Spatial Analyses of Soil Chemical Properties from a Remodeled Paddy Field as Affected by Wet Land Leveling

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Uniformity and leveled distributions of soil chemicals across paddy fields are critical to manage optimal crop yields, reduce environmental risks and efficiently use water in rice cultivation. In this study, an investigation of spatial distributions on soil chemical properties was conducted to evaluate the effect of land leveling on mitigation of soil chemical property heterogeneity from a remodeled paddy field. The spatial variabilities of chemical properties were analyzed by geostatistical analyses; semivariograms and kriged simulations. The soil samples were taken from a 1 ha paddy field before and after land leveling with sufficient water. The study site was located at Bon-ri site of Dalseong and river sediments were dredged from Nakdong river basins. The sediments were buried into the paddy field after 50 cm of top soils at the paddy field were removed. The top soils were recovered after the sediments were piled up. In order to obtain the most accurate spatial field information, the soil samples were taken at every 5 m by 5 m grid point and total number of samples was 100 before and after land leveling with sufficient water. Soil pH increased from 6.59 to 6.85. Geostatistical analyses showed that chemical distributions had a high spatial dependence within a paddy field. The parameters of semivariogram analysis showed similar trends across the properties except pH comparing results from before and after land leveling. These properties had smaller “sill” values and greater “range” values after land leveling than ones from before land leveling. These results can be interpreted as land leveling induced more homogeneous distributions of soil chemical properties. The homogeneous distributions were confirmed by kriged simulations and distribution maps. As a conclusion, land leveling with sufficient water may induce better managements of fertilizer and water use in rice cultivation at disturbed paddy fields.

Key words: Remodeled paddy field, Semivariogram, Kriging, Spatial heterogeneity

Results of spatial analyses of a soil chemical property; Semivariogram analysis (Top) and kriged maps (bottom) of organic matter (OM) distribution from a remodeled paddy field before land leveling (a) and after land leveling (b).

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Introduction

Soil is where plants or crops are rooted and they draw water and nutrients. Soil properties are heterogeneous across a wide range of scales (Dexter, 2002). Therefore soil properties are distributed spatially heterogeneous in nature. Managing spatial heterogeneity of soil properties, such as chemical properties or fertility is recognized as an important factor to increase crop production and reducing environmental risks (Yasrebi et al., 2009). Crop cultivation under spatially heterogeneous conditions of soil chemical properties can result in decrease of crop yields due to nutrient deficiencies as well as excessive fertilizer application (Redulla et al., 1996). The spatial heterogeneity of soil properties can be quantified by geostatistical analyses.

Geostatistical analyses can provide reliable estimates at unsampled locations provided that the sampling interval resolves the variation at the level of interest (Kerry and Oliver, 2004). Geostatistics has been applied as a means to describe spatial patterns by semivariograms or fractal and to predict unsampled locations by kriging. This method can apply to quantify the interpolation of spatial patterns from point data (semivariogram) and to estimate distribution of properties at the interest scale (kriging) (Western et al., 1998). Semivariogram analysis has been applied to quantify variability of soil physical property distribution, such as porosity or pore structure (Cisloro and Votrabova, 2002; Posadas et al., 2003), soil moisture distribution (Western et al., 1998; Western et al., 2004; Brocca et al., 2007), microbiological property distribution (Goovaaerts, 1998; Matumbu et al., 2014), crop yield distribution (Miller et al., 1987; Green and Erskine, 2004) and soil chemical property distribution (Markus and McBratney, 2001; Yasrebi et al., 2009; Li et al., 2010).

Korean government carried out the four major river restoration project from 2009 to 2011. During this project, river sediments were dredged from the basins of the rivers. These sediments were buried into paddy fields. This project was called the agricultural land remodeling project. In selected paddy field areas, 50 cm of top soils were removed and set aside during the burials of sediments. After the top soils were removed, the sediments from river basins were piled up to 2–3 m. Then the 50 cm of top soils were spread out on top of the sediment burials. As a result, 7,726.9 ha of paddy field areas in Korea were disturbed by this process. Especially, 50 cm of top soils were disturbed seriously and resulted in destruction of soil structure (Chun et al., 2015) and clustering of soil chemical distributions (Sonn et al., 2012). Land preparation for paddy fields requires many practices; ploughing, harrowing, puddling and leveling. In most of arable land preparation, leveling is the final operation. As paddy field surface is flooded, leveling of surface is essential to decrease percolation of water and uniform productivity per unit area (Mihara, 1996). Unlike land leveling on upland surface, land leveling on the surface paddy fields requires sufficient water during the leveling process to easily level the surface of fine texture soils and settle down gravels into subsurface (wet land leveling). Wet land leveling in paddy field is puddling paddy field with standing water of 5–10 cm depth. This wet land leveling of paddy field results in reducing leaching of water or decrease percolation of water, killing the weeds by decomposition, facilitating transplantation of paddy seedlings by making the soil softer and decrease of water and nutrient losses by reduced hydraulic conductivity. Effects of land levelling in paddy fields have been reported as reduction of soil erosion (Mihara, 1996), increase in crop productivity (Osari, 2003) and efficient use of water in rice cultivation (Cabangon and Tuong, 2000). Previous studies of the remodeled paddy fields focused on negative results of soil physical and chemical properties after the remodeling. There is a need to suggest a method which can alleviate these negative effects on the remodeled paddy fields in Korea.

The objectives of this study were to investigate spatial variation of soil chemical properties from the remodeled paddy fields and to find effects of land levelling in spatial variation of soil chemical properties.

Materials and Methods

Sampling site The remodeled paddy field was located in Bon-ri site of Dalseong, Gyeongsangbuk-do, Korea and the sediments were dredged from Nakdong river basins (Fig. 1a). The texture of the top soil was silt loam. Before the remodeling, the soil was classified as the Gyuam series; fine silt, mixed, mesic family of Anthraquic Eutrudepts. The remodeling project was conducted during 2009 and 2011. As explained above, the top soils of the paddy field were removed down to 50 cm and then the river sediments were buried up to 2 m. After piling the sediments, the top soils which were set aside were spread out on the top of the sediment. The soil samples were taken from 2011 to 2012. The first samples were taken after the top soils were recovered and before land leveling (Fig. 1b) in November, 2011. In next April, the paddy field was flooded with 10 cm layer of water for two weeks and moving soil from the higher location to the lower location within the field to achieve even soil surface. The second samples were taken two weeks later after wet land leveling applied on the surface of the paddy field (Fig. 1c). The area of the study site was 1 ha and divided into 5 m by 5m grid units for sampling (Fig. 1a). Soil samples were taken from the surface of every grid unit within the site and total number of samples were 100. Every sample was labeled to keep the location or coordination within the site.

Soil property analyses The soil samples were analyzed for chemical properties; pH, organic matter (OM), available
phosphate (avail. $P_2O_5$), potassium (K), and exchangeable cations (Ca and Mg). The chemical properties were analyzed by “Method of soil and plant analysis” (NIAST, 2000) in National Institute of Crop Science. All the chemical properties were applied to characterize spatial distributions.

**Geostatistics analyses** In this study, spatial variation was defined by semivariogram to quantify variations of soil chemicals across the site. Semivariogram shows the average variance found in comparisons of samples taken at an increasing distance from one another, the lag interval (Goovaerts, 1998). The semivariogram was calculated by

$$r(h) = \frac{1}{2(n-h)} \sum_{i=1}^{n-h} \left| z(x_i + h) - z(x_i) \right|^2$$

(Eq. 1)

Where $r(h)$ is the number of lag pairs at distance interval (m) $h$, $n$ is the number of data, and $z$ is the value of the parameter at location $x_i$ and $x_i + h$. The graph of $r(h)$ versus $h$ is fitted by a mathematical model (e.g. spherical, exponential etc.). With this model, nugget variance, spatial variance and the range can be found (Fig. 2) (Brooker, 1986). The nugget variance $C_0$ is the theoretical variance of two observations at a distance of 0 m. The range $A_0$ is the lag distance, where two points show the highest variance. Points situated at a shorter distance than the range show spatial dependence. The sill $C$ is the maximum variance due to distance ($A_0$) and the difference between sill and nugget variance ($C - C_0$) is the portion of the variance due to spatial effects. $C - C_0$ is zero when there is no spatial structure. The magnitude of spatial dependence was calculated using the index of $C / (C_0 + C)$. As this index approaches 1.0, a greater proportion of the total sample variance is spatially structured (Jackson and Caldwell, 1993). Kriging predictions were performed at each chemical property by using the corresponding semivariogram models. The semivariogram calculation and kriged maps were produced by GS+ (version 5.1.1, Gamma Design Software, Plainwell, Michigan).

**Statistical analyses** Statistical analyses were performed to test differences among average soil chemical properties. F-test and analysis of variance (ANOVA) were applied to all the data at 95% significant level.

**Results and Discussion**

**Descriptive results of land leveling effects on soil chemical properties** Average values of chemical properties did not show significant differences between samples before and after wet land leveling treatment ($p > 0.05$) (Fig. 3 & Table 1). Average values of pH were ranged from 6.59 and...
**Fig. 3.** Histograms and fitted curves for chemical properties from the remodeled paddy field: a. distribution of pH, b. organic matter content (OM), c. available P$_2$O$_5$ (P$_2$O$_5$), d. potassium (K), e. calcium (Ca), and f. magnesium (Mg).

**Table 1.** Characteristics of soil chemical properties before and after land levelling from the remodeled paddy field.

| Property          | Period | Mean     | Min   | Max   | CV    | Skew$^a$ | Kut$^b$ |
|-------------------|--------|----------|-------|-------|-------|----------|---------|
| pH (1:5)          | Before | 6.59 ± 0.18 | 6.00  | 7.00  | 2.73  | -0.51    | 0.07    |
|                   | After  | 6.85 ± 0.15 | 6.22  | 7.23  | 2.18  | -0.38    | 2.31    |
| OM (g·kg$^{-1}$)  | Before | 13.79 ± 2.19 | 10.28 | 25.17 | 15.88 | 1.85     | 7.06    |
|                   | After  | 11.57 ± 0.81 | 9.07  | 14.29 | 7.00  | 0.25     | 1.28    |
| P$_2$O$_5$ (mg·kg$^{-1}$) | Before | 94.17 ± 44.06 | 39.67 | 27.66 | 46.79 | 1.44     | 1.87    |
|                   | After  | 49.61 ± 8.49 | 30.29 | 82.39 | 17.11 | 1.05     | 1.94    |
| K (cmol·kg$^{-1}$) | Before | 0.11 ± 0.02 | 0.08  | 0.20  | 18.18 | 1.68     | 6.52    |
|                   | After  | 0.06 ± 0.01 | 0.05  | 0.10  | 16.66 | 0.66     | 0.91    |
| Ca (cmol·kg$^{-1}$) | Before | 4.44 ± 1.34 | 1.81  | 7.63  | 30.18 | -0.26    | -0.39   |
|                   | After  | 2.54 ± 0.39 | 1.78  | 3.65  | 15.35 | 0.67     | -0.24   |
| Mg (cmol·kg$^{-1}$) | Before | 1.06 ± 0.71 | 0.43  | 1.59  | 66.98 | -0.38    | -0.57   |
|                   | After  | 0.61 ± 0.09 | 0.43  | 0.83  | 14.75 | 0.60     | -0.53   |

$^a$Skew: Skewness, $^b$Kut: Kurtosis
Table 2. Semivariogram parameters of soil chemical properties before and after land leveling from the remodeled paddy field.

| Property       | Period | Model        | Nugget \( C_0 \) | Sill \( C_0 + C \) | Range \( A_0 \) (m) | \( C/(C_0+C) \) | \( R^2 \) |
|----------------|--------|--------------|------------------|-------------------|---------------------|----------------|---------|
| pH (1:5)       | Before | Exponential  | 0.03             | 0.05              | 30.99               | 0.40           | 0.38    |
|                | After  | Exponential  | 0.03             | 0.05              | 30.99               | 0.40           | 0.65    |
| OM (g·kg\(^{-1}\)) | Before | Spherial     | 0.98             | 6.19              | 9.04                | 0.89           | 0.99    |
|                | After  | Spherial     | 0.53             | 1.07              | 30.99               | 0.50           | 0.58    |
| \( P_2O_5 \) (mg·kg\(^{-1}\)) | Before | Exponential | 387.00           | 2267.00           | 6.74                | 0.83           | 0.99    |
|                | After  | Exponential | 57.40            | 114.81            | 52.77               | 0.50           | 0.58    |
| K (cmol·kg\(^{-1}\)) | Before | Spherial     | 0.00             | 0.00              | 6.32                | 0.00           | 0.98    |
|                | After  | Spherial     | 0.00             | 0.00              | 22.11               | 0.00           | 0.95    |
| Ca (cmol·kg\(^{-1}\)) | Before | Exponential | 0.49             | 1.91              | 4.56                | 0.74           | 0.95    |
|                | After  | Exponential | 0.13             | 0.26              | 30.99               | 0.50           | 0.50    |
| Mg (cmol·kg\(^{-1}\)) | Before | Exponential | 0.06             | 0.13              | 16.31               | 0.54           | 0.47    |
|                | After  | Exponential | 0.01             | 0.01              | 92.97               | 0.00           | 0.28    |

Fig. 4. Semivariogram results for soil chemical properties from remodeled paddy fields before and after land leveling; pH, organic matter content (OM), available \( P_2O_5 \), potassium (K), calcium (Ca) and magnesium (Mg) content.
land leveling effects on soil chemical properties at soybean uplands and found significant differences in chemical properties, such as decrease of pH and OM and increase of exchangeable cations. Dobermann (1994) concluded that land leveling and land preparation were one of main factors that caused field variations of chemical properties. Land leveling can create variations of properties or homogeneity in fields based on field conditions. In this study, land leveling was applied with sufficient water to level soil surface and this produced no significant changes in average values of chemical properties.

**Geostatistics analyses of land leveling effects on soil chemical properties**  
All the chemical measurements from every sampling point were applied to calculate semivariogram by Eq. 1. Based on the semivariogram calculation and geostatistical analyses, the best fit semivariogram models of the chemical properties were the exponential model for most of properties except OM and K which had the spherical model (Table 2 & Fig. 4). Before the wet land leveling, all properties except pH and Mg had the best fit models with high predictive capability ($r^2 \geq 0.95$). The best fit model efficiencies ($r^2$ values) decreased for all properties except pH due to the leveling ($r^2 \leq 0.95$). Both before and after the wet land leveling, the model fit was very poor for the pH and Mg ($r^2 \leq 0.65$), In Table 2, available $P_2O_5$ had high nugget values ($C_0$) and it indicated microscale effects and sampling/measurement errors (Goovaerts, 1997). Isaaks and Srivastava (1989) defined that the sill values ($C_0 + C$) are also the variance values of random soil properties. Therefore, the sill values decreased from all properties except K after the leveling, which meant that distributions of soil chemicals decreased in randomness after the leveling. In general, the range values increased after the leveling except pH, indicating greater spatial autocorrelation among the sampling points at the 5 m spacing. In other word, the homogeneity of these properties across the study field increased after the leveling and sampling space can be greater after the leveling. Increase of homogeneity in soil properties were reported by Brye et al. (2004) and Oztekin (2013). Sonn et al. (2012) compared spatial variability of soil chemical properties between a 5 year old general paddy field and a remodeled paddy field. They found that range values of pH, organic matter content and available $P_2O_5$ from a remodeled

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**Fig. 5. Semivariogram results for soil chemical properties from remodeled paddy fields before land levelling; pH, organic matter content (OM), available $P_2O_5$, potassium (K), calcium (Ca) and magnesium (Mg) content.**
paddy field tended to decrease compared to ones from general paddy field. In this study, the results of the range values showed the similar trend except pH. The ratio \( C / (C_0 + C) \), representing inherent variability in the data, explained the highest variability (0.89) in OM and no variability in K before the leveling. After leveling, the ratio \( C / (C_0 + C) \) decreased overall across chemical properties except pH which had no change. After the leveling, 5 m spacing was too large to represent a spatial dependency for Mg and K. In other word, 5 m sampling space was not able to characterize spatial distributions of the Mg and K properties. In order to characterize spatial distributions these properties, it is needed to take samples smaller sampling space than 5 m. The spatial distributions of all soil properties except pH were altered by the wet land leveling. Khan et al. (2007) reported that leveling effect on soil pH can be varied due to irrigation or rainfall differences. In this study, water layer was applied uniformly across the field. Therefore the wet land leveling did not affect soil pH distribution.

The spatial distribution maps concurred changes occurred by the wet land leveling (Fig. 6). Except pH, most of properties showed more homogeneous distributions across the study field. The values of chemical properties tended to decrease after the leveling except pH. The spatial distribution maps of pH were altered to some degree by the leveling. In the maps, the pH values from post-leveled soils increased across the study field. The land leveling induced slightly more alkaline. As expected, most soil chemical properties had more uniform or homogeneous distributions across the study field and this may provide easier and efficient fertilizer management and irrigation planning for rice cultivation. Sonn et al. (2012) concluded that the remodeled paddy field showed more heterogeneity of soil chemical properties compared to a matured
paddy field. This study also confirmed that the remodeled paddy field had more heterogeneous distributions of soil chemical properties, but these heterogeneity decreased by the wet land leveling. This phenomenon was observed from matured paddy field properties as Sonn et al. (2012) described. The wet land leveling stimulated maturity of paddy field after the remodeling.

**Conclusions**

This study showed that land leveling significantly affected the magnitude, spatial variability, and spatial distribution of the soil chemical properties from the remodeled paddy fields. The average values of the properties did not significantly change, but the homogeneity of spatial distributions increased. The remodeled paddy fields will result in reduced productivity and uneconomic management due to heterogeneous distributions of soil chemical properties. Applying the wet land leveling reduced these negative effects from the remodeled lands or severely disturbed top soil fields. Research about effects of continuous leveling on remodeled paddy fields should be needed to improve productivity and water managements for rice cultivation.

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