Sustainable agriculture in the semi-arid agro-pastoral interweaving belt of northern China

A case study of west Jilin province

Pan Xiangliang, Deng Wei, Zhang Daoyong, Li Fei and Wang Yongjie

Abstract: *The semi-arid agro-pastoral interweaving belt (SAPIB) is an important ecological zone in northern China and an important food base. However, sustainable agricultural development has been restricted by both natural and socioeconomic factors. It is inherently vulnerable because of its unfavourable climate and geological and hydrogeomorphological conditions. Agricultural production has been impaired by frequent natural disasters, salinization and desertification. Moreover, irrational agricultural policies and practices, poverty and other socioeconomic factors have brought about degradation in the SAPIB. The authors argue that the basis for a sustainable strategy is to transform it by increasing exergy input, changing the cultural outlook and harmonizing interactions between the component subsystems. Finally, a series of proposals based on notions for a sustainable strategy is put forward.*

Keywords: *sustainable agriculture; vulnerability; degradation; SAPIB*

Pan Xiangliang, Deng Wei, Li Fei and Wang Yongjie are with the Northeast Institute of Geography and Agricultural Ecology, Chinese Academy of Sciences, ChangChun, Jilin 130021, People's Republic of China. Pan Xiangliang is also with the Institute of Nuclear Energy, Tsinghua University, 100084, People's Republic of China. E-mail: xiangliangpan@163.com. Zhang Daoyong is with the Department of Transportation Engineering, Jilin Institute of Architecture and Engineering, Changchun, Jilin 130021, People's Republic of China.

The semi-arid agro-pastoral interweaving belt (SAPIB) is the transitional belt lying in northern China, within which forestry and animal husbandry interplay or frequently alternate with each other. It is the main food and agricultural base of China. Because of its special geographical situation, SAPIB also acts as an ecological barrier for central and eastern China's agricultural systems. It blocks the encroachment of desertification from the north and conserves the water sources of rivers that support agricultural systems. But, since SAPIB is climatically situated in the transitional zone between a humid and an arid zone (Figure 1), insufficient precipitation (yearly precipitation generally ranges from 250 mm to 500 mm) and large climatic differences determine the fragile vegetation types, soil types and landscapes within it. SAPIB thus has a highly intrinsic vulnerability to climatic change. As a result of human activities over the last few centuries, SAPIB has also gradually been

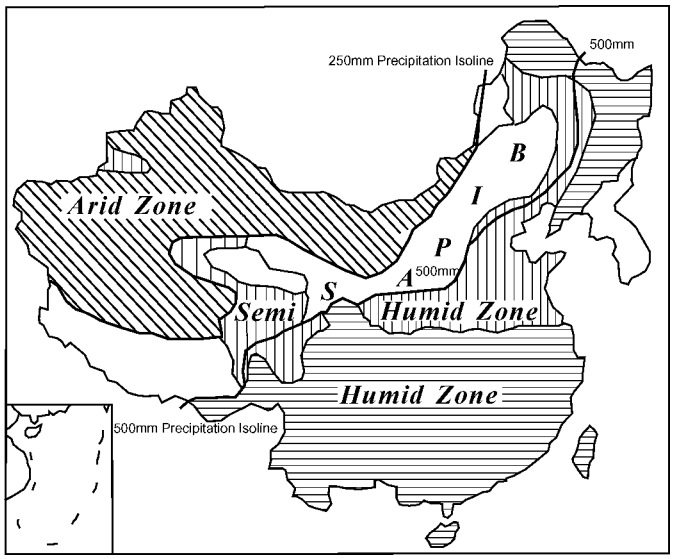

Figure 1. The SAPIB in North China.
Note: not to scale.
Source: Cheng Xu, 1999.

degraded and has lost its ability to curb desertification. So, not only has it suffered frequent natural disasters such as droughts, floods, salinization and desertification, but it has been damaged even further by the hand of man.

West Jilin province is a typical zone. The main agro-eco-environmental problems are typically those due to population, land, food, economy and society, and a role for sustainable agriculture.

Characteristics of the study site

The study site lies between 46°18'N–43°59'N and 121°38'E–126°30'E and includes SongYuan and BaiCheng districts. It has a total area of 47,801 km² and a total population of 489,650,000. There are four national-level poverty counties in west Jilin province, where annual per capita income is less than RMB1,700 (RMB8.1 = US$1).

Climate

The whole area is affected by the East Asia monsoon and is dominated by a semi-arid temperate climate. Seasons alternate between dry and windy springs, humid and warm summers with intensive rainfall, windy and dry

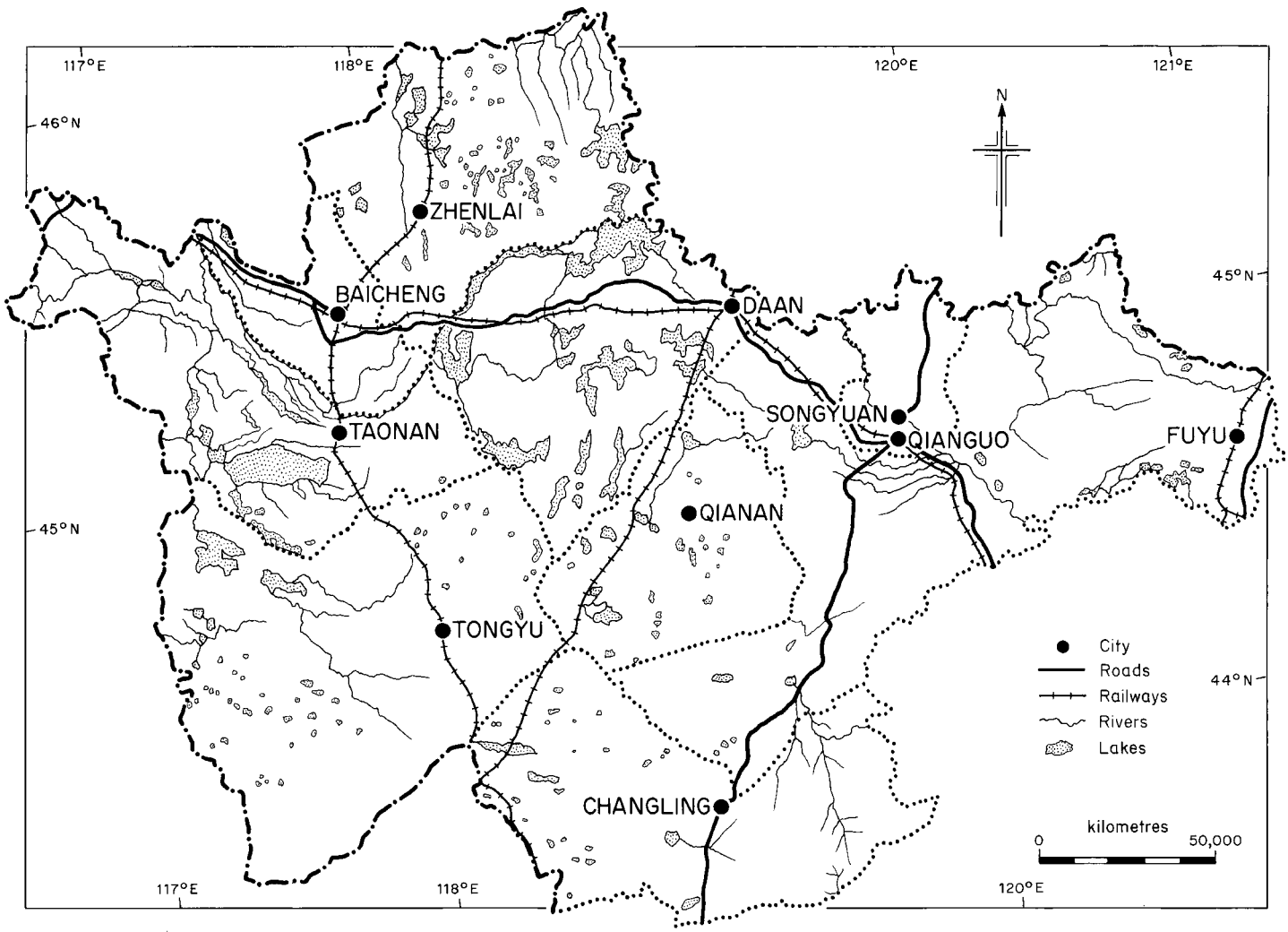

Figure 2. Geographical location of drainage in west Jilin.

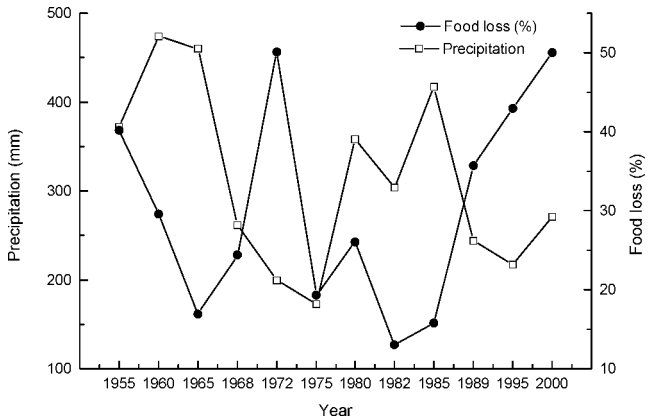

Figure 3. Food production loss due to drought in BaiCheng.

autumns and long, cold dry winters. Precipitation varies greatly within and between years. Seventy to eighty per cent of the total precipitation occurs between the middle of June and mid-August. In addition, while precipitation decreases from 420–460 mm in the east to 350–420 mm in the west, evaporation increases from 1,200–1,600 mm in the east to 1,500–1,900 mm in the west. The annual average temperature is 2–5ºC and diurnal variation is pronounced. The top soil layers are frozen in mid-November and melt the following April. The frost-free season lasts 130–165 days.

Soil and strata

The study area lies at an altitude of 110–140 m on a slope of only 1/7,000–10,000. Depressions, wetlands and lakes cover the low plain. The Quaternary sediment is 50–100 m thick and the upper part is composed of alluvial and lacustrine loess-like sandy clay, and silty sand. The middle is composed of lacustrine silty clay sandwiched between sand layers and the lower part of lacustrine sand and gravel. The east stripped high plain, at an altitude of 180–250 m, spreads along the boundary between Changling and Qianguo counties. Gully erosion is prevalent in the east high plain, which is formed from loess-like clay, and the erosion coefficient is about 4,250 t/km^2.

Drainage

Except for a few river branches, including the Tao'er, Huolin and Second Songhuajiang rivers, which are sparsely distributed in the study area (Figure 2), the main rivers, including the Songhuajing and Nenjiang rivers, flow only through the northern edge of the study area. Furthermore, the tributaries are entirely supplied by upstream precipitation and are dry during the dry season. The Huolin river is dry for most of the year due to the water-capture project upstream in the Inner Mongolia autonomous district. Overall, the surface drainage system of the study area is characterized by large non-contributing areas and slow run-off.

Natural obstructive factors – intrinsic vulnerability

Frequent extreme climatic events

In the last four decades, droughts and floods have frequently compromised the study site, thereby increasing salinization and desertification and severely restricting sustainable agricultural development.

In some local regions, such as QianAn, Changling, Zhenlai, Tongyu and Taonan, drought (mainly spring drought) occurs nearly every year, not only because of insufficient precipitation, but also from the effects of high evaporation and poor water-holding capacity of soil. Moreover, the drought usually occurs throughout the crop growth season (see Table 1), which directly and greatly reduces food production (Figure 3). In 1995, for example, Tongyu and Da'an suffered great spring and summer droughts, with only 60 mm of precipitation in 200 days, and maize production consequently fell by 70% (Deng and Lu, 1996). In subsequent years, drought caused substantial food production losses, especially in 2000 when food production decreased by 50% and crops were ruined almost everywhere. The average annual food loss due to drought is up to 2.5×10^9 kg (Xiao *et al*, 2001).

Similarly, frequent droughts have caused serious damage to grassland, which directly impairs livestock production. Deng and Liu (2000) used climate change models (CCMs) to predict the future climate change of SongNen plain. The results showed that in the future, drought frequency would increase and monthly levels of soil moisture in the plant root zone would decrease, leading to a reduction in primary productivity by 2–4% across the whole steppe.

Drought not only directly reduces food production and steppe productivity generally, but also brings about soil

Table 1. Drought occurrence during crop growth stages in west Jilin.

Crop growth stages	Seed germination		Heading (spring wheat)		Florescence fertilization (maize), tillering (rice)		Production and maturing		Number of years of observation
	Times	*F (%)*	*Times*	*F (%)*	*Times*	*F (%)*	*Times*	*F (%)*	
BaiCheng	29	91	23	72	13	41	23	72	32
Qian'an	24	92	19	73	10	38	18	69	36
Changling	23	77	19	83	10	33	18	60	30
SongYuan	18	75	16	67	8	33	15	63	24
Time	1 April–20 May		21 May–30 June		1 July–10 August		11 August–10 September		

Notes: F = frequency.
Source: adapted from Deng and Lu, 1996.

salinization and desertification, which further indirectly affect agricultural development.

Floods

Despite generally insufficient precipitation in the study area, the highly uneven distribution of precipitation within the year and the low, flat landscape cause frequent flooding, which reduces food production, damages property, causes loss of human life and brings about substantial soil erosion and other complications. In BaiCheng district, the floods of 1957, 1986 and 1998 reduced food production by 38%, 20% and 22% respectively. During the 1998 flood in Songhuajiang, 7,522 km^2 of land was flooded, causing direct economic losses of more than RMB5.2 billion.

Salinization

Soil salinization has been a serious environmental problem in west Jilin province, which not only restricts agricultural development, but also threatens the survival of humankind. For example, villagers of Kangjiawopen village in Da'an county have had to leave their homes because of salinization. In 1958, about 0.94×10^6 ha, or 27% of the total area of available land, was affected by salt; in 1984 this became 1.15×10^6 ha, or 33% of the total area; and in 2001, 1.61×10^6 ha, or 46% of the total area. From 1984 to 2001, not only did the total salt-affected area increase rapidly, but the rate of increase in size of the highly affected area was more rapid than earlier (from 0.32×10^6 ha to 0.65×10^6 ha (Figure 4). All this leads to a corresponding decline in the area available for cultivation and productivity of both grassland and arable crops.

Salinization of land in west Jilin province is the product of natural hydrogeological and geomorphological events and damaging human activity. First, the Tao'er and Huolin rivers originate from the adjacent Daxinganling mountains, whose surface rocks are mainly andesite, liparite, basic basalt, tuff and granite. These weathered rocks, rich in MgO, CaO, Na_2O and K_2O, have been etched by rivers, and a large amount of salts and debris has been transported into the mid-downstream plain (ie middle low plain in the study site), and have deposited about 25–35 m of Quaternary sediment, which provides abundant salt for salinization.

Second, the unfavourable hydrological conditions and dry climate drive salinization. In the West and East Piedmont plain, the sediment is mainly gravel and the slope is relatively steeper; there is a higher infiltration rate and faster groundwater run-off. Therefore, the salts leached from the top soil layers by rainfall can be rapidly transported downward by groundwater run-off. When the middle low plain is reached, groundwater run-off slows and dissolved salts are retained by soil and accumulate to high concentrations. As a result of this, in the West Piedmont inclined plain and east high plain there is a lower degree of mineralization, reduced hardness, lower salt concentrations in the groundwater and a deeper water table. In the middle low plain, however, the conditions are worse: almost stagnant groundwater, run-off without discharge except for evaporation, a shallow water table and a higher degree of mineralization, all of which are favourable for salinization. Furthermore, the semi-arid climate, characterized by low precipitation and very high evaporation, combined with unfavourable hydrological conditions, increases land salinization. Therefore, in the thematic map (TM) image, salinization mainly occurs in the middle low plain, while the area of saline land area and its degree of salinization in the east high plain and West Piedmont inclined plain are smaller.

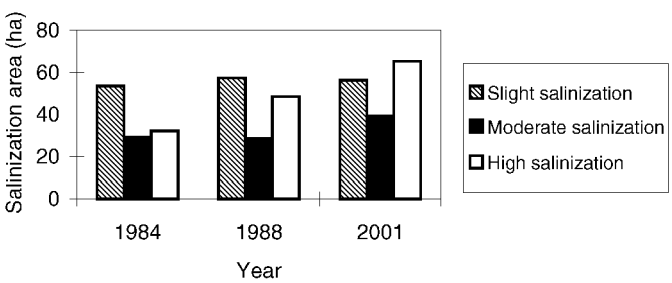

Figure 4. Changes in the salinity of land in west Jilin.
Note: The degree of salinization is presented on the basis of sodium adsorption ratio (SAR): SAR<40 = slight; SAR 40–90 = moderate; SAR>90 = high.

Human activities exacerbate the salinization and produce secondary salinization. Overgrazing reduces ground cover, thereby increasing evaporation, soil temperature and soil organic decomposition. The $NaHCO_3$ and Na_2CO_3 produced after decomposition of soil organic matter are highly soluble in soil liquid (up to 500g/l) at higher soil temperatures. Higher concentrations of Na^+ exchange more Ca^{2+} in soil colloid and thus aggravate salinization (Zhang, 1994). For example, in the 1980s, up to 56% of grassland was salt-affected through overgrazing. The upstream water-capture project blocked the hydraulic link between the floodplain and the river, destroyed the water–salt balance and induced salinization. Extensive irrigation agriculture without appropriate drainage can also produce secondary salinization.

Desertification

Desertification is another important contributor to the destruction of the environment and consequently obstructs agricultural development. There are about 8.28×10^5 ha of affected land, and this has decreased by about 10.7% compared with 1986. However, the moderately and highly desertified areas in 2002 have increased about 5% and 4% respectively, compared with 1986.

As with salinization, desertification in west Jilin province is the product of natural factors and human activity. First, the thick Quaternary loose fine sandy sediment provides a material source. Second, in west Jilin province, there about 140 days of level-5 wind and about 30 days of level-8 wind, and the windy days occur during the dry season. So winds and a dry climate together drive the desertification process. Third, population explosion, overgrazing, excessive agricultural reclamation and upstream water resource interception projects accelerate desertification.

Scarcity of water

There are a few river branches that are sparsely distributed in west Jilin province. The whole region is a non-contributing area and suffers from prolonged water

Table 2. Agricultural production value structure of west Jilin province in 1998.

	Plantation		Forestry		Husbandry		Fishery	
	RMB	*Percentage*	*RMB*	*Percentage*	*RMB*	*Percentage*	*RMB*	*Percentage*
SongYuan	649,346	69.62	7,872	0.85	258,943	27.76	16,527	1.77
BaiCheng	220,588	54.40	8,059	1.99	148,716	36.68	28,075	6.93
Total	869,934	65.01	15,931	1.19	407,659	30.46	44,602	3.34

Source: 1999 Jilin Yearbook.

shortage. On average there are about 4.41×10^9 m^3 of surface water resources and 34.25×10^9 m^3 groundwater resources. Water resources per capita and farmland water resources are 791 m^3 per annum and 2,108 m^3 ha^{-1} per annum respectively, which are far lower than China's per capita water resource (2,260 m^3 per annum) or per hectare farmland water resource (21,627 m^3 ha^{-1} per annum). Precipitation is the main water source, accounting for about 90% of total water source. Agricultural water demand accounts for more than 80% and precipitation and soil water cannot meet crop water demand, which undoubtedly results in substantial food loss. According to a study carried out by Zhang *et al* (2001), rice, maize and sorghum, the three main crops in west Jilin, have water deficits of 55–78 mm, 148–160 mm and 110–138 mm respectively, compared with those of 1986.

Socioeconomic obstructive factors

Historical problems

A long agricultural history and agricultural policy changes have had profound influences on the environmental evolution and regional development of west Jilin province. According to 'Liao History', the region was suitable for cropping and grazing before the Liao Dynasty due to its fertile land and luxuriant growth of grass. Land desertification occurred in some regions of west Jilin province with the development of agriculture in the twelfth century. After the thirteenth century, the environment recovered with the southward movement of the Yuan and Ming Dynasty and shrinkage of agriculture. However, from the mid-eighteenth century, during the Qing Dynasty, farmers were obliged to reclaim grassland at extremely low land prices, and steppe landscape was gradually replaced by farmland, rangeland and sand dune. In some riparian zones, mobile sand dunes had dominated the landscape.

Since the 1950s China's economy has recovered after decades of war and, in order to sustain the rapidly growing human population, the government put forward the 'food first' agricultural policy. Although this policy played an important role in solving the problem of people's survival, it was contrary to 'agricultural environmental' law. In west Jilin province, the land is suitable for husbandry or some complementary combination of arable cropping and husbandry because of extensive grassland and the limitations of climate. However, under the 'food first' policy, farmers had no choice but to fell large areas of forest and burn grassland to reclaim more land for food production. From 1958 to 1981, the farmland area increased from 1,326,000 ha to 1,730,000 ha, while the area of grassland decreased from 2,529,000 to 1,726,000 ha. Almost 64% of the grassland suffered from desertification or salinization. During this period, the environment suffered unprecedented damage.

From the statistics for agricultural production (Table 2), it is clear that arable farming predominates in the agricultural structure, which indicates that the 'food first' policy still has a strong influence over farmers' agricultural activities and local government decision making.

In recent years, the government has been aware of the seriousness of environmental problems and tried to seek various measures to prevent and cure the severely damaged environment. However, although the increasingly serious environmental crisis has been curbed to some degree, the environment in west Jilin province has still deteriorated because of previous ruinous destruction, the intrinsic vulnerability of the agricultural system, low technology and current agricultural policy.

Dilemma of the household contract responsibility system

At the end of the 1970s, in order to encourage farmers, the Chinese government reformed the land tenure policy and introduced a system of household contract responsibility, in which remuneration was linked to output. Farmland was distributed to farmers on the basis of the size of their families. Farmers had the right of land use, allowing them to engage in any agricultural activities according to their own wishes. Under this household contract responsibility system, farmers worked with unprecedented enthusiasm and their standard of living has been enhanced greatly over the last two decades. For example, the average rural annual income per capita increased from RMB140 in 1988 to RMB1,256 in 1996. However, this household contract responsibility system has begun to be an obstacle to more advanced productivity since farmers have become increasingly satisfied with their situation. Although farmers are eager to continue improving their lifestyle, they feel tied to the land. The idea that land is their lifeblood is deeply rooted. Most farmers never seek other ways to earn money, and even despise marketing. The only thing they feel they can do is to produce more food on the limited area of land they farm, or reclaim more farmland at the cost of the environment. But they find it almost impossible to increase food productivity because of their poverty and outdated production systems. Most of them have no money to buy inorganic fertilizer.

The broad and flat topography in west Jilin province is suitable for mechanized farming, but the current household contract responsibility system blocks the redistribution of land and thus the introduction of large-scale, more efficient mechanized agriculture. The ultimate consequence of the household contract responsibility

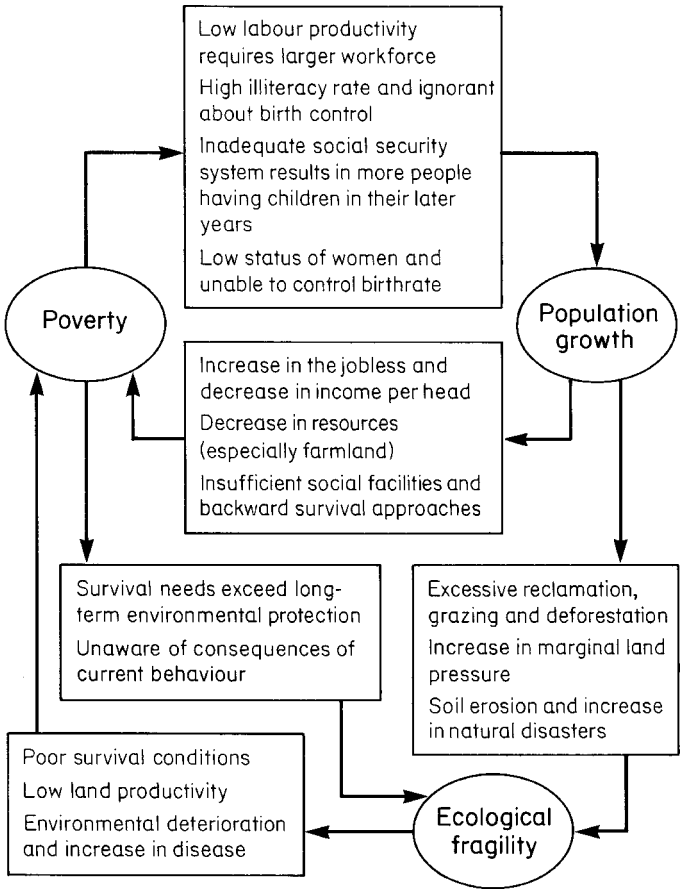

Figure 5. Vicious cycle: poverty–population growth–ecological fragility.
Source: based on Liu and Li, 2001.

system is to obstruct the transfer of labour from agriculture to other industries, or from agricultural regions to non-agricultural regions. Labour mobility is essential if poverty-stricken regions are to be developed and incomes increased.

The household contract responsibility system is clearly no longer suitable for large-scale socialized production because it blocks labour movement and land circulation. It is this which is mainly responsible for the poverty of farmers and consequently the deteriorating environment.

Poverty and the uneducated population

In west Jilin province, most counties are among the poorest in China, with annual per capita incomes of less than RMB1,700. Moreover, the whole of poverty-stricken west Jilin has been caught up in the vicious cycle of poverty, population growth and a fragile environment (Figure 5).

Poverty always leads to a poor social security system, high illiteracy, low labour productivity and finally population growth. In west Jilin there is no social security system for farmers' later years. A commonly held view is that parents must have as many children as possible, especially male children, to support them in their old age. Boys are particularly important because they become part of the workforce and contribute to standards of living. As a result, the population in Jilin province increased from 1.5 million to 3.7 million between 1949 and 1980. At the end of the 1970s, a family planning policy was established for the whole nation, yet the total population has still increased rapidly. By 2000, west Jilin had a total population of 4.71 million, 69% of which was agriculture-based. Fourteen per cent of these people are illiterate or semi-illiterate, and only 0.20% have received higher education.

High rates of illiteracy among agricultural populations prevent the widespread adoption of modern agricultural technologies and management techniques. Extensive cultivation, which is entirely dependent on the climate and characterized by animal tillage power and manual procedures, is still the commonest agricultural production system. Arable farmers, therefore, simply reclaim grassland and start planting crops when there is a need to support a larger population. After two or three years, the newly reclaimed land becomes infertile due to overplanting and poor management, and is abandoned. Desertification quickly follows.

Livestock farmers, on the other hand, when faced with the same challenge, raise more livestock, which leads to overgrazing and grassland degradation through desertification and salinization. In addition, poverty fosters the survival of backward practices that seriously damage the environment. For example, in west Jilin, 85% of farmers live in earth houses. These earth houses need great amounts of soil for construction and annual repair. They are easily eroded by rainfall, and solvent salts are transported to, and accumulate in farmland and grassland, leading to grassland degradation, land salinization and desertification.

Figure 6 shows population growth and environmental degradation in 1949 and 2000. The fragile environment, on the other hand, aggravates the poverty of farmers by threatening farmers' survival and health and lowering land productivity.

Management by local governments and the market economy

Short-sighted decision making, poor management and neglect of developing market economies by local governments are also responsible for poverty and fragile agricultural environments. First, over a long period of time, local governments have overlooked basic education,

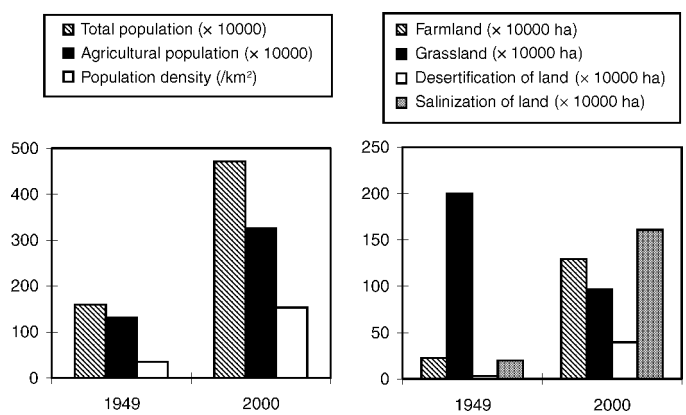

Figure 6. Population growth in 1949 and 2000 (left); land use and land degradation in 1949 and 2000 (right).
Note: Some data are from the *Yearbooks of Jilin Province*.

skills training and basic infrastructure construction, and have placed emphasis only on food production. Under such poor administration, farmers receive no incentive to overcome their illiteracy and incompetence. Furthermore, local governments fail to encourage training and mobility of the labour force even when agriculture is depressed. As a result efficient agriculture becomes impossible, but farmers are unable to transfer from agriculture to other industries, or from west Jilin province to other relatively advanced regions. Second, the government's welfare policy of supporting those who are incapable of supporting themselves might also be questioned as there is then no inducement for the poor to break away from the fetters of poverty. Third, local governments seldom provide business support information for agricultural producers, thereby impeding the marketing of products. Farmers do not know which products are in demand, where the best markets are, or what prices they should ask. In addition, some corruption within governments overburdens the farmers and reduces their incomes. There is also unhelpful government interference, on occasion, in price manipulations to farmers' disadvantage.

Conclusions and some proposals for sustainable agriculture in SAPIB

The SAPIB is an important ecological barrier in North China. It has highly intrinsic vulnerability owing to an unfavourable climate, geological and hydro-geomorphological conditions. Additionally, agricultural production and the health of the whole SAPIB have been impacted severely by frequent natural disasters, land salinization and desertification. Damaging agricultural policies and activities, poverty and other socioeconomic factors have also driven and accelerated the degradation of the SAPIB.

We offer the following suggestions in an attempt to overcome some of these problems and to work towards a sustainable strategy for the region:

- **Modify the 'food first' agricultural policy and industrial structure.** In the SAPIB system, agriculture, (especially arable) is highly vulnerable to climate change, and the irrational use of land amplifies this vulnerability. However, arable production accounts for and encourages a disproportionately large percentage of total production under the 'food first' agricultural policy. Reform of this current agricultural policy is overdue, and the aim should be to reduce the agriculture percentage and increase the share of other industries, thereby improving system stability. Within agriculture, arable production should be decreased and animal husbandry increased. Farmland with low productivity should be returned to woodland or grassland.
- **Free farmers from the bondage of land and transform extensive agricultural practices into eco-nursing intensive agriculture.** Although the system of household contract responsibility, with remuneration linked to output, has made a great contribution to farmers' standards of living, it has now imposed substantial constraints on sustainable development of the SAPIB system because it fetters labour transfer and blocks the adoption of relatively advanced, intensive agriculture. It is proposed, therefore, that the household contract responsibility system should be reformed and that redundant farmers transfer from agriculture to other industries, or from the SAPIB region to more economically advanced areas, thereby improving land redistribution and promoting eco-nursing intensive agriculture. Released land should not be reclaimed, but should return to grassland or woodland.
- **Adopt techniques appropriate for sustainable agriculture.** Proper techniques are the prerequisite and guarantee for sustainable agriculture. All agricultural techniques should be based on the principles of biological symbiosis and multi-level recycling of resources. In the SAPIB of west Jilin, techniques for water-saving (irrigation) agriculture and avoidance of salinization should be a first consideration, possibly through the introduction of various agricultural–ecological engineering models. In addition, treatments for degraded grassland, infertile sandland and salt-laden land are critically needed. Finally, the introduction of improved varieties of crop, pasture and livestock and further processing of agricultural products are to be favoured.
- **Stimulate the construction of towns and infrastructure.** Towns, the centres of rural economies, play important roles in developing enterprises, improving farmers' standards, absorbing superfluous labour and boosting rural market economies. However, most towns in west Jilin are small and there is almost no infrastructure. Such small towns fail to provide appropriate foci for the population, goods and materials. They are also unable to attract outside investment, which inhibits the formation of markets, culture and information network systems, perhaps in association with roads and railways.
- **Create a Changchun–Songyuan–Baicheng–Haerbing economic axis belt and reinforce regional economic cooperation.** Changchun city and Haerbing city are the capitals and economic centres of Jilin and Heilongjiang provinces respectively. These two capital cities lie to the east and north of the SAPIB of west Jilin. Songyuan city and Baichen city to the west and east respectively are the biggest cities in the SAPIB. There is a railway connecting these four cities. It is proposed to create a Changchun–Songyuan–Baicheng–Haerbing economic axis belt, through which products, technology, labour, capital and other socioeconomic facilities may be contained but allowed to influence and trade with neighbouring regions. Furthermore, it is proposed to develop preferential policies to attract capital, human talent and projects to stimulate cooperation with other relatively advanced areas.
- **Create systems for the rational use of water.** Water shortage has long been a constraint on sustainable agriculture in west Jilin province. The rational use of limited water resources directly determines the success of sustainable agriculture. It is proposed to develop widespread rainfall collection projects, scientifically to demonstrate the feasibility and scale of river-capture projects, to use flooding as an important water resource and to construct flood protection zones such as flood plains to store water for crops during dry seasons.

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