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Potential Feedback of Agroecosystem to Climate Changes

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농업생태계의 기후변화 관련 피드백 기능

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요 약

지구규모의 대기-지표-생물권(**Atmo-Geo-Bio-Sphere**)간의 끊임없는 상호작용(**Interaction**)과 피드백(**Feedback**)의 결과로 야기되는 기상변화는 아직도 이해를 위한 우리의 노력이 더욱 요구되고 있는 자연현상이다. 지구상의 모든 생물은 궁극적으로는 환경변화에 순응하여 생태계의 안정을 유지하는 방향으로 진화할 것이므로 생물자원의 관리분야라 할 수 있는 농업생산도 결국 기상자원의 변화에 효율적으로 적응하기 위한 인간활동인 것이다. 최근 빈발하고 있는 세계적인 이상기상의 출현은 일시적인 현상이 아니라 과도한 인간활동에서 야기된 대기질의 악화에 기인하는 비가역적이고 비선형적인 현상이라는데 불확실성과 심각성이 매우 크다. 지구상의 모든 농업생태계는 기상의 영향을 크게 받을 뿐만 아니라 반대로 기상에 커다란 영향을 미치는 중요한 생물권의 일부로 인식되고 있다. 농업활동의 결과는 항상 크던 작던 간에 대기조성에 영향을 미치게 되고 이는 다시 상호작용과 피드백에 의해 기상과 기후를 변화시키는 동인이 될 수 있다. 지구환경변화와 농업과의 관계는 지금까지는 주로 "기후변화가 농업생산에 미치는 영향"에 대한 접근방법을 택하여 왔다. 여기에서는 이와는 달리 "농업활동이 기후변화와 변동에 미칠 수 있는 가능성과 잠재력"에 대한 접근방법을 이용하여 농업과 기상과의 상호작용과 피드백효과를 새로운 시각에서 조견하고자 하였다. 상호작용 중 먼저 기후학적 변화원인으로 관심대상이 되고 있는 농업생태계의 온실기체 방출과 고정의 측면에서 이와 연관성이 높은 농업활동별로 온실가스의 방출/고정에 미치는 영향을 소개하고, 다음으로 생물지리화학적 및 생물지리물리학적 해석 방법을 검토 소개하였다. 한편 농업활동에 따른 지표면 특성의 변화가 국지기상 변화에 미치는 영향에 대한 검토를 에너지수지와 수분수지 관점에서 소개하였으며, 끝으로 농업활동의 근거지인 농촌지역의 인문사회학적 변화와 농업활동간의 관계, 그리고 이들이 기후변화/변동에 미칠 수 있는 잠재적 영향력을 살펴보았다.

핵심어 : 기후변화, 기후변동, 농업생태계, 영향평가, 온실기체, 상호작용, 피드백, 대기조성, 이산화탄소, 탄산가스

I. INTRODUCTION

Terrestrial ecosystems and climate are closely coupled. Changes in climate and the carbon dioxide concentration of the atmosphere cause changes in the structure and function of terrestrial ecosystems. In turn, changes in the structure and function of terrestrial ecosystems influence the climatic system through biogeochemical processes that involve the land-atmosphere exchanges of radiatively active gases such as carbon dioxide, methane and nitrous oxide, and changes in biogeophysical processes that involve water and energy exchanges (Melillo *et al.*, 1995b).

Agricultural ecosystems are part of terrestrial ecosystems where human activities have been intensively made in order to meet food and fiber demands. Along with the industrial progress during the past centuries, the expansion of intensive agriculture gave more pronounced influences on the earth's surface. This report intends to review potential impacts of various agricultural activities on local/global scale

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climate change in terms of the disturbances in energy and water as well as source/sink of greenhouse gases (GHGs).

1.1. Effects, feedback and uncertainties

The combined consequences of the effects and feedback are essential for the evaluation on the future state of the atmosphere or of terrestrial ecosystems. The conversion of forests and other ecosystems(e.g., wetlands) to pastures and arable lands have increased the atmospheric concentrations of CO_2 and other greenhouse gases(Houghton *et al.*, 1996). This increase in GHG concentrations alters the radiative balance of the atmosphere by absorbing and reemitting some of the infrared radiation emitted from the earth's surface. The result is that less heat is "lost" to space than in the absence of GHGs and, consequently, the earth's surface is becoming warmer.

1.2. Local environment change and GHGs

Land-use-related GHG emissions (e.g., nitrous oxide from soils or methane from agricultural activities) greatly depend on "local" environmental conditions and human activities (Turner *et al.*, 1995). Scientifically speaking, this is an exciting era, in which large-scale global environmental change is pushing the advancement of both basic and applied research on smaller scales. It is necessary to integrate the knowledge from cell to leaf to plant to plot to ecosystem, and on to region and the world. The relatively small-scale physiological and ecological processes in the biosphere play an important role in this respect.(Leemans, 1997).

II. Agroecosystem as C Sink/Source

2.1. Plants as C Pools

Compared with a global C flux estimate of 5.5-6.5 Gt C a^{-1} resulting from fossil fuel combustion, these fluxes from land conversions are surely significant. The major C pools are plants (Living biomass; partitioned into leaves, branches, stem and roots) and soil (Dead biomass; litter, humus and stable humus plus charcoal). The driving force of the C cycling among these pools is the Net Primary Production(NPP). NPP is gross primary production, (= the photosynthetically fixed C), minus the respiration loss of C within a plant. The partitioning of NPP among the different plant compartments is defined by fixed fractions. All plant and soil compartments are characterized by a specific lifetime. The partition fractions, life times and initial NPP are defined uniquely for each compartment and land cover type.

2.2. Changes in C Pool

The transient change in land cover has a great impact on all C pools of the terrestrial biosphere. The most common conversion is the conversion of forests to agricultural land or pastures. Most of the aboveground biomass (leaves, branch, stem and litter) of warm mixed forest, tropical dry forest/savanna, tropical seasonal forest and tropical rain forest is burnt at the site. In all other regions and land cover types the phytomass enter the humus pool. Only a small fraction (2-3%) does not burn and enters the charcoal pool. (Fearnside, 1991).

The land cover change thus leads to an instantaneous flux of C to the atmosphere and NEP will become strongly negative. Due to the high levels of the soil C pools, decomposition will also accelerate and remain at a relatively high level for several years. Later, NEP will level off but remains negative, so that converted land will act as a C source.

2.3. Soil C Pool

Another important conversion is the conversion of grasslands(pastures) into agricultural land (e.g. arable lands). For tropical grasslands, we assume that all aboveground biomass is burnt and only a very small fraction is converted to charcoal. For temperate grasslands we assume that all aboveground biomass enters the litter pool. NEP will also be negative after these conversion, but not so strong as after deforestation. Due to the relatively small changes in soil C pools, NEP will gradually decrease to zero with time.

2.4. Reversed C Cycle

C Cycle should also reflect reversed land cover change processes, such as reforestation (forest to forest) or forestation (agricultural land or pastures to forests). For these conversions NEP will be driven by NPP. Gradually all C pools will become saturated with the C values characteristic for a steady state situation. These conversions lead to an uptake of C by the biosphere. NEP is positive and the converted land will act as a sink for CO_2. This is because soil decomposition rates tend to adjust slowly to the above ground changes, and it can take many years before an equilibrium state is reached, where C uptake equals C decomposition. Impacts such as shifting vegetation zones due to a changing climate or more effective use of moisture resources (Vloedbeld and Leemans, 1993) can be taken into account.

2.5. Feedback Processes

Feedback processes modify NPP and/or NEP. Some feedback processes increase NEP(negative feedback), while others decrease NEP(positive feedback). Feedback processes potentially can have a strong influence on the C cycle and thus on the final atmospheric C concentrations. (Vloedbeld and Leemans, 1993). The most important feedback processes with respect to the C cycle are impact of temperature change on photosynthesis and respiration(plant growth), response of soil respiration to climate change, CO_2 fertilization, and shifts in vegetation patterns due to changes in water use efficiency and climate.

2.6. Region-specific Effects

The influence of the C cycle and land-use and land-cover change on atmospheric CO_2 concentration is clearly important. The rates of basic physiological and ecosystem processes are influenced by temperature, moisture, and nutrient availability. The latter is mostly a soil property but is altered by decomposition processes and management, such as adding fertilizer. Climate change will be different according to region and alters photosynthetic, respiration, and soil decomposition rates accordingly (Leemans R., 1997). Furthermore, enhanced CO_2 concentrations lead to CO_2 fertilization and improved WUE (Eamus, 1992). Land-use-related greenhouse gas emissions(e.g., nitrous oxide from soils or methane from agricultural activities) greatly depend on "local" environmental conditions and human activities (Turner *et al.*, 1995).

2.7. Resource Availability

The demand for agricultural and forest products (food, fodder, fiber and traditional and modern biomass) is linked to the regional availability of agricultural and forest resources. Available land resources are calculated on the spatial grid, characterizing local climate, terrain, soil, and topography. If current resources are inadequate to satisfying demand, land use expands into natural vegetation, converting it into land-cover classes such as agricultural land, pastures, or regrowth forests. This process results in deforestation and increased GHG fluxes toward the atmosphere. Agricultural land can either expand or contract according to technological and socioeconomic circumstances (Leemans R., 1997).

III. Feedback of Agroecosystem to Climate

3.1. Agricultural Production

Currently, humans use approximately 3.2% of the global net primary production (NPP; Vitousek et al., 1986) of ecosystems for food and fodder. However, total NPP used directly (e.g., food, fuelwood, and fiber), indirectly (e.g., land clearing), or lost as a consequence of human activities is much higher (ca. 38.8% of terrestrial NPP; Vitousek *et al.*, m 1986). Furthermore 11 and 25% of the natural land cover have been converted to cropland and pastures, respectively, whereas only 6% is protected in its natural state (Morris, 1995).

3.2. Land-use shifts and GHGs

Humans nowadays control large shifts in land use that modify or change the current land cover. Land use shifts involve processes such as changing forest cover to crop and range lands; loss and degradation of productive crop and range lands through overgrazing, drought and other (natural and anthropogenic) factors; conversion of wetlands, urbanization, etc. Land-use shifts are also caused by natural processes such as vegetation dynamics, response to environmental change and disturbances, such as storms, fire and flooding. (Leemans and van den Born, 1994)

3.3. Land Cover Conversions

Recent research indicates that human-induced conversions (e.g., changing land use management such as fertilizer use and irrigation practices) of land cover have significance for the functioning of the earth system. The influences of these land cover and land use changes become globally significant through their accumulative effects. Most recent land cover and land use modification and conversion is clearly driven by human use, rather than natural changes.(CLUE, 1999)

3.4. International Concerns

Concerns on global environmental change have led to important international multidisciplinary research programs(IGBP, IUDP), assessments of current scientific understanding (IPCC) and international treaties(FCCC, Biodiversity Convention and Agenda 21). The development of plausible future scenarios for global environmental change is a special requirement for the adequate implementation of such international conventions.

IV. Biogeochemical aspect of Feedback

4.1. Global Carbon Budget

Land ecosystems of the Earth contain about 2,200 GtC; an estimated 600 GtC in vegetation and 1600 GtC in soils. These land carbon stocks are changing now and are likely to continue to change in the future in response to changes in any or all of the following factors; area of agricultural land, age structure of forests, climate, and chemistry of atmosphere and precipitation.

Analyses based on atmospheric CO_2 and $^{13}CO_2$ measurements suggest that the terrestrial biosphere is currently a net carbon sink. Such analyses quantify the strength of this sink as 0.5-1.9 Gt/yr during the 1980s, and as high as 2.6 GtC/yr during 1992-3; they also suggest that the tropics have been a net carbon source, implying even greater rates of carbon storage in mid- to high latitudes. Direct observations to establish the processes responsible for this carbon storage are, however, lacking (Melillo *et al.*, 1995a).

4.2. CH_4 and CO_2 releases

Methane is produced in flooded organic soils as a result of anaerobic respiration (methanogenesis), and CH_4 emissions from natural wetlands are estimated to contribute about 20% to the global emissions of this gas to the atmosphere (Prather *et al.*, 1995). Factors increasing CH_4 flux would include northward spread of peat-forming areas into the high latitudes (enhanced by increased precipitation) and faster carbon turnover due to warmer temperatures (Christensen and Cox, 1995). Factors decreasing CH_4 flux would include drier conditions (lower water table) in extant peatlands (Roulet *et al.*, 1992), and drying-out and/or permafrost melting leading to loss of peat-forming areas in the continental interiors (Gorham, 1995).

However, if CH_4 flux declines in some regions due to drying, this would imply an additional flux of CO_2 to the atmosphere due to enhanced aerobic respiration and, perhaps, large-scale oxidation of the peat by erosion and fire (Hogg *et al.*, 1992). This is of concern because as much as 450 GtC may be stored in high latitude peats(Botch *et al.*, 1995). Like the possible carbon "spike" due to transient vegetation changes, this possible source of carbon to the atmosphere represents a potential positive feedback that has not been adequately quantified (Nisbet and Ingham, 1995).

4.3. N_2O budget

The major N_2O-producing process is denitrification. Denitrification is promoted by high nitrate supply and low soil oxygen concentration. Warmer soils promote more rapid nitrogen cycling and often more nitrate, while wetter soils lead to low soil oxygen levels. Where soils become warmer and wetter, the production of N_2O will increase, but the global magnitude of this increase has not been estimate (Melillo *et al.*, 1995a).

The nitrous oxide budget is largely controlled by microbial processes in soils. Today, the warm, moist soils of the tropical forests are probably the single most important source of N_2O. Land-use and the intensification of agriculture in the tropics appear to be increasing the size of the N_2O source from this region. The microbial process responsible for the production of most of the N_2O is denitrification; the assimilatory reduction of oxides of nitrogen that produces N_2 as well as N_2O. The rate of denitrification is controlled by oxygen(O_2), nitrate (NO_3) and carbon. Moisture has an indirect effect on denitrification by influencing O_2 content of soil. If other conditions are appropriate, then temperature becomes an important controller of denitrification.

V. Biogeophysical aspect of Feedback

5.1. Land-surface changes

Vegetation mediates the exchange of water and energy between the land surface and the atmosphere, and thereby affects climate. As biomes shift, the climate will be affected. For example, high latitude warming is expected to cause forests to spread into tundra. This change would be expected to increase the warming in northern mid- to high latitudes by more than 50% over 50-150 years because of the lower albedo of forests during the snow season. Such feedback will, however, be modified by land-use changes such as deforestation.

Understanding the significance of land cover change for the C Cycle is not possible without additional information on land use. Land cover changes are mostly driven by human activities, and land-use practices themselves have also major direct effects on environmental processes and systems (Turner *et. al.*, 1990). Recent estimates of C fluxes related to land-use changes seem to converge towards values between 1 and 2 Gt C a-1. (Detwiler and Hall, 1988; Houghton *et al.*, 1990)

5.2. Changes in Vegetation Structure

Compositional and structural changes will occur over a longer period than functional changes and these may not keep pace with rapid environmental change, so complex transient effects may result. Vegetation structure is determined not only by the types of plants present but also by the height and foliage cover they attain. Foliage cover, often expressed as leaf area index(LAI), is constrained by resource availability (water, carbon, nitrogen). LAI decreases as water availability declines.

Along moisture gradients, vegetation composition and structure change due partly to replacement of drought-sensitive by drought-tolerant (or more deep-rooted) plant types, and partly to reductions in the LAI of each type (Walter, 1979). Values for LAI are typically low enough to prevent drought damage in most years (Neilson, 1995), so maintaining annual NPP near maximal for the environment (Haxeltine *et al.*, 1996). Changes in water availability will therefore affect LAI, but the response may be modified by changes in CO_2.

Vegetation structure also changes with light availability, summer temperature and growing season length. From boreal forest to high-arctic tundra, trees are gradually replaced by shrubs and grasses as NPP declines. Comparable vegetation gradients occur at high elevations in all latitudes(Walter, 1979).

5.3. Effects on Hydrologic Cycle

The hydrological cycle is strongly modulated by the Earth's vegetation. Active regulation of water, energy and carbon fluxes by the vegetation make it an important factor in regulating the Earth's hydrologic cycle and in the formation of the climate. Consequently, human induced conversion of vegetation cover has been an important driver for climate change (BAHC, 1999).

VI. Effects on Land-surface Parameters

6.1. Albedo

Vegetation mediates the exchange of water and energy between the land surface and the atmosphere (Hostetler *et al.*, 1994). The main land-surface parameters influenced by vegetation structure are surface albedo (normal and snow-covered), roughness length (affecting boundary-layer conductance), canopy conductance and rooting depth. Snow-free surface albedo for total short-wave radiation ranges from ~0.15 in closed forests to 0.4-0.5 in hot deserts (Henderson-Sellers and McGuffie, 1987). The largest effect of snow cover is on low vegetation types such as grasslands and tundra, where the snow-covered albedo can be up to 0.8.

6.2. Canopy Conductance

Roughness length increases with vegetation height: tall forests therefore present a boundary-layer conductance that is much larger than short grasslands, Canopy conductance is influenced by foliage density, plant nitrogen content, atmospheric CO_2 content and drought stress (Schulze *et al.*, 1994). At present ambient CO_2, most natural vegetation types have a maximum stomatal conductance of 3-6 mm/s while field crops have a higher conductance, up to 12 mm/s (Kelliher *et al.*, 1993). Canopy conductance increases asymptotically with leaf area index, towards a value of about 3-4 times stomatal conductance for a closed canopy. Stomatal closure under midday conditions of high evaporative demand acts to restrict canopy conductance. This closure occurs sooner as soil moisture supply is reduced and vapour pressure deficit increases.

VII. Effects of Land-Surface Changes on Climate

7.1. Precipitation

The sensitivity of climate to changes in these different land-surface properties varies regionally. For example, albedo effects are important in controlling precipitation in climatic regimes where precipitation is controlled by large-scale dynamics or convection;

canopy conductance and rooting depth are important in regimes where a large proportion of precipitation arises by recycling of evapotranspiration from the land surface (Rinddd, 1984).

Through raising albedo and/or lowering evapotranspiration, large-scale deforestation tends to reduce moisture convergence and precipitation. The potential area of tropical rain forests and seasonal forests is therefore reduced. More generally, albedo exerts a strong control over evapotranspiration and precipitation in the tropics and subtropics (Mylne and Rowntree, 1992).

Albedo changes in the high latitudes can also have major effects. Bonan *et al.*(1992) examined the sensitivity o f global climate to boreal deforestation (replacement of the boreal forests by tundra). The large increase in snow-covered albedo resulted in colder winters and a longer snow season. Such sensitivity studies suggest that large biogeophysical effects of vegetation structure on climate could be brought into play by land-use change.

7.2. Evapotranspiration

Halving of surface conductance, with no change in leaf area, would lead to reduced evapotranspiration rates, increased surface air warming about 0.5 C averaged over terrestrial areas, compared with 1.1 to 2.5 C which is predicted for the combined effects of radiative forcing and aerosols, and in some regions increase soil moisture storage (Pollard and Thompson, 1995). The net physiological effect of CO_2 on climate would be to reduce evapotranspiration and increase soil moisture, relative to the scenarios based on radiative forcing alone. Such studies underline the sensitivity of the simulated hydrological cycle to land-surface properties that are determined by ecosystem functional and structural responses to climate and CO_2. The vertical structure of the planetary boundary layer may limit the effect of changes in stomatal conductance on evapotranspiration (Monteith, 1995).

7.3. Physiological Processes

The rates of basic physiological and ecosystem processes are influenced by temperature, moisture, and nutrient availability. The latter is mostly a soil property but is altered by decomposition processes and management, such as adding fertilizer. Climate change will be different according to region and alters photosynthetic, respiration, and soil decomposition rates accordingly. Furthermore, enhanced CO_2 concentrations lead to CO_2 fertilization and improved WUE (Eamus, 1992). Here, plant type (C3, C4, CAM; annual or perennial; herb, shrub, or tree) and the ecosystem structure highly determine the response (Krner, 1993).

7.4. C Cycle

The total flux between the terrestrial C cycle and the atmosphere represents the logical outcome of these local fluxes. NPP is partitioned over different plant parts (e.g., leaf, branches, trunks, and roots), each with a specific longevity. With time, C will enter to the C pool of the soil and subsequently be decomposed. Decomposition resulted in a C flux to the atmosphere. The Net Ecosystems Productivity (NEP) was thus a function of NPP and the soil decomposition rate. Both are strongly influenced by complex environmental factors. Each land-cover type (cf. Ecosystem) had a characteristic NPP, which was adjusted for local climatic and soil conditions, and global atmospheric conditions;. The C fertilization effects and changes in WUE. The impacts of these effects are important but that the actual outcome depends on plant type, temperature, altitude, nutrients, and moisture availability.

VIII. Susceptible/Vulnerable Factors

8.1. Modification of Land Surface Conditions

The demand for agricultural and forest products (food, fodder, fiber, and traditional and modern biomass) is linked to the regional availability of agricultural and forest resources. Available land resources are calculated on the spatial grid, characterizing local climate, terrain, soil and topography. If current resources are inadequate to satisfying demand, land use expands into natural vegetation, converting it into land-cover classes such as agricultural land, pastures, or regrowth forests. This process results in deforestation and increased GHG fluxes toward the atmosphere. Because the intensification of agricultural productivity is calculated on the basis of technological and socioeconomic assumptions, agricultural land can either expand or contract. Abandoned agricultural land converts into the early successional phase of the potential natural vegetation, often with increasing C densities through time.

8.2. Changes in Agricultural Land

Agricultural land occupies almost one fifth of the earth's terrestrial surface (Olson, 1983). A substantial portion of this land was once forested and so contained relatively large carbon stocks in both trees and soils. The conversion of forests to agricultural lands releases carbon, mostly from trees. To the atmosphere through burning and decay. Conversely the regrowth of forests on abandoned lands withdraws carbon from the atmosphere and stores it again in trees and soil. The net flux of carbon from the land to the atmosphere primarily associated with agricultural expansion for 1980 has been estimated at between 0.6 and 2.5GtC/yr(Houghton, 1995). IPCC (1994) indicates that the net emission from changes in tropical land-use was 1.6+1.0 GtC/yr for the period 1980 through 1989 (Schimel *et al.*, 1995).

8.3. Changes in the Age Structure of Forests

Young and middle-aged forests accumulate carbon, while old-growth forests accumulate little if any carbon. Forests of the Northern Hemisphere's mid-latitudes that were harvested in the early and middle parts of the 20th century are still regrowing and accumulating carbon. Estimates of rates of carbon accumulation related to forest regrowth in these regions range between 0.7 and 0.8 GtC/yr for the 1980s (Melillo *et al.*, 1988) have argued that the fate of the cut wood must also be taken into account when evaluating the net effect of forest harvest and regrowth in the global carbon budget; that is, the rate at which the carbon in the cut wood is returned to the atmosphere as a result of burning and decay must be considered. They concluded that the net effect of forest harvest and regrowth for the middle and high latitudes of the Northern Hemisphere on terrestrial net carbon storage was approximately zero in the 1980s. It must be recognized that there are considerable uncertainties associated with estimating the fate of cut wood, including wood left at the harvest sites, fire wood, and wood products such as paper and lumber (Melillo *et al.*, 1988).

8.4. Changes in the frequency of fires, insect outbreaks and other disturbances

Changes in the frequency of fires, insect outbreaks and other disturbances can also alter the age structure of forests and affect their capacity to store carbon. Disturbance regimes are affected by climatic conditions such as warming and drought. The boreal forest regions of 'Canada have experienced increased rates of disturbance, especially spruce budworm outbreaks and fire. As a consequence, these forests have switched from being a sink for atmospheric CO_2 to being a carbon source to the atmosphere, albeit a small one. (Kurz and Apps, 1995).

8.5. Air Pollution

The burning of fossil fuels causes changes in the chemistry of the atmosphere and precipitation. Fossil fuel burning can lead to the production of air pollutants such as sulphur dioxide and ozone that are toxic to plants. These air pollutants can decrease NPP and carbon storage (Allen and Amthor, 1995). The burning of fossil fuels can also lead to increases in nitrogen in precipitation. Up to some cumulative level, increased nitrogen inputs to nitrogen-limited ecosystems, such as many temperate and boreal forests of the northern hemisphere, can cause increases in NPP and carbon storage.

8.6. Availability of Nutrients

Enhanced photosynthesis and increased nutrient availability increase NPP if decomposition and nutrient mineralization are enhanced (Bonan and Van Cleve, 1992; Melillo et al., 1995b). Low soil moisture decreases NPP which may reduce photosynthesis through decreased stomata conductance (Gifford, 1994) or decreased decomposition and mineralization (Parton *et al.*, 1995). Elevated temperature may also increase plant respiration and so reduce NPP (McGuire *et al.*, 1992), although this effect may have been overestimated. The effects of precipitation and cloudiness on NPP can also be positive or negative in different situations.

Soil respiration is generally accelerated by higher temperature, producing an increase in the release of CO_2 from terrestrial ecosystems.(Kirschbaum, 1995). It is thought that in many ecosystems the increase of soil respiration with temperature is steeper than any increase of NPP with temperature, so that the net effect of warming is to reduce carbon storage.

IX. Rural Factors

9.1. Urban-Rural Interfaces

The prospect of tremendous growth of urban centers is staggering to perceive in the coming decades in Asia. Urban centers in Asia will number over 15, accounting for over 60% of the cities with populations greater than 10 million people. The urban growth is greatly modifying the surrounding area and impacts of these changes on croplands, fuel resources and water supply will be tremendous. How these areas plan to cope with this burgeoning problem, and what effects will have the rural areas is and will increase in its importance in the coming decade.

As this growth in population levels of urban centers continues, issues related to competition for natural resources become increasingly a major factor in determining the viability of these urban areas. Questions related to the type of social structural entities that are needed to maintain the urban centers need to be addressed. In addition to institutional questions, a better understanding of the social properties, for instance the kinds of laws and cultural practices, that characterize various urban centers are needed. This set of sectoral issues will rely more heavily on the understanding of social-economic topics. New integration techniques may be needed to address these issues.

9.2. Social Processes

Understanding of the relationships between population growth and land-use change requires a dee- per understanding of both natural and social processes. Moreover, while the most significant factors influencing these relationships may differ from place to place. Understanding this context is necessary to understanding the evolving relationships among people and land, consumption, and the broader environment.

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