Ecological Indicators 74 (2017) 198–204

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

The emergy of metabolism in different ecosystems under the same environmental conditions in the agro-pastoral ecotone of northern China

Xiajie Zhai[a,b], Ding Huang[a,b], Shiming Tang[a], Shuiyan Li[a], Jianxin Guo[a], Yuejuan Yang[a], Hongfei Liu[a], Jinsheng Li[a], Kun Wang[a,b,*]

[a] *Institute of Grassland Science, China Agricultural University, Beijing 100093, China*
[b] *GuYuan National Grassland Ecosystem Field Station, Hebei Province 076550, China*

ARTICLE INFO

Article history:
Received 2 June 2016
Received in revised form
16 November 2016
Accepted 17 November 2016
Available online 25 November 2016

Keywords:
Agro-pastoral ecotone
Emergy evaluation
Ecosystem
Grassland
Farmland

ABSTRACT

The sustainability of ecosystem productivity and rules governing ecosystem development are important topics of scientific research. The emergy approach is an effective method for investigating these topics, especially when used to evaluate systems that have developed under the same environmental conditions, such as climate and soil. In this paper, emergy differences between terrestrial ecosystems were studied in Guyuan County, a region representative of the agro-pastoral ecotone in Hebei Province, China. A combination of field tests and a questionnaire survey were carried out between June and August 2015. The ecosystems studied included natural grassland, artificial grassland, field crops and commercial crops. These four ecosystems were further subdivided into a total of ten ecosystems. Natural grassland was divided into free-grazing and mowed ecosystems; artificial grassland consisted of oat, Chinese leymus and corn silage; field crops included naked oats, flax and wheat; and commercial crops consisted of cabbage and potatoes. The results showed that the rain input of 4.78×10^{14} seJ/ha/yr constituted the highest renewable natural resource emergy and that the purchased emergy inputs of the ten ecosystems ranged from 3.53 to 147.67×10^{14} seJ/ha/yr. Natural resource emergy input was the basic power to maintain the ecosystem, and purchased emergy input was the direct cause of the development of the ecosystems. Groundwater was the most important non-renewable purchased energy for the production of economic crops. The emergy investment ratios (EIR) for potatoes (27.81) and cabbage (19.03) were higher than those of the other ecosystems, but mowed and artificial Chinese leymus grassland had the higher emergy self-sufficiency rates (ESR). Natural grassland, artificial Chinese leymus grassland and traditional grain crops had a low environmental load and high sustainability, whereas potatoes and cabbage had a high environmental load and low sustainability. Overall, rain-fed artificial grassland has a high development potential from the perspective of environment and productivity.

1. Introduction

The sustainability of social-ecological systems is an important topic of scientific research (Krausmann et al., 2013; Liu et al., 2015). Land-use/land-cover change (LUCC) is the most direct manifestation of the effects of human activity on Earth's natural ecosystems and serves as a link between human social and economic activities and natural ecological processes (Mooney et al., 2013). The agro-pastoral ecotone in northern China has gradually become fragmented into a variety of ecosystems in an interlocked mosaic pattern in the interface area between nomadic and agrarian cultures (Zhang et al., 2007). LUCC research focuses on the monitoring and simulation of the dynamic land-use change process along with the coupling of human and environmental systems, material cycles, biosphere-atmosphere interactions, surface radioactive forcing and the sustainable utilization of environmental resources (Rindfuss et al., 2004; Meyfroidt et al., 2013; Mooney et al., 2013). The rapid development of the Chinese economy and population growth have been closely associated with excessive consumption of natural resources and severe land deterioration (Brouwer, 2004; Ji and Chen, 2006; Chen and Chen, 2007; Feng et al., 2009). Therefore, the sustainable utilization of environmental or ecological resources for

---

* Corresponding author at: Institute of Grassland Science, China Agricultural University, Beijing 100093, China.
E-mail address: wangkun@cau.edu.cn (K. Wang).

http://dx.doi.org/10.1016/j.ecolind.2016.11.028

agriculture and animal husbandry in China has been a major challenge. Traditionally, agricultural and pastoral research has focused on increasing yields and enhancing the economic efficiency of different production systems (Rydberg and Haden, 2006; Kemp et al., 2013). However, the ecological costs have not been considered sufficiently, thus leading to severe ecological deterioration in the agro-pastoral ecotone in northern China (Zhang et al., 2007). Hence, there is a need for more integrated accounting procedures that consider both the economic and ecological costs when evaluating production systems to provide a balanced view of comparative resource use. Emergy synthesis is an accounting tool that considers both the environmental and economic inputs that are directly or indirectly required by a process to generate a product and it measures real wealth, independent of financial considerations (Odum, 1988; Brown and Ulgiati, 2004; Ulgiati et al., 2007; Ghaley and Porter, 2013; Zhang et al., 2016). The Chinese Academy of Sciences and the Natural Science Foundation of China, the U.S. Environmental Protection Agency, the EU, and the Italian National Agency for New Technologies, Energy and Sustainable Economic Development are pursuing projects to evaluate the assessment capability of emergy (Geng et al., 2013). Many studies have conducted emergy analyses of large regions such as nations (Ulgiati et al., 1994; Wright and Østergård, 2016; Zhang et al., 2016), cities (Zhang et al., 2011), counties (Ma et al., 2014), forests (Li et al., 2014), grassland (Dong et al., 2012, 2014) and crop production systems (Martin et al., 2006; Ghaley and Porter, 2013; Patrizia et al., 2014; Zhang et al., 2016). Databases at all levels are necessary to help emergy become a practical policy-making instrument for sustainable or circular development (Geng et al., 2013). Because previous studies were mainly performed at large spatial scales, there is a lack of experimental research at small spatial scales. Additionally, most studies focused on the development of plant communities (Soliveres et al., 2015), make little use of databases or focus on the emergence of mechanisms and rules governing ecosystem development under the same environmental conditions, such as climate and soil. The aim of this paper is to analyze the emergy differences among systems, find consistencies in input and output between different ecosystems operating under the same environmental conditions, evaluate the sustainability of these ecosystems and present data support for research on ecosystem development and government policy decisions in the agro-pastoral ecotone in China.

2. Materials and methods

2.1. Study site

The research was conducted at the National Field Station for Grassland Ecosystems in Guyuan County (latitude 41°46′N, longitude 115°40′E, elevation 1430 m), Hebei Province, China (Fig. 1). The area has a semi-arid continental monsoon climate with a frost-free period of 80–110 days. The annual (1982–2009) mean precipitation is approximately 430 mm (ranging from 350 to 450 mm), and approximately 80% of the precipitation is concentrated in the growing season between June and September. The annual mean air temperature is 1.4 °C. The minimum monthly mean air temperature is −18.6 °C in January, and the maximum is 21.1 °C in July. *Leymus chinensis* is the dominant species of this grassland, and the soil is Calcic-orthic Aridisol (Wang et al., 2015; Chen et al., 2015). Crops mainly consist of naked oats, flax, wheat and corn silage.

2.2. Experimental design and treatments

Four land-use types, including natural grassland, artificial grassland, field crops and commercial crops, were selected for the study. The natural grassland was divided into free-grazing and mowed grassland ecosystems; the artificial grassland was comprised of three ecosystems: oats, Chinese leymus and corn silage; field crops included naked oats, flax and wheat; the commercial crops considered were cabbage and potatoes; thus, there were ten ecosystems in total. All of the ecosystems have been in stable use for over 5 years.

Field sampling was carried out in August 2015. Aboveground biomass and underground biomass (0–30 cm) were measured using the harvest method. The dry weight of biomass was measured after drying at a temperature of 65 °C for 48 h. Cabbage, potatoes and corn silage were cut into several pieces for drying. From June to July 2015, status questionnaires were given to 5 households for each ecosystem. The questionnaire consisted mainly of questions concerning basic farming metrics such as yield, area, and population; material inputs such as seeds, manure, labor, diesel, iron fencing, electrical power, ground water, nitrogen, phosphorus, potassium, compound fertilizer, pesticides, agricultural films; and economic outputs such as gross income, cost and net income.

2.3. Data statistics and analysis

In emergy synthesis, the system boundary is defined to assess the inputs and outputs of the system studied (Fig. 2). The inputs and outputs crossing the boundary of analysis were inventoried. Local renewable inputs consisted of sun, wind, rain, seeds, manure and labor, and local non-renewable inputs consisted of topsoil loss, groundwater, diesel, iron, electricity, fertilizer, pesticide and agricultural films (Table 1 and 2). Labor input consisted of the various costs incurred between land preparation and harvest. The units given in joules and grams were then multiplied by solar transformity coefficients to convert to units of solar emjoules (seJ). The value of emergy can be obtained using the following equation: Emergy = available energy of an item × transformity (Odum, 1988; Campbell, 2001; Dong et al., 2012). Conversion of the different flows into emergy was done with reference to the geobiosphere emergy baseline of 12E + 24 seJ/year in the latest work (Brown et al., 2016; Campbell, 2016); therefore, we transformed data from other studies to our chosen baseline. For example, data which were relative to the 9.26E + 24 and 15.83E + 24 seJ/year baseline were converted to the 12E + 24 seJ/year by multiplying by a conversion factor of 1.3 and 0.758.

3. Results

3.1. Emergy flows including input, composition and output

Natural resource inputs included local renewable (R) and local non-renewable (N) inputs. Because the sun, wind and rain were co-products of coupled processes, the chemical potential energy input of rain (4.78×10^{14} seJ/ha/yr, Table 1), which constituted the highest emergy flow of the three, was considered to be the entire renewable resource emergy flow to avoid overestimating renewable inputs; the renewable resource emergy flow was considered to be the same for each ecosystem in the study area.

The main categories of purchased emergy and emergy flows into all of the ecosystems are summarized in Tables 2 and 3. Table 3 lists the purchased emergy inputs for each ecosystem and categorizes them as renewable organic emergy (O) or non-renewable industrial purchased emergy (P). Renewable organic emergy includes seeds, manure and labor; non-renewable industrial purchased emergy includes diesel, iron fencing, electrical power, ground water, nitrogen, potassium, compound fertilizer, pesticides and agricultural films. For comparison, all flows were expressed in units of annual solar emergy (seJ) per hectare. There was a significant variance in