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Quantifying the Spatial Patterns of Soil Redistribution and Soil Quality on two Contrasting Hillslopes

Y. Li, M.J. Lindstrom, M. Frielinghaus, H.R. Bork*

ABSTRACT

The soil redistribution from erosion processes may result in the spatial variability patterns of soil quality within the landscape. The objectives of this study were to (i) quantify spatial patterns and controlling processes of soil redistribution due to water and tillage erosion, and (ii) correlate soil quality parameters with soil redistribution along the hillslope transects for different land use management systems in the Loess Plateau near Yan'an, China. Water erosion data were derived from ^{137}Cs measurements and tillage erosion from the simulation of a Mass Balance Model along the hillslope transects. Soil quality measurements, i.e. soil organic matter, bulk density and available nutrients were made at the same sampling locations as the Cs-137 measurements. Results were compared at the individual site locations and along the hillslope transects through statistical and applied time series analysis. The results showed that soil loss due to water erosion and soil deposition from tillage are the dominant soil redistribution processes in the hillslope segment between 23-40 m, and soil deposition by water erosion and soil loss by tillage are dominant processes occurring in the hillslope segment beyond 80 meters within the cultivated landscape. However, land use change associated with vegetation cover can significantly change both the magnitudes and scale of these spatial patterns within the hillslope landscapes. There is a strong interaction between the spatial patterns of soil erosion processes and soil quality. It was concluded that soil loss by water erosion and deposition by tillage are the main cause for the occurrence of significant scale dependency of spatial variability of soil quality along hillslope transects.

INTRODUCTION

The spatial variability patterns of soil erosion and their impacts on soil quality within the landscape is being considered as a basis for making management decision for sustainable cropping systems in China. Early estimation of the suspended sediment indicates that soil erosion in the Yellow River Basin, China causes considerable losses of N, P and other soil nutrients (Zhu, 1984). However, serious gap in knowledge about the spatial relationship between erosion and soil quality exists for the "homogenous loess soil" within changing landscape structure and vegetation cover in the Loess Plateau. Therefore, soil quality management has been neglected for soil conservation strategies and land use planning decisions in this region. This has mainly been due to the difficulty of obtaining the detailed spatial erosion data and linking these data to soil quality parameters within hilly landscapes with different land use.

Cesium-137 technique allows the assessment of both spatial patterns and rates of soil redistribution in the landscape (Ritchie and McHenry, 1990; Walling and Quine, 1993; Quine et al., 1994). But erosion data derived from cesium-137 and soil quality parameters cannot explain much of the variability identified in complex soil landscapes (Montgomery et al., 1997).

Geostatistical techniques and time series analysis show promise for developing new insights into soil-landscape patterns and processes (Nielsen et al., 1983; Wendroth et al. 1997; Zhang, 1998). Numerous applications of geostistatistics in soil investigation in the past 10 years are mainly focused on interpolation of soil attributes across the landscapes. However, less attention has been paid to the underlying spatial processes of soil erosion within the landscapes. We believe that ^{137}Cs integrated with time series provide great potential for i) determining the similarities of spatial variability patterns and the scale of dependent variability in soil redistribution processes from landscape scale to a regional scale and ii) for linking them to soil quality for a large heterogeneous basin. To meet this need, an investigation was conducted on two similar hillslopes with different land use in the Loess Plateau. The objectives were to (i) quantify spatial patterns and controlling processes of soil redistribution caused by tillage and water erosion and (ii) compare these patterns with the spatial patterns of soil quality parameters across the landscape.

MATERIALS AND METHODS

Study Area

The field sampling and investigation were conducted in the Yangjuangou dam reservoir catchment (Li et al., 1997). The catchment has an area of 2.02 km^2, 1025-1250 m above mean sea level, located near Yan'an city, northern Shaanxi province in China (36° 42′ N, 109° 31′ E). It is a secondary tributary of the Yanhe River. This study area is typical of China loess plateau with long-term cultivation history. Soils

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in the study area are Calcaric-Cambisols (FAO, 1997), uniformly textured and weekly structured. The typical particle size distribution of this soil is 20% sand, 55% silt and 25% clay by weight. The mean annual rainfall is 550 mm and rainfall patterns are highly variable both monthly and annually. Seventy per cent of the rainfall occurs between July and September. Soil erosion is the result of runoff scouring, human reclaiming natural vegetation or cultivating on steep slopes up to 40° and the extremely weak resistance of loess to erosion when lacking vegetation cover (Li, 1995). The forest distributed on hillslopes is planted forest including *Pinus tabulaeformis*, *Robinia psendoacacia.* The grass in the catchment is natural grass including *Bothriochloa ischaemum, Themeda triandra var. japonica, and Carex filipes,* etc. The crops grown on the farmland are potato (*Solanum tuberosum* L.), soybean (*Glycine max* L.), and millet (*Panicum miliacem* L.).

Field Sampling and Survey

Soil samples for the determination of spatial patterns in ^{137}Cs were collected from the top to the bottom of the hillslope in April 1997. Two downslope transects were established on similar topographic features, one hillslope was cultivated and the other had a mixed land use, over a length of 240m (Figure 1). The mixed land use hillslope contained an upper permanent vegetated portion (over a length of 140 meters) and lower cultivated portion (over a length of 100 meters). The vegetated portion of the mixed land use hillslope had been used for arable land before 1982. Both hillslopes had southwest aspects Slope measurements were taken for the cultivated hillslope and the upper vegetated portions of the mixed land use hillslope at 5m intervals, and for the lower cultivated portions of the mixed land use hillslope at 1–5 m intervals using a theodolite. The two hillslopes were divided into five landscape locations, i.e. 30–40 m length for summit, 40–60 m length for upper, 60 m for middle, and 50 m for the lower and foot portions of the hillslopes. The range of slope gradients in the five landscape positions were: 3–15 degrees, summit; 28 –33 degrees, upper; 12 –31degrees, middle; 14-28 degrees, lower; and 8–23 degrees, foot.

Two to four (9.95 cm diameter) cores were taken at the interval of 10 m along each transect, to a depth of 40 cm and then combined for determination of ^{137}Cs inventories.

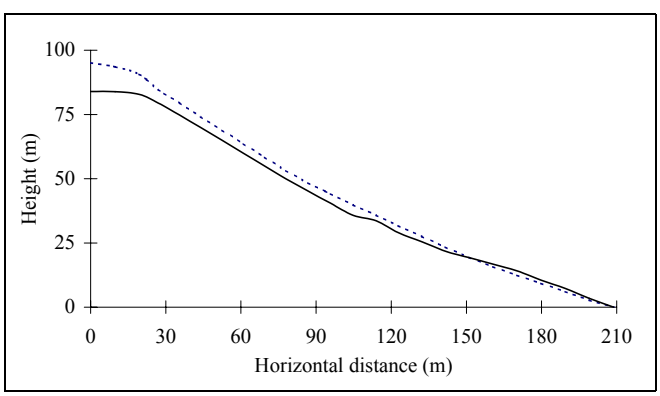

Figure 1. **Profile of cultivated hillslope (dash line) and mixed land use hillslope (solid line).**

Reference sites for determining the ^{137}Cs fall-out in the study area was established at undisturbed, uneroded, level terraced fields constructed in 1954 and uncultivated grassland within the catchment. A mean value of 2390 Bq m^{-2} was determined as the actual fallout of ^{137}Cs in the study area. For the soil quality parameters, bulk density was determined over the 40 cm sampling depth, while available nitrogen (N), phosphorus (P), and organic matter (OM) were for the surface 10 cm.

Soil Sample Analysis

All samples were air-dried and passed through a 2 mm sieve and weighed. The sieved samples were analyzed for ^{137}Cs using a high efficiency gamma spectroscopy unit with multi-channel analyzer (Li et al., 1997). The cesium-137 content of samples was detected at 662 keV and using counting times of 80,000-86,400s, which resulted in analytical precision of ±6 percent for ^{137}Cs. The results of ^{137}Cs were originally calculated on a unit mass basis (Bg kg^{-1}) and were then converted to an inventory value (Bq m^{-2}) using the total weight of bulked core soil sample and the sampling area. Soil bulk densities (Mg m^{-3}) calculations were based on volume of bulked soil cores and oven dried mass determinations (Pennock et al., 1994). Available soil N (mg kg^{-1}) was determined by using micodiffusion (Bremner, 1965), and available P (mg kg^{-1}) was determined using the method described by Olsen and Sommers (1982). Organic matter (% by weight) was measured by wet combustion (Nelson and Sommers, 1982).

Determination of Soil Redistribution Rates

Total soil redistribution rates for cultivated land can be calculated using the following equation:

$$R = R_t + R_w \qquad [1]$$

where R (t ha^{-1} yr^{-1}) is the net soil redistribution rate due to tillage R_t (kg m^{-2} yr^{-1}) and water R_w (kg m^{-2} yr^{-1}). For a given point along a flow line, the tillage-derived soil redistribution rates R_t (kg m^{-2} yr^{-1}) can be calculated using the following equation (Govers et al., 1994, 1996):

$$R_t = (F_{Q,\,out} - F_{Q,\,in})/L_i = \phi(\sin\beta_i - \sin\beta_{i-1})/L_i = R_{t,out,i} - R_{t,in,i} \qquad [2]$$

where $F_{Q,\,out}$ and $F_{Q,\,in}$ are the downslope sediment output or input flux (kg m^{-1} yr^{-1}) from the contour slope length L_i (m) of the *i*th segment, and ϕ (kg m^{-1} yr^{-1}) is a constant related to the tillage practice involved, β_i and β_{i-1} are the slope angles (degrees) of the *i*th and (i –1)th segments, and $R_{t,out,i}$ and $R_{t,in,i}$ (kg m^{-2} yr^{-1}) are the downslope sediment fluxes output or input of the ith slope segment due to tillage erosion. Values of the parameter ϕ in Eq. [2] may be estimated from the erosion rate R_1 (kg m^{-2} yr^{-1}) for an eroding point from the first slope segment at the top of the slope (with length L_1 and slope angle β_1, assuming that water erosion is significant due to the limited slope length and that there is no tillage input to this point):

$$\phi = R_1\, L_1 / \sin\beta_1 \qquad [3]$$

For a point along a flow line, the water-induced erosion (R_w, kg m^{-2} yr^{-1}) can be estimated by solving the Eq. [4] numerically (Walling and He, 1999):

$$dA(t)/dt = (1 - \Gamma)I(t) - (\lambda + P R_w/d)A(t) \quad [4]$$

where:
$A(t)$= cumulative ^{137}Cs activity per unit area (Bq m^{-2});
R= erosion rate (kg m^{-2} yr^{-1});
d= cumulative mass depth representing the average plough depth (kg m^{-2});
λ= decay constant for ^{137}Cs (yr^{-1});
$I(t)$= annual ^{137}Cs deposition flux (Bq m^{-2} yr^{-1});
Γ= percentage of the freshly deposited ^{137}Cs fallout removed by erosion before being mixed into the plough layer;
P= particle size correction factor.

The annual soil loss (t ha^{-1} yr^{-1}) for the eroding point on uncultivated land was estimated using a Profile Distribution Model as the following (Walling and Quine, 1999):

$$Y = \frac{10}{(t-1963)P} ln(1 - \frac{X}{100})h_0 \quad [5]$$

where:X = percentage ^{137}Cs loss in total inventory in respect to the local ^{137}Cs reference value (Bq m^{-2}) (defined as $(A_{ref}-A_u)/A_{ref}$);

h_0 = coefficient describing profile shape (kg m^{-2})
t = year of sample collection (yr);
P = particle size correction factor.

For a depositional location, the deposition rate R' can be estimated from the excess ^{137}Cs inventory $A_{ex}(t)$ (Bq m^{-2}) (defined as differences in the values between measured total ^{137}Cs inventory in the sampling point A_u and reference inventory A_{ref}) and the ^{137}Cs concentration of deposited sediment C_d (Bq kg^{-1}) (Walling and He, 1999) :

$$R' = \frac{A_{ex}}{\int_{t_0}^{t} C_d(t')e^{-\lambda(t-t')}dt'} = \frac{A_u - A_{ref}}{\frac{P'}{\int_S RdS}\int_S A_{ref}\left(1 - e^{-R/h_0}\right)dS} \quad [6]$$

Evaluation of Spatial Variability

Usually when a variable is sampled in the field, the mean and the variance are determined to reflect the sampled population, assuming that sampling occurred randomly and representatively (i.e. classic statistics – observations are independent of each other and, in general, are normally distributed). Most soil properties, however, occur with a regular pattern across the landscape. Moreover, these patterns develop spatially, temporally, or in both domains (Wendroth et al., 1997), which cannot be described using classic statistics. Using standard correlation methods, Kachanoski et al. (1985) found that micotopography and A-horizon parameters were not related. However, considering the sampling coordinates of the parameters, and applied cospectral and spectral analysis techniques, Kachanoski et al found that spatio-periodical relations did exist. We are assuming that the changes in the scale dependence of the spatial variability of soil redistribution due to tillage and water erosion may be in the frequency domain, as quantified using the spectral analysis such as power spectrum and squared coherency (Nielsen, personal communication, 1998).

The power spectrum $f(\lambda)$ of the process x_i as a function of wave length λ (distance dependence) is obtained using Fourier transformation (Wendroth et al., 1997):

$$f(\lambda) = \sum_{-\infty}^{\infty} C(h)exp[-2\pi i\lambda h] \quad [7]$$

where i^2=-1. Power spectrum separates the variation or fluctuation of a series of observations into periodical components, and reflects the amplitude and frequency regardless of phase or distance shift. Therefore it may be useful for quantifying the dominant spatial processes and detecting the effects due to the regular pattern of agricultural operations and changes in landscape structure and land use.

To better understand the erosion impacts on soil quality, we compared the squared coherence variations of soil redistribution and slope angles with the selected soil quality parameters using spectral coherency analysis (Wendroth et al., 1997). The squared coherence $K_{yx}(\lambda)$, as a measure of frequency dependent correlation, can be determined for the two series of observations according to:

$$\kappa_{yx}(\lambda) = \frac{[f_{yx}(\lambda)]^2}{f_x(\lambda)f_y(\lambda)} \quad [8]$$

where $f_{yx}(\lambda)$ is the cross spectrum (Shumway, 1988). $K_{yx}(\lambda)$ is analogous to the coefficient of determination with values between 0 and 1. It equals 1 at all frequencies (1/wave lengths) if one series is an exact linear correlation with another series. Therefore, spectral coherency reflects the quality of regression at the frequency domain between two series of variables.

RESULTS AND DISCUSSIONS

Spatial variability Patterns of Soil Redistribution

To quantify the spatial variability patterns of soil redistribution processes and their scale of dependency on slope angle and land use changes, comparisons in two contrasting hillslopes with different land use are made here using classic statistics and spectral density analysis (Wendroth et al., 1997). Basic statistical properties and power spectrum of data of soil redistribution rates and slope angle are presented in Table 1 and Figure 2.

The inventories in ^{137}Cs, net soil loss and deposition rates varied greatly for the two contrasting hillslopes with different land use, while slope angle means are similar between the two slopes. Over the two hillslopes, soil redistribution resulted in heterogeneous soil properties due to soil loss and/or deposition from tillage and water erosion as indicated by CV value >75% even though slope angles were homogenous (CV < 40%) (Table 1). Compared to the mixed land use hillslope, cultivation on steep hillslope increased the net soil loss by 124% and decreased available P by 13%, available N by 56%, OM by 62%, and bulk density by 5%. This clearly indicated that land use change

Table 1. Descriptive statistics for soil redistribution rates and soil quality parameters

Variables	Max.	Min.	Average	SD	CV
Cultivated hillslope (n=24)					
^{137}Cs(Inv,Bq m^{-2})	4321	349	965	960.8	100
Soil loss by tillage(Rt,t $ha^{-1}yr^{-1}$)	94	0	6	18.7	325
Soil deposition by tillage(Rtd,t $ha^{-1}yr^{-1}$)	27	0	5	7.8	159
Soil loss by water (Rw,t $ha^{-1}yr^{-1}$)	165	0	54	41.1	76
Soil deposition by water (Rwd,t $ha^{-1}yr^{-1}$)	63	0	4	14.9	364
Net soil loss (NR,t $ha^{-1}yr^{-1}$)	161	0	56	41.5	74
Net soil deposition (NRd,t $ha^{-1}yr^{-1}$)	76	0	5	19.1	361
Slope (degree)	33	5	20	8.0	39
Available phosphorus (P,mg kg^{-1})	2.4	1.0	1.7	0.3	19
Organic matter (OM,%)	0.8	0.2	0.4	0.1	25
Available nitrogen (N,mg kg^{-1})	26.2	9.6	16.7	3.2	19
Bulk density (BD,g cm^{-3})	1.3	1.1	1.2	0.1	5
Mixed land use hillslope (n=24)					
^{137}Cs(Inv,Bq m^{-2})	3011	363	1601	735.1	46
Net soil loss (NR,t $ha^{-1}yr^{-1}$)	124	0	25	36.2	143
Net soil deposition (NRd,t $ha^{-1}yr^{-1}$)	40	0	4	9.5	218
Soil loss by water (Rw,t $ha^{-1}yr^{-1}$)	124	0	21	29.8	145
Soil deposition by water (Rwd,t $ha^{-1}yr^{-1}$)	9	0	1	2.6	339
Slope (degree)	30	1	21	8.1	38
Available phosphorus (P,mg kg^{-1})	3.8	1.2	2.0	0.6	32
Organic matter (OM,%)	2.0	0.4	1.1	0.5	45
Available nitrogen (N,mg kg^{-1})	74.5	17.5	38.2	14.8	39
Bulk density (BD,g cm-3)	1.3	1.0	1.2	0.1	5

Table 2. Correlation coefficients of soil redistribution rates with slope angle and soil quality variables

	Rt	Rtd	Rw	Rwd	NR	NRd	Slope	Inv
Cultivated hillslope (n=24)								
Slope	-0.41	-0.37	0.61	-0.40	0.44	-0.41	1.00	-0.48
Availa P	-0.12	0.52	-0.34	0.43	-0.44	0.42	-0.46	0.41
OM	0.09	0.53	-0.47	0.65	-0.43	0.68	-0.51	0.72
Avail N	0.22	0.38	-0.53	0.66	-0.42	0.68	-0.64	0.70
BD	0.23	-0.03	0.23	-0.08	0.31	-0.12	0.32	-0.23
Mixed land use hillslope (n=24)								
Slope	-	-	<0.03	<0.03	<0.03	<0.03	1.00	0.26
Availa P	-	-	0.03	-0.01	0.47	-0.18	-0.12	-0.40
OM	-	-	-0.29	0.47	-0.49	0.07	0.16	0.61
Avail N	-	-	-0.23	0.28	-0.43	-0.05	0.08	0.39
BD	-	-	0.27	-0.41	0.22	-0.53	-0.01	-0.41

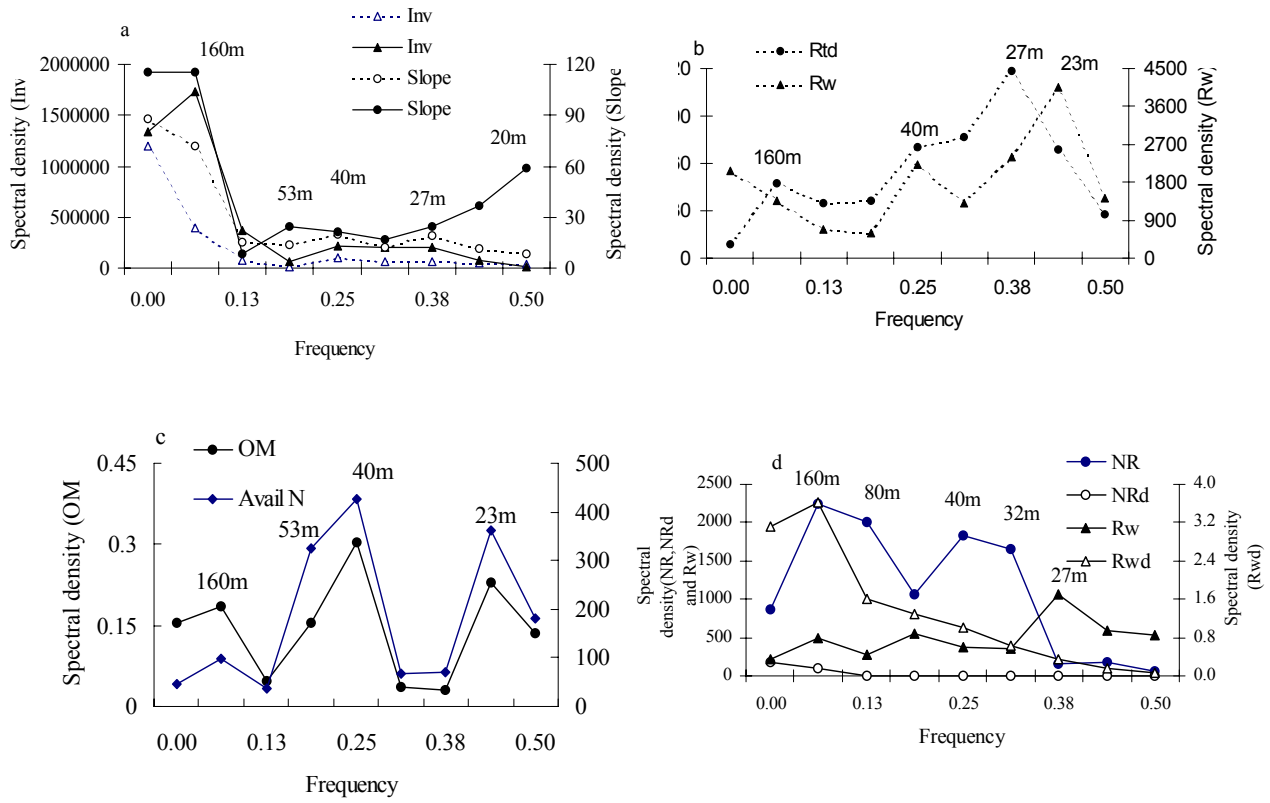

Figure 2. Power spectrum of soil redistribution rates and slope angles over the cultivated hillslope (dash line) and mixed land use hillslope (solid line): (a) ^{137}Cs inventories (Inv) and slope angles (Slope); (b) soil loss by water (Rw) and soil deposition by tillage (Rtd); (c) soil loss by tillage (Rt) and soil deposition by water (Rwd); (d) net soil loss (NR), net soil deposition (NRd), Rw and Rwd.

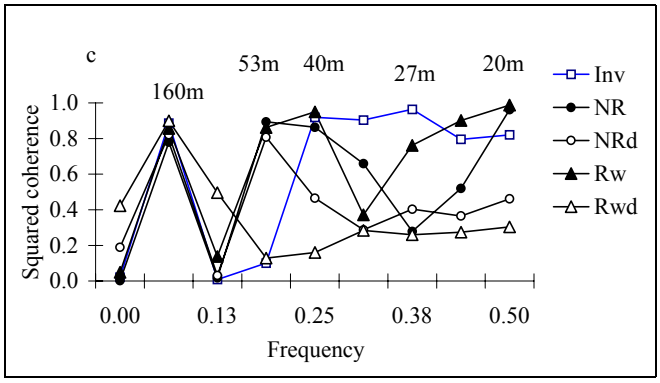

Figure 3. Squared coherence of ^{137}Cs inventories and soil redistribution rates vs slope angles on the cultivated hllslope (dash line, Figures 3a and 3b) and mixed land use hillslope (solid line, Figure 3c).

for the steep hillslopes from farmland to grassland or forested land is effective in reducing quantity of soil loss and improving soil quality in the study area. However, this does not quantify the effects of conservation practices (grass and forest) to the scale of variability patterns of the erosion processes. This prompted the study to determine if the spatial variability patterns of soil redistribution are consistent in the two contrasting hillslopes by spectral density analysis (Figure 2).

There are two evident peaks that occur at wavelengths (1/Frequency) of about 27-40m and 160m in the power spectrum for ^{137}Cs inventories that are related to erosion processes on the two contrasting hillslopes (Figure 2), when compared to wave lengths for slope angles at the 20-27m, 40-53m and 160m hillslope locations. Peaks in power spectrum wavelengths for net soil loss occur at the 32-40m and 80-160m segments for the hillslope with mixed land use (Figure 2d) and at the 23m, 40m and more than 160m hillslope locations on the cultivated hillslope. These peaks appear at approximate frequencies indicating land use change does not obviously change the overall spatial patterns of soil redistribution by water erosion, due to a combined impact by steep slopes with a long-term tillage operations in the study area. On the contrary, land use change from farmland to forest and grassland has significant role in the scale of spatial patterns of net soil export within the landscapes (Table 1, Figures 2b and 2d).

Spatial patterns of soil redistribution by tillage operations can be described by power spectrum wavelengths for soil deposition at the 27m, 40m and 160m hillslope locations (Figure 2b) and at the 27m, 53m and 160m hillslope locations for soil loss (Figure 2c), respectively. Evidently, soil loss by water erosion and deposition by tillage are dominant soil redistribution processes at 23-40m segment, and soil deposition by water erosion and soil loss by tillage are dominant processes occurring at more than 80m hillslope

locations within the landscape. This is closely related to the changes in field boundary and slope location. Moreover, the similar spatial patterns of soil movement by water erosion and tillage deposition reflect accelerating mechanism of soil loss due to water erosion by tillage operation thus decreasing soil quality on cultivated slopes of the study area.

Effects of Slope gradients and Land Use Change on Spatial Variability

Patterns of Soil Redistribution

To further determine whether the spatial variability patterns of soil redistribution coincide with that of the slope angle and land use changes, a systematic analysis of correlation coefficients and squared coherence of two series of variables were made for the two contrasting hillslopes (Table 2 and Figure 3).

Soil redistribution rates by tillage and water erosion show a significant correlation with slope angle ($r = 0.40$; $p < 0.05$) over the cultivated hillsope, but not significant for the hillslope with mixed land use (Table 2). The spectrum of squared coherence of erosion processes over the cultivated hillslope (Figure 3a) shows a strong coherency at the 20 to 80m segment for soil deposition by tillage and at the 23 to 160m segment on cultivated hillslope for soil loss by water erosion. Strong coherence peaks in the spectrum for soil loss by tillage appears at the 20m, 40m and 160m hillslope locations and only one strong peak for soil deposition by water erosion at the more than 160m hillslope location. These indicate similarities in the spatial variability patterns of soil deposition by tillage (Rtd) and loss by water erosion (Rw) vs. slope angle and differences of soil loss by tillage (Rt) and deposition by water erosion (Rwd) vs. slope angle across the cultivated hillslope landscape (Figure 3a). For the mixed land use hillslope, strong squared coherence of soil loss rate by water vs. slope angle occur at the 20-27m, 40-53m segments and 160m hillslope location, but not as strong at the hillslope locations as that the cultivated hillslope (Figure 3c).

These spatial relationships can be further confirmed by squared coherence of Cs-137 inventory, net soil loss and deposition vs. slope angle, as is shown in Figures 3b and 3c. This quantitatively explains why net soil loss rates do not increase with slope length of more than 60m or elevation alone on arable land due to the contribution to total soil redistribution processes from tillage translocation and tillage erosion (Bussaca et al., 1993; Montgomery et al., 1997; Martz and deJong, 1987; Zhang et al., 1997). Changes in conservation practices or the changes in slope angle curvature strongly effects soil redistribution processes by both tillage (Lindstrom et al., 1992) and water erosion (Young and Mutchler, 1969).

Contributions of Soil Redistribution to Spatial Patterns of Soil Quality

There exist significant differences in averages of organic matter and available N and bulk density between two contrasting hillslopes (Table 1). When compared the correlative coefficients of soil quality parameters with net soil loss, significant negative correlation at $\alpha = 0.05$ level for all nutrient variables (Table 2). These indicate that removal of soil nutrients by erosion have resulted in serious lowering of soil quality within the cultivated hillslope.

However, quantifying the spatial patterns of soil erosion impacts on soil quality is much more challenging, especially in the soil landscape with "homogenous loess materials". Moreover, there is no initial information about the quantification of spatial patterns of soil nutrients in this region. We suggest as a solution to this problem, construction of the spectral density functions of soil quality patterns and comparison with soil erosion processes using squared coherence analysis (Wendroth et al., 1997).

Typical strong peaks occur at long wavelength of 160m (or >160m) in the power spectrum for available nitrogen and available phosphorus, organic matter on the cultivated hillslope (Figures 4a and 4b) even though several weak peaks at short wavelengths of 27-53m. But typical strong peaks in the power spectrum occurs at short wavelengths of 23m and 40-53m for available nitrogen and organic matter and 53-160m for available phosphorus on the mixed land use hillslope (Figure 4c and 4d). Peaks in power spectrum of bulk density occur at short wavelengths of 20-32m and more than 160m on the two slopes (Figures 4b and 4d). These reflect variability patterns and scale of soil erosion impacts on soil quality due to field boundary, land use and landscape location.

The spatial patterns of erosion impacts on soil quality may be further quantified by the squared coherence of soil quality variables vs. ^{137}Cs inventories, as shown in Figure 5. High squared coherence for cultivated hillslope occurs at long wavelength of more than 80m and specially at short wavelength about 20-40m, corresponding to the scale of variability patterns of soil deposition by tillage and soil loss by water (Figure 5a and Figure 2b). This provides evidence that soil loss by water and soil deposition by tillage are the main reason for the occurrence of significant scale dependency of spatial variability of soil quality on the cultivated hillslope. For the hillslope with different land use, the spectrum of squared coherence between ^{137}Cs inventories and soil quality variables shows different patterns as that for cultivated hillslope and strong coherence for several short wavelengths but especially for long wavelengths of more than 80m (Figure 5b). This provides some evidence that soil conservation practice (grass and forest) can greatly affect the spatial variability patterns and its scale dependency of soil erosion on soil fertility, thus increase soil quality.

CONCLUSIONS

We have demonstrated a conjunctive method of ^{137}Cs technique integrated with time series analysis for determining the similarity and variability of soil erosion and soil quality and quantifying the scale of dependent variability between them within landscape with different land use. This method has shown promise for quantifying spatial patterns of soil redistribution by tillage and water erosion within the landscapes. This method appears to have utility for identifying changes in soil quality indicators that have both predictable spatial patterns and strong coherency with ^{137}Cs measurement.

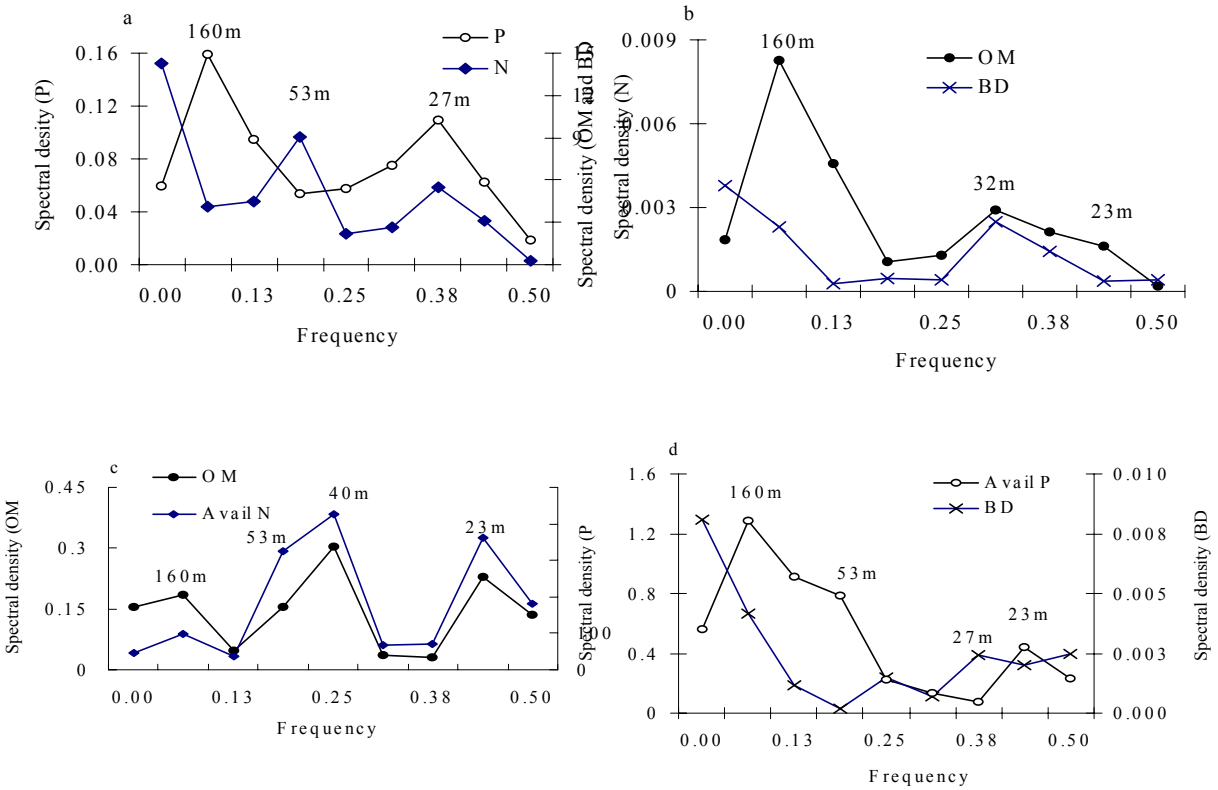

Figure 4. Power spectrum of soil quality parameters on the cultivated hillslope (Figures 4a and 4b) and mixed land use hillslope (Figures 4c and 4d): available phosphorus (P), available nitrogen (N), organic matter (OM) and bulk density (BD).

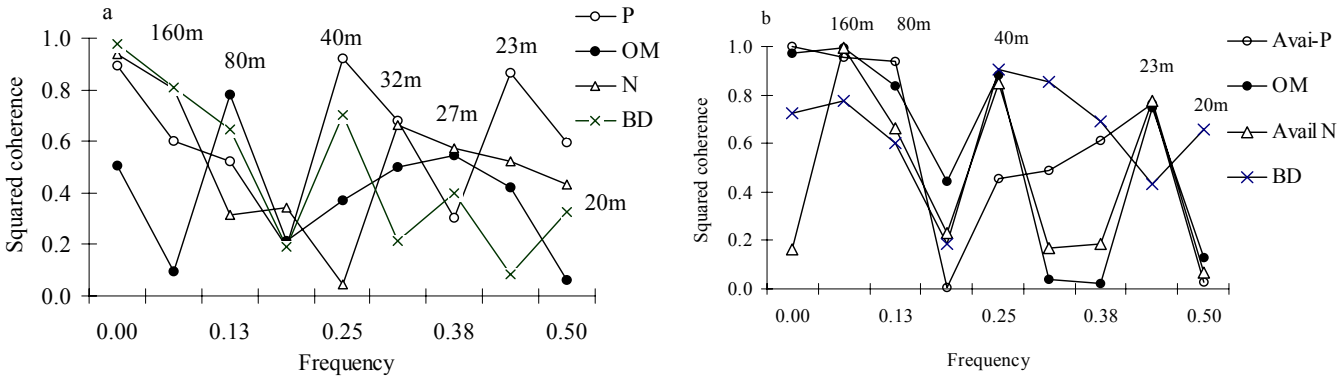

Figure 5. Squared coherence of soil quality parameters vs ^{137}Cs inventories on the cultivated hllslope (Figure 5a) and mixed land use hillslope (Figure 5b).

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