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# Assessing the effectiveness of split fertilization and cover crop cultivation in order to conserve soil and water resources and improve crop productivity

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## ABSTRACT

Intensive agricultural practices implemented to secure increased crop yields have potentially negative environmental effects due to the generation of sediment and nutrients from agricultural fields. The monsoon climate and current agricultural practices on mountainous landscapes of the Haean catchment in South Korea have significantly affected water quality by transporting sediment and nutrients to downstream water bodies. The aim of this study is to suggest strategies for a permanent reduction of sediment and nitrate from this catchment through an efficient application of best management practices (BMPs). We applied three BMPs; split fertilizer application (SF), winter cover crop cultivation (CC), and a combination of the two (SFCC) to major dryland crops (cabbage, potato, radish and soybean) in order to investigate their effectiveness at the catchment scale through the Soil and Water Assessment Tool (SWAT) model. We found that the SF scenario reduced nitrate pollution while sediment and crop yield did not change relative to the baseline (BL) scenario. The application of the CC scenario reduces both sediment and nitrate load while crop yields increased. The combination of split fertilization and cover cropping (SFCC) showed the highest positive effect on reducing sediment and nitrate and increasing crop yields compared to a single application. We estimated the variability in the effectiveness of BMPs for major crop types and could demonstrate that specific sites and crop types, such as soybean, were less influential in reducing sediment and nitrate loads. Those sites and crops could be considered for additional BMP measures to mitigate water deterioration by target pollutants. Recommendations for BMP applications should also consider minor crops and other land use types in order to reduce overall water pollution and efficiently improve crop yields in this catchment.

## 1. Introduction

In recent decades, agricultural production has been intensified to meet the food demand of a growing population. Worldwide, the intensification of agricultural production is consistent with negative environmental impacts, including deterioration of water and soil resources (Lal, 2008; Matson et al., 1997; Tilman et al., 2002). Agricultural mismanagement such as over-fertilization, inappropriate pesticide application, over-tillage as well as over-grazing trigger nutrient leaching and soil erosion which can turn agricultural ecosystems into non-productive areas (Scherr and Yadav, 1996). Land degradation and soil losses are threats not only to economic and social welfare by decreasing yields and farmers income, but also ecosystem services such as soil protection, water and nutrient regulation, and water provision (water availability and quality). From a regional perspective, absolute agricultural land degradation was found to be highest in Asia, accounting for 206 million hectares (Oldeman, 1994; Scherr and Yadav, 1996). Meanwhile, the world wide degradation of productive farmland was recognized and a trend reversal by achieving global zero net land degradation by 2030 was postulated by the UN Convention to Com-

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bat Desertification (Stavi and Lal, 2015; UNCCD, 2012). Instead of focusing solely on productivity and profits, sustainable agricultural production should comprehensively integrate biological, chemical, physical, ecological, economic, and social aspects to secure food supply, human welfare, and environmental resources (Lichtfouse et al., 2009). Generally, soil loss rates are up to ten-fold higher (10–100 t $ha^{-1}$ $yr^{-1}$) than soil formation rates on cultivated land (Pimentel et al., 1987). However, the extent of soil erosion does not only depend on management practices but also on natural factors such as climate and topography. The amount and intensity of rainfall events and water infiltration capacity of soils, contributing to the magnitude of surface runoff formation, also determine the vulnerability of soils to water erosion. Cultivated and bare soils on slopes in monsoon-driven regions therefore constitute risk areas for erosion (Morgan, 2005). In some areas, the total amount and the intensity of monsoonal events are predicted to increase under future changing climate conditions (Park et al., 2010). Thus, the vulnerability of soils and the need for management practices to ensure the conservation of agricultural farmland is especially important in areas prone to monsoon conditions.

Moreover, in these regions over-fertilization causes high levels of nitrate and phosphorus leaching through surface flow and percolation into aquatic systems thus deteriorating fresh water resources. Tilman et al. (2002) reported that only 30–50% of the applied nitrogen fertilizer and ~45% of phosphorus fertilizer is taken up by crops. A significant amount of the applied nitrogen and a slightly smaller portion of the applied phosphorus are lost from agricultural fields (Pradhan et al., 2015). The mountainous agricultural landscape in South Korea is characterized by a very high level of chemical fertilization which continuously increased from 230 kg $ha^{-1}$ in 1980 to 450 kg $ha^{-1}$ in the mid 1990s (Shim, 1998). The current management practices for dryland vegetable agriculture amplifies soil erosion and nutrient leaching under the influence of the East-Asian summer monsoon in South Korea (Kettering et al., 2012; Arnhold et al., 2013; Ruidisch et al., 2013a,b).

In order to reduce non-point source pollution, the adaptation of agriculture best management practices (BMPs) have been promoted and encouraged through subsidies in many places worldwide. However, in some areas, policies and incentives to encourage farmers to adapt BMPs are still missing. To maintain productive farmland and to prevent soil and nutrient loss is not only the responsibility of local farmers but also of governmental institutions and local communities. To pave the way for a sustainable agriculture, which ensures appropriate yields as well as environmental benefits, policy makers, watershed managers and farmers need evidence of the effectiveness of such BMPs under local conditions. To cope with this cross-functional task and to assist water resource managers in assessing the impact of management and climate on water supplies and non-point source pollution in watersheds and large river basins, the SWAT model (Soil and Water Assessment Tool) was developed in the early 1990's (Neitsch et al., 2011; Arnold and Fohrer, 2005).

Using the SWAT model, the effectiveness of BMPs such as filter strips, spring litter application, optimal grazing management, terraces, sediment basin features, fertilizer and manure management, and various tillage practices have been analyzed by researchers worldwide (Chiang et al., 2012; Lam et al., 2011; Santhi et al., 2006; Strauch et al., 2013; Tuppad et al., 2010; Ullrich and Volk, 2009). These studies have reported the considerable efficacy of BMPs to reduce non-point pollution (sediment and nutrient load) depending on the respective catchment properties and the extent of applied BMPs and BMPs combinations.

Many studies of BMP implementation are limited to the evaluation of the effectiveness of BMPs to reduce non-point source pollution ranging from the field to watershed level. Very few BMP applications (Amon-Armah et al., 2013) assess the impacts on both crop yield and water quality pollutants (sediment, nitrate). In addition, the effectiveness of BMPs implemented for different crop types is missing from the literature. In the Haean catchment of South Korea, BMPs with focus on tillage and fertilization optimization were proposed based on field measurements and plot scale modeling results (Arnhold et al., 2013; Kettering et al., 2013; Ruidisch et al., 2013a,b). These studies argued that the most effective BMPs in dryland vegetable production are fertilizer optimization with regard to timing and application volume and winter cover crop cultivation to reduce sediment and nutrient loss. We thus hypothesize that the implementation of a cover crop and split fertilizer applications reduces the sediment and nitrate level significantly in comparison to conventional agricultural management practices. In order to evaluate how these recommendations apply to different crops in an effort to decrease sediment and nutrient loss at the catchment level, we use the SWAT model. In our study we aim to:

(i) estimate *crop yields* from the dominant dryland agricultural crops including cabbage, radish, soybean, and potato under current management practices
(ii) quantify *sediment loss* and *nitrate loss* from the area of these specific dryland agricultural crops, as well as for the entire catchment area under current management practices
(iii) estimate *crop yields* and quantify *sediment loss* and *nitrate loss* for the individual crop types and the whole catchment when applying BMPs. In our study BMP scenarios include the implementation of (a) cover crop cultivation after the primary growing season, (b) split fertilization, and (c) the combination of both.
(iv) provide useful *recommendations for farmers and policy makers,* who could redesign agriculture management practices in order to meet both higher crop yields and thus higher farm income as well as environmental benefits through soil and water resource conservation.

## 2. Materials and methods

### 2.1. Study area

The Haean catchment (62.7 $km^2$) is located in the Kangwon Province of South Korea between 38°13′– 38°20′N and 128°5′–128°11′E (Fig. 1). The mountainous catchment is dominated by intensive agriculture, where large amounts of sediment and nutrients are released during monsoonal rainfall and transported downstream into the Soyang reservoir. The Soyang reservoir is the largest reservoir in the country and was constructed in 1973 for multiple purposes including drinking water provision for the inhabitants of Seoul (Kim et al., 2000). The elevation of the Haean catchment ranges from 340 to 1320 m with an average slope of 28% and a maximum slope of 84%. The high mountains surrounding the catchment are covered by deciduous and coniferous forests (56.7%). The hill slopes near the forest edges are dominated by cultivation of annual cash crops, primarily cabbage, potato, radish, and soybean (7.8%), perennial crops such as orchards and ginseng (8.3%), and other dryland crops including maize, pepper, rye, and sunflowers (4.1%). The flat areas in the catchment center are dominated by rice paddies (8.2%). The remaining area is covered by field margins, residential, and fallow lands (14.9%). The soils of the Haean catchment are dominated by Cambisols formed from weathered granite. The dominant soil texture class is loamy sand which accounts for 59.4% of the catchment area, followed by Sand silt with 27.5% and sand and clay with 10.5 and 2.7%, respectively. The yearly maximum and minimum average temperatures were 12.5 and 2.5 °C, respectively, and the average annual precipitation is 1658 mm, based on 13 years weather station records in the Haean