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# Cropland disturbance intensity: Plot-scale measurements, multilevel determinants and applications in rural environmental protection

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ABSTRACT

Currently, China is focusing significant efforts to resolve its problems of environmental pollution. For rural environmental protection, it is critical to identify farming practices that pose a negative environmental impact and potential areas with high environmental pollution risk. This study presents a methodology for the development of a novel index, specifically targeted at the assessment of the plot-scale cropland disturbance intensity (CLDI). Different farming practices during each crop management stage that potentially induce both physical and chemical disturbances were systematically evaluated. The rough set method was utilized to avoid subjectivity during weight allocation. Furthermore, an ordered logit model was applied to analyze critical factors that affect CLDI as well as to identify potential areas of rural environmental protection in the mountainous regions of southwestern China. Our results indicate that tillage contributed most to the physical disturbance, and the widespread application of inorganic fertilizers was the main reason for the high level of chemical disturbance. Cropland plots in traditional farming areas received a more intensive physical disturbance. However, for areas where off-farm work is popular and with broad participation in China's Sloping Land Conversion Program, cropland plots suffered from the most intensive chemical disturbance. The model results show that both household and plot level variables significantly influenced the CLDI ($R^2 = 0.65$, $P < 0.01$). At the household level, critical variables that positively affected the CLDI included the scale of the agricultural laborer, cash income, and cultivated land area per agricultural laborer. The intensity of chemical disturbance increased with increasing off-farm work. At the plot level, distance from the household negatively impacted CLDI, while the distance to the nearest forest posed a positive influence. To achieve a reduction of soil erosion and non-point source pollution control in the study area, we suggest to prioritize cropland plots with a distance radius of 150 and 800 m from households, respectively.

## 1. Introduction

Land change science effectively reveals the reciprocal influences between global change and local effects, such as livelihoods, environmental impacts, and ecosystem services (McCusker and Carr, 2006; Song et al., 2015; Tang et al., 2005; Turner et al., 2007). However, most of the published studies still emphasize the quantity over the quality aspect of land use change, such as the land cover change and the land use intensity, respectively (Erb, 2012; Kuemmerle et al., 2013). This is partly due to the better accessibility of the required data, existence of well-defined classification systems, and natural science based approaches can solve the former study more easily (Erb, 2012).

Land use intensity (LUI) studies focused on measuring LUI and related impacting factors. In measuring LUI, scholars either resorted to evaluate a single dimension of agricultural activities or to a multidimensional approach. The former is mainly based on inputs (fertilizer, pesticide, and density of livestock units) (Herzog et al., 2006; Kuehling et al., 2016), outputs (productivity measurement in mass, energy, and monetary value) (Turner and Doolittle, 1978), or some surrogates such as cropping frequency (Shriar, 2000) and yield gap (Lobell et al., 2009). While the later attempts to comprehensively consider inputs, outputs, and system level outcomes in an appropriate way (Erb et al., 2013; Riwthong et al., 2015). The integration of several farming management metrics into a single index is presumed to be a more appropriate way to evaluate LUI (Armengot et al., 2011). However, despite the systematic consideration of agrochemical application (Armengot et al., 2011; Herzog et al., 2006), farming practices with high risks of soil erosion were considered separately (Aziz et al., 2013; Orts et al., 2000;

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Ruysschaert et al., 2007).

To reveal the impacting factors of LUI, results typically differed greatly due to differences of study objects and variations in research scales. Regional biophysical conditions such as infrastructure and climate are typically considered as impacting factors at the macro-scale (Kuehling et al., 2016). For landscape and household scale studies, impacting factors such as crop types, family asset structures, and education levels of family members have mainly been considered (Hao et al., 2015; Lu et al., 2012). However, most micro-scale LUI studies homogenized farming practices on cropland plots that belonging to the same household; however, this approach cannot reflect the LUI discrepancies among cropland plots due to the heterogeneity of their biophysical conditions and the different management behaviors of farmers. Such discrepancies should not be ignored, particularly in the mountainous areas of China. In rural China, the cropland assignment strategy follows the principle of the collocation of cropland plots with both combined cropland location and soil quality (Zhao, 2011), which resulted in extremely dispersed cropland plots for each household.

Currently, China is vigorously advocating green development, and making great efforts to promote environmental protection, to ensure the reconstruction of lucid waters and lush mountains. China has vast mountainous rural areas, and the situation of environmental pollution in rural China is severe (Xi et al., 2015). Soil erosion and non-point source pollution are considered as important agro-environmental issues that not only threat the quality of local cropland and drinking water, but have also off-site impacts on sedimentation and surface water pollution (Huang et al., 2013; Prosdocimi et al., 2016). However, the limited funds in combination with the vast target areas make the identification of farming practices with negative environmental impacts and potential areas with high environmental pollution risks critical.

To compensate for the existing defects in current land change science and LUI studies, we focused on describing the quality aspect of land use change from the perspective of human disturbance. For cropland, this aspect can be simplified as the extent of human disturbances inflicted on cropland plots during each individual farming management stage.

The objective of this study was to present a methodology that comprehensively measures cropland disturbance intensity (CLDI) at the plot-scale. Farming practices during each individual crop management stage that may either induce physical or chemical disturbances on cropland were fully considered. This study furthermore analyzed the determinants of CLDI at both the household and the plot level. Based on these results, we explored rural environmental conservation approaches in the mountainous areas of southwestern China.

## 2. Materials and methods

### 2.1. Study areas

Data were collected in three catchments of the Baoxing county, Sichuan province, China (Fig. 1). Baoxing is located at 102°28′–103°02′ E and 30°09′–30°56′ N, occupyies 3144 $km^2$, and comprises three rivers: the Xi River, the Dong River, and the Baoxing River. Mountainous terrain dominates Baoxing county (99.7% of the county area), forming a relative height difference of 4567 m. The weather conditions of Baoxing belong to the subtropical monsoon climate zone, resulting in annual temperatures of 14 °C with average annual precipitations of 950 mm. By the end of 2014, the population density of Baoxing reached about 19 per square kilometer, and the real GDP per capita was 5667 dollars (Sichuan Provincial bureau of statistics of China, 2014).

Cropland in Baoxing is mainly composed with rain-fed dry land, and paddy fields are rare. The dominant food crop in this region is spring maize (*Zea mays* L.), which is commonly grown as a sole crop. Some farmers are accustomed to intercrop it with either sweet potato (*Ipomoea batatas*) or white kidney beans (*Phaseolus vulgaris* Linn.). Cash crops produced in Baoxing are favored as ingredients for numerous traditional Chinese medicinal remedies (such as *Saussurea costus* and *Achyranthes bidentata* Blume).

Baoxing is one of the most important habitats for the panda in China, and it is one of the world's 25 biodiversity hotspots (Myers et al., 2000). Consequently, the environmental quality is critical and the work of rural environmental renovation faces many challenges.

### 2.2. Data collection

The arable land in the three catchments was divided into individual plots at 100 × 100 m. Marginal plots with an area of less than one third of the plot area (< 0.3 ha) were removed. The target plots were selected via the stratified random sampling method with a total sample size of 80, occupying 10.4% of the total plots in all three catchments. A more detailed description of catchment selection and plot sampling can be found in Appendix S1 of the Supplementary Material.

Data were collected during July 2015 via field surveys and household interviews using structured questionnaires. The plot survey was conducted with the assistance of local village cadres. Biophysical conditions of the cropland plot (e.g. plot area, slope, soil depth, distance from the nearest forest, and distance from the plot to the household) were recorded. Input and output information of each crop management stage during the last crop rotation were assessed. In this study, one crop rotation referred to a length of one year; however, without using an exact starting or ending time point due to different crops. For long crop rotations longer than one year, we only collected the information during the last year. If the plot has been fallowed or converted to forest, the reasons for this change have also been recorded.

For household interviewing, we designed our questionnaire with reference to the Sustainable Livelihoods Framework (DFID and U.K., 1999), designing it to understand how household level factors affect CLDI. The following information has been included in the questionnaire: possession of different kinds of livelihood assets, off-farm work, consumption, cash income, animal production, and agricultural production. For the analysis in this study, only a subset of the variables was used. Data were collected via face-to-face interviews with householders or farmers, and this process took about 2–3 h. We also informally interviewed numerous village cadres and hosts of local crop hospitals to retrieve information, which enabled us to verify the data collected from household interviews. Valid questionnaires (n = 76) had an effective rate of 95%.

### 2.3. CLDI index calculation

#### 2.3.1. CLDI indicators

For plot-scale CLDI measurement, we systematically considered farming practices that exerted cropland disturbance during the whole crop management stages. Since irrigation is rarely performed in the study area, the influence of irrigation disturbance has not been considered here. The CLDI was discerned as either physical disturbance (PD) or chemical disturbance (CD), based on the different disturbance modes and disparate environmental effects. PD involves direct disturbance of cropland and mainly causes soil erosion, whereas CD refers to agrochemical application with severe non-point source pollution. Nine farming practices, involving six crop management stages, were screened as CLDI indicators (Table 1).

Measurement of the screened indicators and their relative importance to the related CLDI indices require the use of the Delphi method (Okoli and Pawlowski, 2004). We invited 16 experts of the following three local government agencies, including the land and resources bureau, the water bureau, and the environmental protection bureau to assist with the assessment. Each marking table lists two levels of indicators, where the first level is composed of the nine screened indicators, while the second level is composed of sub-indicators for ease of quantification.

Data were cross-checked for consistency prior to normalization.

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