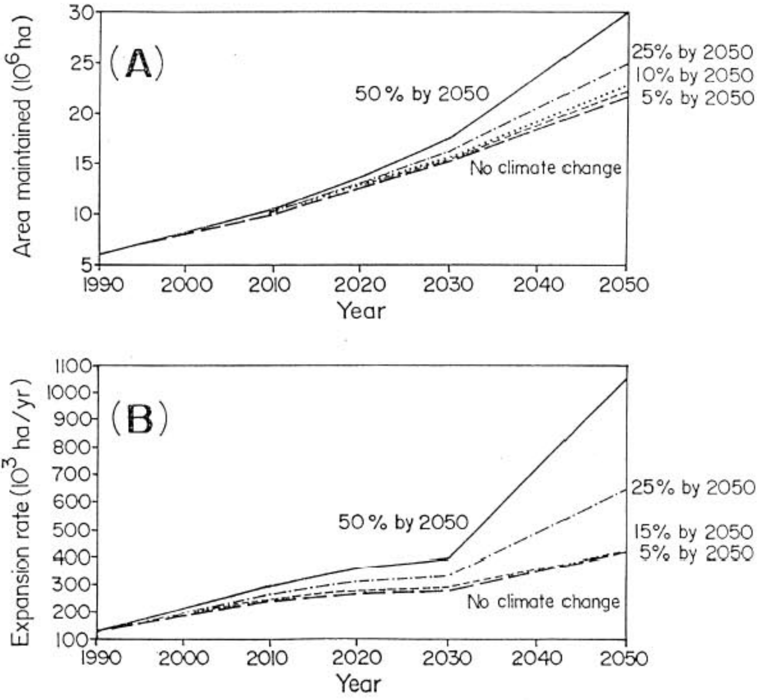
50
40
30
20
10
0
Yield (m³/ha/year)
Species 4
Species 3
Species 2
Species 1
Composite curve
0
500
1000
1500
2000
2500
Annual rainfall (mm/year)

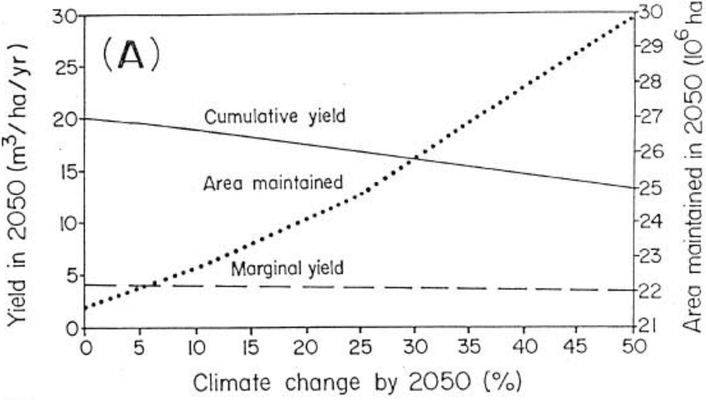


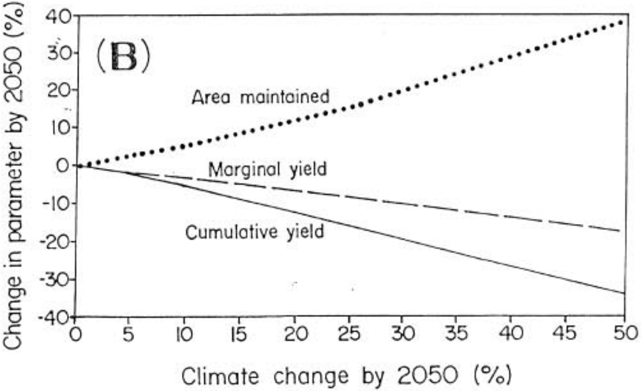
Climatic change
Initial area available
-
-
Fraction of available area planted
Precipitation
-
+
+
Cumulative yield
+
Marginal yield
+
Cumulative area planted
+
-
Plantation production
Total demand for plantation wood
+
-
+
Area increment



(A)
Marginal yield (m3/ha/yr)
35
30
25
20
15
10
5
0
1990
2000
2010
2020
2030
2040
2050
Year
No climate change
50% by 2050
5% by 2050
10% by 2050
25% by 2050
(B)
Cumulative yield (m3/ha/yr)
32
30
28
26
24
22
20
18
16
14
12
1990
2000
2010
2020
2030
2040
2050
Year
No climate change
50% by 2050
5% by 2050
10% by 2050
25% by 2050


(A)
Area maintained (10^6 ha)
50% by 2050
25% by 2050
10% by 2050
5% by 2050
No climate change
Year
(B)
Expansion rate (10^3 ha/yr)
50% by 2050
25% by 2050
15% by 2050
5% by 2050
No climate change
Year


(A)
Yield in 2050 (m³/ha/yr)
Area maintained in 2050 (10⁶ ha)
Cumulative yield
Area maintained
Marginal yield
0
5
10
15
20
25
30
21
22
23
24
25
26
27
28
29
30
0
5
10
15
20
25
30
35
40
45
50
Climate change by 2050 (%)


(B)
Change in parameter by 2050 (%)
Area maintained
Marginal yield
Cumulative yield
40
30
20
10
0
-10
-20
-30
-40
0
5
10
15
20
25
30
35
40
45
50
Climate change by 2050 (%)