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Climate Change and CO_2

- Role of Terrestrial Vegetation -

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Abstract: The recent status of the climate change issue is firstly addressed. Considering the increase in global population, the most serious climate change problem should be solved together with food, energy resources and other environmental problems. The role of terrestrial vegetation in the carbon balance is reviewed next and it is recognized that the role of terrestrial vegetation is large, and the afforestation should come after or together with the prevention of deforestation. Though biomass is one of the ways to reduce the atmospheric CO_2 using renewable energy, the energy conversion efficiency is much lower than that of PV (photovoltaic). In the case of afforestation, though CO_2 reduction per unit area may be lower than biomass, necessary energy for this measure is low with high gain. The plantation should be done in areas other than agricultural lands; grass, unused, semiarid or arid land. The area of unused land with sufficient available water is small so semiarid and arid land should come as the target of a large scale afforestation. Finally the present status of our technology development for arid land afforestation in Western Australia is introduced. The necessity and difficulty of its extension to other dry areas is discussed.

Key Words: Afforestation, Arid land, Carbon storage, Climate change, Terrestrial vegetation

1. Introduction

It was a very hot summer in Japan. I remember that I was always writing the same words every year. “Abnormal climate” means very rare climate appearing once per three decades or so. Therefore, the appearance of abnormal climate itself is not abnormal, but recently the frequency of its appearance is “abnormally” high.

In the present paper, first of all, the outline of the climate change issue is summarized. Considering the increase in global population, the most serious climate change problem should be solved together with the food, energy resources and other environmental problems. Then the role of terrestrial vegetation in the carbon balance is reviewed (Kojima, 1998). Finally, our trial of arid land afforestation in Western Australia is addressed and importance and difficulty of arid land afforestation are discussed. We love to contribute to the global environment by this tool, though we do not have any desert in Japan.

2. History of Climate Change Issues

2.1. Climate change as a global environmental issue

I firstly found a report on carbon dioxide concentration increase, in a book of “The Limits to Growth” (Meadows *et al*., 1972), though the comment on it was just “anthropogenic”. In 1988, IPCC (Intergovernmental Panel on Climate Change) was established. Its reports have been published on 1990 (FAR, 1st. Assessment Report), 1995 (SAR), 2001 (TAR) and 2007 (AR4). The fifth report (AR5, 5th Assessment Report) will be completed in 2013/2014.

2.2. Kyoto Protocol

In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was adopted at the Earth Summit held at Rio de Janeiro. In Dec. 1997 (Dec.), Kyoto Protocol was adopted at COP3 (3rd. Conf. Parties), Third Conference of Parties to UNFCCC. Though United States had withdrawn from it, it became effective in Feb. 2005 by ratification by Russia. The essences of the Kyoto Protocol were as follows:

a) by the period of 2008 to 2012 compared to 1990 levels (compared to 1995 levels for HFC, PFC, SF6),
b) reduction in greenhouse gas emissions at least -5% of the total for developed countries; e.g., -8% for EU, -7% for USA, and -6% for Japan,
c) in terms of CO2-equivalent; ×21 for methane, ×310 for N_2O, ×1300 for HFC, ×6,500 for PFC and ×23,900 for SF_6.
d) emission trading, joint implementation, and clean development mechanism.
e) In addition to the above,inclusion of the effects of land-use changes, namely CO_2 absorption by forests established after 1990 was also incorporated.

For Japan, more than half of the duty-bound reduction of

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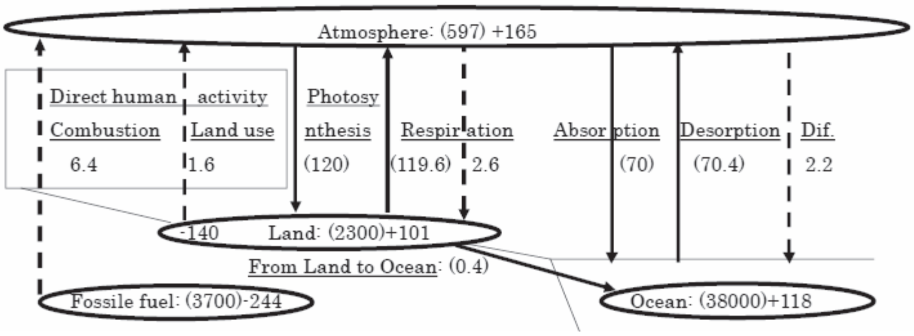

Fig. 1. The global carbon cycle for the 1990s; fluxes by arrows in GtC/y and stocks in circles in GtC. Vales in parentheses indicate those before 1975 and others, additional ones at 1994.

Table 1. Amounts of carbon stored in various terrestrial ecosystem (Kojima, 1998).

Ecosystem	Area (10^8 ha)	Organic matter (GtC)		Density (tC/ha)			Net production (GtC/yr)	Production density (tC/ha/yr)	TC* (yr)	
		Living	Dead	Living	Dead	Total			Living	Total
Tropical forests	18 [24.5]	270 [461]	126 [147]	150 [188]	70 [60]	220 [248]	13.6 [22.2]	7.5 [9.1]	20 [21]	29 [27]
Temperate forests	12 [12.0]	130 [174]	153 [108]	110 [145]	130 [90]	240 [235]	7.1 [6.7]	5.9 [5.6]	19 [26]	40 [42]
Boreal forests	13 [12.0]	110 [108]	225 [156]	85 [90]	175 [130]	260 [220]	4.3 [4.3]	3.3 [3.6]	26 [25]	79 [61]
Woodland and shrublands	8 [8.5]	40 [22]	80	50 [26]	100	150	2.4 [2.7]	3.0 [3.2]	17 [8]	50
Freshwater and swamps	4 [4]	4 [13.5]	80	10 [34]	200	210	1.25 [3.1]	3.1 [7.8]	3.2 [4]	67
Tropical grasslands	13 [15]	7 [27]	104	5 [18]	80	85	1.95 [6.1]	1.5 [4.1]	3.6 [4]	57
Temperate grasslands	9 [9]	9 [6.3]	135	10 [7]	150	160	2.25 [2.4]	2.5 [2.7]	4.0 [3]	64
Agricultural land	14 [14]	14 [6.3]	84	10 [4.5]	60	70	4.2 [4.1]	3.0 [2.9]	3.3 [2]	23
Tundra	8 [8]	4 [2.3]	160	5 [2.9]	200	205	0.4 [0.5]	0.5 [0.6]	10 [5]	410
(Semi) deserts	45 [42]	5 [6.1]	26	1 [1.5]	6	7	0.9 [0.7]	0.2 [0.2]	5.5 [9]	35
Abandoned land	5 [—]	15 [—]	40	30 [—]	80	110	1.25 [—]	2.5 [—]	12 [—]	44
All land areas	149 [149]	608 [826.5]	1,213 [—]	41 [55.5]	81 [—]	122 [—]	39.6 [52.8]	2.7 [3.54]	15.4 [15.7]	45 [—]

6% had been achieved by this term. After the termination of appointed term, now the reduction duty by Kyoto Protocol has been extended to 2020, but Japan, the country which experienced the devastative earthquake in 2011, has decided to withdraw from it, as has the United States.

3. Role of Terrestrial Vegetation and Desert

3.1. Role of terrestrial vegetation in the carbon cycle

Figure 1 (simplified from IPCC, 2007) shows the global carbon cycle. The carbon accumulation in atmosphere is 3.2 Gt-c/y (6.4+1.6-2.6-2.2), which is directly calculated from increased CO_2 concentration in the atmosphere. Between atmosphere and land vegetation, around 120 Gt-C/y is exchanged and it is almost globally balanced (in the level less than 0.1 Gt/y) before industrial revolution. Recently, 1.6 Gt/y is released (cumulatively 140 Gt until 1994) by land use change (mainly deforestation), which is estimated by the land use data by FAO etc., and the data given in **Table 1**. On the other hand, as the missing sink calculated from other sectors, land is estimated to be absorbing 2.6 Gt/y (cumulatively 101 Gt), which is explained by increase in per area biomass, namely the fertilization effect by increased CO_2 concentration.

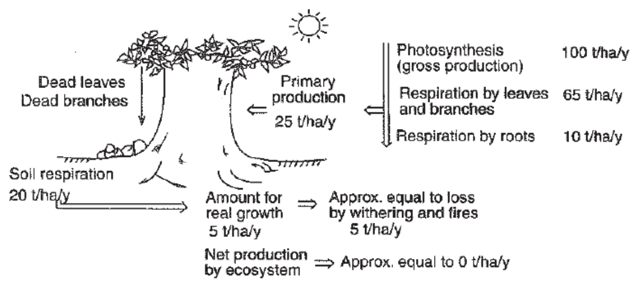

Fig. 2. The cycle of materials in forest (dry organic matter basis, Kojima, 1998).

As shown in Figure 1, terrestrial vegetation has a significant impact on carbon stock/cycle. Land vegetation contains four times the carbon amount of the atmosphere. Furthermore, twenty times more carbon dioxide is exchanged with the atmosphere by means of photosynthesis than that released from fossil fuels. The increased amount of CO_2 in atmosphere is twice the amount of the CO_2 released from deforestation.

Forests are also considered to convert solar into chemical energy by recycling carbon as shown in **Figure 2**. However,

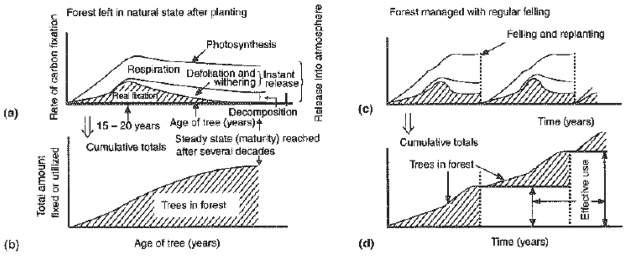

Fig. 3. Forest growth and carbon fixation (Kojima, 1998).

the efficiency of solar energy use in tropical rainforests is only 0.25%, at most even when all the net primary production of organic matter is considered as energy. Only about 20% of that is retained in the tree in the form of branches and trunks. Furthermore, about 30% of that retained energy can be utilized as generated electricity from wood. The total conversion efficiency is less than 0.02%, which is much less than 10% of the efficiency of a solar cell. Accordingly, the forests do not have a large role to play when considering vegetation as a tool for the conversion of solar energy.

3.2. Importance of arid land afforestation

Table 1 classifies each of the Terrestrial ecosystems in the world. It gives the sizes of the areas they cover, carbon-equivalent stock of living vegetative matter and dead substances, density (total stock divided by the area), net primary production (flow), and the amount of production per unit area (production density). Furthermore, the time constant (*i.e.* minimum time required for a complete exchange of carbon stock) is obtained by dividing the stock by flow; the value is given for both living matter and for living matter plus dead matter combined.

From differences in the data of the amount of carbon in living matter in tropical forests and in tropical grasslands (savanna), it was calculated that conversion of the tropical forests into grasslands would result in the loss of about 16 Gt-C/ha.

Trends of carbon fixation rate and its cumulative value after plantation are shown in **Figure 3 (a)** and **(b)**, respectively, when a forest is left without clearing. It is true that trees absorb carbon dioxide and store the carbon in their body while they are growing, but this stops after they reach maturity. The rate of carbon fixation reaches a peak at about 15 - 20 years after planting; and then the accumulation is virtually ceases. In this sense, the situation can be regarded as being virtually the same as subterranean storage (CCS: carbon capture and storage). The difference is that in the case of afforestation it is sufficient to just dig a hole in the ground and plant a sapling. After plantation, the tree will grow on its own, and carbon will accumulate naturally. Namely the necessary amount of energy for carbon fixation is small. In addition to the above

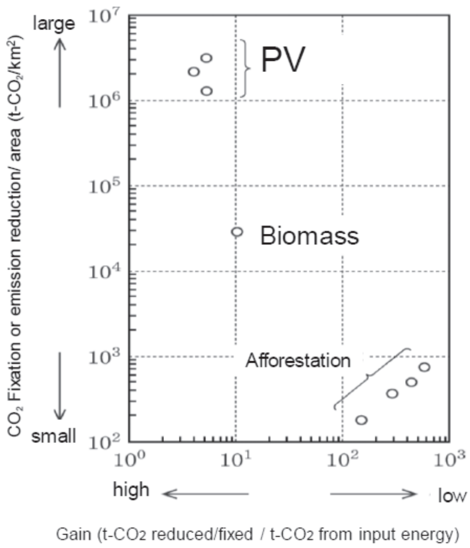

Fig. 4. Relative importance of PV, biomass and afforestation (Kojima *et al.*, 1999).

difference, the material stocked in the tree is an organic material not carbon dioxide, and the disadvantage of that is it takes quite a while to achieve. However, the time required is at most 20 to 30 years, which is sufficiently short in the context of the carbon dioxide problem.

The other problem concerns the amount of available space and quantities that can be stored. The density of organic matter in tropical and other forests is over 200 t-C/ha. If deserts could be transformed into tropical forests, over 200 t-C/ha is accumulated, but it would be necessary to afforest about 32 million ha each year to mitigate the annual carbon release from fossil fuel of 6.4 Gt/y shown in Figure 1. If considering natural sink in ocean of 2.2 Gt/y and that in terrestrial vegetation of 2.6 Gt/y, and the release by deforestation is stopped, the amount of carbon which should be sequestered is reduced to a quarter of 1.6 Gt/y, with necessary annual afforestation area of 8 million ha/y. Not completely the same carbon amount as but comparable to the desert afforestation is expected to be stored by changing form agricultural land, abandoned land or grass land to the dense forest. The plantation should be done in the other areas than agricultural land where our food is produced. Some grass lands for pastures have the same role as agricultural land. The area of unused lands with sufficient water is limited, so, semiarid and arid lands should be the target for large scale afforestation.

Considering the area of 4.2-4.5 billion ha of desert in Table 1, carbon sequestration by arid land afforestation can be regarded as the measure of more than 500 years.

3.3. Afforestation and biomass production

Figure 4 shows the relative role of solar, afforestation and

Fig. 5. Global distribution of arid area (Kojima and Egashira, 2011).

biomass. By introduction of PV (photovoltaic), huge amounts of CO_2 emission can be reduced by replacing fossil fuel power generation. However in the case of PV, energy for the production of PV modules leads to CO_2 emission, so the gain is little. Furthermore, the produced electricity should be transported to its destination, and cannot be installed in the desert area far from cities. In the case of afforestation, the amount of required energy is little, but the carbon which can be stored per unit area is little compared to CO_2 emission by PV installation. Biomass energy production locates at the moderate place between them. We must put the right man in the right place.

It looks promising to use the surplus biomass from the afforestation area as energy, because the CO_2 emission equivalent to the harvested wood can be reduced, if used for alternative energy such as electricity production. However, additional energy for harvesting should be minimized because the averaged amount of carbon stock is reduced compared to the case that the afforested area is left without clearing, as is expected in Figure 3. According to Righelato and Spracklen (2007), much more CO_2 is expected be mitigated by tropical cropland afforestation than by bioenergy production using the land, though the present estimation of 30 years will be changed when the evaluation term is changed.

3.4. Difficulty of arid land afforestation

Some semiarid and arid lands are said to be formed by industrial activities, such as mining, metallurgy, ceramics manufacturing, and farming. This means these areas are essentially possible to be afforested if we introduce some technologies that guide the route from present stable but arid vegetation to another ideal stable ecosystem with much more trees. However, the problem is "how to get, manage and supply sufficient water to the root area" under the arid condition.

4. Conclusion

The colleagues of the author are now trying to develop some technologies for afforestation of arid areas in Western Australia and are getting some fruitful results (Kojima *et al*., 2006). However, considering some of deserts have very limited annual precipitation compared to Australia as shown in **Figure 5**. Some strategy to extend the afforested area from moderately dry area to severely dry area is necessary, but I believe this should be possible from the view point of water recycling.

References

IPCC (2007): *IPCC Fourth Assessment Report: Climate Change 2007(AR4): Working Group I: The Physical Science Basis*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., Fig. 7.3 (http://www.ipcc.ch/).

Kojima T. (1998): *The Carbon Dioxide Problem: Integrated Energy and Environmental Policies for the 21th Century*, CRC Press/ISBN-13: 9789056991272/.

Kojima T., Tahara K., Inaba A. (1999): Relative importance of solar PV, bio-mas energy and afforestation as measures for CO_2 Problem. *Proc. Intern. Conf. on Role of Renewable Enery Technology for Rural Development*, pp.81-85, Oct. 12-14, 1998, Kathmandu, Nepal.

Kojima T., Hamano H., Abe Y., Tanouchi H., Egashira Y., Saito M., Law J., Takahashi N., Yamada K. (2006): Basic Data of Research Project on Large Scale Afforestation of Arid Land for Carbon Fixation near Leonora in Western Australia. *Journal of Arid Land Studies,* **16**(3): 167-174.

Kojima T., Egashira Y. eds. (2011): *Arid Land Afforestation against Climate Change*, Korona, Tokyo (in Japanese).

Meadows D.H., Meadows D.L., Randers J., Behrens III W.W. (1972): *The Limits to Growth*. Universe Books, New York.

Righelato R., Spracklen D.V. (2007): Carbon Mitigation by Biofuels or by Saving and Restoring Forests? *Science*, **317**: 902.