# Chapter 9
# Ecological and Environmental Impact

**Abstract** In this chapter we review the ecological impact of the Grain for Green. Because the Grain for Green is primarily a reforestation and ecological restoration program, the success or failure of the Grain for Green depends in large part on its ecological impact. Its ecological impact can be assessed using such indicators as the amount of land converted and afforested, changes in vegetative cover, water surface runoff and, very importantly, soil characteristics. Unfortunately there is no nation-wide assessment of the ecological impact of the Grain for Green, so it can only be gauged from case studies in selected regions. Most studies concur that the physical properties of the soil, including soil fertility, porosity, and nutrients, have improved, and soil erosion and river sedimentation have slowed down. However, most researchers agree that the impact of the Grain for Green in arid areas has not always been positive, given its emphasis on trees, rather than shrub or grass. Another important environmental impact of the Grain for Green is that of the amount of carbon sequestered by soil and trees. Unlike for the ecological impact on vegetation, water and soil, there are province- and nation-wide studies done on the impact of the Grain for Green on carbon sequestration.

**Keywords** Ecological impact • Soil fertility • Soil porosity • Soil nutrients • Soil erosion • Sedimentation • Water balance • Water runoff • Carbon sequestration

## Introduction

Because the Grain for Green is primarily a reforestation and ecological restoration program, the success or failure of the GfG depends in part on its ecological impact. Its ecological impact can be assessed using indicators that are immediately observable, such as the amount of land converted and afforested, changes in vegetative cover, water surface runoff and, very importantly, soil erosion (Table 9.1). Based on these indicators, most researchers agree that the program has been successful (except, according to many researchers, in the arid northern region), even though unfortunately there is no nation-wide assessment of the ecological impact of the GfG, so it can only be gauged from case studies in selected regions. In the following pages we review case studies carried out in Guizhou, Hubei, Shaanxi, Gansu and Hunan Provinces. These studies concur that the physical properties of the soil,

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**Table 9.1** Indicators of ecological changes through GfG-led vegetation restoration

| | |
|---|---|
| Conservation of water resources | Vegetation coverage |
| | Annual runoff coefficient |
| | Land water storage |
| | Area ratio of the soil erosion |
| Conservation of soil and water | Soil erosion modulus |
| Soil amelioration | Soil bulk density |
| | Soil porosity |
| | Amount of organic matters |

Source: Yang (2005)

including soil fertility, porosity, and nutrients, have improved, and soil erosion and river sedimentation have slowed down. However, most researchers agree that the impact of the GfG in arid areas has not always been positive, given its emphasis on trees, rather than shrub or grass. Another important environmental impact of the GfG is that of the amount of carbon sequestered by soil and trees. Unlike the ecological impact on vegetation, water and soil, there are province- and nation-wide studies done on the impact of the GfG on carbon sequestration. The first part of this chapter looks at soil fertility and the conservation of water resources, as well as the impact of the GfG on soil erosion in arid areas. The second part of the chapter looks at the changes in carbon sequestration brought about by the GfG.

## Conservation of Soil and Water Resources

### *Soil Characteristics, Soil Erosion and Water Runoff*

Luo et al. (2003) examined changes in Boluo Village of Qingzhen Town (Guizhou Province) over 3 years. The study area is influenced by a humid subtropical monsoon climate and has an annual temperature of between 14 °C and 16 °C. The annual precipitation is 1,100–1,200 mm. In total 50 soil samples were collected from land with 15°, 25° and 35° slope, with and without GfG reforestation. Not surprisingly, the researchers observed that runoff became more severe when the degree of land slope increased. Reforestation reduced the loss of soil nutrients due to runoff, and let to a recovery of soil fertility: organic matter, nitrogen (N), phosphorus (P) and potassium (K) all increased after the GfG was implemented, although there was no significant change in the pH value (Table 9.2). Also, the permeability coefficient of saturated soils increased soil hold capacity by 1.66 times after reforestation, compared to the soil with no reforestation (Table 9.3).

Although satisfactory effects were observed and tested in soil conservation, Mei and Xiong (2003) questioned the performance of the GfG in water conservation. Luo et al. (2006) studied the physical properties of the soil on which four different species were planted through the GfG: *Triploid Chinese white poplar*, *Alnus cremastogyne*, *Cunninghamia lanceolata*, and *Hybrid Bamboo*. The ability to conserve

**Table 9.2** Amount of Yellow Soil Nutrients with and without the GfG

| Land use | | pH | Organic Matter (k/kg) | N (k/kg) | P (mg/kg) | K (mg/kg) |
|---|---|---|---|---|---|---|
| Without GfG | Average | 5.46 | 24.76 | 1.42 | 618.5 | 105 |
| (n = 10) | Std | 0.87 | 13.83 | 0.73 | 165.8 | 41.2 |
| With GfG | Average | 5.38 | 26.46 | 1.62 | 725.8 | 110 |
| (n = 13) | Std | 0.79 | 12.05 | 0.68 | 185.6 | 32.5 |

Source: Luo et al. (2003)

**Table 9.3** Permeability test of Yellow Soil

| Land use | Soil Moisture (%) | Saturated Soil Moisture (%) | Permeability Rate (mm/min) | Permeability Coefficient $K_{10°C}$ |
|---|---|---|---|---|
| Without GfG | 7.25 | 29.62 | 7.93 | 5.63 |
| With GfG | 11.47 | 38.425 | 11.49 | 9.34 |

Source: Luo et al. (2003)

water is reflected in the physical properties of the soil, in particular soil porosity. Luo et al. (2006) conducted their study in Tianquan County of Sichuan province and collected soil samples each July from 2002 to 2005. In Tianquan County, the annual mean temperature is 15.1 °C and annual precipitation is 1,735.6 mm. The physical properties of the soil are an important indicator of soil fertility. *Alnus cremastogyne* had the smallest annual non-capillary porosity but the average value of lower soil layers (20–40 cm) already reached 16 %. The largest annual non-capillary porosity was found for *Cunninghamia lanceolata* and its average value of upper soil layer is as much as 61 %. The average capillary porosity of the four vegetation types is 40.43 %. The findings suggest that all four species assessed by Luo et al. (2006) were transforming the porosity of the soil from capillary porosity to non-capillary porosity, an indicator of improving soil fertility. Similar trends were also observed in the maximum and minimum moisture capacity.

Pan et al. (2006) looked at the same issue in Zigui County (Hubei Province) which joined the GfG in 2000. Zigui County has an area of 2,472 km$^2$ and a population of 398,000. It has a subtropical continental monsoon climate with an annual average temperature of 18 °C and annual precipitation of 1,100 mm. In 1999, 126,000 hm$^2$ were affected by soil erosion (52 % of the total land area) according to statistics from the local government. The study lasted from 2000 to 2005 and investigated the impact of ten different species (Table 9.4). Apart from the physical properties of the soil, the study also assessed the water holding capacity of the soil. Pan et al. (2006) found that total and non-capillary soil water storage increased by 42.5 % and 221.4 % respectively (Table 9.4 shows the extent to which the species introduced improved the non-capillary water storage capacity of the soil). Pan et al. (2006) concluded that such an important improvement in the ability of the soil to hold water help reverse desertification.

**Table 9.4** Frequency and index of water holding capacity of soil of different conversion type of the ten most common species introduced by the GfG in Zigui County (Hubei Province)

| | Converted Area (hm$^2$) | Proportion of total converted area (%) | Total porosity | Non-capillary porosity | Total soil water storage | Non-capillary soil water storage |
|---|---|---|---|---|---|---|
| Large tangerine (Amorpha) | 2,904.5 | 22.4 | 46.3 | 2.40 | 3,700.1 | 184.3 |
| Black Locust | 1,957.8 | 15.1 | 44.8 | 2.50 | 2,688.1 | 150.1 |
| Chestnuts | 1,831.8 | 14.1 | 48.8 | 1.1 | 1,952.4 | 44.2 |
| Walnuts | 1,678.8 | 13.0 | 44.9 | 1.75 | 2,694.3 | 105.1 |
| Amorpha | 487.7 | 3.8 | 50.8 | 3.2 | 2,032.2 | 128.1 |
| Cypress(Amorpha) | 73.2 | 0.6 | 44.9 | 0.4 | 1,796.0 | 16.0 |
| Fir | 69.7 | 0.5 | 44.1 | 1.8 | 3,087.0 | 126.4 |
| Bamboo | 42.6 | 0.3 | 50.8 | 6.12 | 2,539.4 | 306.0 |
| Oak tree | 7.4 | 0.1 | 45.5 | 4.8 | 1,820.3 | 192.2 |
| Masson pine | 6.6 | 0.1 | 44.7 | 1.8 | 1,788.1 | 72.0 |
| Cropland | | | 42.3 | 1.03 | 1,691.2 | 41.2 |

Source: Pan et al. (2006)

**Table 9.5** Analysis of the influence on sediment production 2001–2002

| Year | Study Area | Annual Surface Runoff (m$^3$) | Sediment Yield (kg/100 m$^2$) | Soil Erosion Modulus (t/km$^2$/year) |
|---|---|---|---|---|
| 2001 | Pai Li Po | 14.56 | 75.53 | 755.3 |
| | Lao Ma Yuan | 14.56 | 110.2 | 1,102 |
| | Shui Jing Po | 14.56 | 96.8 | 968 |
| 2002 | Pai Li Po | 21.33 | 7.84 | 78.4 |
| | Lao Ma Yuan | 21.33 | 17.38 | 173.8 |
| | Shui Jing Po | 21.33 | 18.57 | 186.7 |

Source: Mei and Xiong (2003)

Similar positive results were found at a site in Shaanxi Province. In the Chaigou Watershed of Wuqi County, the average soil moisture and moisture-holding capacity in GfG plots after 5 years was 48 and 55 % greater, respectively, than those in non-GfG plots (Liang et al. 2006; Liu et al. 2002).

Mei and Xiong (2003) expanded such research to 10 villages in Qingzhen Town of Guizhou Province, where the GfG had converted a total area of 56.26 km$^2$ (84,390 mu) between 2000 and 2002. Mei and Xiong (2003) followed the national standards for soil and water conservation testing (SD239-87) to assess the ecological impact of the GfG. The GfG successfully conserved the soil (Table 9.5), especially when *Pennisetum hydridum* and *Silphium perfoliatum L.* were planted. In the study area, the soil erosion modulus dropped from 2,500–5,000 t/km$^2$/year in 2000 to 78.4–185.7 t/km$^2$/year in 2002, equal to a drop of 38,563.6 t of surface soil loss annually.

Yang et al. (2006) analyzed the effect of soil and water conservation on cropland that returned to forest in Wuqi county (northern Shaanxi Province) through field

**Table 9.6** Annual soil erosion moduli (t/km$^2$/year)

| Year | Vegetation coverage (%) | Erosion modulus |
|---|---|---|
| 1997 | 19.2 | 15,280.2 |
| 2000 | 36.5 | 11,478.8 |
| 2002 | 49.6 | 8,800.7 |
| 2004 | 69.8 | 5,865.1 |

Source: Yang et al. (2006)

**Table 9.7** Bulk density of soil of different depth before and after the GfG (g/cm$^3$)

| | Before the GfG | | | | After the GfG | | | |
|---|---|---|---|---|---|---|---|---|
| Depth | Trees | Shrubs | Grass | Average | Trees | Shrubs | Grass | Average |
| 0–20 cm | 1.45 | 1.40 | 1.42 | 1.42 | 1.30 | 1.27 | 1.38 | 1.32 |
| 20–40 cm | 1.43 | 1.45 | 1.49 | 1.46 | 1.30 | 1.32 | 1.29 | 1.30 |
| 40–60 cm | 1.38 | 1.47 | 1.48 | 1.33 | 1.21 | 1.31 | 1.27 | 1.26 |
| 60–80 cm | 1.46 | 1.48 | 1.53 | 1.49 | 1.28 | 1.33 | 1.23 | 1.28 |

Source: Yang et al. (2006)

**Table 9.8** Chemical characteristics before and after the GfG

| | pH | Organic matter (g/kg) | Total nitrogen (g/kg) | Total Potassium (g/kg) | Total Phosphorus (g/kg) |
|---|---|---|---|---|---|
| Before GfG | 8.41 | 5.9 | 0.47 | 21.3 | 1.41 |
| After GfG | 8.20 | 13.8 | 1.32 | 25.2 | 2.20 |

Source: Yang et al. (2006)

observation and experimental studies. The characteristics of the landscape in the northern Shaanxi Province Loess Hills (spurs, ridges, valleys and ravines) together with sparse vegetation coverage and concentrated precipitation, contributed to this area having the most severe soil erosion (erosion modulus 10,000–20,000 t/km$^2$/year) in Shaanxi Province. In Wuqi county, almost 57 % of the land has a slope no less than 25° and the total area of soil erosion was 3,693 km$^2$, making it one of the counties with the greatest soil erosion. The implementation of GfG since 1998, as well as a prohibition of animal grazing, increased the vegetation cover and decreased the erosion modulus (Table 9.6). Both the physical and chemical characteristics of the soils greatly improved after implementation of the GfG, in particular the bulk density of the soil (Table 9.7), and its chemical characteristics (Table 9.8). Yang et al. (2006) concluded that returning cropland to forest and prohibiting grazing in mountainous areas are the most effective approaches to control soil erosion and water loss in the Loessy Hills region.

Yang (2005) also found significant ecological benefits of the GfG in Zhongba Village of Zijui County, Hubei Province (located in the lower section of upper Yangtze River). After the village joined the program in 2000, a total of 132.49 hm$^2$ were afforested or reforested in Zhongba Village, among which 36.37 hm$^2$ were economic forests and 84.79 hm$^2$ were ecological forests. Yang (2005) found that through the GfG, 17,258.8 $m^3$ of water and 11,158.5 $m^2$ of non-forested land were conserved. The runoff on the reforested land was 77.5 %, 85.2 % lower than the runoff on slope cropland, with a runoff coefficient between 0.0195 and 0.0296. Yang (2005) concluded that the GfG program considerably improved water conservation.

Similarly, Wang et al. (2007d) found that in Zigui County (Hubei Province), 3,085 ha of cropland (8.1 % of total cropland in Zigui County) were converted to forest in 2000, lowering soil erosion by 54,900 t a year between 2000 and 2005. Five years after the start of the GfG program, surface runoff was reduced by 75–85 % and soil erosion by 85–96 % on converted plots, compared to steeply-sloping non-GfG plots on which crops were grown.

Another study in Hunan province by Li et al. (2006) also supported earlier findings that the GfG reduces surface runoff and soil erosion. In Hunan Province, between 2000 (when the program began) and 2005, soil erosion declined by 30 %, and surface runoff dropped by approximately 20 %.

### *Impact on Desertification and Soil Erosion*

Ma and Fan (2005) argued that the GfG conversion of farmland to forestland also reduces water consumption because the land no longer needs to be irrigated. They found that 516,000 $m^3$ of water were saved in 2003 through reduced irrigation on 4,300 ha of GfG-converted land in Minqin county (Gansu Province). In that area, desertification dropped not only because of increasing tree cover, but also indirectly because tree stems and leaves can absorb air dust, reduce wind speed on the soil surface by 30–50 %, and increase air humidity 15–25 %.

Another study, however, produced different results. Zhang et al. (2011) examined the landscape-level impact of the GfG in arid environments, and found that the impact of reforestation programs on the water balance is not always positive. The research was carried out between 1998 and 2005 in a northern part of China's Shaanxi Province, where the researchers randomly selected five counties out of the total 25 that participated in the GfG program (Table 9.9). The study area has

**Table 9.9** Changes in the vegetation cover of five counties in Shaanxi Province from 1998 to 2005

| | Total vegetation cover (%) | | | | | |
|---|---|---|---|---|---|---|
| Year | Jingbian | Ansai | Baota | Yanchang | Luochuan | Average |
| 1998 | 19.5 | 22.1 | 28.5 | 21.5 | 56.9 | 29.7 |
| 1999 | 19.6 | 22.7 | 28.4 | 22.9 | 57.2 | 30.1 |
| 2000 | 21.5 | 24 | 29.7 | 24.5 | 58.2 | 31.6 |
| 2001 | 22 | 25.5 | 31.5 | 26.1 | 59.8 | 32.9 |
| 2002 | 23.7 | 27.7 | 34.8 | 28.9 | 62 | 35.4 |
| 2003 | 25.9 | 31.1 | 37.1 | 32.7 | 64.9 | 38.3 |
| 2004 | 26.4 | 33 | 39.4 | 35.9 | 66.5 | 40.3 |
| 2005 | 27.9 | 35.3 | 41 | 38.6 | 67.9 | 42.2 |

Source: Zhang et al. 2011

**Table 9.10** Soil moisture of the abandoned cropland and reforested cropland after conversion

| Length of Year | 0–1 | 1–2 | 2–3 | 3–4 | 4–5 | 5–6 | Average |
|---|---|---|---|---|---|---|---|
| Abandoned cropland percent | 16.6 | 10.48 | 10.27 | 11.42 | 10.05 | 10.04 | 11.48 |
| Reforested cropland percent | 6.14 | 5.99 | 7.49 | 7.54 | 8.13 | 8.10 | 7.23 |

Source: Zhang et al. (2011)

experienced severe soil erosion, of up to 15,000 t/km$^2$ per year. Yellow clay, with a degree of porosity of 52.1 %, is the major soil type in this area, contributing to 75 % of the total. The total vegetation cover in areas covered by the GfG increased from 29.7 % in 1998 to 42.2 % in 2005. However, the survival rate of the forests averaged only 49 % in the seventh year. Further, Zhang et al. (2011) found that abandoned cropland may retain water better than trees planted through reforestation programs (Table 9.10). They concluded that abandoned lands and natural vegetation recovery can retain the water in the soil at the lowest cost. Reforestation can achieve similar results only when the species of plants are carefully selected and the reforested lands are monitored and tested for a considerable period of time. The study concluded that afforestation may remain a valuable tool but should be limited to the planting of native or other species that will not exacerbate soil water shortages. These may include stable communities of natural desert steppes, or dwarf shrubs that maximise water-use efficiency, and possibly even lichen species in more severely degraded environments (Zhang et al. 2011).

In yet another study, Wang et al. (2007c) argued that the conversion of cropland into forestland has been overly emphasized in arid areas, and that it would be better to grow native plants of grass or scrubs. Through a survey of 208 counties in desertification-affected northern China, they found that few areas have water conditions that are suitable for planting trees: 88.3 % of the study area has an arid or semi-arid climate with an annual precipitation of less than 400 mm, which is suitable for grass or scrub growth but unsuitable for forest growth (Wang et al. 2007c). Although some successful cases have been reported, the overall survival rates of planted trees are very low, about 30 % (Jiao 2005), and dropping to only 10 % in some areas (Shen et al. 2003). While Uchida et al. (2005) considered water deficit problems as the most important cause for the low survival rate and slow growth rate of the vegetation, Wang et al. (2007c) argued that the inappropriate choice of tree species, careless planting and inadequate management were equally important. Wang et al. (2007c) argued that large-scale afforestation may also cause potential environmental problems, such as increasing evapotranspiration and intensification of soil erosion, desertification and sandstorms, all of which result in great waste of manpower and money. Compared with planting trees, planting drought-tolerant grasses and scrubs requires much lower investment and are favorable to most of northern China (Wang et al. 2007c).

The findings of Wang et al. (2007c) were further supported by a survey conducted by Zhang et al. (2011). Zhang focused on five randomly selected counties (Jingbian, Ansai, Baota, Yanchang, Luochuan) from the 25 counties in northern Shaanxi

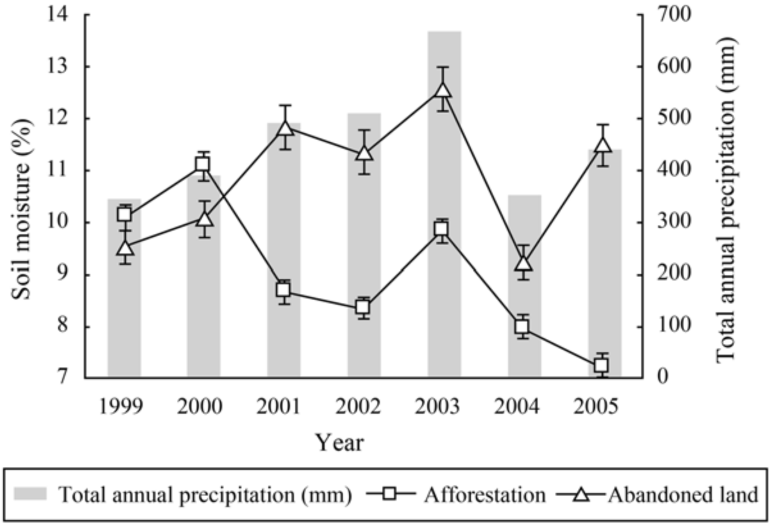

**Fig. 9.1** Changes in total soil moisture (%) at a depth of 6 m during the growing season, 1999 to 2005 (Source: Zhang et al. (2011))

Province that are covered by the GfG. Historically, severe soil erosion has occurred in these areas, at an average rate of approximately 15,000 t per km$^2$ per year. From 1998 to 2005, total annual precipitation averaged 461.7 mm, ranging from 366 mm in Jingbian County to 609.4 mm in Luochuan County (Cao et al. 2009a; Zhang et al. 2011). During the same period, the potential evapotranspiration in the study area averaged 793.7 mm per year, well above average precipitation.

Zhang et al.'s results (2011) suggest that the policies of prohibiting cultivation and grazing in steep terrain were significantly more effective than the afforestation policy. This finding offers a valuable strategy for environmental restoration in similar remote rural regions, both in China and around the world (Zhang et al. 2011). Figure 9.1 summarizes the changes pertaining to soil moisture from 1999 to 2005 (afforestation in the region started in 1998). A linear regression of the total annual precipitation against the soil moisture shows a strong and positive correlation in the abandoned land plots ($R=0.91$, $p<0.01$), but a very weak and nonsignificant correlation in the afforestation plots ($R=0.01$, $p>0.05$) (Fig. 9.1). Although correlation does not imply a causal relationship, the findings could be explained as follows: when grassland is restored using unsuitable tree species, there may be insufficient precipitation to permit a balance between the available soil moisture and the vegetation cover, leading to a risk of declining soil moisture (Zhang et al. 2011). The researchers concluded that large-scale afforestation in this vulnerable arid and semi-arid region could increase the severity of water shortages, decrease vegetation cover in afforestation plots, and adversely affect the number of species present. The exclusion of livestock from overgrazed areas and the elimination of cultivation in marginal areas had the biggest positive effects on the restoration of vegetation cover, whereas tree planting had a strong negative effect in vulnerable areas (Zhang et al. 2011).

## Carbon Sequestration

While studies on the consequences of the GfG on soil recovery and water conservation require extensive fieldwork and therefore are predominantly site specific, studies on carbon sequestration are often done using satellite images and existing international, national and provincial datasets, and do not require fieldwork. For this reason they are often carried out on a much larger scale. In the following section we review two such studies, one done on Yunnan province, the other on the whole of China.

In Yunnan Province, after a pilot phase in 2000–2001, the GfG was implemented in 126 counties, which corresponds to most of the province. Over 95 % of forests established through the GfG in Yunnan Province were ecological forests. The Yunnan Provincial Forestry Department (YPFD) estimated the carbon sequestered through the GfG in the province by using data on the area of tree species planted during 2000–2007 (Chen et al. 2009). The department developed four scenarios for GfG area stands to be planted annually between 2008 and 2010, and options for harvesting the trees. According to technical regulations for ecological forests, these trees may not be cut until they are mature. so, the basic assumption was that planted forests are not harvested until mature. The carbon sequestration potential of these converted forests is expressed as the carbon stock changes in the tree biomass and soil organic matter. The GfG lands, are largely degraded croplands or barren lands that generally have a low initial Soil Organic Carbon (SOC) stock. The YPFD developed empirical growth curves for different tree species, based on data from the National Forestry Inventory on the growth of existing forests in Yunnan Province. These growth curves were then used to estimate the carbon stocks in the tree biomass pools, using basic wood density, biomass expansion factors and carbon fractions. Empirical factors were also introduced to estimate the stock change in SOC under the GfG.

The YPFD found that the GfG would contribute significantly to carbon sequestration in Yunnan Province (Table 9.11), whether the area planted for each species is estimated using Scenario A, which uses the planned goal of reforestation by the GfG, or Scenario B, which uses the average annual area reforested from 2005 to 2007. Scenario A implies that the reforestation (and restoration of the original vegetation) goals of the governmental will be fulfilled, and the planting area (including the area converted to grassland) of the GfG will be up to 1.238 Mha. In this case, the carbon sequestered will be up to 54.128–56.621 TgC by the year 2050 (Chen et al. 2009). Under scenario B, the area planted by the GfG will be up to 1.139 Mha and the carbon sequestered will be up to 49.918–52.083 TgC by the year 2050 (Chen et al. 2009). The carbon sequestered by the seven major tree species accounts for 43.27–50.56 % of the total carbon sequestered through GfG-led land use/land cover changes. By 2050, the total carbon sequestered by the vegetation introduced through the GfG is expected to be up to 10.82–12.27 % of the carbon stocks of

**Table 9.11** Area planted and carbon sequestration of the three most common tree species/species group under the GfG Program in Yunnan Province

| Tree Species | Planted area 2000–2007 (ha) | Carbon Sequestration Potential (TgC) | | | | |
|---|---|---|---|---|---|---|
| | | 2010 | 2020 | 2030 | 2040 | 2050 |
| *Pinus armandii* | 77,369.8 | 0.436–0.442 | 3.505–3.624 | 5.399–5.829 | 5.965–6.468 | 6.175–6.715 |
| *Eucalyptus* spp. | 74,116.1 | 1.172–1.187 | 2.822–3.024 | 3.612–3.905 | 4.127–4.472 | 4.374–4.755 |
| *Pinus yunnanensis* | 65,193.2 | 1.111–1.121 | 2.977–3.166 | 4.151–4.472 | 4.879–5.279 | 5.205–5.655 |

Source: Chen et al. (2009)

forest ecosystems in Yunnan province in the 1990s (Chen et al. 2009). Table 9.11 displays the data for the three most common species.

Using official statistics from the program, Ostwald et al. (2011) estimated the nation-wide amount of carbon that has been sequestered by the GfG. They collected information from forestry statistics at the national and province level and from the scientific literature on the locations of plantations, the physical characteristics of the locations, the species planted, the rate of increment per year, and survival rates. To estimate the carbon sequestration performance of the GfG, they established a baseline of what would plausibly have happened in the absence of the program. Due to the targeted soils' degraded character with high erosion and unsustainable agriculture, the soils were assumed to contain no carbon when the program was initially implemented. Carbon sequestration was then calculated according to three different approaches based on (1) net primary production, (2) figures from IPCC's greenhouse gas inventory guidelines, and (3) mean annual increment. The carbon pools included in the calculation were above and below ground biomass, with the latter at a ratio of 0.26 to the former (Ostwald et al. 2011).

The calculation, done in 2009, revealed that conversion of cropland and barren land over the first ten years generated carbon sequestration ranging from 222 to 468 million tons of carbon (MtC), with the IPCC approach yielding the highest estimate (312 MtC). The other two approaches showed similar results (around 250 MtC). The median of 246 MtC corresponds to 14 % of the carbon emitted in the year 2009. This would mean an annual sequestration range from 22–47 MtC per year, with a median of 25 MtC. If taken on a hectare basis, a carbon content of 11–23 tC per hectare indicates low productivity. Sichuan has the largest amount of carbon sequestered through the GfG-induced land cover/land use change, with 31.7 million tons of carbon, while Tibet has the lowest, with 209,000 t of carbon (Fig. 9.2). Figure 9.2 shows that in most provinces a similar amount of carbon was sequestered through the transformation of barren land and cropland, though slightly more had been sequestered through the transformation of barren land. Ostwald et al. (2011) estimated that nationwide, 53.6 % of the carbon sequestered through the GfG between 1999 and 2008 was on land that had previously been barren, while 46.4 % was on former cropland. Only Xinjiang, Qinghai, Shaanxi, Sichuan and Jilin have larger carbon sequestration through cropland conversion than through barren land conversion (Ostwald et al. 2011).

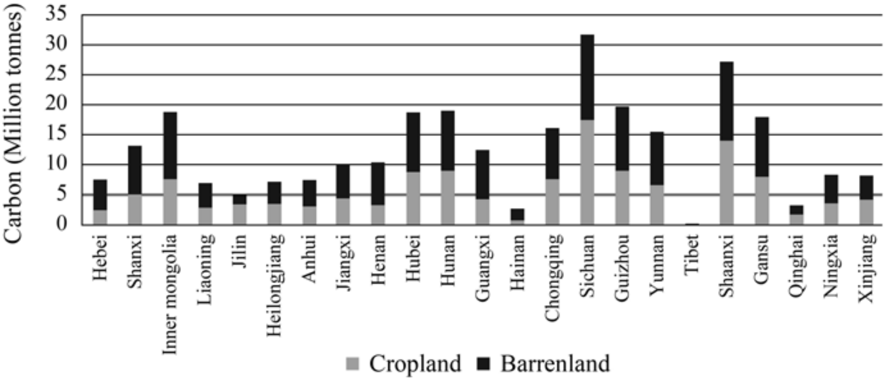

**Fig. 9.2** Average amount of carbon sequestrated by conversion of cropland (46.4 %) and barren land (53.6 %) under the GfG 1999–2008 (Source: Ostwald et al. 2011)

## Conclusions

This chapter has reviewed some of the problems with the GfG, focusing on the conservation and improvement of soil conditions and fertility, conservation of water resources, and carbon sequestration. We have argued that the ecological consequences of the GfG have generally been positive, especially in relation to soil fertility and the improvement of soil conditions. The GfG has also been positive in terms of improving water balance and reducing siltation. However, there is considerable controversy around the consequences of the GfG in arid areas, centered around the choice of planting trees. In these areas, the trees' survival rate is low, evapotranspiration increases and may be higher than the precipitation, and the water table is further reduced. Shrubs and native vegetation may be better choices in these areas. On the other hand, the GfG has contributed considerably to carbon sequestration, especially through planting ecological trees, which may not be cut until mature. While researchers agree that the GfG overall has had a positive ecological impact, broader, nation-wide conclusions are difficult to draw because of the absence of nation-wide studies. Except for carbon sequestration, studies are limited to small case studies, but the extent to which findings may be extrapolated to the rest of the country is questionable, given the diversity of ecological, climatic, and socio-economic conditions in China.