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論 文 内 容 の 要 旨

1. Background and objectives

Afghanistan remains very poor, and the living standards are among the lowest in the world. Almost 80% of the population depends on agricultural activities and 90% of the population lives in rural areas. Agriculture plays an indispensable role in their livelihoods. Although total arable land is 12%, only 6% is cultivated. The climate of the country is arid and semi-arid with cold and relatively rainy in winter and hot summer. Rainfall is infrequent with very low precipitation around 300 mm yr^{-1} annually, but having high rainfall intensity. Afghanistan is suffering from lack of data, information, particularly soil and water conservation plans. Therefore, soil erosion is one of serious problems throughout the country due to the topography of the landscape, arid and semi-arid climates, barren nature of the land and desertification. However, little attention has been paid to address soil erosion problem in the country, particularly in Paktya Province. Hence, this study was conducted to estimate soil erosion through the application of the Universal Soil Loss Equation (USLE) on GIS and to discuss the effective conservation practices. As effective conservation practices, crop management and gypsum mineral ($CaSO_4.2H_2O$) application in agricultural lands were evaluated to reduce sediment concentration in runoff as well as soil erosion in agricultural lands.

2. Current agricultural conditions and constraints

Paktya Province is based on agricultural economic with 61% of the population depending on agricultural activities. About 96% of the population lives in the rural areas. Most of these agriculture-related activities fall within small-scale production systems with only a few farmers being self-sufficient. To identify the current agricultural conditions and constraints, a questionnaire survey was conducted in Dawlatzai Village of Gardez District, Paktya Province. The main problems

that Paktya Province is facing are; soil degradation, deforestation, inadequate of irrigation water, poor extension services and inadequate of agricultural inputs. In addition, based on the survey conducted in the study area, 32% of the farmers responded that soil erosion happens very severely and 50% responded as severely. It means that more than 80% of farmers require proper conservation strategies for holding soil fertility and reducing soil erosion.

3. Estimation of soil erosion based on USLE and GIS

Soil erosion risk mapping was done using empirical model, the Universal Soil Loss Equation (USLE) on ArcGIS platform. The USLE model can be used as predictive tools for assessing soil loss, conservation planning and project planning. Different components of the USLE model were used with mathematical equations. This study identified that the rainfall erosivity factor (R-factor) observed with an installed rainfall gauge for a year at 217.5 MJ mm ha^{-1} h^{-1} yr^{-1} made a good agreement with that calculated at 207.7 MJ mm ha^{-1} h^{-1} yr^{-1} based on the annual amount of rainfall for the Gardez Basin. Also, soil erodibility factor (K-factor) was obtained from the soil classification map of the country. And the K factor ranged from 0.038 to 0.063 t ha h ha^{-1} MJ^{-1} mm^{-1}. The LS factor was calculated from Digital Elevation Model (DEM), LS factor values were in the range from 0 to 176. Crop management factor was calculated based on the national land cover map. Additionally, there are no conservation practices for the study area; hence a conservation practice factor P-factor was assigned 1 in the calculation. The data layers extracted for R, K, LS, C and P factors were multiplied within the raster calculator of ArcGIS spatial analyst tool to generate the soil loss map. Also, the land use map of the study area was prepared and the average annual soil losses from different land uses were determined for recognizing priority areas for application of soil conservation practice.

On the other hand, the USLE model was calibrated by the erosion pin method. The results of the calibration indicated that the observed soil losses with the erosion pin method in the field showed certain agreements with the calculated soil losses based on the USLE model in this study.

4. Conservation strategy by crop management and amending soil with gypsum mineral

Although there are many soil conservation practices, crop management and gypsum application have been focused in this study. Preventing soil erosion with cultivating crops is a common farming practice in agricultural lands. Also, gypsum mineral is an amendment widely accepted in the recent days because of its availability in most regions and relatively low-cost. To evaluate the effectiveness of crop management and gypsum application in reducing sediment concentration in runoff with eliminating soil erosion in agricultural lands, a field experiment was conducted in Dawlatzai Village

using a portable rainfall simulator. Four erosion plots, as gypsum-treated plot, clover cultivated plot, maize cultivated plot and control plot were designed. For the gypsum-treated plot, gypsum at the rate of 5 t ha^{-1} was applied. The experimental results indicated that total soil losses from gypsum-treated, clover and maize cultivated plots were reduced to 33%, 8% and 46% of that from the control, bared plot. Gypsum mineral, slightly increased EC of surface runoff because it is sparingly soluble salt but did not change largely the pH values of surface runoff. So, it was considered that gypsum is not a liming agent and does not neutralize the hydrogen ion in the soil solution. As crop cultivation is not available during the period of insufficient irrigation water in Dawlatzi Village of Gardez District, research interest was focused on gypsum application as an alternative conservation strategy. So, an additional experiment was conducted for discussing more detail about the effects of gypsum application in the laboratory using two different soil textures; one is sandy loam and the other loamy soils. The results showed that reduction in surface runoff by 38.8% was observed for sandy loam soil and 37.0% for loamy soil texture compared to the control. Likewise, infiltration into the soils was increased at 2.3 times for sandy loam and loamy soil textures compared to the control. Consequently, total soil losses from gypsum-treated plots were significantly reduced to 39.7 and 18.1% of the losses from the control for sandy loam and loam soils, respectively. Soil particles were well flocculated in gypsum-treated plot compared to the control. This flocculation phenomenon could have contributed towards the increased infiltration into the soil and the reduced sediment concentration and soil erosion in the gypsum-treated plot.

Accordingly, it was concluded that the conservation practice factor P-factor with gypsum application at 5 t ha^{-1} was in the range from 0.18 to 0.40 based on the field and laboratory experiments.

5. Evaluation of gypsum application as conservation practice factor using USLE with GIS

To determine the effectiveness of gypsum application as a conservation practice in Dawlatzai Village, P-factor was assumed as 0.33 based on the results of the field experiments. The maximum soil losses at 79 t ha^{-1} yr^{-1} from the agricultural lands without any conservation practices decreased to 20 t ha^{-1} yr^{-1} when gypsum application is done as a conservation practice. Accordingly, it was concluded that conservation practice with applying gypsum mineral in agricultural lands in Dawlatzai Village is one of the effective ways for reducing soil erosion.

6. Conclusions and recommendations

According to the results of the questionnaire survey conducted in the initial stage of this study, soil erosion is one of the main agricultural problems in Paktya Province. Therefore, this study dealt with

the estimation of soil erosion through the application of the Universal Soil Loss Equation (USLE) on ArcGIS platform and to discuss the effective conservation practices. Although there are many soil conservation practices being applicable in Paktya Province, crop management and gypsum application have been focused in this study. Preventing soil erosion with cultivating crops is a common farming practice in agricultural lands. Also, gypsum mineral is an amendment widely accepted in the recent days because of its availability in most regions and relatively low-cost. To evaluate the effectiveness of crop management and gypsum application in reducing sediment concentration in runoff with eliminating soil erosion in agricultural lands, a field experiment was conducted in Dawlatzai Village using a portable rainfall simulator. The experimental results indicated that total soil losses from gypsum-treated, clover and maize plots were reduced to 33%, 8% and 46% of that from the control.

As crop cultivation is not available during the period of insufficient irrigation water in Dawlatzi Village of Gardez District, research interest was focused on gypsum application as an alternative conservation strategy. So, an additional experiment was conducted for discussing more about the effects of gypsum application in the laboratory using two different soil textures as sandy loam and loamy soils. The results showed that total soil losses from gypsum-treated were 39.7 and 18.1% of the losses from the control for sandy loam and loam soils, respectively. Soil particles were well flocculated in gypsum-treated plot compared to the control, and it was considered this flocculation contributed to reduce sediment concentration and soil erosion.

Accordingly, the estimated P-factor with gypsum treated at 0.33 was substituted into the Universal Soil Loss Equation (USLE) for re-calculating the maximum soil losses in Dawlatzai Village. The calculated results indicated that the soil losses at 79 t ha^{-1} yr^{-1} from the agricultural lands without any conservation practices changed to 20 t ha^{-1} yr^{-1} when gypsum application is done as a conservation practice.

Consequently, it was concluded that conservation practice with applying gypsum mineral in agricultural lands in Dawlatzai Village is one of the effective ways for reducing soil erosion, especially during the period of insufficient irrigation water. It is suggested and recommended that farmers in Paktya Province apply gypsum mineral on their farmlands for reducing surface runoff and soil loss. Therefore, gypsum mineral application should be adopted as a policy and be provided through agricultural extension services to farmers to enhance their knowledge and skill regarding its benefits and proper application in their agricultural lands for reducing soil erosion.

和文要旨

本研究は，アフガニスタン国パクティア州の土壌劣化地域を対象として，汎用土壌流亡量

予測式 Universal Soil Loss Equation (USLE) に基づき GIS を適用して面的な土壌流亡量の把握と現地で適用できる土壌保全対策について論議したものである。研究初期の段階で，パクティア州ダウラザイ村の現地農家を対象として，農業の現状と課題に関するアンケート調査を実施した結果，土壌侵食に起因した土壌劣化，森林伐採，灌漑水不足，農業普及の未整備，劣悪な農業資材等の問題が明らかとなった。特に土壌侵食に関しては，32%の現地農家が「非常に厳しい」と，50%が「厳しい」と回答し，合わせて 80%以上の現地農家が土壌侵食による土壌劣化を問題視していることから，本研究では土壌侵食の把握と現地で適用できる土壌保全対策について論議を進めることとした。

現地で適用できる土壌保全対策には様々な手立てが考えられたが，作物栽培による土壌植被を検討するとともに，灌漑水が不足し作物を栽培できない期間にも適用可能で現地で容易に入手できる石膏（硫酸カルシウム・2 水和物）添加による土壌保全対策を提案して研究を進めた。ダウラザイ村に設置した畑地圃場試験枠および大学研究室内のモデル試験枠を適用して，土壌侵食の抑制効果を評価した。現地での畑地圃場試験の結果，クローバー栽培では 8.0%にまで，トウモロコシ栽培では 46%にまで，流亡土量を削減できることが示された。また，石膏添加によっても 33.0%にまで流亡土壌を削減できることが実証された。併せて，大学研究室内のモデル試験枠を適用して石膏添加による土壌侵食の抑制効果を詳細に検討した結果，石膏添加によって 18%から 40%にまで流亡土量を削減することに成功した。これは土壌粒子に吸着した Na イオンが Ca イオンに置換して，表面流去水中の懸濁粒子が分散から凝集に変化することに起因したものであると，土壌懸濁水の分散凝集実験からも考察できた。

これらの結果から汎用土壌流亡量予測式に作物管理因子（C 因子）を 0.08 および 0.46，および保全因子（P 因子）を 0.33 として予測式に適用し，パクティア州ダウラザイ村を対象として保全対策前後における土壌流亡量の比較を行った。その結果，保全対策前には最大で 79 t/ha/y であった土壌流亡量は，本研究で扱った保全対策によって 20 t/ha/y 以下に抑えられることが明らかとなった。本研究を通して，無耕作期間の保全対策として，現地で容易に入手できる石膏を施用することで，効果的に圃場で発生する土壌侵食とともに流亡土量を削減できることが定量的に明らかになった。

審 査 報 告 概 要

本研究では，アフガニスタン国パクティア州の土壌劣化地域を対象として，汎用土壌流亡量予測式（USLE）に基づき GIS を適用して面的な土壌流亡量の把握と現地で適用できる土壌保全対策について検討した。先ず作物栽培による土壌植被を検討するとともに，現地で容

易に入手できる石膏添加による土壌保全の効果について,同州ダウラザイ村に設置した圃場試験枠および研究室内のモデル試験枠を適用して評価した。その結果，クローバー栽培では8.0%にまで，トウモロコシ栽培では 45.5%にまで，流亡土量を削減できることを示した。また，乾季には多くの畑地で灌漑水が不足し作物を栽培できないため，乾季にも適用可能な石膏添加による土壌保全対策を提案し，実験的に評価した結果，33.0%にまで流亡土壌を削減できることを実証した。これは土壌粒子に吸着したNaイオンがCaイオンに置換して，懸濁粒子が分散から凝集に変化することに起因したものであると,懸濁粒子の分散凝集実験からも確認した。さらに,これらの結果から汎用土壌流亡量予測式に作物管理因子(0.08,0.46)および保全因子（0.33）を各々適用し，ダウラザイ村を対象として保全対策前後における土壌流亡量の比較を行った。その結果，保全対策前には最大で79 t/ha/yであった土壌流亡量は，本研究で扱った保全対策によって20 t/ha/y以下に抑えられることを明らかにした。

これらの得られた研究成果は,アフガニスタン国の土壌保全技術として適用可能であることなどを評価し，審査員一同は博士（農業工学）の学位を授与する価値があると判断した。