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REVIEW

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Formation causes and recovery of the "Black Soil Type" degraded alpine grassland in Qinghai-Tibetan Plateau

Abstract The formation causes and ecological rebuilding of the "Black Soil Type" degraded alpine grassland are summarized. The formation of the "Black Soil Type" degraded grassland was caused mainly by climate warming, decreasing glaciers, overgrazing, and damage by rats. The ecological restoration of the "Black Soil Type" degraded alpine grassland relies not only on grassland building, but also on reasonable management and planning of grassland resources. Guaranty measures for developing the alpine grassland animal husbandry in a healthy way include intensifying the educational investment in pasture regions, practicing long-term contracts for grassland, and strengthening the grassland legislation. The authors believe that the Qinghai-Tibetan Plateau ecosystem has a special characteristic inertia or "inert gases", which weaken the self-renewing capability of the ecosystem and makes its structure frail. The inertia characteristic may be the important reason that makes ecological rebuilding so difficult; in addition, other problems need to be studied deeply to provide scientific bases for the ecological building in the Qinghai-Tibetan Plateau.

Keywords Qinghai-Tibetan Plateau, headwater area of Yangtze-Yellow Rivers, "Black Soil Type" degraded grassland, inert ecosystem

1 Introduction

Qinghai-Tibetan Plateau, as the trigger region of China (Ding et al., 2003; Feng, 1998), is one of the major animal husbandry bases in China. In recent years, the degraded grassland area has reached about 4.251×10^7 hm^2, accounting for 33% of the available area. The "Black Soil Type" (i.e. "Black Soil Patch") degraded grassland covers an area of approximately 7.0319×10^6 hm^2, accounting for 16%–54% of the total degraded grassland. Most of the degraded grassland is created in the headwater areas of the Yangtze and Yellow Rivers of the Qinghai-Tibetan Plateau, which is well known as the "water tower" of China (Ma et al., 2002). The "Black Soil Type" degraded grassland is subordinate to bare land which is formed by severely degraded alpine meadow whose dominant species is from the genera of *Kobresia*. It is also an island nature scene formed by the deterioration of the native plants. The bare soil is black, so we called it "Black Soil Type" degraded grassland (Ma and Lang, 1999). It has also been called "Black Soil Patch", "Black Soil Slope", and "Black Soil Hill". The "Black Soil Type" degraded grassland is a recapitulative name which does not have any genetic meaning (Li, 2002). It often appears at the foot of sunny slopes of mountains and at the bottomland behind mountains. In recent years, it has expanded to hillsides and hilltops in local areas, which obviously have the characteristic of section range (Ma et al., 1999). The ecological environment of the headwater areas of Yangtze-Yellow Rivers has been increasingly deteriorated by the expansion of the "Black Soil Type" degraded grassland, intimidating the environment of humans and livestock and disturbing the sustainable development of the grassland animal husbandry (Zhou, 2001). At present, the difficult problems faced in recovering the ecological environment are the accelerating degradation, the deepest harm from the degraded grassland, and the difficulty of its control.

2 Reasons for "Black Soil Type" degraded grassland

2.1 Changes in climate and glacier

The "Black Soil Type" degraded grassland of Qinghai-Tibet Plateau is mainly seen in the headwater areas of Yangtze-Yellow Rivers (Zhang et al., 1998). This indicates that alpine meadow with a special ecological location could be degraded into "Black Soil Type" and is associated with the climate of the special ecological location and the geological variance.

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According to a study on the change of the Qinghai-Tibetan Plateau's climate and hydrology, over the past 40 years, the changes lie in the higher temperature and the higher precipitation. The increased precipitation has occurred mainly in the spring and winter during the past 15 years. The precipitation in summer has tended to decrease and has deeply affected the growth of plants. It is the hottest area in the Qinghai-Tibetan Plateau and has one of the largest ranges of temperature increase. The annual mean air temperature in the headwater areas of Yangtze-Yellow Rivers has risen by 0.44°C; the biggest change in the Qinghai-Tibetan Plateau area. However, in April, May and September, the air temperature decreases. The frail ecosystems are sensitive to climate changes. Decreasing glaciers and melting frozen soil have caused most of the alpine meadow and grassland degradation (Ding, 1996; Wang et al., 2001a; Sun, 1996; Tang et al., 1998; Yang et al., 2004; Yang and Jia, 2003). In the next 100 years, the temperature of Qinghai-Tibetan Plateau will increase by 3°C; both the glacier area in the headwater areas of Yangtze-Yellow Rivers and the proportion between glacier and water will also decrease. As the glacier area shrinks and the evaporation in meadows and marshes increase, most of the lakes will run dry, the runoff of rivers will be reduced, swampland will be degraded, while the desert area will expand, and grasslands will be further degraded. These problems could be even more severe (Wang et al., 2001a; Shen et al., 2002; Xu et al., 2003; Johns et al., 1997). Some scholars believe that the local drying and climate warming lead to the melting of the frozen soil. It is the main factor for grassland degradation (Wang et al., 2000). The frozen soil of alpine pasture is closely related to the vegetation (Wang and Zhao, 1999; Wang et al., 2001b). The study on frozen soil shows that the frozen soil and the freeze-thaw process are associated with the ecological environment. The frozen soil and the climate not only control the change of the earth's surface structure but also affect the growth of the plants. If the earth's surface conditions are destroyed, and the balance between the frozen soil and the growth of the earth's surface plants is disturbed, the speed of degradation of the grassland will be accelerated (Wu et al., 2003; Cao et al., 2003). The degradation of most of the frozen soil may result in less water content of the soil in the roots. On drier soil surface, most of the precipitation is in solid state, especially in the summer when precipitation is not continuous, so air temperature rises. This does not benefit plant growth and plant breeding, but may cause the degradation of the vegetation in large areas (Wang and Cheng, 2001). The decreasing glacier area is the best evidence that the climate is getting warmer (Li, 1996a; Yang et al., 2003). The long-term effect of the warming climate will make the alpine marsh ecosystem run dry (Qiu and Zhang, 2000) and the native plants will no longer be the climatic climax plants in this area. Their community will be degraded to deflected climax plants community (Zhang et al., 2004; Wang, 2003). It is believed that, although climatic factors lead to native plants having no adaptation to changes in the climate, a new vegetation structure that is adapted to changes in the climate does not form because of the special climatic condition in alpine frigid zone. For example, if "Black Soil Type" degraded, grassland could not form in the headwater areas of the Yangtze-Yellow Rivers, instead, gramineous plants and other plants would substitute for sedge as the dominant species because their numbers had risen (Wang and Cheng, 2001). Therefore, at present, there is no best evidence to prove that the changes in the climate directly resulted in the formation of the "Black Soil Type" degraded grassland, but at least they are the driving factors (Zhang et al., 1998). The headwater areas of the Yangtze-Yellow Rivers are alpine marsh ecosystems; the warming climate has a significant impact on the wetland ecosystem, which inevitably leads to grassland drought and changes in the native vegetation as well (Chen et al., 2002).

2.2 Overgrazing and rat damage

Overgrazing in alpine meadows will deteriorate the structure of the plant community and finally result in the degradation of grasslands (Brockway et al., 2002). Many experiments have shown that the change in the structure of the community was caused by grazing. So overgrazing and unsuitable grazing can lead to the decrease of the regenerative ability of meadow vegetation and the degradation of soil and meadow (Wang et al., 1989; Yang et al., 1989; Zhou, 2001; Su et al., 2004). Long-term grazing may also decrease the biomass of the meadow vegetation and seriously reduce the return of litter to the soil. At the same time, the degradation of meadows can result in the decrease of amination, nitrification, and nitrogen fixation. The decrease of microorganism diversity may lead to the rapid decrease of soil fertility (Li et al., 1989; Zhou, 2001). These factors will weaken the flow of energy and substance circulation in the ecosystem, finally resulting in the disruption of the ecosystem as well as the maladjustment of its function.

Rat damage may accelerate soil degradation and stop the succession of vegetation. The extent of rat damage is significantly correlated to the extent of vegetation breakage (Fan et al., 1989). A report on the degraded grassland in Qinghai-Tibetan Plateau by the American Embassy in 1966 (US Embassy, 1996) revealed that the effect of excessive consumption of biological matter on the meadow was not due to natural climatic factors but to irreversible cultivation of the grassland by the Chinese. This led to severe degradation from the 1960s to the 1970s.[1] A lot of studies about the "Black Soil Patch" degraded grassland indicate that overgrazing not only changes the structure of grassland community, but also changes the soil and its microorganisms and causes the freeze-thaw process in frozen soil, especially in the places with severe overgrazing and rat damage (Li and Huang, 1995; Li

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and Huang, 1996; Huang and Li, 1996). The vegetation destruction by rats results in the damage of the sod layer, poor soil quality and soil looseness. The eroded soil gradually becomes thinned by wind and water in winter, and finally the "Black Soil Patch" is formed. The process of formation of a bald spot is affected by several integrated factors (Liu et al., 1999; Yan et al., 2003; Zhang 1999; Zhang et al., 1998; Li, 2002; Zhou, 1998; Bai et al., 2002). Why did the spot shape first occur in the degraded grassland in this region instead of a wide area? Our study showed that rat damage was an important factor leading to the formation of the bald spot. When a large area of grassland degradation occurred, the bald spot first appeared in the area with severe rat damage, from which "Black Soil Patch" gradually started to spread (Liu et al., 1999; Zhang, 1999; Bai et al., 2002). Therefore, rat damage plays an important role in the formation process of "Black Soil Patch".

The studies on the occurrence of "Black Soil Patch" in grazing areas show that "Black Soil Patch" can also be formed in excessive grazing pastures (Liu et al., 1999; Yan et al., 2003; Bai et al., 2002). So, both overgrazing and rat damage can accelerate the formation of the "Black Soil Patch" in pastures where the climate is warming (Li, 2002; Wang, 2003; Zhou et al., 2003).

2.3 Problems of "inert ecosystem" of alpine meadow in Qinghai-Tibetan Plateau

The degradation of grassland caused by overgrazing and climate changes is a global problem (Li, 2002; Li et al., 2002; Yang and Yang, 2004). The study by Li (2002) showed that "Black Soil Patch" occurred in regions at altitudes of 3 600–4 500 m and the conditions for the formation could not be beyond this range. This is because the reduction of livestock and human activities in higher elevations could not form the "Black Soil Patch" degraded grassland, and lower altitudes did not have the special natural climatic conditions conducive to its formation. Perhaps it is related to the unique ecosystem structure and ecological processes in the region. The low activity of soil nutrients in alpine meadow and its stock reproduction may result in the poor ability of grassland vegetation regeneration (Zhou, 2001). Therefore, it is hard to restore any destroyed ecosystem or "inert ecosystem". Using "inert" to describe the concept of the Qinghai-Tibetan Plateau ecosystem is due to its poor abilities in energy flow, substance circulation, information transfer, self-renewal and so on, in comparison with other ecosystems. Although without direct evidence, in terms of the special natural conditions in Qinghai-Tibetan Plateau alpine grassland ecosystem, it is unquestionable (Xie et al., 2003). In addition, the Qinghai-Tibetan Plateau ecosystem is fragile (Wang and Zheng, 1999). "Inertia" mainly embodies the poor self-renewal capacity of the ecosystem and low dynamic ecosystem while "frailty" means that the ecosystem will be easily damaged. "Inertia" results in low vitality of alpine meadow under special climatic conditions. Vegetative growing season is greatly shortened, which can limit the ability to regulate the ecosystem. Therefore, the overgrazed grassland can hardly be restored, degrading gradually into "Black Soil Patch". However, the specific "inert ecosystem" still needs further studies.

3 Restoration of "Black Soil Type" degraded grassland

From the early 1960s, grassland scientists and technologists have made a lot of hard exploration work in the Guoluo and Yushu areas of Qinghai Province, and have made remarkable achievements in the management of the "Black Soil Type" degraded grassland. The major measures include setting up grassland enclosures (Li, 1992; Li and Dong, 2002; Zhou, 1986), planting artificial or semi-artificial grassland (Li et al., 1993; Li, 1996b; Li and Huang, 1996; Li, 1999; La and Liang, 2000; Peng et al., 1980), reducing grazing grassland, controlling rats, pests and poisonous weeds (Ma and Li, 1999; Wang, 2000), establishing nature reserves (Wang et al., 2001a), as well as, comprehensive management (Ma and Lang, 1998; Wang et al., 1995; Wang and Cheng, 2001). Recently, more mature programs have been developed regarding management practices that were put in use to restore the low and moderately degraded grassland and rebuild the severe "Black Soil Type" degraded grassland. These include prohibition of livestock grazing to encourage growth of the plant community, prevention and elimination of poisonous plants and weeds, addition of fertilizers, and planting of artificial and semi-artificial grassland (Ma et al., 2002; Huo, 1985). A series of appropriate grasses have been bred from propagation experiments such as *Elymus dahurlcus*, *Elymus nutans*, *Elymus sibiricus* and so on (Ma and Lang, 1999; Ma et al., 2002). The grassland needs to be enclosed for two years to encourage the growth of the plant community, followed by rotational grazing in special allotments (Li, 1992; Li and Dong, 2002; Zhou, 1986). Supplementary feeding of grassland animals should be strengthened, while the rodents on grassland should be controlled in the spring (Li, 1999), and the areas where poisonous plants and weeds are seriously spreading should be controlled (Ma et al., 2002). Since "Black Soil Patch" fertilizer is not enough, the artificial grassland in the "Black Soil Patch" should be properly fertilized (Ma et al., 2003). In addition, the function of artificial grassland and semi-artificial grassland depends on grazing management, so we have proposed a suitable grazing management measure in the alpine meadow (Ma and Lang, 1999; Ma et al., 1999). In the ecological construction of integrated grassland, the grassland agricultural system should be established to improve economic efficiency of animal husbandry in the region, to reduce the pressure on natural grassland, and gradually restore the "Black Soil Beach" degraded grassland (Ma and Lang, 1998). Results from domestic studies show that the pace of grassland degrading can be slowed by constructing artificial grassland (Ma et al., 2002; Shen et al., 2001). The

same results have been obtained in foreign countries (Kanda et al., 2002). Therefore, it is effective enough to manage "Black Soil Type" through eliminating rats, establishing artificial grassland, reducing the pressure on grazing and fertilizing. Properly planning and utilizing grassland in the region are the effective measures to prevent "Black Soil Patch" from further spreading (Wang and Cheng, 2001).

Ecosystem restoration measures for the degraded grassland cannot guarantee the grassland's long-term healthy development, so the problem of utilizing and protecting grassland should be fundamentally resolved (Ma et al., 1999; Wang et al., 2001a; Zhou et al., 2003). First, we should establish rational usage rules. For example, practicing a long-term contract system and actively implementing the "Grassland Law", which can not only effectively protect herders' interest but can also spur the herders' initiative and enthusiasm to improve the protection of grassland. Second, we should carry out the overall planning of the grassland, put up the development planning for the protection of the headwater areas of Yangtze-Yellow Rivers and insist on the implementation. In the protected area, rational planning of grassland animal husbandry should be carried out. Local government should intensify the investment in grassland animal husbandry, especially in the infrastructure construction. Third, the State should carry out compulsory education in pastoral areas, particularly in the Qinghai-Tibetan Plateau to raise the levels of the pastoralists' culture so that they would gradually become senior managers of grassland and the final beneficiaries of high-tech grassland management. This is not only the basic measure for national development in the region, but also a long-term measure. We may see the tremendous impact after 50 years of compulsory education on the development in pastoral areas. Therefore, we must carry out special preferential policies in order to ensure the rapid development in these areas.

4 Conclusions

The global degradation of grassland occurs differently in different regions. In headwater areas of Yangtze-Yellow Rivers of Qinghai-Tibetan Plateau, it is represented as "Black Soil Patch", "Black Soil Slope", etc. The climate and other environmental factors influence plants and vegetation (Gong and Wang, 2002); zonal climax vegetation is a product of a long-term development of natural history and modern natural conditions, and its formation and distribution are controlled by the climate (Zhou and Zhang, 1996). Soil is an ultimate factor in "soil-grass-livestock" system. Most researches concerned about soil have attributed factors, but have not deeply studied the measures of soil recovery. Therefore, we should begin with soil rebuilding as quickly as possible, because it takes a very long time to improve soil through vegetation. Some pioneer and appropriate plant species have been bred to improve the degraded grassland by long-term working experience (Ma et al., 2002). Although some scholars have advised enhancing grassland management after the recovery, grassland will still gradually degrade year after year. It is more difficult to recover grassland merely through the native plant species (Li, 1996b), because it is difficult to enhance soil microbial activities, nutrition pool, and the activities of the propagation bank.

The design and implementation in details about ecological restoration should be combined with ecological protection (Peng and Lu, 2003). The planning and implementing of eco-protection sites in headwater areas of Yangtze-Yellow Rivers can provide a good environment for the rehabilitation and reconstruction of degraded grassland in this region (Wang et al., 2001a; Wang et al., 1997; Wu and Yu, 2001). Grassland degradation is only one part of the degradation of the whole grass industry system. An integrated analysis from all the grassland agricultural interfaces and "soil-grass-livestock-socio-economic-demographic" composite system can make the whole system develop in a healthy way. Grassland management is an important guarantee for ensuring the healthy development of the grassland animal husbandry and grassland vegetation. Large-scale artificial grasslands abroad have been constructed for many years, and most artificial grasslands have realized their sustainable development under rational management. Practical experience has demonstrated that rational management is an important guarantee for restoring the "Black Soil Type" degraded grassland (Wytrzens, 1999).

It is so difficult to restore the alpine degraded ecosystem due to the unique "inertia" of Qinghai-Tibetan Plateau grassland. So, the unique "inertia" of alpine meadows should be properly reconstructed or activated in eco-restoration to improve energy flow and material-cycle capabilities of the system, and to further strengthen the recovery of grassland vegetation. There are many problems to be solved, such as the breeding reservoir capacity, effective capacity, nutrition pools, energy supplement, and so on. Present studies have provided a basis for the reconstruction of the "inertia" of Qinghai-Tibetan Plateau alpine grassland (Huang et al., 1996), for example, the initial study of seed storage capacity, propagation bank (Deng et al., 1997; Deng et al., 2001), grassland fertilization (Ma et al., 2003; Zhou et al., 2000), and so on. The inert ecosystem problem of alpine meadow on the Qinghai-Tibetan Plateau needs further experiments and studies. We hope that researches in this field can provide a better theoretical basis and technological support for restoring and reconstructing the damaged ecosystem in the headwater areas of Yangtze-Yellow Rivers in Qinghai-Tibetan Plateau.

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