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Chapter 1 Introduction

1.1 Study background

1.1.1 Need for water erosion risk assessment

Land degradation is one of the challenging issues for mankind since the adverse impact on human welfare and environment is greater now than ever before (Lal and Stewart 1990). Especially, land degradation in drylands is often designated as desertification. The term desertification was raised as a major environmental issue at the United Nations Conference on Human Environment in Stockholm in 1972 and has drawn much attention to date. One outcome of this attention reached the publication of "World Atlas of Desertification" (UNEP 1992, 1997). After defining desertification as 'land degradation in arid, semiarid and dry subhumid areas resulting from various factors, including climatic variations and human activities', UNEP (1997) estimated that 1 billion ha in the world, or 20% of the total drylands (not including the hyper arid areas), are currently being degraded by human activities. Of the drylands, the semiarid Mediterranean region is characterized by severe soil degradation, particularly by water erosion (UNEP 1997) due to its climatic regime (Langbein and Schumm 1958) and the generally sparse vegetation cover.

In this region, the countries of the Middle East have experienced the rapid increase of population. For example, the mean annual growth rates of population from 1961 to 1990 were as high as 3.40% in Syria, 3.30% in Iraq, and 2.69% in Yemen, in contrast to 0.91% in Japan (FAO 1997). To meet food demand of the increasing population, these countries have been subjected to socioeconomic changes that might enhance water erosion (Johnson 1993; Sghaier and Seiwert 1993; Mainguet 1994). The sedentarisation of previous nomadic peoples has resulted in livestock concentration around the settlements, and the encroachment of cropland onto the traditional grazing areas pushed the herders into more marginal rangeland. Thus, the increase of the stocking rate in rangeland enhances the risk of serious water erosion due to the decrease of the vegetation cover (Bari et al. 1995) and deterioration of soil physical conditions through trampling (Warren et al. 1986a, b).

Besides grazing, cropping in former rangeland can enhance water erosion through the decrease of the vegetation cover (Morgan 1995) and the reduction of the infiltration rate due to compaction by farm machinery (Fullen 1985). In addition, crop residue management in the current agricultural production system might also accelerate water erosion in cropland. In this system, after the harvest of cereal grains in spring, the stubbles and straw are left in a field during the dry summer for grazing, or taken out as supplemental feed in rainy winter (Smith and Elliot 1990). As a result, the soil surface is exposed to rainfall directly when the rainy season begins.

Under these circumstances, we are strongly urged to develop sustainable land management that can satisfy the growing demand of food and feed and, at the same time, alleviate water erosion. For this purpose, we should evaluate the impact of current land use on water erosion and specify suitable places for each land use in terms of sustainable production. Unfortunately, however, in the developing countries where the population increases much more rapidly, little quantitative information on the relationship between actual land use and water erosion is available. Even much less is the geographical evaluation of the water erosion risks that can identify the susceptible zones to water erosion and should be an indispensable part for sustainable land use planning.

1.1.2 Factors controlling water erosion

The water erosion risks can be evaluated by the integration of the factors controlling water erosion: the erosivity of rainfall and the erodibility of the soil, slope of the land and the nature of the vegetation cover (Morgan 1995).

Rainfall

Soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff. Many attempts have been made to express the erosivity of rainfall as an index. One of the well-known indices is R factor in the Revised Universal Soil Loss Equation (RUSLE) model (Renard et al. 1997). R is calculated on yearly basis by summing up the EI_{30} value of each rainstorm. The EI_{30} value for a given rainstorm equals the product of total storm energy (E) times the maximum 30-min intensity (I_{30}).

Soil erodibility

Erodibility defines the resistance of the soil to both detachment and transport. Although a soil's resistance to erosion depends in part on topographic position, slope steepness and the amount of disturbance, the properties of the soil are the most important determinants. Erodibility varies with soil texture, aggregate stability, shear strength, infiltration capacity , organic matter content and chemical comopsition, as reviewed by Morgan (1995). A more commonly-used index of erodibility is the K value of the RUSLE which represents the soil loss per unit of EI_{30}, as measured in the field on a standard bare soil plot, 22m long and at 5° slope (Renard et al. 1997). The K value may be estimated if the grain-size distribution, organic matter content, structure and permeability of the soil are known.

Slope

Erosion would normally be expected to increase with increases in slope steepness and slope length as a result of respective increase in velocity and volume of surface runoff.

Vegetation cover

Vegetation acts as a protective layer or buffer between the atmosphere and the soil. The above-ground components, such as leaves and stems, absorb some of the energy of falling raindrops, and running water, so that less is directed at the soil, while the below-ground components, comprising the root system, contribute to the mechanical strength of the soil.

1.2 Study objectives

In this thesis, the author intended to evaluate water erosion risks and to seek the alternative ways of sustainable land use in northeastern Syria. To achieve this final goal, the author established the following objectives:

1) to evaluate the impact of grazing and tillage on water erosion through the field experiment (Chapter 3),
2) to investigate relationships among the factors controlling water erosion (Chapter 4), and
3) to evaluate the water erosion risks geographically using Landsat TM images and a Geographical Information System (GIS) and discuss options for the sustainable land use (Chapter 5).

Chapter 2 Study area

2.1 Location

Abd Al-Aziz mountain region, where this study was conducted, is located in the Hassakeh province, northeastern Syria (Fig. 2.1). The study area was about 900 km^2, 27 km from north to south and 33 km from east to west.

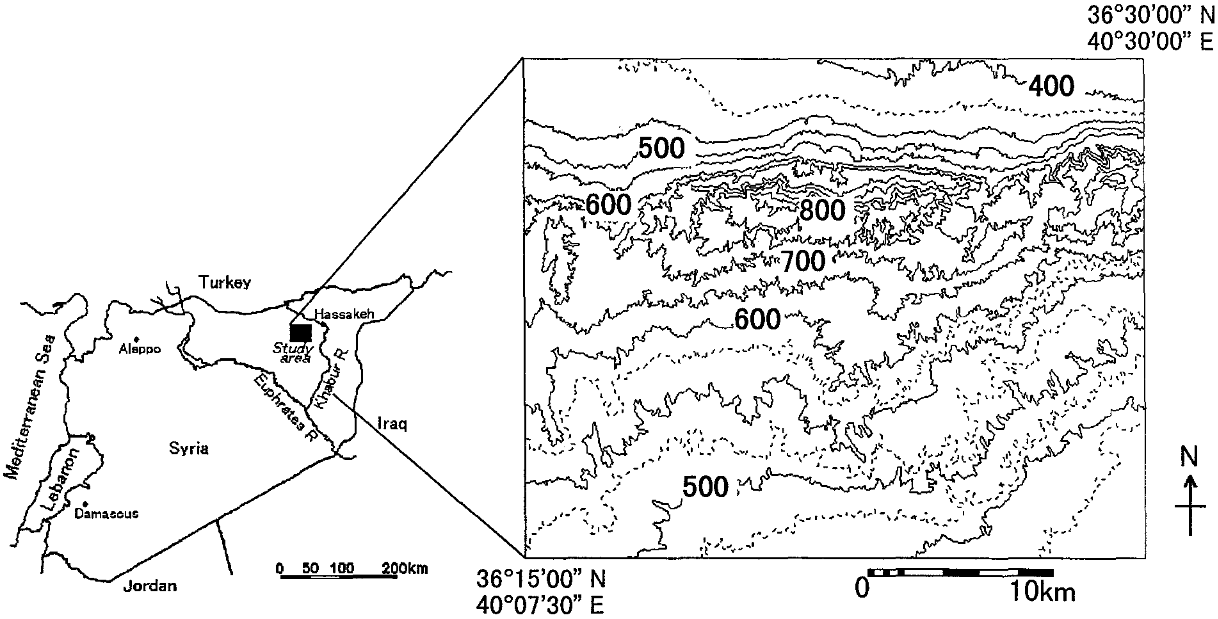


Figure 2.1 Location of the study area. Soild and dotted lines indicate contour lines at intervals of 50 and 25 m, respectively. Figures indicate the altitude above sea level.

2.2 Natural environments

2.2.1 Landscape

Altitude of the area ranges between 400 and 940 m above sea level. Three major landscapes are found; mountainous area in the central part, northern foot-plain and southern foot-plain. As clearly shown in the topographic map (Fig. 2.1), the mountainous area has the steep north slopes (Plate 2.1) and the moderate south slopes (Plate 2.2).

2.2.2 Climate

The climate is classified as subtropical semiarid Mediterranean (FAO-Unesco 1977). According to the data collected at a meteorological station in this area in 1995, the mean annual temperature was 16.2°C. The coldest month was January with a mean temperature of 4.0°C and the hottest was August with a mean temperature of 29.2°C. Average annual precipitation was about 300 mm. The rainy season occurs from October through April, and a hot and dry climate prevails from May to September (Fig. 2.2). Rainfall characteristics are described in relation to water erosion in Chapter 3.

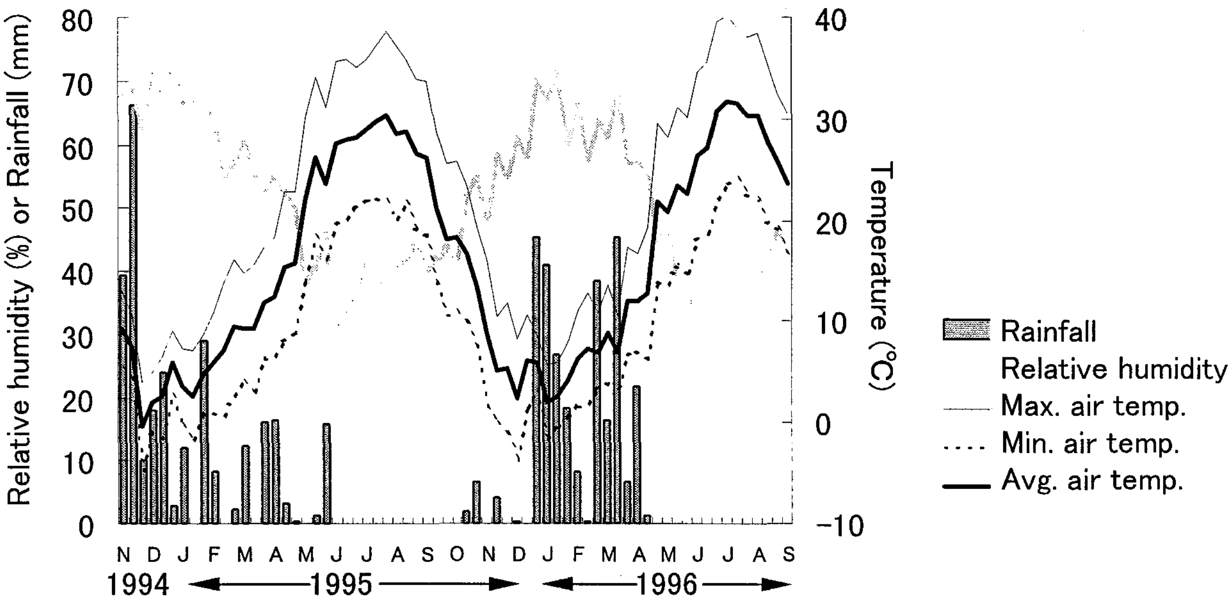


Figure 2.2 Meteorological conditions in the study area. Rainfall, relative humidity and air temperature were measured at the meteorological station located at northeastern part of the study area from Novemeber 1994 to September 1996.

2.2.3 Geology and soil

Parent materials are consolidated carbonate sediments, e.g. limestone, dolomite and marl (FAO-Unesco 1977). Gypsum was also found in some locations. In the central mountainous area, they are mainly Cretaceous and Paleogene, while they are Neogene on the northern and southern foot-slope. Shallower soils are mainly classified as Lithic Xerorthents and soils deep enough to satisfy the criterion of identifiable secondary carbonates are classified as Typic Calcixerepts (Soil Survey Staff 1998). Dominant clay minerals were smectite, kaolin, chlorite and clay mica.

2.2.4 Vegetation

Main indigenous plant species in the rangeland are *Artemisia herba-alba*, *Noaea mucronata* and *Salsola vermiculata* as shrub species, and *Poa bulbosa*, *Nardurus maritimus*, *Lopochloa phleoides* and *Silene coniflora* as herbaceous species (Hirata et al. 1998).

2.3 Land use

Table 2.1 summarizes the land use in the study area and Fig. 2.3 depicts its distribution.

Table 2.1 Land uses in the study area.

	Area (km^2)	(%)
rangeland	604	(67)
afforested	32	(4)
protected	148	(16)
grazed	424	(47)
cropland	297	(33)
total	901	(100)

2.3.1 Grazed rangeland

Mountainous area in the central part of the region has been utilized for extensive grazing as natural rangeland particularly in winter and spring (Hirata et al. 1998) (Plate 2.3). In this season, flocks of sheep and goats not only in the study area but from the surrounding area come to graze with temporary tents (Plate 2.4) since the region outside the study area has been cultivated since 1950s (Beaumont et al. 1988) and few feed resources are available there in spring.

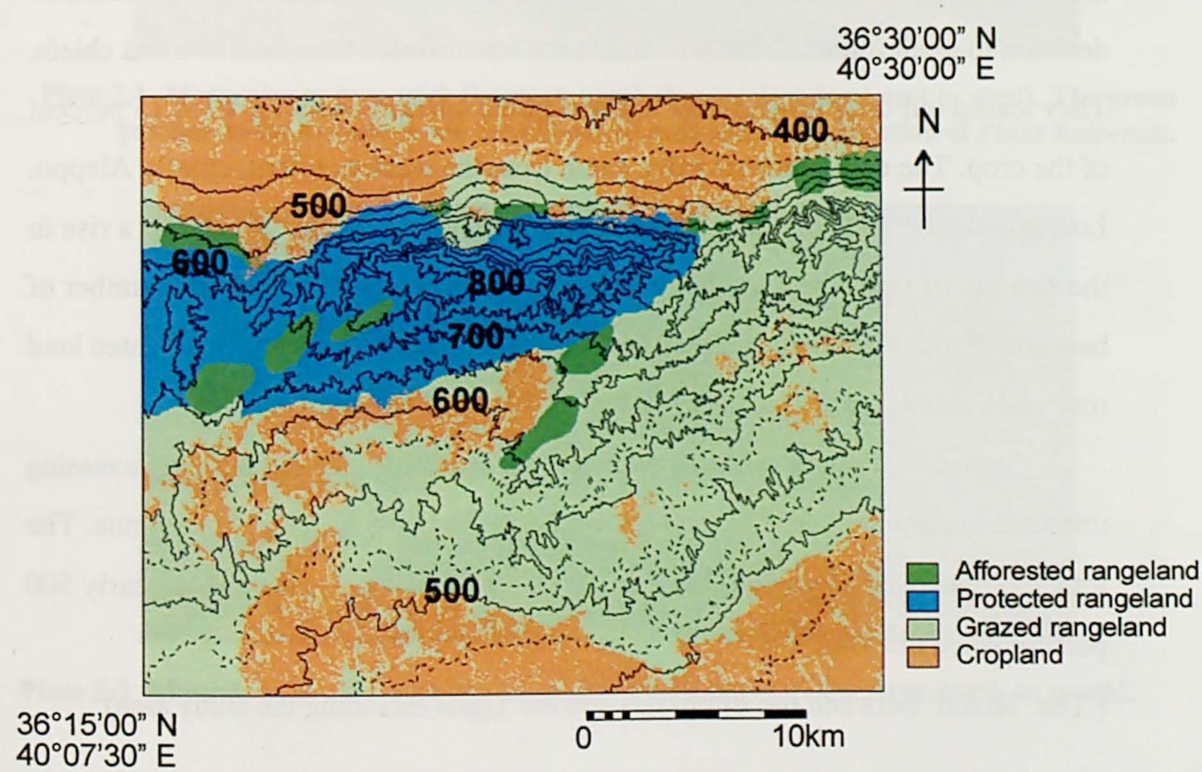


Figure 2.3 Land use map of the study area.

2.3.2 Protected and afforested rangeland

Sixteen percent and 4% of the rangeland has been preserved by the government policy as the protected area from grazing since 1994 and the afforested area, respectively. The afforestation activities started in late 1970s with the plantation of *Pinus halpensis*, *Pistacia* spp., *Prunus amygdalus*, and so on (Plate 2.1). Grazing in the afforested area is also prohibited.

2.3.3 Cropland

Thirty-three percent of the study area, mainly located in the flat topography in the central part and the foot-plain in the northern and southern parts, has been cultivated since 1950s.

2.3.3.1 Encroachment of cultivation

The history of the expansion of the cultivation in this area has been fully described by Beaumont et al. (1988).

> The outbreak of the Second World War forced the countries of the Middle East to provide all their own food. At the same time, large numbers of British and French troops were garrisoned in the region or were operating in adjacent parts of North Africa and had to be fed. Syrian response to the situation was to initiate reclamation in the recently pacified Jezira*. Economic exploitation was facilitated by a government decision to grant immense areas of fertile but uncultivated state land to tribal chiefs. They leased out their rainfed land to town-based entrepreneurs for 10 to 15 percent of the crop. The entrepreneurs often came from the western towns, chiefly Aleppo. Low population force them to adopt mechanized methods, as is shown by a rise in the number of tractors from about 30 in 1942 to 500 in 1950 and in the number of harvesting and threshing machines from about 20 to 430. The area of cultivated land rose from about 216,000 ha in 1942 to 302,200 in 1945.
>
> Capital accumulation during the War, a rising national population and increasing urbanization and industrialization allowed developments in Jezira to continue. The total cultivated area was 1,400 km^2 in 1960, representing an increase of nearly 500 percent since the War.
>
> (*The 'island' between the Euphrates and the Tigris including the study area)

2.3.3.2 Cultivation practices

Main crops are rainfed barley and wheat in the rainy season without fertilizer or herbicide. A small portion of the lands is cultivated with cotton by furrow irrigation for which wells are used. Cultivation practices are almost same since the cultivation started in 1950s. Croplands are plowed with a tractor once before sowing at the beginning of the rainy season. After the harvest of cereal grains (Plate 2.5) at the end of the rainy season, stubbles and straw are grazed (Plate 2.6) or taken out for supplemental feed during the rainy winter. No crop is cultivated in the dry season. Croplands are under fallow every three or four years and plowed two to three times during the fallow period for weeding and water harvest.

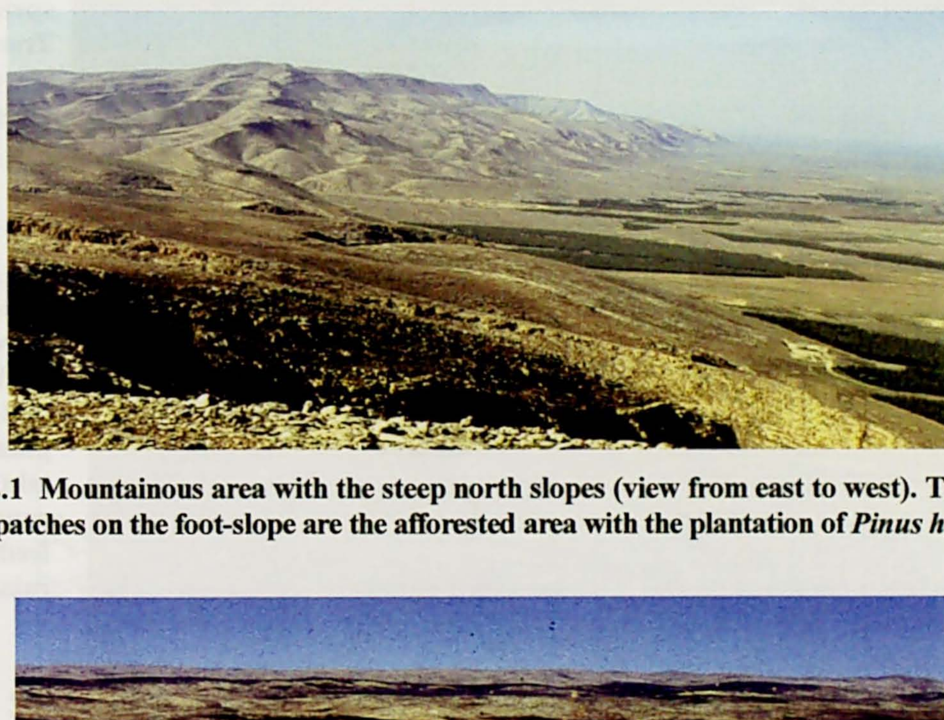


Plate 2.1 Mountainous area with the steep north slopes (view from east to west). The green patches on the foot-slope are the afforested area with the plantation of *Pinus halpensis*.

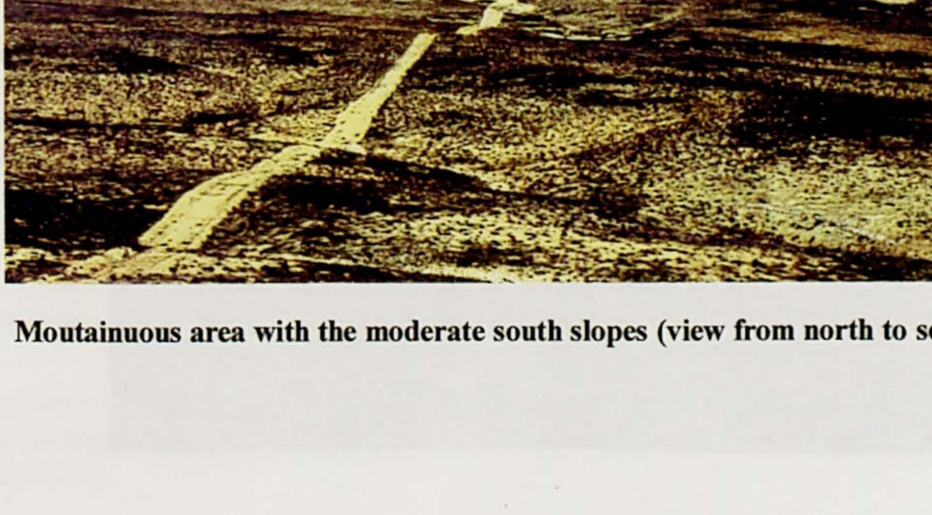


Plate 2.2 Moutainuous area with the moderate south slopes (view from north to south).

Plate 2.3 Grazing in rangeland.

Plate 2.4 Tent appearing in spring. Traditionally, tent is woven out of the goat hairs.

Plate 2.5 Barely harvested fields in northern foot-plain. The piles of straw are taken out for supplemental feed during a rainy winter.

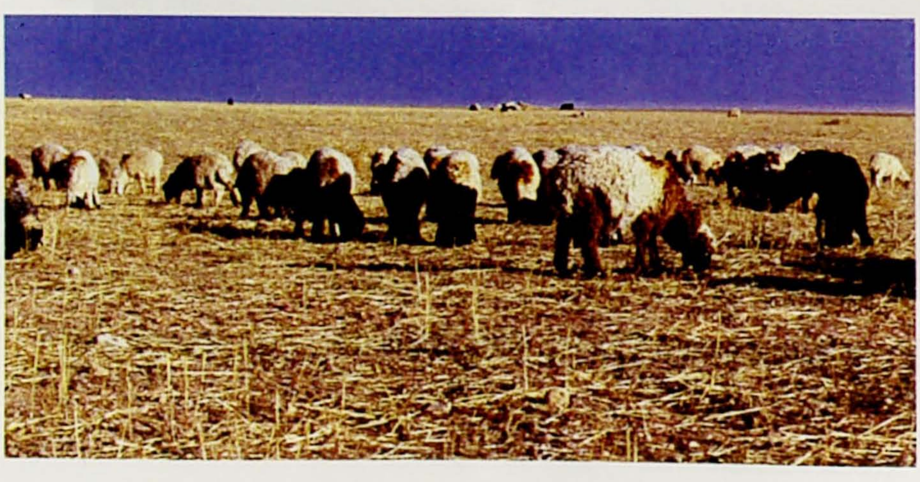


Plate 2.6 Stubble grazing in the harvested fields in summer.

Chapter 3 Impact of grazing and tillage on water erosion

3.1 General

Grazing may enhance water erosion primarily through its impact on soil and vegetation. It will deteriorate soil physical conditions through trampling. Warren et al. (1986a, b), working on the influence of livestock trampling on soil hydrologic characteristics, found that trampling decreased infiltration rate and increased sediment production. Heavy grazing will further decrease the vegetation cover and expose soil surface to rainfall (Bari et al. 1995). Additionally, cropping enhances water erosion through the decrease of the vegetation cover (Morgan 1995) and the reduction of infiltration due to soil compaction by farm machinery operation (Fullen 1985).

However, most of the studies have been conducted under experimental conditions, sometimes too extreme to evaluate the real risk of water erosion. Thus, in this chapter, the impact of grazing and tillage on water erosion under actual land use is evaluated through field experiments by discussing the relationship between the occurrence of water erosion and the

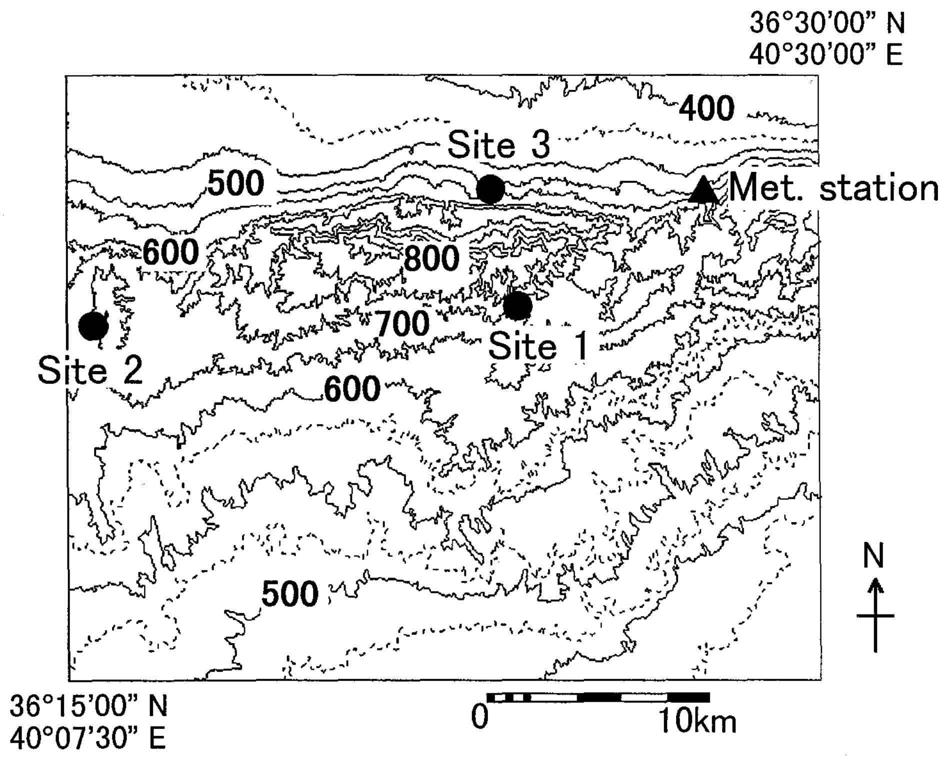


Figure 3.1 Location of the experimental sites and the meteorological station. Solid and dotted lines indicate contour lines at intervals of 50 m and 25 m, respectively. Figures indicate the altitude above sea level.

factors controlling water erosion, i.e. rainfall, slope gradient, soil properties and vegetation coverage.

3.2 Materials and methods

3.2.1 Layout and conditions of the experimental sites

3.2.1.1 Layout of the experimental plots

The author selected three sites in the study area to evaluate the impact of grazing and tillage on water erosion (Fig. 3.1). At each site, the author set up two plots on slopes with a similar gradient and adjacent to each other but differing in the types of land use (Table 3.1). The dimension of each plot was 21 m in length and 1.8 m in width, 37.8 m^2 in enclosed area (Plate 3.1a). At the lower end, the author installed two adjacent tanks, 1 m long and wide and 0.5 m deep, to collect runoff water and soil sediment. These tanks were connected by a divisor which allowed one seventh of the overflowing water and sediments in the upper tank to flow into the lower one.

Table 3.1 Brief description of the experimental plots.

Plot	Site	Land use	Landscape	Slope gradient	Soil classification	Dominant plant species Herbaceous	Dominant plant species Shrub
P1g	1	g (grazed)	mountain	9°	Lithic Xerorthent	*Bromus* spp., *Psilurus* spp.	None
P1p	1	p (protected[a])	mountain	11°	Lithic Xerorthent	*Lopochloa* spp., *Papaver* spp.	*Noaea mucronata*
P2g	2	g (grazed)	mountain	7°	Typic Calcixerept	*Lopochloa* spp., *Poa* spp.	*Noaea mucronata*
P2p	2	p (protected[a])	mountain	6°	Typic Calcixerept	*Lopochloa* spp., *Nardurus* spp.	*Noaea mucronata*
P3f	3	f (fallow[b])	foot-slope	2°	Typic Calcixerept	*Anabasis* spp., *Lolium* spp.	None
P3g	3	g (grazed)	foot-slope	2°	Typic Calcixerept	*Bromus* spp., *Lopochloa* spp.	*Artemisia herba-alba*

[a] protected for about 10 years
[b] barley cultivated for about 10 years before the fallow period

3.2.1.2 Conditions of the experimental sites

Site 1 and Site 2 (Plates 3.1 and 3.2)

To analyze the grazing impact on water erosion, at Site 1 and Site 2 in the mountainous area, the author set up one plot in the grazed area (P1g at Site 1 and P2g at Site 2) and the other in the protected one (P1p and P2p), as shown in Table 3.1. Grazing in P1g and P2g was not controlled but depended on the decision of local shepherds. P1p and P2p had been protected from grazing for about 10 years. Soils at Site 1 were shallow and classified as Lithic Xerorthents. Soils at Site 2 were classified as Typic Calcixerepts.

Site 3 (Plate 3.3)

At Site 3 on the northern foot-slope, the author set up one plot in the tilled fallow area (P3f) and the other in the grazed one (P3g), as shown in Table 3.1. Before cultivation started about a decade ago, P3f had been grazed in the same manner as P3g. P3f was tilled by a tractor just before the experiment started and left without any cultivation practice during the experiment. Grazing in P3g depended on the decision of local shepherds as in the case of P1g and P2g. Soils at Site 3 were classified as Typic Calcixerepts.

Slope gradients and the dominant plant species in these plots are shown in Table 3.1.

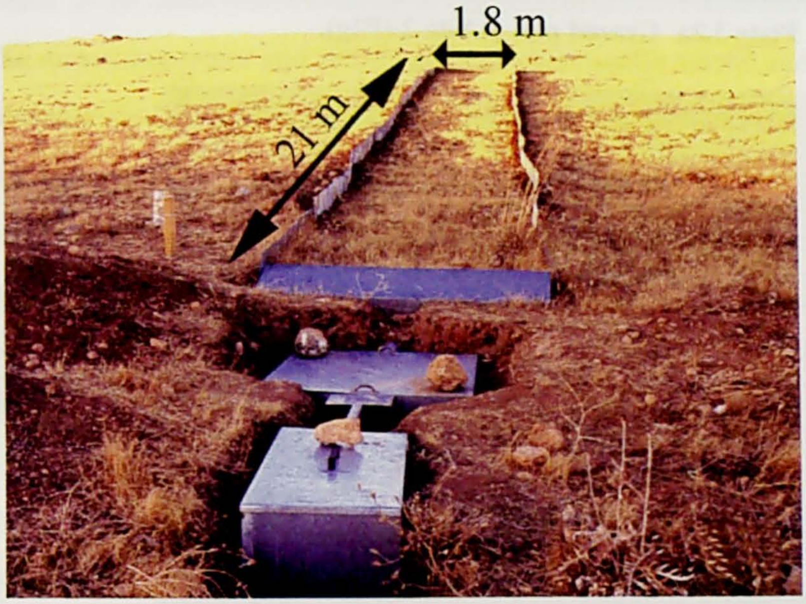


Plate 3.1a Grazed plot at Site 1 (P1g). Dimension of the plot was 21 m in length and 1.8 m in width.

Plate 3.1b Protected plot at Site 1 (P1p).

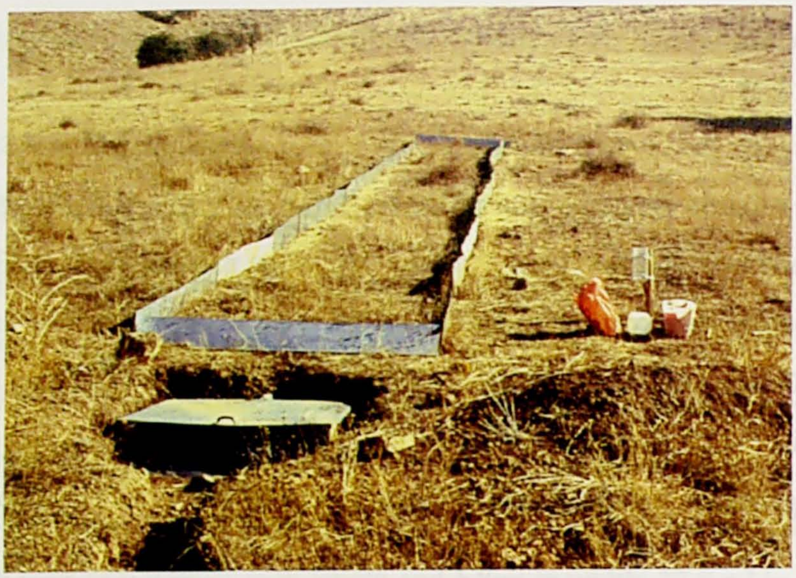


Plate 3.2a Grazed plot at Site 2 (P2g).

Plate 3.2b Protected plot at Site 2 (P2p).

Plate 3.3 Fallow and grazed plots at Site 3 (P3f and P3g).

3.2.2 Methods of field measurement

3.2.2.1 Rainfall

A self-recording rain gauge (Campbell Scientific, Inc.) of the tipping-bucket type and with a 0.1 mm detecting power, was installed at the meteorological station (Fig. 3.1). The rainfall data were recorded from November 1994 to September 1996.

3.2.2.2 Runoff water and sediment yield

Amount of runoff water and soil sediment trapped in the tanks was measured every time after considerable rainfall event in the 1994/95 and the 95/96 rainy seasons. Depth of water in the tanks was measured for the estimation of runoff. After drainage of the supernatant, the remaining water and sediments were thoroughly stirred and an aliquot of the suspension was sampled, then air-dried. After oven-drying at 105°C for 24 h, a portion of the air-dried sediment sample was weighed to calculate the sediment yield. The amount of runoff water and the soil sediments in each measurement were summed up to calculate the total runoff and soil loss, respectively, for each season.

3.2.2.3 Soil surface coverage

According to the method of Bonham (1989), the author measured the vegetation coverage in the experimental plots by applying a point transect method in April and October 1995, and February and May 1996. A 25 m-long line was set along the plot and the vegetation on the line was recorded at intervals of 50 cm. The percentage of the frequency of shrub and herbaceous species on the line was referred to as plant contact.

Coverage of rock fragments on the soil surface was measured to represent the area covered with rocks, which was greater than 2 cm in diameter, in a quadrat of 1 m^2 with four replicates in all the plots.

3.2.3 Soil sampling and methods of analysis

3.2.3.1 Soil sampling

Soil samples were collected from the surface horizons in all the plots in May 1996. The depth of the surface horizon and selected physicochemical properties are shown in Table 3.2. For the analyses of the above-mentioned properties, air-dried, <2.0 mm sieved fine earth was used. For the aggregate stability tests, aggregates with diameters ranging between 1.0 and 2.0 mm were sieved out from the undisturbed soils.

Table 3.2 Selected physicochemical properties in the experimental plots.

Plot[a]	Depth of surface horizon (cm)	pH (H_2O)	EC ($mS\ m^{-1}$)	Total nitrogen[b] ($g\ kg^{-1}$)	$CaCO_3$[b] ($g\ kg^{-1}$)	Particle size distribution[c] ($\times 10\ g\ kg^{-1}$) C. Sand	F. Sand	Silt	Clay
P1g	11	7.68	35.7	2.13	322.5	0.8	15.6	37.6	46.0
P1p	6	7.77	32.8	1.84	539.2	3.0	15.9	37.6	43.6
P2g	4	7.74	43.9	2.16	273.3	0.2	16.9	42.0	40.9
P2p	4	7.69	49.2	2.45	282.5	0.5	15.5	37.6	46.5
P3f	10	7.92	27.4	0.76	520.0	3.0	20.9	37.5	38.7
P3g	3	7.67	41.1	1.40	514.2	6.1	16.4	38.6	39.0

[a] Refer to Table 3.1 for the abbreviations of the plots.
[b] Oven-dry basis
[c] Oven-dry basis after removal of $CaCO_3$

3.2.3.2 Analytical methods for selected soil physicochemical properties

The pH and electrical conductivity (EC) were measured with glass electrodes using a 1 : 1 (w/v) suspension of soil and deionized water. Total nitrogen content of the soil and the sediment samples was determined by a dry combustion method with a NC analyzer (NC-800-13N, Sumika). For particle size distribution, after the removal of calcium carbonate ($CaCO_3$) by 1 mol L^{-1} sodium acetate solution at pH 5 (Gee and Bauder 1986), the coarse and fine sand fractions were determined by the sieving method, and the silt and clay fractions by the pipette method. The content of $CaCO_3$ was determined by a back-titration method (Ryan et al. 1996). In this method, after the dissolution of $CaCO_3$ in a soil sample with an excess of 1 mol L^{-1} HCl, the remaining amount of HCl was back-titrated with a 0.5 mol L^{-1} NaOH solution to calculate the content of $CaCO_3$, assuming that one mole of HCl consumed is equivalent to one half mole of $CaCO_3$.

3.2.3.3 Measurement of soil aggregate stability

Since the influence of the initial water content on the soil aggregate stability had been noted (Le Bissonnais et al. 1989), both air-dried and prewetted aggregates were examined by a wet-sieving test with a single sieve (Kemper and Rosenau 1986). For the determination of the air-dried aggregate stability, the author dropped 10 grams of the air-dried aggregates (1.0

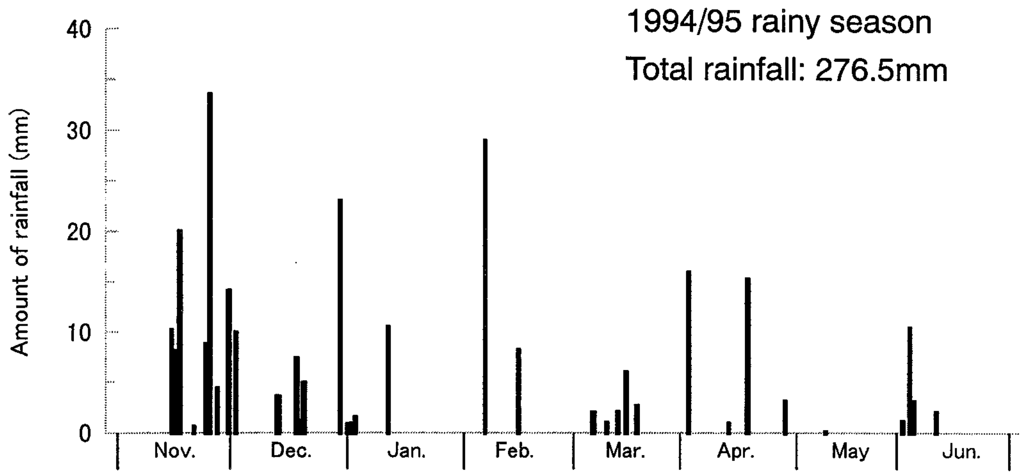
– 2.0 mm) onto a sieve with an opening of 0.25 mm placed in water, then sieved them by raising and lowering with a distance of 5 cm at a stroke of 30 times min^{-1} for 5 min. For the determination of the prewetted aggregate stability, the author moistened the air-dried aggregates gently and gradually by mist spraying and sieved them in water using the same procedure as that applied for the air-dried aggregate stability. Following the calculation of the oven-dried weight of the initial aggregates examined and of the air-dried and the prewetted aggregates remaining on the sieve after wet-sieving, the proportion of the weight of the latter to that of the former was represented as an index of the air-dried aggregate stability and the prewetted aggregate stability, respectively.

3.3 Results and discussion

3.3.1 Rainfall characteristics

The total amount of rainfall was almost the same in both seasons, i.e. 276.5 mm in the 1994/95 season and 281.7 mm in the 1995/96 season. Figure 3.2 shows the distribution pattern of the rainfall events in each season. A rainfall event was the one defined by Wischmeier (1959) as a continuous event in which the interval between the rainfall periods did not exceed 6 hr. The 94/95 season showed a unimodal pattern and 37% of the total rainfall amount occurred in November. After November, the rainfall events took place intermittently. In the 95/96 season, the distribution pattern was bimodal and 40% of the rainfall amount was concentrated in January and 35% in March. Except for these two months, the rainfall events were scarce with a small amount of rainfall.

The author plotted the amount (mm) of each rainfall event against its maximum 30-min rainfall intensity (mm h^{-1}), I_{30}, in Fig. 3.3. Five rainfall events with >10 mm h^{-1} of I_{30} were recorded in the 94/95 season and 2 in the 95/96 season, indicating that the frequency of the intensive rainfall events was larger in 94/95 than in 95/96. This indication is in agreement with the values of the rainfall erosivity index (R) calculated according to the method of Wischmeier and Smith (1958) in each season, i.e. the R value was 27 kJ mm m^{-2} h^{-1} in 94/95 in contrast to 16 kJ mm m^{-2} h^{-1} in 95/96. In both seasons, however, more than 80% of the rainfall events occurred at I_{30} <10 mm h^{-1}. These results confirm that, contrary to the common assumption for the arid and semiarid areas that rainfall events show a high intensity, most of the rainfall events showed a rather low intensity in the temperate semiarid regions, as reported



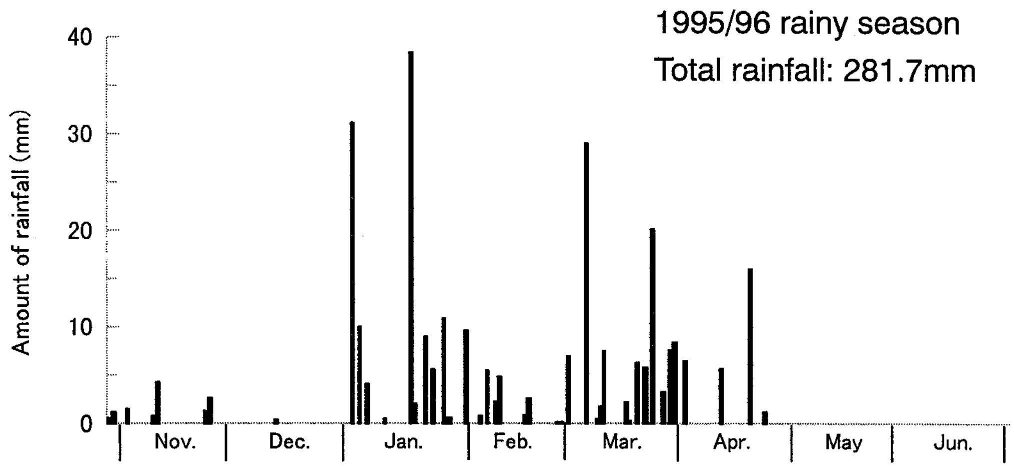


Figure 3.2 Rainfall distribution in the study area in the 1994/95 and 1995/96 rainy seasons.

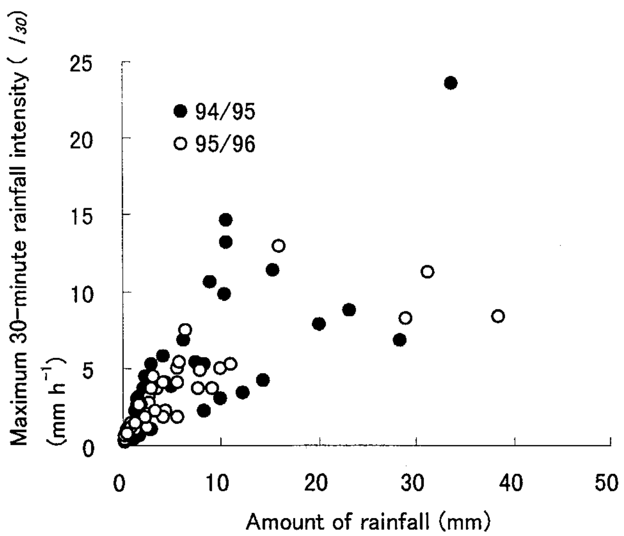


Figure 3.3 Scattergram of the amount of rainfall with maximum 30-mimute intensity (I_{30}).

by Bryan and Campbell (1980) for Canada, Castillo et al. (1997) for Spain, and Zhu et al. (1997) for China.

3.3.2 Seasonal changes of vegetation coverage

Coverage of herbaceous and shrub species referred to as plant contact at each site in April and October 1995 and February and May 1996, is shown in Figs. 3.4, 3.5 and 3.6.

Site 1 and Site 2

The plant contact of the herbaceous species in P1g ranged from 66.0% in February 1996 to 94.0% in May 1996 and was similar to that in P1p ranging from 76.0% in May 1996 to 93.1% in April 1995 (Fig. 3.4). On the other hand, shrub species (*Noaea mucronata*) were found only in P1p. Consequently, the total plant contact of shrub and herbaceous species in P1g was lower than that in P1p throughout the experimental period. As shown in Fig. 3.5, the total plant contact in P2g and P2p was almost identical during the experiment. The total plant contact in P2g ranged from 78.0% in February 1996 to 96.0% in May 1996, and that in P2p ranged from 70.0% in February 1996 to 96.0% in May 1996. P2g and P2p differed in the contribution of shrub species to the plant contact which was larger in P2p than in P2g. During the dry season between April and October 1995, the plant contact decreased in all the plots except for P1p.

Site 3

Since P3f had been used as cropland, no shrub species were found (Fig. 3.6). The decrease in the plant contact of herbaceous species from 75.0% in April 1995 to 0.0% in October 1995 in P3f and from 67.9% in April 1995 to 14.7% in October 1995 in P3g was due to grazing and drying up during the dry season. As the rainy season proceeded from October 1995 to May 1996, herbaceous species seemed to grow. Thus, the shrub species (*Artemisia herba-alba*) in P3g contributed to the total plant contact relatively more at the beginning of the rainy season than in the succeeding period.

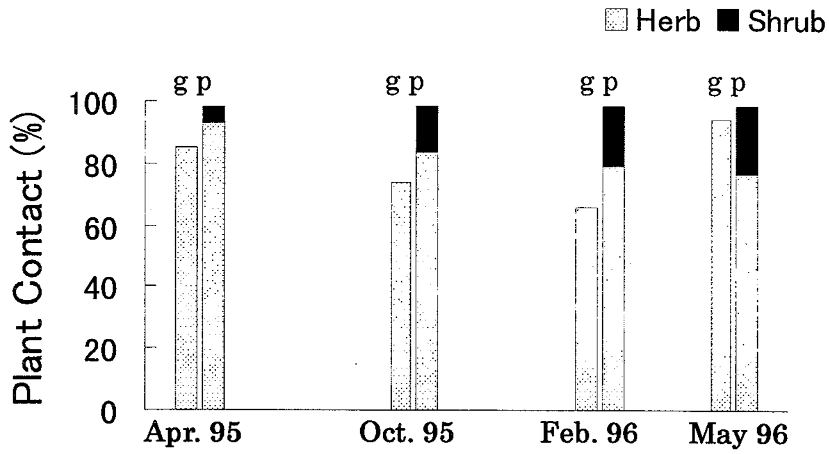


Figure 3.4 Seasonal changes of plant contact in P1g (g) and P1p (p).

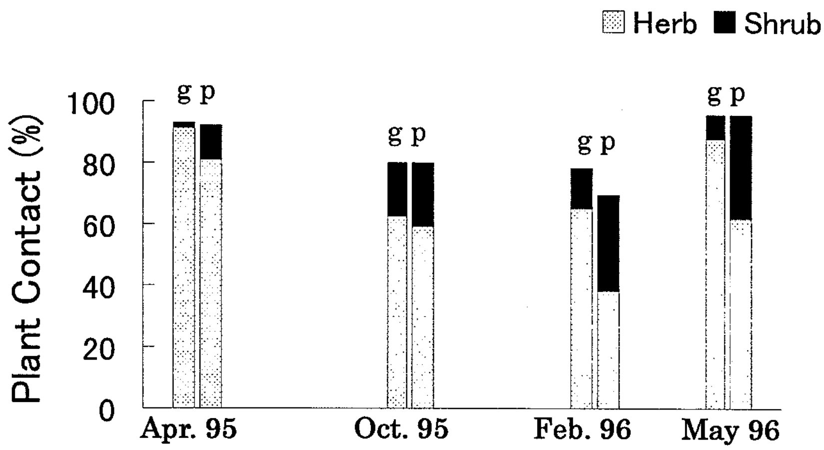


Figure 3.5 Seasonal changes of plant contact in P2g (g) and P2p (p).

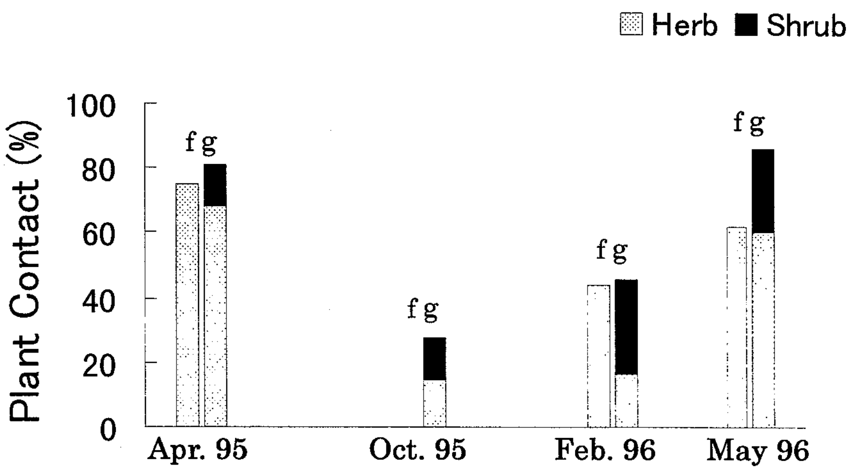


Figure 3.6 Seasonal changes of plant contact in P3f (f) and P3g (g).

3.3.3 Influence of landscape on water erosion

In both seasons, P1g and P2g in the mountainous area showed a runoff and soil loss comparable to, or even lower, than those in P3g on the foot-slope (Table 3.3). The lower magnitude of water erosion in P1g and P2g, whose slope gradients were higher than that of P3g (Table 3.4), can be ascribed to the fact that the high level of the soil surface coverage with vegetation and rock fragments could reduce the raindrop impact and that the soils with stable aggregates were able to withstand its impact. Table 3.4 shows that the average of the total plant contact was 79.8% in P1g and 86.8% in P2g in contrast to 60.3% in P3g, the rock coverage being also significantly higher in P1g and P2g than in P3g at the $P < 0.05$ level. In addition, the air-dried aggregate stability in P1g and P2g was 67.4 and 61.2 $\times 10^{-2}$ kg kg^{-1}, respectively, which was higher than 41.6 $\times 10^{-2}$ kg kg^{-1} in P3g (Table 3.4).

Table 3.3 Results of the soil erosion measurement in the two rainy seasons (1994-1996).

Plot[a]	1994/95 Runoff (mm)	1994/95 Soil loss (kg ha^{-1})	1995/96 Runoff (mm)	1995/96 Soil loss (kg ha^{-1})
P1g	1.0	103.1	1.3	25.6
P1p	1.2	0.0	0.0	0.0
P2g	1.3	393.3	3.8	125.8
P2p	2.6	77.9	4.5	98.8
P3f	52.4	1448.4	6.8	197.1
P3g	9.8	374.9	3.2	25.1

[a] Refer to Table 3.1 for the abbreviations of the plots.

Table 3.4 Selected parameters relevant to water erosion in the experimental plots.

Plot[a]	Slope gradient	Aggregate stability ($\times 10^{-2}$ kg kg^{-1}) Air-dried	Aggregate stability Prewetted	Rock coverage ($\times 10^{-2}$ m^2 m^{-2}) average[b] (SD[d])	Plant contact (%) average[c] (SD[d]) Herb	Shrub	Total
P1g	9°	67.4	98.6	28.2 (13.0)	79.8 (10.6)	0.0 (0.0)	79.8 (10.6)
P1p	11°	65.0	91.8	5.6 (2.7)	82.9 (6.5)	15.1 (6.5)	98.0 (0.0)
P2g	7°	61.2	94.6	6.9 (8.2)	76.7 (13.2)	10.1 (6.1)	86.8 (7.9)
P2p	6°	68.6	95.5	6.7 (1.8)	60.2 (15.4)	24.3 (9.4)	84.5 (10.2)
P3f	2°	36.7	85.8	3.0 (0.4)	45.3 (28.4)	0.0 (0.0)	45.3 (28.4)
P3g	2°	41.6	83.6	2.1 (1.0)	39.7 (24.5)	20.6 (7.5)	60.3 (24.2)

[a] Refer to Table 3.1 for the abbreviations of the plots.

[b] Average of four replicates.

[c] Average of four measurements throughout the experiment.

[d] Standard deviation.

3.3.4 Rainfall characteristics and water erosion

Among the previous studies on the relationship between rainfall characteristics and water erosion, Wischmeier and Smith (1958) adopted the rainfall erosivity index (R) to relate annual soil loss, and several authors defined the threshold value in terms of the amount or intensity of a rainfall event, above which the occurrence of water erosion is certain (Wischmeier and Smith 1958; Morgan 1995; Zhu et al. 1997). In this study, however, there was no significant relationship between the magnitude of water erosion (runoff and soil loss) and the rainfall characteristics such as the amount, I_{30}, and the erosivity index, R. One of the reasons may be that the rainfall characteristics at the experimental sites were not always consistent with those at the meteorological station, which is distant from the experimental sites, as shown in Fig. 3.1.

In spite of the absence of quantitative relationship between rainfall characteristics and water erosion, the difference in soil loss in P3g between 374.9 kg ha^{-1} in the 94/95 season and 25.1 kg ha^{-1} in the 95/96 season (Table 3.3) might be ascribed to the difference in rainfall erosivity, as indicated above, since the conditions of soil and vegetation were considered to be identical in the two seasons. The plots of Site 1 and Site 2 showed only a small difference in soil loss between the two seasons possibly because the soil surface coverage and aggregate stability in these plots were high enough to reduce the difference in rainfall erosivity. The difference in soil loss in P3f between 1448.4 kg ha^{-1} in the 94/95 season and 197.1 kg ha^{-1} in the 95/96 season cannot be explained only by the difference in rainfall erosivity. The soil conditions in P3f might have varied between the two seasons since the soil in P3f could be undergoing the settlement after the mechanical disturbance by tractor tillage prior to the experiment.

As shown in Fig. 3.2, the intervals between the rainfall events frequently exceeded 1 week or more. This intermittent nature of rainfall is likely to enhance the magnitude of water erosion. It is possibly supported by the fact that as the interval between two rainfall events was longer, the soil surface became drier and the less stable soil aggregates were subjected to the rainfall impact since the air-dried soil aggregate stability in the all plots, ranging between 36.7 and 68.6 $\times 10^{-2}$ kg kg^{-1}, was much lower than that of the prewetted one, ranging between 83.6 and 98.6 $\times 10^{-2}$ kg kg^{-1} (Table 3.4).

3.3.5 Influence of land use type on water erosion

Grazing

Both Site 1 and Site 2 showed a slightly larger amount of soil loss in the grazed plots (P1g and P2g) than in the protected ones (P1p and P2p) in both seasons (Table 3.3). Nevertheless, the highest rate of soil loss in these plots was 393.3 kg ha^{-1} in P2g in the 94/95 season, which was negligibly low compared to the tolerance limits of 4,500 – 11,200 kg ha^{-1} yr^{-1} proposed by USDA (Wischmeier and Smith 1978), and the impact of grazing on water erosion was not significant under the present conditions. One of the reasons is that the total plant contact was maintained in the range between 66.0 and 96.0% throughout the seasons in these plots, as shown in Figs. 3.4 and 3.5, which may have protected the soil surface from the raindrop impact. Owing to the high level of plant contact of herbaceous species, P1g and P1p showed a similarly lower amount of soil loss irrespective of the presence of shrub species. The presence of herbaceous species with a higher coverage throughout a year in P1g and P2g implies that these plots were not heavily grazed.

Tillage

The larger amount of soil loss in P3f, 1448.4 kg ha^{-1}, than that in P3g, 374.9 kg ha^{-1}, in the 94/95 season was ascribed to the influence of the mechanical disturbance by tractor tillage in P3f before the 94/95 rainy season. On the other hand, the difference in soil loss between P3f and P3g in the 95/96 season was due to the vegetation coverage. Although the aggregate stability is often recognized as an effective index of soil erodibility (Le Bissonnais 1996a), this was not the case for these plots since the aggregate stability was almost the same for both air-dried and prewetted aggregates (Table 3.4). As for the vegetation coverage, the plant contact of herbaceous species in both plots changed throughout the year in the same manner (Fig. 3.6), and the average value in P3f was comparable to that in P3g, 45.3% and 39.7%, respectively (Table 3.4). Therefore, the additional coverage by shrub species could protect the soil surface effectively in P3g. Based on these results and the apparently opposite results in P1g and P1p which showed a similar level of soil loss irrespective of the presence of shrub species, the coverage with shrub species was considered to be significant for protecting the soil surface when the coverage with herbaceous species is relatively low.

3.3.6 Potential risks of water erosion

3.3.6.1 Risks by grazing

As shown in the previous part, grazing even on steep slopes did not increase the water erosion risk when the vegetation coverage with shrub and/or herbaceous species was maintained at a relatively high level. Although land protection was found to be a good measure to reduce water erosion, this activity may lead to the decrease in the grazing area and could enhance the grazing pressure on the rangeland left for grazing. For this reason, grazing may have to resume in the protected area with maintaining the vegetation coverage. For the rangeland on the foot-slope where the soil is susceptible to water erosion due to the less stable soil aggregates, grazing should be managed carefully to maintain the vegetation coverage.

3.3.6.2 Risks by tillage

Cropland recorded the most serious soil loss rate in this study, or 1,400 kg ha^{-1} in P3f in the 94/95 season. In terms of the amount of soil loss, however, water erosion in the cropland was apparently negligible compared to the tolerance limits of 4,500 – 11,200 kg ha^{-1} yr^{-1} proposed by USDA (Wischmeier and Smith 1978).

In spite of the apparently negligible amount of soil loss in the cropland, the water erosion risk by tillage is not negligible because the author observed the high nitrogen enrichment ratio in P3f. The nitrogen enrichment ratio, determined as the actual amount of total nitrogen in the eroded sediments divided by the amount of total nitrogen expected from the content in the surface soil, was about 2.7 in P3f in both seasons (Table 3.5). This observation suggests that organic matter was selectively removed from the surface soils, as Francis (1990) reported. The depletion of soil organic matter adversely affects the soil productivity due to the decrease

Table 3.5 Nitrogen enrichment ratio of eroded sediments in the fallow area at Site 3 (P3f).

season	Soil loss ($kg\ ha^{-1}$)	Expected N loss ($kg\ ha^{-1}$)[a]	Actual N loss ($kg\ ha^{-1}$)[b]	Enrichment ratio[c]
1994/95	1448.4	1.10	2.82	2.6
1995/96	197.1	0.15	0.43	2.9

[a] Expected N loss was calculated as the soil loss multiplied by the total nitrogen content of bulk soils (0.76 g kg^{-1}, as shown in Table 3.2).

[b] Actual N loss was calculated as the summation of each value of soil loss multiplied by the total nitrogen content of the corresponding sediment sample.

[c] Enrichment ratio was calculated as the actual N loss divided by expected N loss.

of the content of soil nitrogen, because no nitrogen fertilizer is usually applied for the cultivation of rainfed barley.

The decrease of the content of organic matter also affects the soil physical conditions through the lowering of the aggregate stability. The lower air-dried aggregate stability at Site 3 than at Site 1 and Site 2 (Table 3.4) may correspond to the lower content of total nitrogen at Site 3, 0.76 g kg^{-1} in P3f and 1.40 g kg^{-1} in P3g, than at Site 1 and Site 2, ranging from 1.84 to 2.45 g kg^{-1} (Table 3.2). In this regard, Imeson and Verstraten (1985) and Cerdà (1998) suggested the existence of a positive correlation between the aggregate stability and organic matter content for highly calcareous soils. Thus, the selective removal of organic matter reduces the aggregate stability, and consequently increases the soil susceptibility to water erosion. Moreover, since unstable aggregates reduce the water permeability through crust formation (Tanaka et al. 1995), the volume of water infiltrating to soil is reduced, resulting in water shortage critical for rainfed agricultural production in semiarid areas including this study area. Thus, alternative cultivation practices should be developed that can prevent the decrease of the soil organic matter content by water erosion.

Chapter 4 Soil aggregate stability under different landscapes and vegetation types

4.1 General

Among the factors involved in water erosion, the soil factor is usually represented by soil erodibility and defined as the inherent susceptibility of soil to detachment and transport by rainfall and runoff. As an indicator of soil erodibility, the stability of soil aggregates is often used since aggregate breakdown is closely related to crusting that drastically reduces the infiltration capacity and increases runoff, thus leading to water erosion (Le Bissonnais 1996a). Also in this study, soil aggregate stability was found to be significant in determining the degree of soil loss at the three experimental sites, as described in Chapter 3. However, causes of the difference in soil aggregate stability between the sites in the mountain and that on the foot-slope still remain to be determined.

Many authors reported, as reviewed by Le Bissonnais (1996b), that the soil aggregate stability was controlled by several soil primary characteristics, such as soil texture, clay mineralogy, contents of organic matter, Fe and Al oxides and calcium carbonate. On the other hand, only in a few studies were the relationships between the soil aggregate stability and environmental factors such as landscapes (Pierson and Mulla 1990) and vegetation types (Cerdà 1998) examined. For predicting the potential risk of water erosion in a given area, the evaluation of the soil aggregate stability in relation to environmental factors would be more appropriate than that by parameters generally recognized as soil properties, since environmental factors could be determined more readily based on remotely sensed data and/or existing maps.

Thus, this chapter presents the relationships between the soil aggregate stability and environmental factors, i.e. slope gradient and soil surface coverage. These relationships will reveal the environmental conditions promoting the stability of soil aggregates, which may contribute to the development of effective management to increase the soil aggregate stability and thus to alleviate water erosion.

4.2 Materials and methods

4.2.1 Soil sampling and field investigations

The author carried out soil sampling and field investigations in the study area during the 1996 dry season. The author selected 55 sites in the rangeland and 18 in the cropland which represented this area in terms of vegetation types, parent materials and landscapes (Fig. 4.1). Of the 18 sites in the cropland, 10 were selected from fallow fields and 8 from cultivated fields after harvest of rainfed barley or wheat. The author collected 8 sub-samples randomly from the depth of 0 - 5 cm at each site to obtain a composite soil sample. For the analysis of the chemical properties, air-dried, <2 mm sieved fine earth samples were prepared. One to two mm fraction of soil aggregates was sieved out for the soil aggregate stability test.

Slope gradients (SLOPE) at the sampling sites were measured with a clinometer (Nichika Corp. 0207). Soil surface coverage was measured with a point transect method (Bonham 1989) in the rangeland. A 25 m-long line was set across the site, and objects on the line were recorded at intervals of 50 cm and categorized into 5 classes: shrub species (SHRUB),

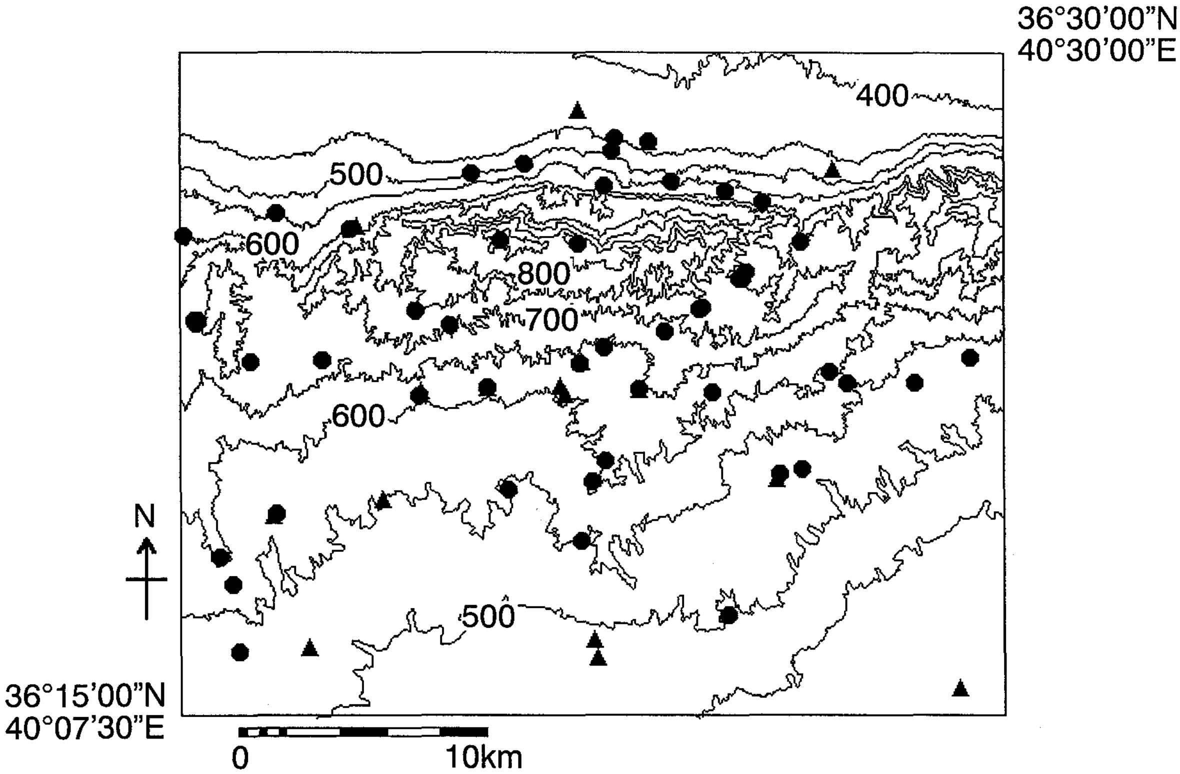


Figure 4.1 Location of the sampling sites in the study area. ●, rangeland; ▲, cropland. Solid lines indicate contour lines at intervals of 50 m. Figures indicate the altitude above sea level.

herbaceous species (HERB), litter (LITTER), gravel with a diameter above 2.0 cm (GRAVEL) and bare soil (SOIL). The percentage of the frequency of each class on the line was calculated.

4.2.2 Methods of soil analysis

The pH (PH), electrical conductivity (EC) and the content of inorganic carbon (INORGC) existing as carbonates were determined by the same method as that described in Section 3.2.3.2. Organic carbon content (ORGC) was determined by wet digestion with a mixture of potassium dichromate and concentrated sulfuric acid (Tyurin 1931).

The air-dried aggregate stability (DAS) and the prewetted aggregate stability (WAS) were determined by the same method as that described in Section 3.2.3.3. The sand content (SAND) represented the proportion of the weight of the primary particles remaining on the sieve with an opening of 0.25 mm after wet-sieving to the initial weight of the aggregates examined.

4.2.3 Statistical analysis

In order to summarize the data obtained from the field investigations and the soil analysis in the rangeland, the author performed a principal component analysis (PCA) with varimax rotation. Using PCA, the author evaluated the relationship among the variables and extracted the factors that might cause the variation in soil aggregate stability. After some factors were identified and interpreted, the factor scores were computed for each sampling site, resulting in new and sole variables for multiple regression analysis. For multiple regression analysis, the author employed a stepwise regression analysis with a significance level of 0.15 for introducing and deleting a variable to obtain the optimum model for predicting the soil aggregate stability.

The identification of the environmental parameters representative of each PCA-derived variable was followed by a stepwise regression analysis using the environmental parameters themselves as the independent variables and soil aggregate stability as the dependent one. All the computations were carried out using SYSTAT (SPSS Inc. 1998).

4.3 Results and discussion

4.3.1 Conditions of soil, landscape and vegetation

Table 4.1 shows the mean values and the coefficients of variance (C.V.) for the soil properties and SLOPE in the rangeland, cropland and the total. The mean value of PH was 7.8 in total, reflecting the high value of INORGC with a mean value of 55.5 g kg^{-1}. The mean value of EC was 49.6 mS m^{-1} in total with exceptionally high values exceeding 100 mS m^{-1} for the five soils derived the parent materials containing high content of gypsum. The mean value of ORGC, 12.8 g kg^{-1}, indicated that the organic matter content was within the average range of the soils in a Mediterranean semiarid environment (Osman et al. 1991). However, it should be pointed out that ORGC in the cropland with a mean value of 8.9 g kg^{-1} was significantly ($P < 0.001$) lower than that in the rangeland with a mean value of 14.0 g kg^{-1}. This may have been caused by the removal of crop residues, selective loss by water erosion (Chapter 3) and decomposition accelerated by disk plowing, which is the major tillage method practiced in the study area, bringing up soil materials with low ORGC from depths of about 20 cm.

The values of SLOPE ranged between 0° and 16° with a mean value of 4.6° in total. SLOPE in the cropland with a mean value of 2.6° was significantly ($P < 0.01$) lower than that in the rangeland with a mean value of 5.3° since the cropland was mainly located on the foot-slope, and not in the mountainous area.

Table 4.1 General chemical properties and aggregate stability of the soils sampled and slope gradient.

	Rangeland 55 sites		Cropland 18 sites		Total 73 sites	
	mean	C.V.(%)[a]	mean	C.V.(%)[a]	mean	C.V.(%)[a]
PH	7.8	1.8	7.9	1.6	7.8	1.7
EC (mS m^{-1})	47.8	62.5	54.9	83.9	49.6	69.3
ORGC (g kg^{-1})[b,c]	14.0	40.8	8.9	24.2	12.8	43.3
INORGC (g kg^{-1})[b,d]	54.8	24.0	57.3	24.2	55.5	24.0
SAND ($\times 10^{-2}$ kg kg^{-1})	23.2	28.3	17.6	58.1	21.8	36.3
DAS ($\times 10^{-2}$ kg kg^{-1})[e]	49.6	27.9	41.0	33.1	47.5	29.9
WAS ($\times 10^{-2}$ kg kg^{-1})[f]	90.8	7.4	86.8	8.4	89.8	7.8
SLOPE (degree)	5.3	63.6	2.6	73.3	4.6	70.7

[a] Coefficient of variance
[b] Oven-dried basis
[c] Organic Carbon
[d] Inorganic Carbon
[e] Air-dried aggregate stability
[f] Prewetted aggregate stability

Table 4.2 summarizes the relative frequency of the soil surface coverage divided into 5 classes for the rangeland. The C.V. values of SHRUB and HERB were 89.6% and 56.1%, respectively, showing that the composition and coverage of vegetation varied spatially. Since the mean values of LITTER and GRAVEL were 2.5% and 7.1%, respectively, which were negligibly small compared to those of SHRUB and HERB, the percentage of the land surfaces exposed, SOIL, was the remainder of the sum of SHRUB and HERB at most sites.

The sampling sites in the rangeland were classified into 4 types based on the soil surface coverage and land use: protected shrubland, grazed shrubland, dense grassland and sparse grassland (Fig. 4.2). First, rangeland was operationally divided into "shrubland" and "grassland" according to the threshold value of 15% of SHRUB. Shrubland was further divided

Table 4.2 Composition of soil surface coverage (%) in the rangeland.

	min.-max.	mean	C.V.(%)[a]
SHRUB	0-62	18.9	89.6
HERB	6-94	41.7	56.1
SOIL	0-68	29.8	59.7
LITTER	0-10	2.5	127.4
GRAVEL	0-42	7.1	130.0

[a] Coefficient of variance

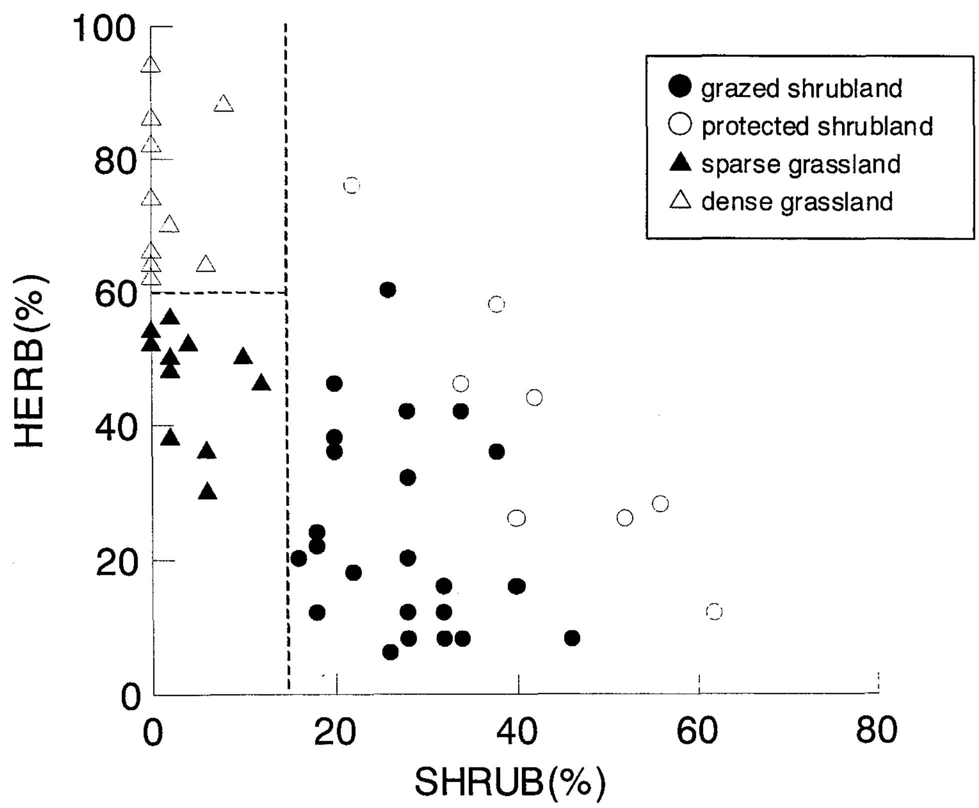


Figure 4.2 Scattergram of the soil surface coverage in the rangeland.

into "protected shrubland" and "grazed shrubland" according to the land use type. The former showed higher values of SHRUB and/or HERB than the latter since the former had not been grazed. Grassland was divided into "dense grassland" and "sparse grassland" by setting the threshold value of 60% of HERB. The dense grassland presumably resulted from protection from grazing although this implication remained to be determined unlike the case of shrubland where vigorous growth of herbaceous species could discriminate the protected shrubland from the grazed one. As a result, out of 55 sampling sites in the rangeland, 8 sites were classified as protected shrubland, 23 sites as grazed shrubland, 11 sites as dense grassland and 13 sites as sparse grassland.

4.3.2 Soil aggregate stability and its relationship with some soil chemical properties

DAS, ranging from 13.5 to 84.6 × 10^{-2} kg kg^{-1}, was moderately correlated with WAS, ranging from 64.7 to 98.6 × 10^{-2} kg kg^{-1} (r = 0.59) (Fig. 4.3). The lower values of DAS than WAS for all the samples were in agreement with the study by Cerdà (1998). It was suggested that wetting by rapid immersion for the measurement of DAS had led to aggregate breakdown by slaking, while the slaking process may not occur in the measurement of WAS. As Ternan et al. (1996) and Unger (1997) suggested, the slaking process played a major role in the breakdown of surface soil aggregates in a semiarid area including the study area where intermittent rainfall causes rapid wetting of the relatively dry soil surface (Chapter 3). Thus, the determination of DAS was considered to be more suitable than that of WAS for the analysis

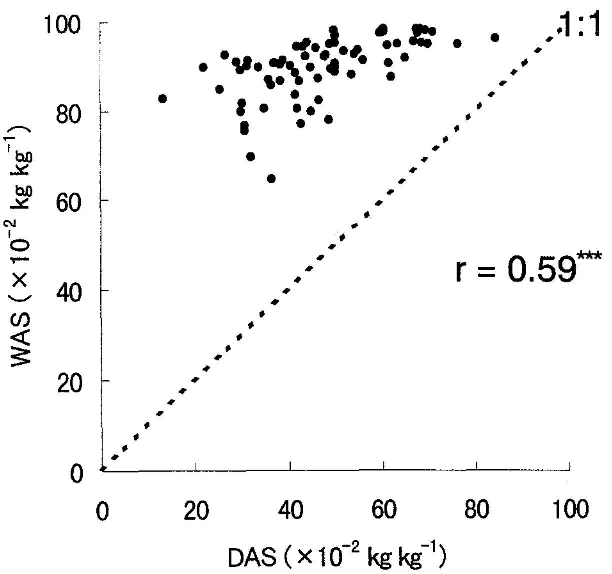


Figure 4.3 Relationship between DAS and WAS.

Table 4.3 Pearson's correlation coefficients between indices of aggregate stability and soil properties.

	DAS	WAS
PH	−0.50 ***	−0.43 **
EC	0.17	0.17
ORGC	0.64 ***	0.64 ***
INORGC	−0.09	−0.23
SAND	0.50 ***	0.08

***p<0.001

of soil erodibility. In addition, the larger scattering values of DAS with a C.V. of 29.9% than those of WAS with a C.V. of 7.8% enabled to discriminate the sites based on the aggregate stability (Table 4.1).

Among the soil properties determined, ORGC showed the highest correlation with DAS or WAS (Table 4.3), suggesting the significant contribution of soil organic matter to the stabilization of the soil aggregates, as many authors pointed out (e.g. Tisdall and Oades 1982; Imeson and Verstraten 1985; Cerdà 1998). Nevertheless, a strong correlation was obtained for the sites in the rangeland (r = 0.69; Fig. 4.4a) while no correlation was found in the cropland (r = 0.14; Fig. 4.4b). Furthermore, no significant relationship was detected between the soil aggregate stability and the other soil properties examined in the cropland (results not shown).

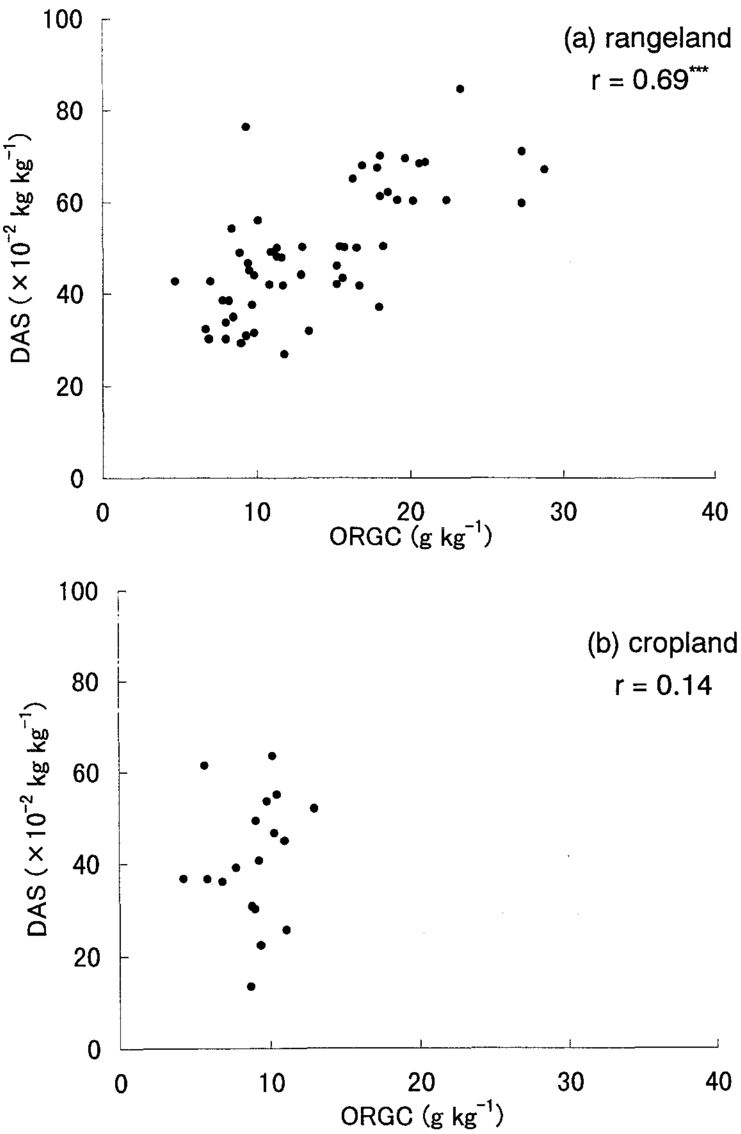


Figure 4.4 Relationship between ORGC and DAS in the rangeland (a) and in the cropland (b).

Considering that the cropland had been utilized as rangeland prior to cultivation, it was reasonable to assume that the original stand of vegetation and soil properties of the cropland had not been appreciably different from those of the rangeland adjacent to the cropland. Thus, the absence of relationship between the soil aggregate stability and ORGC could be partly ascribed to the influence of tillage. Tillage caused a disintegration of soil aggregates (Unger 1997) and temporal variation in soil aggregate stability (Perfect et al. 1990). Method and time of tillage, which varied among the sampling sites, may have affected the soil aggregate stability to a larger extent than the soil chemical properties.

4.3.3 Relationship between soil aggregate stability and environmental parameters

4.3.3.1 Derivation of factors from the measured environmental parameters by PCA

PCA was undergone using SLOPE, the soil chemical properties and the soil surface coverage in the rangeland. LITTER was excluded since the amount was negligibly low at all the sites. The first three principal components (PCs) whose eigenvalues exceeded 1.0 were selected. These PCs were rotated using the varimax method to obtain the factors. The three PCs explained 70.7% of the total variance (Table 4.4).

Table 4 shows the factor pattern for each PC, which is equivalent to the correlation coefficients between the PC and the employed variables. The first component (PC1) showed highly positive correlation coefficients with ORGC and HERB and negative one with SOIL. Since SOIL was the remainder of the sum of SHRUB and HERB at most sites, the strong correlation of both ORGC and SOIL with PC1 can be explained by the fact that the organic

Table 4.4 Eigenvalues and factor pattern for the first three principal components.

Variable	PC1	PC2	PC3
SLOPE	0.34	0.73	0.10
EC	0.02	0.10	−0.84
PH	−0.54	−0.13	0.58
ORGC	0.84	0.30	−0.16
INORGC	−0.52	−0.05	0.51
SAND	0.13	0.23	0.74
SHRUB	−0.14	−0.82	0.23
HERB	0.76	0.38	−0.05
SOIL	−0.92	−0.10	−0.22
GRAVEL	0.13	0.83	0.16
Eigenvalue	2.85	2.21	2.01
Cumulative percentage	28.5	50.6	70.7

matter content varied with the supply of organic materials from existing vegetation. Only HERB, and not SHRUB, contributed to PC1 with SOIL, which can be ascribed to the presence of herbaceous species in both the shrubland and the grassland, while shrub species mainly in the shrubland. SOIL was directly related to the degree of the soil surface coverage. PC1 was referred to as "coverage factor (CF)".

The second component (PC2) is the "slope factor (SF)", since SLOPE, SHRUB and GRAVEL showed high values in the factor pattern. As the slope gradient increased, the amount of eroded soil was assumed to increase, resulting in the relative increase of GRAVEL in the soil surface coverage. The increase in the amount of eroded soil, in turn, would reduce the soil rooting depth, which is not suitable for the growth of shrub species whose tap root penetrates very deeply, sometimes one meter or more, to exploit the limited amount of water (Thalen 1979).

The third component (PC3) gave high values in the factor pattern to EC and SAND. The exceptionally high values of EC in the three rangeland soils derived from parent materials containing high content of gypsum could be attributed to the derivation of PC3. Thus, it was referred to as "gypsum factor (GF)".

4.3.3.2 Relationship between soil aggregate stability and factor scores

Characterization of the derived factors was followed by the computation of the standardized factor scores for each sampling site in the rangeland. Since DAS was adequately represented as the index of soil erodibility, stepwise multiple regression analysis was applied to the factor scores and DAS as the independent variables and the dependent one, respectively. The author assumed the existence of a linear combination of the variables. The most appropriate model obtained in the analysis was:

$$DAS = 8.87 \times CF + 5.69 \times SF + 49.6 \ (r = 0.76). \qquad (1)$$

GF was eliminated from the prediction equation as it did not satisfy the significance level of 0.15. Figure 4.5 shows the relationship between the measured and the predicted values of DAS.

The contribution of CF to DAS suggested the beneficial effect of the soil surface coverage on the soil aggregate stability. This effect could be attributed to the following two aspects; 1) the addition of plant materials may enhance the soil aggregate stability by increasing ORGC showing a high value in the factor pattern of CF, and 2) the coverage of the soil surface mainly with vegetation can protect soil aggregates from the direct impact of raindrops.

The positive contribution of SF to DAS indicated that soil aggregates were more stable on steeper slopes. This can be explained by a shifting-out process under which the unstable aggregate fraction was disintegrated by the raindrop impact and already translocated along steeper slopes, leaving only the stable aggregates behind. On the other hand, the unstable aggregates on gentler slopes tended to remain at the site after disintegration. In addition, considering the translocation of the disintegrated aggregates along the slopes, the gentler the lower slopes were, the larger the amount of disintegrated aggregates on the upper slopes might be added to the lower slopes, resulting in the increase of the amount of unstable aggregates on gentler slopes. This assumption was supported by previous results in Chapter 3, showing that the grazed area on the gentler slope yielded a soil loss comparable to that on the steeper slope during the monitoring of water erosion over two rainy seasons.

The scattergram of the scores of CF and SF (Fig. 4.6) revealed that shrubland could be differentiated from grassland with the scores of SF. The scores of CF could be employed to

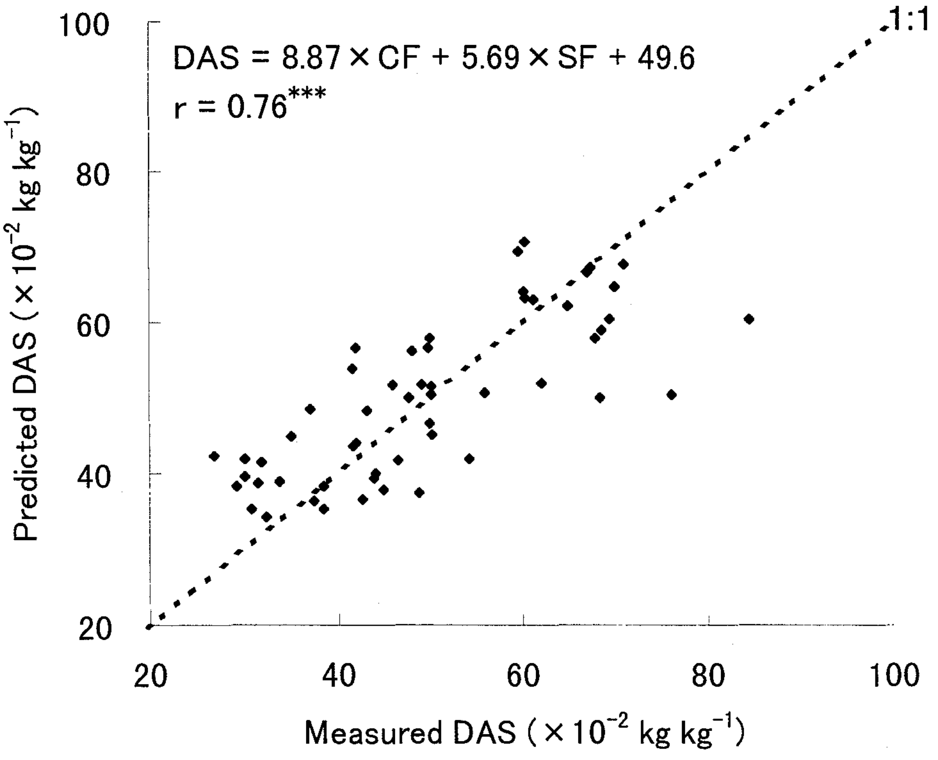


Figure 4.5 Relationship between the measured DAS and the DAS predicted with the standardized scores by the principal component analysis.

divide the shrubland into grazed and protected one, and the grassland into dense and sparse one. Since the sites with positively higher scores of CF and SF showed higher values of DAS based on the multiple regression analysis, land management practices to stabilize soil aggregates should be implemented for the increase of the scores of CF and SF. However, SF was contributed by SLOPE, which is basically inherent to the location. Thus, the improvement of the soil aggregate stability can be achieved through the increase of the scores of CF, namely the increase of the soil surface coverage. From this viewpoint, the protected shrubland and the dense grassland were considered to be suitable for maintaining the soil aggregate stability in the shrubland and the grassland, respectively. Considering the lower scores of SF in the shrubland than in the grassland, we should manage the shrubland with more care to maintain the soil surface coverage.

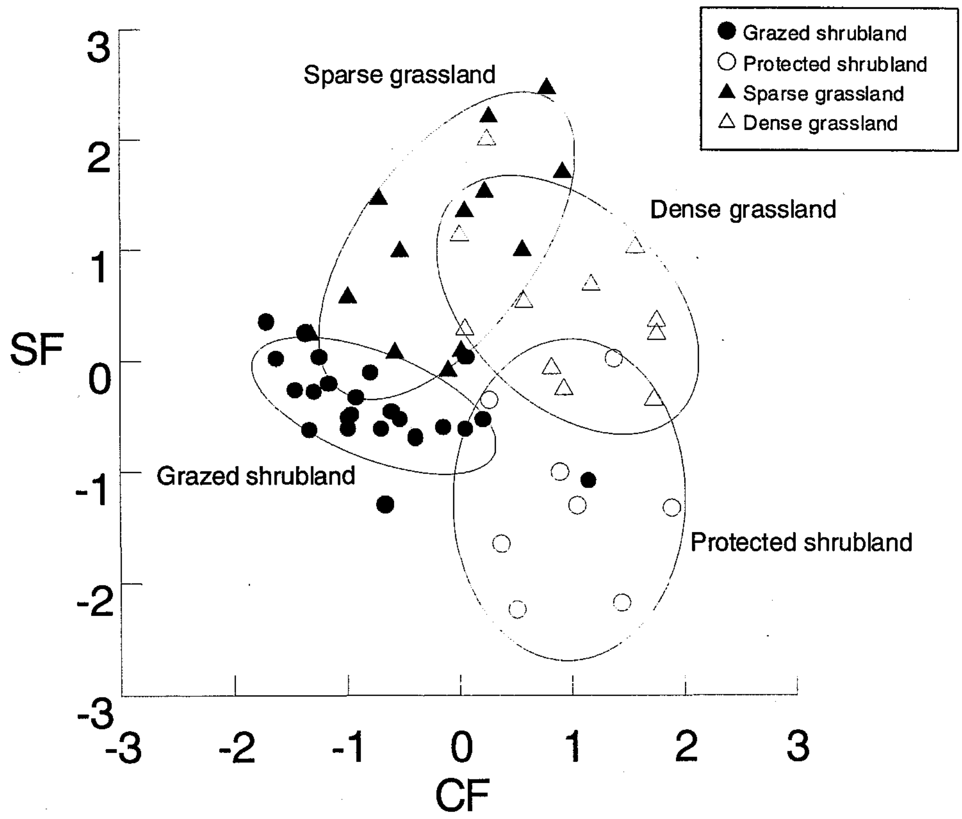


Figure 4.6 Scattergram of the standardized scores of Coverage Factor (CF) and Slope Factor (SF). Each ellipse was determined for each vegetation type by the mean and the covariance of CF and SF with the probability of 0.6827 (standard deviation).

4.3.3.3 Relationship between soil aggregate stability and the measured environmental parameters

Although the soil aggregate stability was found to be predictable by CF and SF, it was not appropriate to apply this relationship for the estimation in the entire study area, because each of these components was contributed by several variables to be measured. Thus, multiple regression analysis was carried out using SOIL and SLOPE as independent variables since SOIL and SLOPE were representative of CF and SF, respectively. The equation obtained was:

$$DAS = -0.319 \times SOIL + 1.90 \times SLOPE + 49.1 \ (r = 0.73). \qquad (2)$$

The correlation coefficients of Eq. (1) and Eq. (2) were 0.76 and 0.73, respectively, implying that minimal distortion of information took place in the multiple regression analysis with the measured environmental parameters. Figure 4.7 shows the relationship between the measured and the predicted values of DAS. Hence, the author was able to estimate the soil aggregate stability based on the readily observed environmental parameters.

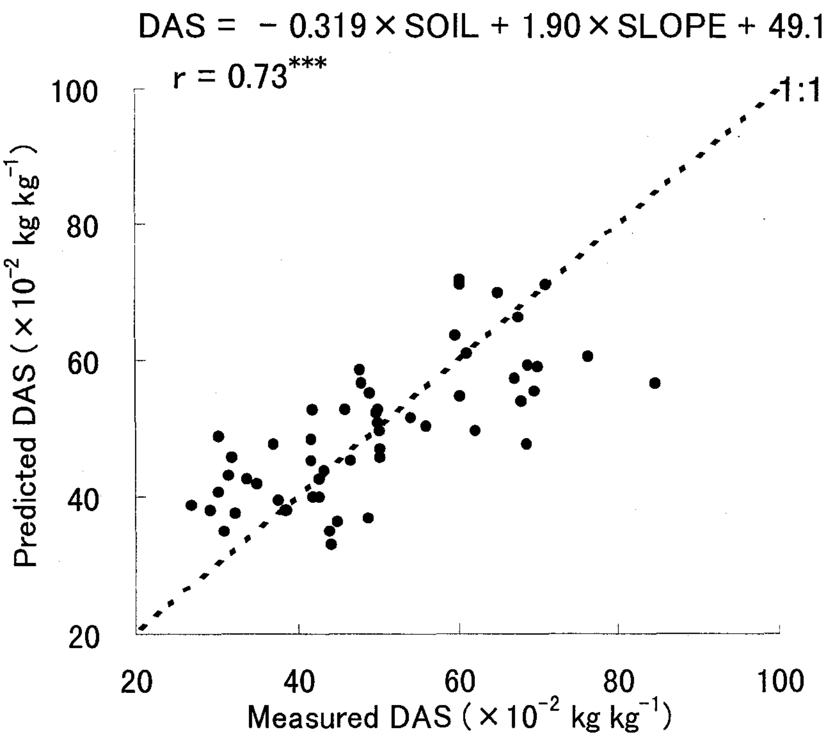


Figure 4.7 Relationship between the measured DAS and the DAS predicted with SLOPE and SOIL.

Chapter 5 Assessment of water erosion risk using Landsat TM and GIS

5.1 General

Many authors assessed the erosion risk using Geographical Information Systems (GIS) (Albaladejo et al. 1988; Giordano et al. 1991; Jürgens and Fander 1993; Navas and Machín 1997). Most of them evaluated factors controlling water erosion, such as rainfall, soil, slope and vegetation, as separate thematic maps, and overlapped the maps to produce a map for the assessment of erosion risk. For this purpose, the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) or its modified version, the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997) has been widely used. In developing countries, however, base maps, especially soil and vegetation maps, that have been used to produce the thematic maps (Renschler et al. 1999; Ogawa et al. 1998) are sometimes not available or crude if any. Analysis with satellite images can be promising to overcome the lack of the base maps (Jürgens and Fander 1993; De Jong et al. 1999).

This chapter presents spatial evaluation of the factors relevant to water erosion in the study area using topographic maps and Landsat TM images. The factors are then integrated into a map for the assessment of the erosion risk on GIS by the RUSLE model and the previous results from the erosion measurement which clarified the relationship between the soil loss and the factors relevant to water erosion (Chapter 3). The recommendation for the sustainable land use is discussed with this risk map, taking the location of villages and tent sites and the current land use into consideration.

5.2 Materials and methods

Among the factors involved in water erosion, slope, soil and vegetation factors were considered in this study since no information about the geographic variation of rainfall in the study area was available.

As the slope factor, the slope gradient was evaluated from topographic maps. Although slope length has also been included in the slope factor occasionally (Renard et al. 1997), estimation of slope length from the maps was difficult and thus not taken into consideration. From the inferences of the previous results (Chapter 3,4), air-dried aggregate stability and soil surface coverage, or the percentage of the area covered by vegetation, gravels and litter, were evaluated as the soil and vegetation factor, respectively, by Landsat TM images for the rangeland. After categorization of the three factors, a rating was assigned to each class of the three factors, and classes of the erosion risk were established on the basis of the RUSLE model and the results from the erosion measurement.

On the other hand, in the cropland, erosion risk was evaluated only by the slope gradient classes since tillage affected the aggregate stability and the most of the cropland was cultivated with barley, and the soil and vegetation factor could be assumed to be same.

Location of villages and tent sites were determined by GPS during the spring season in 1996. The afforested and protected areas were delineated by field investigations and interview with government officials. All the analyses with geographical data were conducted by ILWIS 2.2 (ITC 1998).

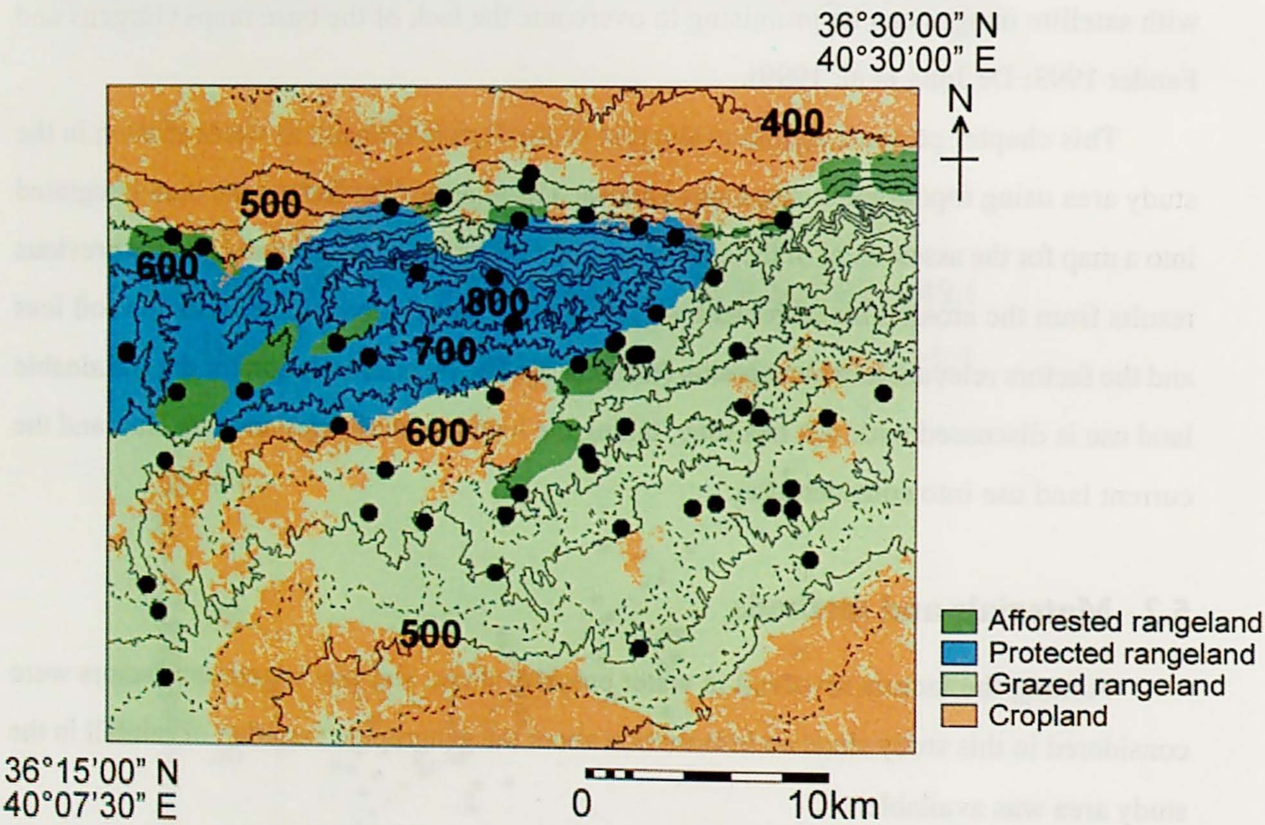


Figure 5.1 Land use map with location of the sites where the training data were acquired for the classification based on Landsat TM images. Figures indicate altitude above sea level. Solid and dotted lines indicate contour lines at intervals of 50 m and 25 m, respectively.

5.2.1 Classification of the slope gradient

From six topographic maps at a scale of 1:25,000, issued by the Syrian General Surveying Organization in 1991, and covering the whole study area, contour lines were digitized at intervals of 25 m in the gentle slope area or 50 m in the steep slope area and geometrically coordinated by Universal Transverse Mercator (UTM) (Fig. 5.1). After the interpolation of the digitized topographic maps at a pixel size of 30 by 30 m matching the resolution of the Landsat TM, the slope gradient in degrees was calculated for each pixel by the digital elevation model. Slope gradients of all the pixels were categorized into 3 classes and the average of slope gradient in each class was calculated.

5.2.2 Classification of the aggregate stability and surface coverage in the rangeland

After categorization of the aggregate stability and surface coverage according to field investigations, supervised classification was performed using Landsat TM images. For this purpose, 58 sites in the rangeland were selected (Fig. 5.1). These sites represented this area and were uniform in 100 by 100 m in terms of vegetation types, parent materials and landscapes with the consideration of the positioning error of a Global Positioning System (GPS) (Trimble Japan, Tokyo). In these sites, field investigations and soil sampling were conducted with positioning by the GPS during the 1996 dry season. The method to determine the aggregate stability was the wet-sieving of air-dried aggregates (Kemper and Rosenau 1986), as described in Section 3.2.3.3. The surface coverage was measured by the point transect method (Bonham 1989), as described in Section 4.2.1. The training data of the aggregate stability and the surface coverage determined in 58 sites were categorized into 3 classes, respectively, so that the frequency in each class should be almost same.

For the supervised classification, two scenes of system-corrected Landsat TM 5 images (Path 172 and Row 35) on 13 April 1994, the end of the rainy season, and 19 August 1994, the end of the dry season were used. Bands 1, 2, 3, 4, 5 and 7 of the two scenes were geometrically corrected with UTM coordinates of 20 control tie points obtained by GPS. With the spatial resolution of 30 m, this study area consisted of 902 lines and 1110 columns.

Before classification of the images by the training data, a principal component analysis was performed for each Landsat TM scene to eliminate redundant information in the six spectral bands (Jürgens and Fander 1993). The first three principal components of both scenes were compiled for supervised classification. The classification was conducted using maximum likelihood method with reference to the training data extended to the surrounding 8 pixels (within the positioning error of GPS) after delineating the rangeland from the cropland according to the existing vegetation map produced by the same scenes (Hirata et al. 2000).

5.3 Results and discussion

5.3.1 Classification of the factors

5.3.1.1 Slope gradient

Slope gradients were categorized into 3 classes: gentle, moderate and steep. The gentle class had the slope gradients in degrees less than 1 with the mean value of 0.54, the moderate class less than 3 with the mean value of 1.74, and the steep class 3 or more with the mean value of 6.15, as shown in Fig. 5.2. As a result, 43% of the study area was classified as gentle slope, 37% as moderate slope and 20% as steep slope.

5.3.1.2 Aggregate stability and surface coverage in the rangeland

From the histogram of the aggregate stability values in the sampling sites (Fig. 5.3), they were categorized into 3 classes: unstable, moderate and stable. The unstable class corresponded to the aggregate stability values less than 40×10^{-2} kg kg^{-1}, the moderate class 40 - 55, and the stable class 55 or more.

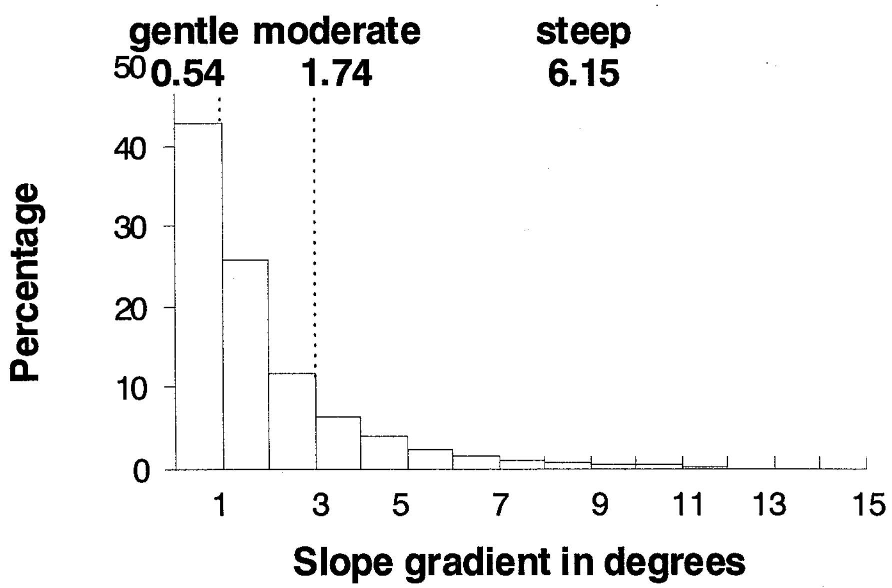


Figure 5.2 Histogram of the slope gradients in the study area. Figures indicate the mean values of slope gradient classes.

As shown in Fig. 5.4, the surface coverage values were categorized into 3 classes: low, moderate and high. The low class had the percentage of surface coverage less than 60, the moderate class 60 - 80, and the high class 80 or more.

The first three principal components of the Landsat TM scenes on April and August 1994 represented 98.9% and 98.6% of the original variance of the six bands, respectively, resulting in a small loss of variance and a data reduction of 50%. Thus, the six images consisting of the first three principal components of both scenes were used for the supervised classification.

After the classification had been performed according to the classes of the training data, the accuracy was examined. Table 5.1 shows that the accuracy of the classification for the aggregate stability was above 80% in all the classes with a mean value of 81.4%. Table 5.2 shows the accuracy of the classification for the surface coverage was above 70% in all the classes with a mean value of 77.5%.

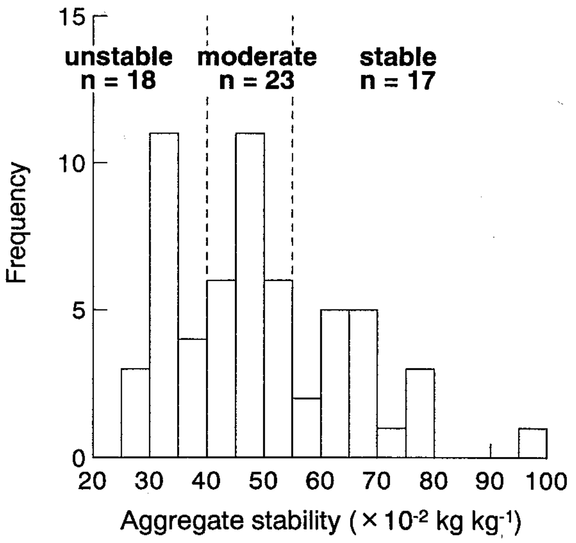


Figure 5.3 Histogram of the aggregate stability in the sampling sites.

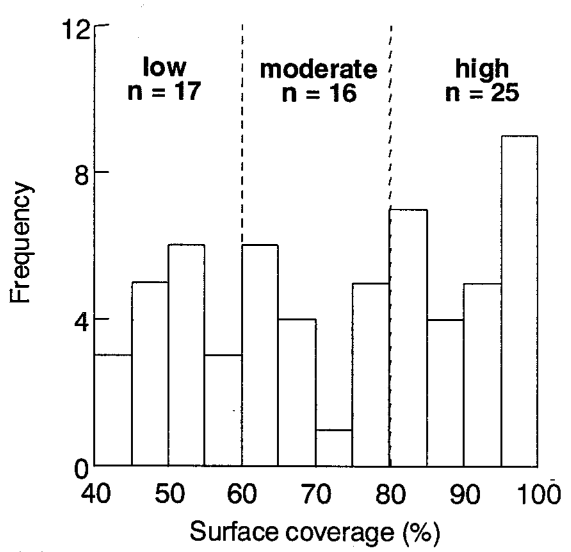


Figure 5.4 Histogram of the surface coverage in the sampling sites.

Table 5.1 Performance of the training data for aggregate stability classified by a series of Landsat-TM images.

Class	Percentage of samples into		
	unstable	moderate	stable
unstable	81.5	13.0	6.8
moderate	8.2	81.2	10.6
stable	0.0	18.4	81.6

Table 5.2 Performance of the training data for surface coverage classified by a series of Landsat-TM images.

Class	Percentage of samples into		
	low	moderate	high
low	70.6	27.5	2.0
moderate	18.1	77.1	4.9
high	4.7	12.6	82.8

5.3.1.3 Relationships among the factors in the rangeland

After the classification of the three factors in all the pixels, the percentage of the aggregate stability classes was calculated in combinations of the classes of the slope gradient and the surface coverage (Fig. 5.5). The stable class was predominant in the high surface coverage and the percentage of the unstable class increased as the surface coverage decreased from the high to the low class. This tendency apparently revealed the positive influence of the surface coverage on the aggregate stability. Moreover, in each class of the surface coverage, the percentage of the unstable class decreased as the slope gradient increased from the gentle to the steep class, suggesting the positive influence of the slope gradient on the aggregate stability. These results were in agreement with the previous results (Chapter 4), indicating that the surface coverage could enhance the aggregate stability through the addition of plant materials and the protection of soil surface from the raindrop impacts, and that the slope gradient could affect the translocation of unstable aggregates from steep slope area.

5.3.2 Establishment of erosion risk criteria

Ratings of the slope gradient classes were determined by applying the RUSLE model (Renard et al. 1997) to the mean values of the classes, yielding 0.13, 0.36 and 1.30 for the gentle, moderate and steep classes, respectively. On the other hand, since no scheme of the rating determination was available for the classes of the aggregate stability and the surface coverage, the author assigned the ratings to each class of these two factors in the simplest way: 1 for stable aggregates and high coverage, 2 for moderate aggregates and coverage and 3 for unstable aggregates and low coverage.

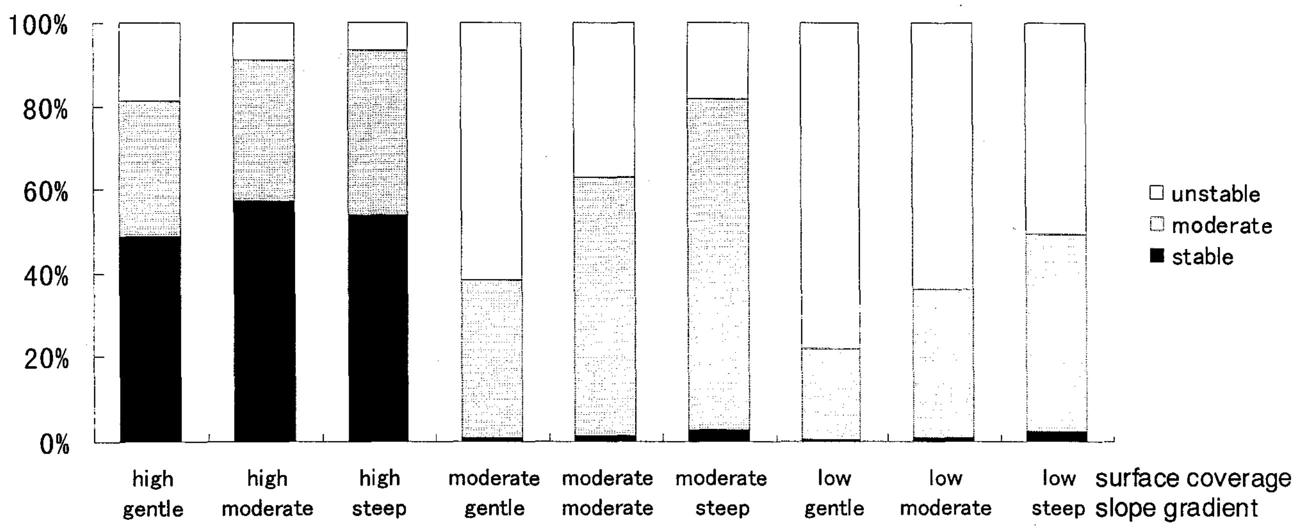


Figure 5.5 Distribution of the aggregate stability classes in each combination of the classes of the slope gradient and the surface coverage in the rangeland.

These ratings were verified with the results from the erosion measurement during the two rainy seasons and field investigations (Table 5.3) (Chapter 3). Except for P3f located in cropland, all the plots were located in the rangeland. Table 5.3 shows that all the plots in the rangeland had the almost same amount of soil loss in both seasons, ranging between 0 and 393.3 kg ha^{-1} in a season. Nevertheless, the combination of the three factor classes of the plots in the mountain, P1g, P1p, P2g and P2p, was different from that of the plot on the foot-slope, P3g. The former were classified into steep slope – stable aggregates - high coverage, while the latter into moderate slope – moderate aggregates – moderate coverage. This result implied that the product of the ratings for the classes of the slope gradient, the aggregate stability and the surface coverage was identical among the plots examined, assuming that the effect of these three factors is multiplicative as the RUSLE model (Renard et al. 1997) have done. The product of the ratings for the plots in the mountain, 1.3, was proved to be similar to that for the plot on the foot-slope, 1.4. Thus, these ratings were assigned to the other combinations of the factors (Table 5.4). Since the amounts of the soil loss in the plots were negligibly low in terms of tolerance limits proposed by USDA (Wischmeier and Smith 1978), the products of

Table 5.3 Results from the water erosion measurement in the 94/95 and the 95/96 rainy seasons (Chapter 3).

Plot	Site	Land use	Landscape	Soil loss (kg/ha) 1994/95	Soil loss (kg/ha) 1995/96	Slope gradient	Aggregate stability[c] ($\times 10^{-2}$ kg kg^{-1})	Surface coverage[d] (%)
P1g	1	g (grazed)	mountain	103.1	25.6	9° (steep)	67.4 (stable)	90 (high)
P1p	1	p (protected[a])	mountain	0.0	0.0	11° (steep)	65.0 (stable)	99 (high)
P2g	2	g (grazed)	mountain	393.3	125.8	7° (steep)	61.2 (stable)	92 (high)
P2p	2	p (protected[a])	mountain	77.9	98.8	6° (steep)	68.6 (stable)	92 (high)
P3f	3	f (fallow[b])	foot-slope	1448.4	197.1	2° (moderate)	36.7 –	50 –
P3g	3	g (grazed)	foot-slope	374.9	25.1	2° (moderate)	41.6 (moderate)	64 (moderate)

Letters in parenthese indicate the name of classses according to the classification of the three factors.
[a] protected for about 10 years
[b] barley cultivated for about 10 years before the fallow period
[c] air-dried aggregate stability
[d] Surface coverage was the percentage of the area covered by vegetation, gravels and litter

Table 5.4 Criteria for erosion risks by the combination of the three factors in the rangeland.

	surface coverage	high (1)			moderate (2)			low (3)		
	slope gradient	gentle (0.13)	moderate (0.36)	steep (1.30)	gentle (0.13)	moderate (0.36)	steep (1.30)	gentle (0.13)	moderate (0.36)	steep (1.30)
aggregate stability	stable (1)	0.1	0.4	1.3	0.3	0.7	2.6	0.4	1.1	3.9
	moderate (2)	0.3	0.7	2.6	0.5	1.4	5.2	0.8	2.1	[illegible]
	unstable (3)	0.4	1.1	3.9	0.8	2.1	7.8	1.2	3.2	[illegible]

Figures in parentheses are the ratings for multiplication.

□ <2.5 : low   ▨ <7.5 : medium   ▩ ≥7.5 : high the ratings less than 2.5 were classified as low erosion risk, those less than 7.5 as medium and those equal to or more than 7.5 as high (Table 5.4).

The erosion risks in the cropland were evaluated according to the slope gradient classes; the cropland on the gentle slope was assigned to low erosion risk area, that on the moderate slope to medium, and that on the steep slope to high. Thus, the classes of the erosion risks in the cropland did not correspond with those in the rangeland.

Although this scheme of the rating determination and classification of the erosion risk gave only qualitative evaluation of erosion risks, the relative risk of water erosion in the study area could be still discussed. Quantitative evaluation would be achieved by the erosion measurement in the sites with the other combinations of the three factors than those used in this study.

5.3.3 Distribution of the erosion risk under different land uses

After the classification of the erosion risk according to the combination of the factors, the erosion risk map was produced (Fig. 5.6) and the distribution of each class was obtained (Table 5.5). Seventy-two percent of the rangeland was classified as the low risk area, indicating that most of the study area was not expected to suffer from the water erosion at the time of this study. The high risk area in the rangeland was found mainly on the steep slopes in the northern part where no vegetation was observed in the field survey. Seventy percent of the cropland was located on the gentle slopes.

To discuss the influence of the afforestation and protection program on the erosion risk in the rangeland, the author estimated the percentage of the classes of the erosion risk and the three factors in each land use (Fig. 5.7). In the afforested rangeland, the low risk area occupied more than 80% (Fig. 5.7a). The larger percentage of stable aggregates and high coverage than the total proved that the afforestation activity could reduce the erosion risk through the increase

Table 5.5 Distribution of the erosion risk classes.

class	Area (%) in total area	Area (%) in rangeland or cropland
Rangeland		
low	49	72
medium	14	21
high	4	6
Cropland		
low	23	70
medium	8	25
high	2	5

of the surface coverage and the aggregate stability. In the protected rangeland, the percentage of the low risk area was slightly less than that in the total (Fig 5.7a) because of the large percentage of the steep slopes (Fig. 5.7b). The large area of steep slopes in the protected rangeland proved that the protection was assigned to the suitable area for soil conservation as a whole. The percentage of the low risk area in the grazed rangeland comparable to those in the afforested and protected rangeland was attributed to the smaller percentage of the steep slopes (Fig. 5.7b) and the grazed rangeland did not seem to be subjected to severe water erosion at the time of this study.

5.3.4 Recommendation for the sustainable land use

In spite of their positive effect on water erosion control in the afforested and the protected rangeland, the afforestation and protection program could enhance the occurrence of water erosion in the grazed rangeland. The programs, along with the encroachment of the cropland since 1950s, reduced the area of the grazed rangeland to about one half of the study area

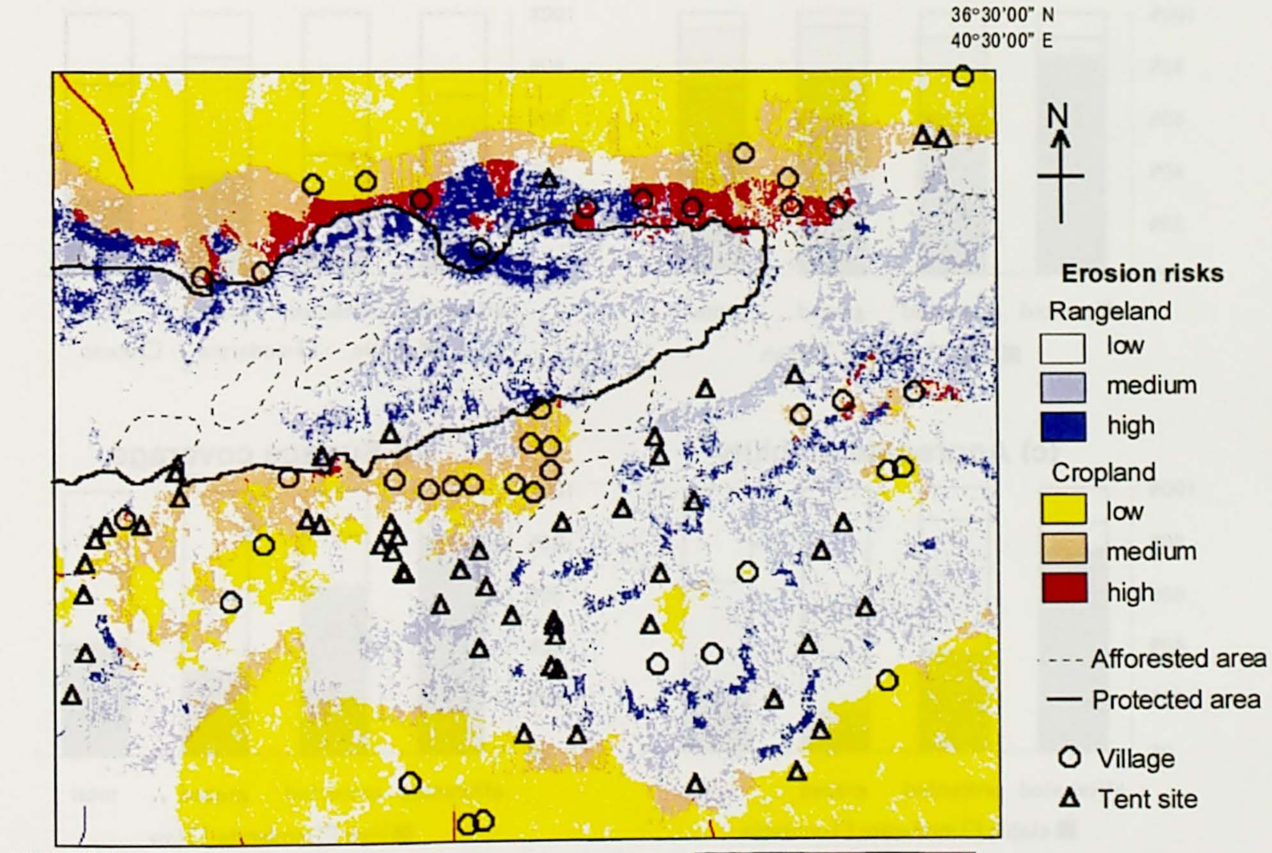


Figure 5.6 Erosion risk map with the location of the villages (○) and tent sites (△). Areas enclosed by dotted and solid lines represent the afforested and the protected areas, respectively.

(Table 2.1) and the tent sites were found to concentrate in the southern part (Fig. 5.6). Assuming that the grazing distance from a village or a tent site was practically within 5 km (Hirata et al. 1998), the whole grazed rangeland has been used to some extent. Thus, the exclusion of the afforested and protected area from grazing area can consequently enhance the grazing pressure in the grazed rangeland, and decrease the surface coverage, resulting in the increase of water erosion. This situation has already been taking place, since the area of the low coverage and unstable aggregates in the grazed rangeland was larger than those in the afforested and grazed rangeland (Fig. 5.7c,d).

In addition, the absence of grazing activities would enhance the risk of wild fires in the afforested and protected rangeland. When above-ground plant materials are not grazed, accumulating plant materials can fire easily in a hot and dry season of the Mediterranean climate as observed during the field investigations. Thomas et al. (1999) indicated that fires increased erosion by exposing soil surface directly to rainfall through combustion of the litter

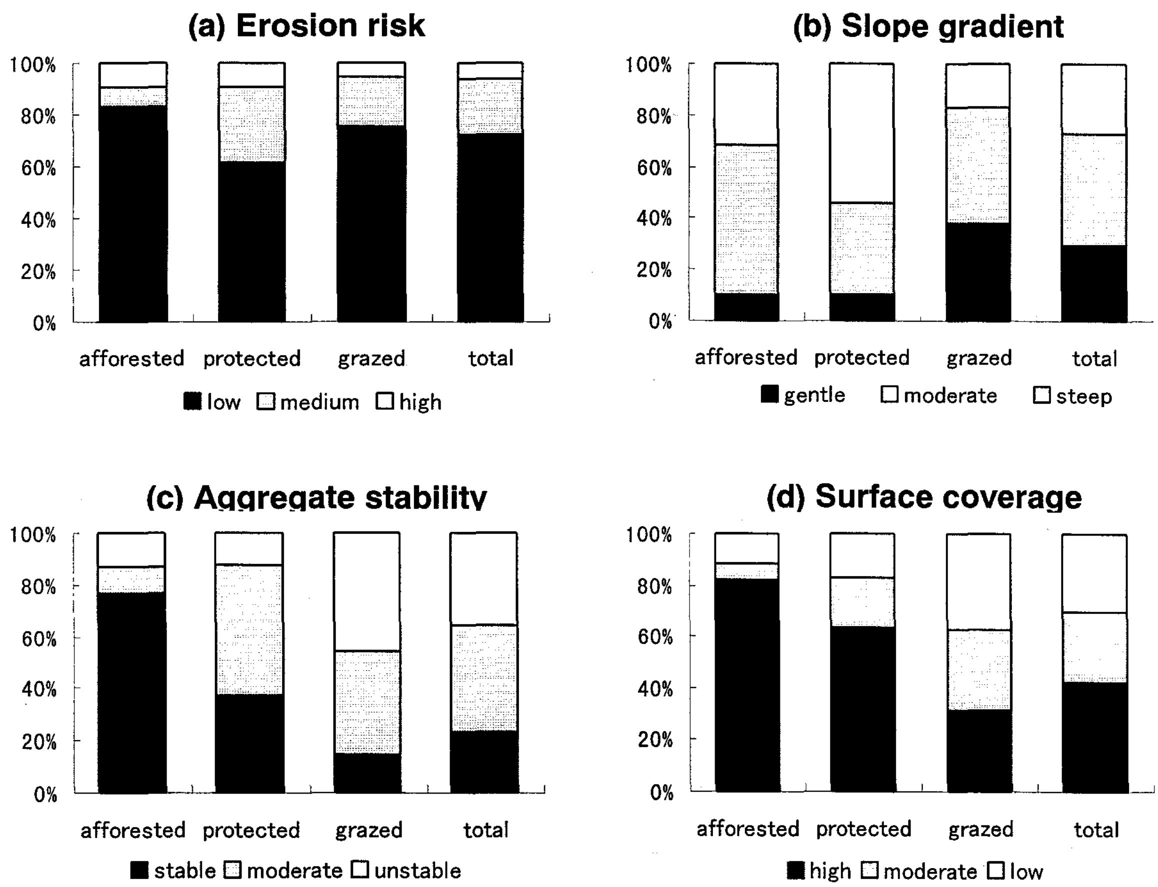


Figure 5.7 Distribution of the classes of the erosion risk (a), the slope gradient (b), the aggregate stability (c) and the surface coverage (d) in the afforested, protected and grazed rangeland and in total.

layer and ground vegetation. Combustion of the vegetation also reduces feed resources seriously. It is, therefore, recommended that some grazing activities be resumed in the protected rangeland with the low risk such as in the western-central part.

Since the cropping causes the accelerated water erosion and the selective loss of the organic matter (Chapter 3), the cropping should be restricted to the gentle slopes. Nevertheless, reconversion of cropland to rangeland does not seem a practical option because the cropping plays the substantial role in the provision of the feed resources from summer to winter (Hirata et al. 1998). Considering that little gentle slope area remains in the northern and southern foot-plain, further encroachment of cropland should be avoided.

Chapter 6 Summary and conclusions

In the Abd Al-Aziz mountain region, northeastern Syria, utilized as afforested, protected and grazed rangeland, and cropland, the author evaluated the water erosion risks and discussed the land use recommendation for sustainable production.

6.1 Impact of grazing and tillage on water erosion

Impact of grazing and tillage on water erosion under natural rainfall condition was investigated during the 1994/95 and 1995/96 rainy seasons at three experimental sites (Chapter 3). For clarification of the grazing impact, the author set the two experimental sites (Site 1 and Site 2) in the mountainous area, each of which consisted of the 21 m × 1.8 m plots in the grazed area (P1g in Site 1 and P2g in Site 2) and in the protected area from grazing (P1p and P2p). At the site on the foot-slope (Site 3), the author set the plots in the cultivated fallow area (P3f) and in the grazed area (P3g) to clarify the impact of tillage. In these plots, the author monitored the magnitude of runoff and soil loss together with some soil properties and seasonal changes of vegetation coverage.

In spite of the gentle sloping, P3g recorded the soil loss comparable to P1g and P2g. It was due to the lower grade of aggregate stability and surface coverage by vegetation and rock fragments. Soil loss at Site 1 and Site 2 was observed to be at the negligible level ranging between 0.0 and 0.4 t ha^{-1} in the rainy season, and the grazing impact on water erosion was not significant because the vegetation coverage was relatively high (> 65%) throughout the experimental period. On the other hand, the amounts of soil loss at Site 3 in 1994/95 were 1.4 t ha^{-1} in P3f and 0.4 t ha^{-1} in P3g, indicating the occurrence of water erosion accelerated by cropping presumably due to the disturbance of soil by tillage and the removal of shrub species. In P3f where the largest amount of soil loss was recorded, the nitrogen content in the eroded sediments was 2.7 times as high as that in bulk soils in the surface horizon, implying that the organic matter was selectively removed from cropland by water erosion.

6.2 Soil aggregate stability under different landscapes and vegetation types

After recognition of soil aggregate stability as an effective index of soil erodibility (Chapter 3), the influence of landscapes and vegetation types on soil aggregate stability was studied at 55 sites in rangeland and 18 sites in cropland (Chapter 4). For the measurement of soil aggregate stability, the wet-sieving test was applied to air-dried and prewetted aggregates. Soil properties were determined in terms of pH, EC, contents of organic carbon, inorganic carbon and sand. Slope gradients at all the sites and soil surface coverage at the sites in the rangeland were also determined.

Due to the slaking process, the stability of air-dried aggregates with a mean value of 47.5×10^{-2} kg kg^{-1} was lower than that of prewetted ones with a mean value of 89.8×10^{-2} kg kg^{-1}. The absence of a significant relationship between the soil aggregate stability and soil chemical properties in the cropland suggested that soil aggregate stability was mainly determined by tillage. Principal component analysis and stepwise multiple regression analysis for the sites in the rangeland indicated that the air-dried aggregate stability could be described by a coverage factor and slope factor ($r = 0.76$). The contribution of the coverage factor suggested that the increase of the soil organic matter content through the addition of plant materials and protection of the soil surface from the raindrop impact could enhance the soil aggregate stability. The positive contribution of the slope factor implied that unstable aggregates on steeper slopes had already been translocated, while stable aggregates remained. Thus, for the preservation of the soil aggregate stability, the soil surface coverage should be improved especially on gentler slopes.

6.3 Assessment of water erosion risk and recommendation for sustainable land use

Water erosion risk was assessed geographically using Landsat TM images and a Geographical Information System (GIS) (Chapter 5). Slope gradient, soil aggregate stability and soil surface coverage were considered as factors controlling water erosion. Slope gradient was calculated from topographic maps by a digital elevation model and categorized into 3 classes. Both soil aggregate stability and soil surface coverage were categorized into 3 classes in the rangeland using the supervised classification of the two scenes of the Landsat TM images. All the factors were then integrated on the basis of the Revised Universal Soil Loss Equation (RUSLE) model and the results from the water erosion measurement (Chapter 3), resulting in the erosion risk map with the 3 classes of the risk in the rangeland. The cropland was classified according to the slope gradient classes. The erosion risk map indicated that the afforestaion and protection programs were effective measures for alleviating water erosion and, at the same time, may accelerate water erosion in the grazed rangeland through the increase of grazing pressure. Thus, the low risk area in the afforested and protected rangeland was recommended to be grazed. Since the cropland has already extended to most of the gentle slope area, further encroachment of cropland will enhance water erosion and should be avoided.

6.4 Further studies needed for sustainable land use

For sustainable land use in the study area, studies on the followings should be warranted.

Establishment of suitable grazing management in the rangeland

Although the grazing activity was recommended to be allowed in the protected rangeland, optimum grazing rate for maintaining vegetation coverage remains to be determined. The basic rule for the optimum use of rangeland is respect for the carrying capacity which can be defined as the maximum stocking rate without causing land degradation. The seasonal fluctuation of the amount of forage in semiarid rangeland including the study area requires the determination of seasonal carrying capacity.

Development of alternative cultivation practices

Alternative cultivation practices to alleviate water erosion should be developed since cultivation practices in the study area were suggested to cause the accelerated water erosion and the selective loss of soil organic matter due to tillage and absence of surface coverage at the beginning of a rainy season. For soil conservation, reconversion of cropland to rangeland would be the best solution, but not realistic. Cereal grains, straw and stubbles produced in the cropland provide livestock with the substantial part of feed resources from summer to winter (Hirata et al. 1998).

For this purpose, one may suggest the incorporation of leguminous crops into the crop rotation since legumes are well known to fix nitrogen symbiotically, and consequently to replenish soil organic matter. However, the marginal amount of rainfall with about 300 mm in a rainy season might make the growth of legumes rather difficult. Collection of native species and a plant breeding program to establish the drought-tolerant legumes are required.

Another option is the adoption of conservation tillage. The effects of many types of conservation tillage, such as no tillage, strip tillage and minimum tillage, on water erosion rates have been extensively examined, as reviewed by Morgan (1995). Since this study revealed that tillage enhanced the magnitude of water erosion greatly, the conservation tillage would be promising. Considering the Morgan's note that the effectiveness of any conservation technique depends on the amount of crop residues left on the surface at the time of greatest erosion risk, we should identify the degree of the surface coverage enough for soil conservation, since crop residues are usually taken out for supplemental feed in the study area.

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Chapter 3

Shinjo, H., Fujita, H., Gintzburger, G., and Kosaki, T. 2000: Impact of grazing and tillage on water erosion in northeastern Syria. *Soil Science and Plant Nutrition*, **46**, 151-162

Chapter 4

Shinjo, H., Fujita, H., Gintzburger, G., and Kosaki, T. 2000: Soil aggregate stability under different landscapes and vegetation types in a semiarid area in northeastern Syria. *Soil Science and Plant Nutrition*, **46**, 229-240

Chapter 5

Shinjo, H., Hirata, H., Koga, N., Fujita, H., and Kosaki, T. 2000: Assessment of water erosion risk using Landsat TM and GIS in a semiarid area in northeastern Syria. (in preparation for submitting to *Journal of Arid Environment*)

Appendices

Appendix 1 Description of the sampling sites. (1/4)

Site ID	NAME	UTM coordinate X	Y	Vegetaion Type[a]	Slide No.	Sampling Date	Parent Material[b]	LANDFORM
1	SABAIZLAM GRAZED	622002	4029608	LALNHH	0.0110	05/04/96	CAL	MID TO BOTTOM OF SLOPE
2	SABAIZLAM PROTECTED	621930	4029535	D-VEGE	0.0120	05/04/96	CAL	MIDDLE OF SLOPE
3	BADIA GRAZED	601764	4029095	LALNHH	0.0210	05/05/96	CAL	MIDDLE OF SLOPE
4	BADIA PROTECTED	601734	4028946	D-VEGE	0.0220	05/05/96	CAL	MIDDLE OF SLOPE
5	KHAZNE FALLOW	619850	4036373	FALLOW	0.0310	05/06/96	CAL	ALMOST FALT PLAIN
6	KHAZNE RANGELAND	619850	4036373	HALN	0.0320	05/06/96	CAL	ALMOST FLAT PLAIN
7	CHAIR TOP GRAZED	630595	4026577	LALNHH	0.0507	05/07/96	GYP	TOP OF THE SLOPE
8	CHAIR BOT GRAZED	630595	4026577	LALNHH	0.0811	05/07/96	GYP	BOTTOM OF SLOPE
9	CHAIR MID GRAZED	630595	4026577	LALNHH	0.1222	05/07/96	GYP	MIDDLE OF SLOPE
10	MAGHLOOJA FALLOW	628916	4037563	FALLOW	1.0102	05/27/96	CAL	ALOMOST FLAT PLAIN
11	SUSA BARLEY	624769	4037235	BARLEY	1.0304	05/27/96	CAL	ALMOST FLAT PLAIN
12	JAFEER BARLEY	606662	4036791	BARLEY	1.0809	05/27/96	CAL	ALMOST FLAT PLAIN
13	JAFEER PROTECTED	603637	4033808	D-VEGE	0.0000	05/27/96	CAL	TOP OF SMALL SLOPE
14	JAFEER GRAZED	603655	4033908	LALNLH	0.0000	05/27/96	CAL	MIDDLE OF SMALL SLOPE
15	SALEM AL BA:T GRAZED	603387	4024616	MAMN	1.1819	05/28/96	CAL	BOTTOM OF SLOPE
16	TEL BISTAN FALLOW	605289	4024695	FALLOW	1.2000	05/28/96	CAL	BOTTOM OF SLOPE FLAT
17	TEL BISTAN GRAZED	605973	4025665	HALN	1.2124	05/28/96	CAL	BOTTOM OF SLOPE
18	MIDLEJIE NEAR RD	612515	4024272	HALN	1.2500	05/28/96	CAL	MIDDLE OF SLOPE
19	MIDLEJIE INSIDE	611895	4022539	LAMN	1.2600	05/28/96	CAL	MIDDLE OF SLOPE
20	HORA SEMI-GRAZED	622850	4029090	LALNHH	1.2700	05/28/96	CAL	MIDDLE OF SLOPE
21	HORA PROTECTED	622750	4029033	LALNHH	1.2800	05/28/96	CAL	MID TO BOTTOM OF SLOPE
22	HORA GRAZED	623235	4029116	LALNHH	1.2930	05/29/96	CAL	TOP TO MID OF SLOPE
23	KREITINA PROTECTED	620808	4025051	D-VEGE	1.3100	05/29/96	CAL	BOTTOM OF SLOPE
24	KREITINA GRAZED	620973	4024603	LALNLH	1.3233	05/29/96	CAL	BOTTOM OF SLOPE
25	MOELED GRAZED	622244	4022001	LAMN	1.3435	05/29/96		TOP OF UNDULATING SLOPE
26	EAST OF AMLLAD GRAZE	628365	4022916	MAMN	1.3738	05/29/96	GYP	GENTLE STEP IN SLOPE
27	NAASRI GRAZED	629964	4020817	LALNLH	2.0100	05/29/96	GYP	UNDULATING SLOPE
28	NAASRI2 GRAZED	629222	4022842	LAMN	2.0203	05/29/96	GYP	MIDDLE OF UNDU. SLOPE
29	NAASRI3 GRAZED	629180	4023694	MAMN	2.0400	05/29/96	GYP	GENTLE STEP IN MID SLOPE
30	TAIRA GRAZED	626930	4029274	LALNHH	2.0500	05/29/96	CAL	MIDDLE OF SLOPE
31	NAASRI BARLEY	630338	4017606	BARLEY	0.0000	05/30/96	CAL	FLAT IN THE PLAIN
32	MARKAB ALI PROTECTED	617774	4030348	LALNLH	2.0607	05/30/96	CAL	MIDDLE OF STEEP SLOPE
33	SUKARA GRAZED	623637	4030787	LALNHH	2.0800	05/30/96	CAL	MIDDLE OF SLOPE
34	SUKARA1 RNG	625978	4032256	LALNLH	2.0900	06/18/96	CAL	MID OF SLOPE
35	SUKARA2 RNG	623753	4031053	LALNLH	2.1011	06/18/96	CAL	MID OF SLOPE
36	SUKARA3 RNG	623533	4030772	LALNLH	2.1200	06/18/96	CAL	MID OF SLOPE
37	SUKARA4 RNG	623658	4030774	LALNHH	2.1314	06/18/96	CAL	BOTTOM OF SLOPE
38	SABA1 PRO	620449	4028664	D-VEGE	2.1516	06/18/96	CAL	RIDGE OF SMALL SLOPE
39	SABA2 BARLEY	619434	4026307	BARLEY	2.1700	06/18/96	CAL	TOP OF SLOPE
40	SABA3 PRO	619434	4026307	D-VEGE	2.1800	06/18/96	CAL	MID OF SLOPE
41	MARKAB_ALI1	616987	4032192	LALNHH	2.2021	06/18/96	CAL	TOP OF SLOPE
42	SABA4 RNG	617991	4028014	LALNLH	2.2223	06/18/96	CAL	MID OF SLOPE
43	MAGHLOOJA1 BARLEY	627279	4035265	BARLEY	2.2500	06/19/96	CAL	GENTLE SLOPE
44	SUSA1 RNG	622917	4033846	LALNLH	2.2600	06/19/96	CAL	MID OF GENTLE SLOPE
45	SUSA2 RNG	622910	4034339	LALNLH	2.2728	06/19/96	CAL	RIDGE OF GENTLE SLOPE
46	KHAZNE1 RNG	620737	4034770	LALNLH	2.2900	06/19/96	CAL	MID OF GENTLE SLOPE
47	GHARA1 FALLOW	616963	4037647	FALLOW	2.3000	06/19/96	CAL	ALMOST FLAT
48	GHARA2 RNG	614852	4035430	HALN	2.3132	06/19/96	CAL	MID OF GENTLE SLOPE
49	OMTLEAL1 RNG	607839	4032812	LALNLH	2.3300	06/19/96	CAL	MID OF SLOPE
50	OMTLEAL2 FALLOW	608086	4032908	FALLOW	2.3400	06/19/96	CAL	MID OF SLOPE

a: Vegetation at the sampling points was classified according to the relative coverage of *Artemisia herba-alba* and *Noaea mucronata*, two dominant shrub species in the study area (Hirata et al. 1998).

HALN: High Artemisia Low Noaea
MAMN: Middle Artemisia and Middle Noaea
LAMN: Low Artemisia and Middle Noaea
LALNLH: Low Artemisia, Low Noaea and Low Herb
LALNHH:Low Artemisia, Low Noaea and High Herb
D-VEGE: Dense Vegetation

b: CAL; Limestone, GYP; Gypsum, C&G; mixture of Limestone and Gypsum

Appendix 1 Description of the sampling sites (Continued).

	Slope		Stone	Rock		Soil	Structure			Soil color	
Site ID	gradient (°)	direction	(%)	(%)	LAND USE	Texture[c]	grade[d]	type[e]	size[f]	at dry	at moist
1	9	S	90	2	GRAZED?	SL	MOD	SABLK	MED	7.5YR4/4	
2	11	S25E	15	2	PROTECTED	SL	WEAK	SABLK	FINE	10YR5/3	10YR4/3
3	7	W	40	2	GRAZED?	SCL	WEAK	SABLK	FINE	10YR6/4	10YR4/4
4	6	N70W	15	2	PROTECTED	SL	MOD	SABLK	FINE	10YR5/4	10YR4/4
5	2	N80E	1	2	FALLOW	SCL	WEAK	SABLK	FINE	10YR6/4	10YR5/6
6	2	N70E	15	2	GRAZED	SL	MOD	SABLK	MED	7.5YR6/4	7.5YR4/6
7	6	W10S	25	50	GRAZED	SL	WEAK	SABLK	FINE	10YR7/3	10YR5/4
8	4	W10S	15	2	GRAZED	SL	MOD	SABLK	FINE	10YR6/4	10YR4/4
9	6	W10S	20	10	GRAZED	SL	MOD	SABLK	VFIN	10YR6/4	10YR4/4
10					FALLOW						
11					BARLEY						
12					BARLEY						
13					PROTECTED						
14					GRAZED						
15					GRAZED						
16					FALLOW						
17					GRAZED						
18					GRAZED						
19					GRAZED						
20					GRAZED?						
21					PROTECTED						
22					GRAZED						
23					PROTECTED						
24					GRAZED						
25					GRAZED						
26					GRAZED						
27					GRAZED						
28					GRAZED						
29					GRAZED						
30					GRAZED						
31					BARLEY						
32					PROTECTED						
33					GRAZED?						
34	15	N30W	90	25	GRAZED	SL	MOD	SABLK	MED	10YR6/3	10YR5/4
35	16	N30E	90	50	GRAZED	SL	MOD	SABLK	MED	10YR5/4	10YR4/4
36	13	S30E	90	50	PROTECTED	SL	WEAK	SABLK	MED	10YR5/3	10YR4/3
37	6	S70E	90	25	GRAZED	SL	MOD	SABLK	MED	10YR6/3	10YR3/3
38	2	S	60	25	PROTECTED	SL	WEAK	SABLK	FINE	10YR6/4	10YR4/4
39	2	W	15	2	BARLEY	SL	MOD	SABLK	MED	10YR6/4	10YR4/4
40	8	S70W	50	25	PROTECTED	LS	WEAK	SABLK	FINE	10YR6/4	10YR4/4
41	9	N70W	90	50	PROTECTED?	L	MOD	SABLK	MED	10YR5/4	10YR4/4
42	9	S40E	90	50	GRAZED	SL	WEAK	SABLK	FINE	10YR6/3	10YR4/4
43	1	N40W	15	25	BARLEY	LS	WEAK	SABLK	MED	10YR6/4	10YR4/4
44	6	N	90	50	GRAZED	LS	WEAK	SABLK	FINE	10YR6/4	10YR5/4
45	7	N	90	10	GRAZED	SL	WEAK	SABLK	VFIN	10YR6/4	10YR4/4
46	4	N10W	90	10	GRAZED	SL	WEAK	SABLK	MED	10YR6/4	10YR4/4
47	1	N	3	2	FALLOW	L	WEAK	SABLK	MED	10YR7/2	10YR6/4
48	3	N60W	60	10	GRAZED	SL	MOD	SABLK	MED	10YR8/2	10YR7/4
49	7	N10W	60	50	GRAZED	SL	WEAK	SABLK	MED	10YR6/4	10YR4/6
50	4	N15W	15	10	FALLOW	SL	MOD	SABLK	M_F	10YR6/4	10YR4/6

c: Soil texture was examined in the field.
d: MOD; moderate, STRG; strong
e: SABLK; subangular blocky
f: MED; medium, COAR; coarse, V.LA; very large, F&M; fine and medium, F_M; fine to medium, VFIN; very fine

Appendix 1 Description of the sampling sites (Continued). (3/4)

Site ID	NAME	UTM coordinate X	Y	Vegetaion Type[a]	Slide No.	Sampling Date	Parent Material[b]	LANDFORM
51	JAFEER1 RNG	604917	4033424	LALNLH	2.3536	06/20/96	CAL	MID OF GENTLE SLOPE
52	JAFFER2 PRO	601218	4032517	D-VEGE	2.3738	06/20/96	CAL	TOP OF HILL
53	JAFEER3 PRO	603844	4027401	D-VEGE	3.0100	06/20/96	CAL	BOTTOM OF SLOPE
54	HASSAN1 RNG	606684	4027497	LALNLH	3.0200	06/20/96	CAL	MID OF SLOPE
55	HASSAN2 RNG	611849	4028888	LALNLH	3.0300	06/20/96	CAL	TOP OF HILL
56	HASSAN3 RNG	613352	4026349	HALN	3.0400	06/20/96	CAL	TOP_BOTTOM OF SMALL HILL
57	HASSAN4 BARLEY	613352	4026349	BARLEY	3.0500	06/20/96	CAL	SMALL SLOPE
58	MIDLEJIE1 RNG	617053	4027354	MALN	3.0600	06/21/96	CAL	TOP OF SMALL HILL
59	MIDLEJIE2 BARLEY	617102	4027385	BARLEY	3.0709	06/21/96	CAL	BOTTOM OF SLOPE
60	MIDLEJIE3 FALLOW	616268	4026418	FALLOW	3.1000	06/21/96	CAL	TOP OF SMALL HILL
61	MIDELJIE4 FALLOW	616422	4026082	FALLOW	3.1112	06/21/96	CAL	BOTTOM OF SMALL HILL
62	DELIYAAN1 RNG	610614	4026067	HALN	3.1300	06/21/96	CAL	TOP OF SLOPE
63	DELIYAAN2 BARLEY	610687	4026222	BARLEY	3.1400	06/21/96	CAL	MIDDLE OF SLOPE
64	DELIYAAN3 FALLOW	609098	4021826	FALLOW	3.1500	06/21/96	C&G	MIDDLE OF SMALL SLOPE
65	DELIYAAN4 FALLOW	609098	4021826	FALLOW	3.1621	06/21/96	C&G	BOTTOM OF SLOPE
66	BISTAN1 RNG	618089	4023380	LALNLH	3.2425	06/22/96	C&G	BOTTOM OF SLOPE
67	BISTAN2 RNG	617524	4022517	LAMN	3.2600	06/22/96	CAL	TOP_MIDDLE OF SLOPE
68	MUAZA1 FALLOW	617646	4016165	FALLOW	3.2700	06/22/96	GYP	GENTLE SLOPE
69	MUAZA2 FALLOW	617720	4015464	FALLOW	3.2829	06/22/96	CAL	GENTLE SLOPE
70	MUAZA3 RNG	617093	4020122	LALNLH	3.3031	06/22/96	CAL	ALONG WITH SMALL WADI
71	MIDLEJIE5 RNG	614189	4022195	MALN	3.3335	06/22/96	CAL	BOTTOM OF SLOPE
72	DELIYAAN IRRIGATED			FIELD(IRR)	3.2223	06/21/96		
73	TAIRA1 RNG	627159	4027017	LALNLH	4.0102	08/04/96	CAL	TOP OF SLOPE
74	TAIRA2 RNG	627851	4026543	HALN	4.0304	08/04/96	CAL	RIDGE OF SLOPE
75	MARZOUKA1 RNG	632904	4027586	HALN	4.0506	08/04/96	CAL	TOP TO BOT OF SMALL SLOPE
76	ABIYAT1 RNG	634837	4023564	MALN	no	08/04/96	CAL	MIDDLE OF SMALL SLOPE
77	KREITINA1 RNG	622403	4026152	LAMN	4.0709	08/06/96	CAL	TOP TO BOT OF SMALL SLOPE
78	AMLLAD1 RNG	625146	4022876	LAHN	4.1011	08/06/96	C&G	MIDDLE OF SMALL SLOPE
79	AMLLAD2 BARLEY	624995	4022685	BARLEY	4.1213	08/06/96	GYP	FLAT IN SLOPE
80	MOELED1 RNG	623043	4017172	HALN	4.1416	08/06/96	GYP	MIDDLE OF SMALL SLOPE
81	TEL BISTAN1 RNG	604910	4021218	HALN	4.2300	08/07/96	CAL	MID OF SMALL GENTLE SLOPE
82	TEL BISTAN2 FALLOW	604790	4021175	FALLOW	4.1922	08/07/96	C&G	BOTTOM OF GENTLE SLOPE
83	TEL BISTAN3 RNG	602615	4019500	MALN	4.2425	08/07/96	CAL	TOP OF THE HILL(H=50M)
84	TEL BISTAN4 RNG	603143	4018404	HALN	4.2830	08/07/96	CAL	MIDDLE OF GENTLE SLOPE
85	DELIYAAN5 RNG	603419	4015681	LAMN	4.3100	08/07/96	CAL	ALMOST FLAT
86	DELIYAAN6 BARLEY	606200	4015866	BARLEY	4.3234	08/07/96	CAL	BOT OF SMALL GENTLE SLOPE
87	GHARA3 RNG	612662	4035067	MAMN	4.3638	08/08/96	CAL	MIDDLE OF GENTLE SLOPE
88	HASSAN5 PRO	610507	4029452	BURNED	5.0406	08/08/96	CAL	TOP TO MID OF SLOPE
89	HASSAN6 PRO	610507	4029452	D-VEGE	5.0709	08/08/96	CAL	TOP OF SLOPE
90	MARKAB ALI2 RNG	613823	4032367	LALNLH	5.1117	08/08/96	CAL	MID OF GENTLE SLOPE
91	KHAZNE2 TOP	617994	4034557	HALN	6.0107	09/17/96	CAL	TOP OF THE SLOPE
92	KHAZNE2 MIDDLE	618317	4035968	HALN	6.0813	09/17/96	CAL	MID OF THE SLOPE
93	KHAZNE2 BOTTOM	618474	4036495	HALN	6.1419	09/17/96	CAL	BOTTOM OF SLOPE BEFORE W/
94	BADIA TOP	601804	4029048	LALNLH	6.2326	09/18/96	CAL	TOP THE SLOPE
95	BADIA BOTTOM	601670	4029111	D-VEGE	6.2732	09/18/96	CAL	BOTTOM OF THE SLOPE
96	AMLLAD TOP	626082	4023033	LALNLH	7.0106	09/20/96	GYP	TOP OF THE SLOPE
97	AMLLAD MIDDLE	626082	4023033	LAHN	6.3738	09/19/96	GYP	MID OF SLOPE
98	AMLLAD BOTTOM	626082	4023033	LAMN	6.3336	09/19/96	GYP	BOTTOM OF SLOPE
99	NAASRI BARLEY	632406	4014198	BARLEY	7.0713	09/20/96	CAL	FLAT IN S PLAIN
100	KHABUL WHEAT	630774	4047897	WHEAT	7.1419	09/21/96	CAL	EDGE OF N PLAIN, NR KHABUL
101	MAGHLOOJA FOREST	628827	4034640	PINE	7.2024	09/21/96	CAL	BOTTOM OF N SLOPE

a: Vegetation at the sampling points was classified according to the relative coverage of *Artemisia herba-alba* and *Noaea mucronata*, two dominant shrub species in the study area (Hirata et al. 1998).

HALN: High Artemisia Low Noaea
MAMN: Middle Artemisia and Middle Noaea
LAMN: Low Artemisia and Middle Noaea
LALNLH: Low Artemisia, Low Noaea and Low Herb
LALNHH:Low Artemisia, Low Noaea and High Herb
D-VEGE: Dense Vegetation

b: CAL; Limestone, GYP; Gypsum, C&G; mixture of Limestone and Gypsum

Appendix 1 Description of the sampling sites (Continued). (4/4)

Site ID	------Slope------ gradient (°)	direction	Stone (%)	Rock (%)	LAND USE	Soil Texture[c]	----------Structure-------- grade[d]	type[e]	size[f]	Soil color at dry	at moist
51	2	N	50	10	GRAZED	CL	MOD	SABLK	FINE	10YR6/4	10YR4/6
52	1	N70E	60	25	PROTECTED	SL	MOD	SABLK	MED	10YR6/4	10YR4/6
53	1	E	60	25	PROTECTED	CL	MOD	SABLK	F_M	10YR6/4	10YR4/6
54	4	N60W	90	50	SEMI_GRAZE	CL	MOD	SABLK	MED	10YR5/4	10YR4/4
55	5	S	60	25	GRAZED	CL	WEAK	SABLK	FINE	10YR6/4	10YR4/6
56	4	W	15	2	SEMI_GRAZE	L	M_S	SABLK	MED	10YR6/4	10YR4/4
57	4	W	50	10	BARLEY	SL	MED	SABLK	FINE	10YR6/4	10YR4/6
58	5	S40E	60	50	GRAZED	SL	MOD	SABLK	FINE	10YR7/4	10YR4/6
59	5	S40E	15	10	BARLEY	SL	MOD	SABLK	MED	10YR6/4	10YR4/6
60	6	S30E	50	25	FALLOW	SL	WEAK	SABLK	FINE	10YR7/4	10YR5/4
61	1	S	15	10	FALLOW	L	WEAK	SABLK	FINE	10YR6/4	10YR4/4
62	9	S20E	40	10	GRAZED	SL	WEAK	SABLK	FINE	10YR7/4	10YR4/4
63	6	S30E	15	10	BARLEY	SL	WEAK	SABLK	MED	10YR6/4	10YR4/6
64	5	N70E	3	10	FALLOW	SL	WEAK	SABLK	M_F	10YR7/3	10YR6/4
65	3	N80E	3	10	FALLOW	L	MOD	SABLK	MED	10YR6/4	10YR4/6
66	3	S30W	40	25	GRAZED	CL	MOD	SABLK	F_M	10YR5/3	10YR4/4
67	7	N60W	15	10	GRAZED	SL	WEAK	SABLK	MED	10YR7/3	10YR5/4
68	2	S70W	3	2	FALLOW	SL	WEAK	SABLK	F_M	10YR6/3	10YR5/4
69	1	N80W	15	2	FALLOW	CL	MOD	SABLK	F_M	10YR5/4	10YR4/4
70	2	S20E	40	25	GRAZED	SL	MOD	SABLK	MED	10YR6/4	10YR4/6
71	3	N30W	15	10	GRAZED	CL	STRG	SABLK	F_M	10YR5/4	10YR4/6
72											
73	3	S1OE	50	10	GRAZED	SL	WEAK	SABLK	MED	10YR6/4	10YR4/4
74	6	S20E	15	10	GRAZED	SL	MOD	SABLK	MED	10YR7/3	10YR5/4
75	5	S30W	50	10	GRAZED	SL	WEAK	SABLK	MED	10YR6/4	10YR4/6
76	4	N	30	10	GRAZED	SL	MOD	SABLK	MED	10YR6/4	10YR4/6
77	4	W	15	25	GRAZED	L	STR	PLATY	LARG	10YR7/3	10YR5/4
78	5	N70W	15	2	GRAZED	SL	WEAK	SABLK	LARG	10YR6/4	10YR5/4
79	2	S30E	15	2	BARLEY	L	MOD	SABLK	MED	10YR6/3	10YR4/4
80	3	N20E	15	2	GRAZED	CL	WEAK	SABLK	FINE	10YR7/4	10YR5/6
81	5	W	15	10	GRAZED	CL	MOD	SABLK	LARG	10YR6/4	10YR4/6
82	1	S60W	3	2	FALLOW	L	MOD	SABLK	LARG	10YR6/4	10YR4/4
83	3	S30E	40	10	GRAZED	CL	STRG	PLATY	V.LA	10YR6/4	10YR4/6
84	2	S20E	15	2	GRAZED	L	MOD	SABLK	MED	10YR6/4	10YR4/6
85	1	S50E	3	2	GRAZED	SL	MOD	SABLK	M&L	10YR6/4	10YR4/6
86	1	S	1	2	BARLEY	CL	MOD	SABLK	F&M	10YR6/4	10YR4/4
87	5	S40W	30	2	GRAZED	L	MOD	SABLK	F&M	10YR6/4	10YR4/6
88					PROTECTED						
89	1	S60E	40	10	PINE-PROTECTE	CL	MOD	CRUMB	MED	10YR6/4	10YR4/6
90	5	S50E	50	10	GRAZED	CL	MOD	CRUMB	FINE	10YR5/4	10YR3/4
91	4	N10E	50	10	NR PROTECTED	SL	MOD	PLATY	COAR	10YR6/4	10YR4/6
92	3	N1OE	50	10	GRAZED	SL	WEAK	SABLK	MED	10YR5/3	10YR4/6
93	3	N10E	50	10	GRAZED	CL	MOD	SABLK	MED	10YR5/4	10YR4/6
94	8	N70W	50	25	PROTECTED	SL	MOD	SABLK	FINE	10YR5/4	10YR4/4
95	4	N70W	50	10	PROTECTED	SL	MOD	SABLK	FINE	10YR5/4	10YR4/6
96	10	N30E	30	25	GRAZED	SL	MOD	PLATY	FINE	10YR5/3	10YR3/4
97	4	N40E	40	10	GRAZED	SL	MOD	PLATY	MED	10YR6/4	10YR4/6
98	1	N30E	15	2	GRAZED	SL	MOD	SABLK	MED	10YR6/4	10YR4/6
99	0		15	2	BARLEY	SL	MOD	SABLK	MED	10YR6/4	10YR4/6
100	0		1	2	IRR WHEAT	L	STRG	SABLK	COAR	10YR6/4	10YR4/6
101	3	N10W	30	25	AFFORESTED	SL	WEAK	CRUMB	MED	10YR4/4	10YR4/3

c: Soil texture was examined in the field.
d: MOD; moderate, STRG; strong
e: SABLK; subangular blocky
f: MED; medium, COAR; coarse, V.LA; very large, F&M; fine and medium, F_M; fine to medium, VFIN; very fine

Appendix 2 Results of soil analysis and vegetation measurment. (1/2)

		Aggregate stability		Soil Chemical Properties						Particl size distribution			Soil surface coverage					Aerial Biomass (kg/ha)				
		($\times 10^{-2}$ kg kg^{-1})		EC	pH	Total N	Org-C	CN	Inorg-C		(%)				(%)				Shrub		Herb	Shrub
Site ID	Horizon	air-dried	prewetted	(mS m^{-1})	(H_2O)	(g kg^{-1})			(g kg^{-1})	clay	silt	sand	Shrub	Herb	Soil	Litter	Stone	green	dry	total		+Herb
1	A	67.4	98.6	35.7	7.68	2.13	17.9	8.4	38.7	36.8	30.4	32.8	0	94	0	0	6	0	0	0	620	620
1	CA			34.2	7.83	0.78	5.7	7.4	51.7													
2	A	65.0	91.8	32.8	7.77	1.84	16.3	8.9	64.7	30.6	26.7	42.7	22	76	0	0	2	74	150	224	736	960
2	AC			26.1	7.95	1.31	10.1	7.7	66.5													
2	CA			27.3	7.99	0.92	7.4	8.0	70.1													
3	A	61.2	94.6	43.9	7.74	2.16	18.1	8.4	32.8	38.3	32.3	29.3	8	88	4	0	0	112	176	289	206	495
3	AB			32.7	7.93	1.47	10.7	7.3	36.7													
3	Bw			32.1	8.04	0.93	6.5	7.0	40.5													
3	CB			97.2	7.77	0.61	3.8	6.3	42.1													
4	A	68.6	95.5	49.2	7.69	2.45	21.1	8.6	33.9	37.9	30.7	31.4	38	58	4	0	0	488	381	869	256	1125
4	BA			34.8	7.94	1.29	9.1	7.0	33.5													
4	Bw			35.0	7.99	0.94	6.8	7.2	38.1													
5	Ap	36.6	85.8	27.4	7.92	0.76	5.9	7.8	62.4	30.5	32.4	37.2	0	62	30	6	2	0	0	0	390	390
5	BA	33.2	92.8	26.0	8.05	0.43	3.8	8.8	61.7													
5	B1			27.2	8.10	0.38	2.4	6.3	63.7													
5	B2			38.5	8.03	0.23	1.9	8.2	70.3													
6	A	41.6	83.6	41.1	7.67	1.40	16.7	11.9	55.8	26.9	30.7	42.4	26	60	14	0	0	177	302	480	326	806
6	BA	41.4	91.3	28.0	7.94	1.09	7.6	7.0	53.9													
6	B			26.7	7.99	0.66	4.4	6.6	58.3													
6	BC			26.5	8.02	0.42	2.7	6.5	64.7													
7	A			167.6	7.47	1.52	11.9	7.8	66.5	23.6	34.5	41.9	2	56	32	0	10					
7	AC	56.0	91.3	164.2	7.67	1.47	10.1	6.9	52.8													
7	C			184.6	7.78	0.42	2.5	5.9	25.4													
8	A	42.0	94.4	38.0	7.76	1.78	15.2	8.5	62.4	26.8	35.4	37.8	0	86	12	0	2					
8	AB	34.5	89.7	27.8	8.11	1.03	7.9	7.7	65.7													
8	BA	28.6	92.2	30.7	8.13	0.74	5.3	7.1	66.0													
8	B1			42.7	8.09	0.47	3.4	7.3	70.1													
8	B2			145.2	7.74	0.40	2.2	5.4	77.6													
9	A	46.0	94.3	31.7	8.00	2.00	15.2	7.6	65.3	28.7	35.9	35.4	0	74	24	0	2					
9	AB	45.9	91.5	37.0	8.15	1.17	8.9	7.6	69.5													
9	B	47.7	94.6	37.0	8.15	1.17	8.9	7.6	69.5													
10	surface	57.8	89.4	32.7	7.94	0.70	7.6	10.9	56.0				0	36	64	0	0	0	0	0	317	317
11	surface	40.2	83.6	33.2	7.95	0.64	6.9	10.8	64.4									0	0	0	2170	2170
12	surface	19.4	72.2	39.2	7.97	1.19	11.8	9.9	43.4									0	0	0	718	718
13	surface	31.7	80.5	34.0	8.02	0.90	9.4	10.4	50.3				30	52	14	0	4	450	299	749	186	935
14	surface	31.1	80.4	30.8	8.04	1.06	9.8	9.2	51.0				8	38	52	0	2	53	215	268	118	386
15	surface	47.4	85.2	35.1	7.88	1.23	11.6	9.4	64.7				36	30	32	0	2	128	436	565	64	629
16	surface	52.3	92.0	35.6	7.95	1.19	10.9	9.2	60.5				0	60	40	0	0	0	0	0	296	296
17	surface	47.6	84.9	48.7	7.93	0.97	8.2	8.5	74.0				34	44	22	0	0	193	373	566	112	678
18	surface	35.3	64.0	41.4	7.91	1.07	10.1	9.5	53.9				30	50	20	0	0	109	248	357	108	465
19	surface	33.4	88.5	177.1	7.61	1.40	11.8	8.4	40.2				14	48	36	2	0	35	210	245	46	291
20	surface	76.5	63.8	52.2	7.70	3.16	35.4	11.2	23.1				0	80	4	0	16	0	0	0	220	220
21	surface	95.1	98.7	59.8	7.62	4.61	46.7	10.1	24.4				0	94	0	2	4	0	0	0	1656	1656
22	surface	78.2	96.4	55.1	7.71	3.03	30.2	10.0	28.7				0	100	0	0	0	0	0	0	140	140
23	surface	63.3	97.5	46.8	7.81	1.60	16.1	10.0	60.6				42	56	0	2	0	374	582	956	984	1940
24	surface	45.4	91.8	34.5	7.94	1.36	12.4	9.1	64.6				26	46	24	0	4	108	183	291	72	363
25	surface	40.6	88.4	34.7	8.03	1.14	10.5	9.2	38.2				24	32	44	0	0	105	433	538	90	628
26	surface	26.9	77.5	94.3	7.82	1.02	8.3	8.1	47.1				28	22	50	0	0	58	172	230	122	352
27	surface	32.1	80.3	34.1	8.08	0.91	7.6	8.3	64.5				10	50	40	0	0	56	102	158	66	224
28	surface	33.6	87.4	173.7	7.70	0.90	7.3	8.2	53.8				26	28	44	0	2	80	87	166	92	258
29	surface	30.1	81.3	33.6	8.08	1.08	8.7	8.0	47.3				32	42	26	0	0	162	361	523	74	597
30	surface	48.2	96.1	44.1	7.94	2.05	18.0	8.8	28.0				0	72	8	0	20	0	0	0	114	114
31	surface	49.9	88.9	59.9	7.71	1.51	14.4	9.5	40.8									0	0	0	978	978
32	surface	58.9	95.1	41.4	7.91	2.15	20.2	9.4	38.0				2	70	12	0	16	0	68	68	230	298
33	surface	47.9	82.6	42.4	7.92	2.74	25.2	9.2	33.0				0	82	8	0	10	0	0	0	238	238
34	surface	60.3	98.6	35.3	7.80	2.21	19.2	8.7	66.4	23.9	36.4	39.7	0	62	18	0	20					
35	surface	71.0	97.8	47.5	7.77	2.94	27.3	9.3	26.6	35.8	32.8	31.4	2	50	26	4	18					
36	surface	60.3	97.7	45.9	7.82	2.50	22.4	9.0	36.6	34.1	28.1	37.8	0	54	8	0	38					
37	surface	67.1	95.8	44.4	7.81	2.99	28.8	9.6	39.3	35.8	34.2	29.9	0	82	10	0	8					
38	surface	50.2	89.9	38.7	7.83	1.54	18.3	11.9	60.3	26.4	30.1	43.5	42	44	10	0	4					
39	surface	55.1	93.7	30.6	7.95	1.09	10.5	9.6	69.6	26.2	22.8	51.1	0	0	0	0	0					
40	surface	47.9	92.2	33.5	7.87	1.12	11.6	10.3	71.7	23.5	27.9	48.7	34	46	18	0	2					
41	surface	59.7	97.7	51.0	7.76	2.72	27.3	10.0	38.8	35.9	35.6	28.5	2	70	8	2	18					
42	surface	49.1	95.0	32.1	7.93	1.15	10.9	9.4	68.1	24.7	24.7	50.6	2	48	34	0	16					
43	surface	49.4	89.5	33.2	7.94	1.00	9.1	9.1	56.2	27.5	31.1	41.4	0	0	0	0	0					
44	surface	67.9	97.6	35.4	7.76	1.77	16.9	9.5	74.4	22.1	29.8	48.1	4	52	20	0	24					
45	surface	69.4	98.0	38.2	7.74	1.90	19.7	10.4	67.2	24.9	28.6	46.5	0	52	22	2	24					
46	surface	50.1	97.1	37.6	7.83	1.60	15.7	9.8	48.5	30.8	26.3	42.9	0	62	18	8	12					
47	surface	25.7	84.9	41.9	7.81	1.23	11.1	9.0	77.6	33.8	43.5	22.7	0	0	0	0	0					
48	surface	38.5	86.5	28.5	7.96	0.95	7.8	8.2	70.5	24.7	31.9	43.4	28	12	52	2	6					
49	surface	48.1	92.5	35.4	7.95	1.31	11.3	8.6	58.3	28.5	29.5	42.0	0	64	18	2	16					
50	surface	53.6	88.3	45.7	7.81	1.17	9.8	8.4	64.1	24.0	25.8	50.2	0	0	0	0	0					
51	surface	35.0	80.5	33.4	8.02	1.04	8.5	8.2	52.4	28.5	31.6	39.9	0	54	34	8	4					
52	surface	41.7	88.6	32.2	7.94	1.25	11.7	9.3	59.0	26.2	35.0	38.8	52	26	18	2	2					
53	surface	31.8	91.3	35.1	7.92	1.45	13.4	9.2	49.3	29.0	34.0	37.0	62	12	16	10	0					

Appendix 2 Results of soil analysis and vegetation measurment (Continued). (2/2)

		Aggregate stability ($\times 10^{-2}$ kg kg^{-1})		Soil Chemical Properties						Particl size distribution (%)			Soil surface coverage (%)					Aerial Biomass (kg/ha)				
				EC	pH	Total N	Org-C	CN	Inorg-C										Shrub		Herb	Shrub
Site ID	Horizon	air-dried	prewetted	(mS m^{-1})	(H_2O)	(g kg^{-1})			(g kg^{-1})	clay	silt	sand	Shrub	Herb	Soil	Litter	Stone	green	dry	total		+Herb
54	surface	49.9	98.0	44.0	7.91	1.67	16.5	9.9	24.2	42.7	32.0	25.3	6	64	14	10	6					
55	surface	50.2	95.2	47.5	7.80	1.85	15.4	8.3	55.0	23.6	31.8	44.6	12	46	36	2	4					
56	surface	37.1	90.7	35.1	7.81	1.81	18.0	9.9	64.1	22.6	37.1	40.3	20	46	28	4	2					
57	surface	63.5	95.1	31.5	7.92	1.13	10.2	9.0	70.0	24.6	34.0	41.4	0	0	0	0	0					
58	surface	31.5	90.1	30.4	8.02	1.05	9.8	9.3	64.3	23.2	33.3	43.5	22	18	48	6	6					
59	surface	46.7	87.4	31.9	7.99	1.04	10.3	9.9	63.3	23.7	32.3	44.0	0	0	0	0	0					
60	surface	45.0	89.6	37.2	7.86	1.11	11.0	9.9	66.2	21.3	29.4	49.4	0	0	0	0	0					
61	surface	40.6	90.1	33.0	8.05	0.99	9.3	9.4	48.3	28.4	37.7	33.8	0	0	0	0	0					
62	surface	76.3	95.2	30.0	7.92	0.99	9.3	9.4	78.7	16.4	30.4	53.2	34	42	18	2	4					
63	surface	39.2	91.3	36.2	7.92	0.86	7.8	9.0	75.9	22.3	37.2	40.5	0	0	0	0	0					
64	surface	61.4	90.8	179.8	7.66	0.66	5.7	8.6	60.1	18.6	21.4	60.0	0	0	0	0	0					
65	surface	36.1	86.9	63.4	7.84	0.74	6.9	9.4	48.9	26.1	29.4	44.5	0	0	0	0	0					
66	surface	43.3	94.5	41.2	7.97	1.66	15.6	9.4	61.0	26.9	33.0	40.2	10	50	34	4	2					
67	surface	54.2	92.9	43.8	7.92	0.99	8.4	8.4	71.5	20.0	32.4	47.5	20	36	34	10	0					
68	surface	52.0	93.6	177.4	7.55	1.46	13.0	8.9	46.5	32.9	32.4	34.7	0	0	0	0	0					
69	surface	22.3	89.8	49.5	7.78	1.07	9.4	8.8	43.4	26.2	31.7	42.1	0	0	0	0	0					
70	surface	44.0	92.2	45.4	8.05	1.08	9.8	9.1	57.0	27.3	30.0	42.7	6	30	56	4	4					
71	surface	29.3	90.9	37.1	7.92	1.05	9.0	8.6	44.3	29.8	36.9	33.3	18	22	52	8	0					
72	surface																					
73	surface	42.0	80.4	35.6	7.99	1.27	10.8	8.5	57.0	25.9	27.4	46.7	6	36	46	0	12					
74	surface	50.0	88.9	37.4	7.80	1.21	11.3	9.4	74.4	21.9	32.6	45.5	38	36	24	0	2					
75	surface	50.2	90.6	39.1	7.79	1.43	13.0	9.1	53.1	25.2	28.4	46.4	28	32	40	0	0					
76	surface	30.9	76.9	37.3	7.92	1.06	9.3	8.8	59.3	21.7	37.1	41.2	18	12	68	0	2					
77	surface	42.7	86.6	35.7	7.97	0.84	7.0	8.3	77.9	20.0	32.6	47.4	26	6	52	4	12					
78	surface	42.8	77.0	43.7	7.92	0.49	4.7	9.7	66.6	16.6	20.5	62.9	32	16	50	0	2					
79	surface	36.7	64.6	28.4	8.07	0.51	4.3	8.5	71.7	16.7	19.9	63.4										
80	surface	32.4	69.7	29.8	8.03	0.79	6.7	8.5	62.0	19.8	27.5	52.7	32	12	54	2	0					
81	surface	30.2	79.7	36.8	8.04	0.87	6.9	7.9	62.6	21.1	25.8	53.2	28	42	30	0	0					
82	surface	30.2	81.8	54.8	7.89	1.12	9.0	8.1	45.5	26.3	34.7	39.0										
83	surface	38.5	90.5	50.9	7.96	1.00	8.2	8.2	53.9	25.0	35.7	39.3	18	24	52	4	2					
84	surface	37.5	90.8	38.2	7.99	1.11	9.7	8.8	54.6	23.0	31.6	45.4	46	8	42	4	0					
85	surface	26.9	92.7	158.1	7.67	1.42	11.8	8.3	40.7	31.0	37.9	31.1	20	38	38	4	0					
86	surface	13.5	82.8	43.9	7.97	1.03	8.7	8.4	31.4	36.3	38.1	25.6										
87	surface	33.8	89.9	35.9	8.01	1.03	8.0	7.8	53.1	26.2	31.1	42.6	28	8	50	0	14					
88	surface																					
89	surface	68.4	98.3	53.6	7.70	2.22	20.6	9.3	45.0	29.9	33.6	36.5	56	28	10	6	0					
90	surface	60.2	98.2	53.6	7.72	2.39	20.2	8.4	31.1	37.4	30.6	31.9	0	66	12	4	18					
91	A	46.6	82.3	33.8	7.97	1.12	9.4	8.4	63.5	23.9	28.1	47.9	40	16	36	0	8					
91	BA	50.8	92.3	24.1	8.20	0.84	6.5	7.8	64.5													
91	B	40.7	93.9	24.4	8.19	0.42	3.4	8.0	67.0													
91	CB			27.6	8.01	0.28	2.6	9.2	69.0													
92	A	45.0	79.8	39.3	7.81	1.10	9.5	8.6	56.4	24.6	30.1	45.3	32	8	58	0	2					
92	BA	46.7	86.0	26.5	8.14	0.69	5.6	8.1	58.7													
92	B	43.1	93.2	27.1	8.25	0.38	3.5	9.2	60.1													
92	CB			39.3	8.01	0.23	2.5	10.8	63.5													
93	A	48.9	77.9	36.8	7.84	1.10	8.9	8.1	55.5	23.2	32.1	44.8	34	8	56	0	2					
93	BA	38.1	78.2	25.3	8.13	0.83	6.3	7.6	55.9													
93	B	33.6	90.0	22.8	8.28	0.47	3.8	8.0	58.9													
93	CB			23.0	8.30	0.28	2.8	9.8	64.5													
94	A	70.0	94.9	56.9	7.67	2.25	18.1	8.0	39.4	26.8	31.7	41.5	2	38	16	2	42					
94	BA	50.1	77.4	32.9	8.04	1.39	10.0	7.2	39.6													
95	A	62.1	87.6	56.6	7.69	2.17	18.6	8.6	45.1	29.2	31.3	39.4	40	26	22	8	4					
95	BA	57.6	90.3	39.3	7.90	1.47	11.8	8.0	47.9													
95	B	49.5	96.3	28.7	8.14	0.44	3.5	8.0	58.6													
95	CB			28.2	8.13	0.31	2.6	8.3	62.6													
96	A	84.6	96.3	164.9	7.33	2.84	23.3	8.2	46.9	24.4	30.8	44.8	2	56	36	0	6					
96	CA	75.3	90.0	163.5	7.84	0.67	5.0	7.4	19.2													
97	A	30.2	89.3	99.9	7.60	1.02	8.0	7.9	59.9	18.4	21.6	60.0	28	20	50	0	2					
97	BA	36.0	96.8	75.8	7.93	0.62	4.6	7.5	58.4													
97	B	30.9	96.8	182.5	7.67	0.46	3.3	7.2	61.7													
98	A	44.2	95.5	60.6	7.69	1.52	12.9	8.5	44.8	26.1	32.4	41.5	16	20	56	8	0					
98	AB	35.1	89.7	44.9	7.91	1.14	9.2	8.0	46.0													
98	B1	31.7	85.6	52.2	7.99	0.66	5.3	8.0	49.5													
98	B2	41.7	94.3	189.5	7.60	0.33	2.6	7.9	56.9													
99	A	30.8	75.6	41.9	7.89	1.06	8.8	8.3	33.8	29.2	39.1	31.8										
99	AB	22.6	71.3	37.4	8.14	0.68	5.2	7.7	35.5													
99	B1	36.9	95.3	48.2	8.12	0.28	2.0	7.0	44.6													
99	B2	53.7	96.5	41.0	8.15	0.22	1.9	8.6	45.8													
100	Ap	51.7	94.6	71.9	8.11	0.67	6.0	8.9	53.9													
100	B1	21.0	85.0	174.9	7.76	0.22	2.3	10.3	61.1													
100	B2	26.5	97.5	213.0	7.70	0.17	1.6	9.7	52.6													
101	A	73.1	97.5	50.6	7.73	3.45	33.0	9.6	61.6													
101	AB	58.4	98.4	32.1	8.18	1.55	13.2	8.5	66.6													
101	B1	48.5	97.5	28.3	8.26	0.64	5.3	8.3	73.5													
101	B2	44.1	96.2	30.6	8.36	0.46	3.9	8.4	70.4													

Appendix 3 Soil profile description of selected sampling sites.

Site ID 1 (Sabaizlam grazed)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;622002 Y;4029608)
Topography: South facing straight slope; gradient 9°
Parent material: limestone
Vegetation: Herbaceous species (*Lolium* spp.)
Survey date: May 4, 1996
Soil sample: 1A, 1CA

Hor.	Depth(cm)	Soil profile description
A	0- 11/18	Brown (7.5YR4/4); moderately dry; Sandy loam; moderate medium subangular blocky; slightly hard; slightly sticky, plastic; many very fine roots; common fine pores; few gravels; shallow finger printing; distinctive few fine carbonates; abrupt wavy boundary to
CA	- 50	Brown (7.5YR4/6); moderately dry; Sandy clay loam; weak fine subangular blocky; soft; sticky, plastic; few fine roots; common fine pores; abundant pebbles and cobbles; shallow finger printing; distinctive few fine carbonates; clear smooth boundary to
C	- 57+	

Site ID 2 (Sabaizlam protected)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;621930 Y;4029535)
Topography: South 25° East facing straight slope; gradient 11°
Parent material: limestone
Vegetation: *Noaea mucronata*, Herbaceous species
Survey date: May 4, 1996
Soil sample: 2A, 2AC, 2CA

Hor.	Depth(cm)	Soil profile description
A	0 - 6	Dull yellowish brown (10YR5/3); dry; 10YR4/3 when moist; Sandy loam; weak fine subangular blocky; soft; slightly sticky, plastic; many fine roots; few fine pores; common gravels; shallow finger printing; clear smooth boundary to
AC	- 17	Dull yellowish brown (10YR5/4); moderately dry; 10YR4/4 when moist; Sandy clay loam; moderate medium subangular blocky; soft; slightly sticky, plastic; common fine roots; common fine pores; common pebbles and cobbles; shallow finger printing; distinctive common fine carbonates; abrupt wavy boundary to
CA	- 36	Dull yellowish brown (7.5YR5/4); moderately dry; 10YR 4/4 when moist; Sandy clay loam; moderate medium subangular blocky; slightly hard; slightly sticky, plastic; common very fine roots; common very fine pores; abundant pebbles and cobbles; shallow finger printing; distinctive few fine carbonates; abrupt smooth boundary to
R	- 40+	

Site ID 3 (Badia grazed)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;601764 Y;4029095)
Topography: West facing straight slope; gradient 7°
Parent material: limestone
Vegetation: Herbaceous species
Survey date: May 5, 1996
Soil sample: 3A, 3AB, 3Bw, 3CB

Hor.	Depth(cm)	Soil profile description
A	0 - 4	Dull yellow orange (10YR6/4); dry; 10YR4/4 when moist; Sandy clay loam; weak fine subangular blocky; soft; slightly sticky, plastic; abundant coarse roots; common fine pores; common pebbles; shallow finger printing; clear smooth boundary to
AB	- 17	Brown (7.5YR4/6); moderately dry; Clay loam; moderate fine subangular blocky; soft; slightly sticky, very plastic; common fine roots; common fine pores; common pebbles; shallow finger printing; distinctive few fine carbonates; clear smooth boundary to
Bw	- 37	Brown (7.5YR4/4); moderately dry; Clay loam; moderate medium subangular blocky; soft; slightly sticky, plastic; common fine roots; many fine pores; common pebbles; shallow finger printing; distinctive common fine carbonates; clear smooth boundary to
CB	- 63+	Brown (7.5YR4/4); moderately dry; Clay loam; moderate fine subangular blocky; soft; slightly sticky, plastic; few very fine roots; common fine pores; many pebbles and cobbles; shallow finger printing; distinctive common fine carbonates.

Site ID 4 (Badia protected)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;601734 Y;4028946)
Topography: North 70° West facing straight slope; gradient 6°
Parent material: limestone
Vegetation: *Noaea mucronata,* Herbaceous species
Survey date: May 5, 1996
Soil sample: 4A, 4BA, 4Bw

Hor.	Depth(cm)	Soil profile description
A	0 - 4	Dull yellowish brown (10YR5/4); dry; 10YR4/4 when moist; Sandy loam; moderate fine subangular blocky; soft; slightly sticky, slightly plastic; many fine roots; common fine pores; common pebbles; shallow finger printing; clear smooth boundary to
BA	- 21	Brown (7.5YR4/4); moderately dry; Sandy clay loam; moderate medium subangular blocky; soft; slightly sticky, plastic; many very fine roots; common fine pores; common pebbles; shallow finger printing; distinctive common fine carbonates; clear smooth boundary to
Bw	- 41	Brown (7.5YR4/4); moderately dry; Clay loam; moderate medium subangular blocky; soft; sticky, very plastic; few fine roots; common fine pores; abundant pebbles and cobbles; shallow finger printing; distinctive few fine carbonates; clear smooth boundary to
C	- 65+	Brown (7.5YR4/4); moderately dry; Clay loam; weak fine subangular blocky; soft; sticky, very plastic; few very fine roots; few fine pores; many cobbles; shallow finger printing.

Site ID 5 (Khazne fallow)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;619850 Y;4036373)
Topography: North 80° East facing straight slope; gradient 2°
Parent material: limestone
Vegetation: Cultivated fallow
Survey date: May 6, 1996
Soil sample: 5Ap, 5BA, 5B1, 5B2

Hor.	Depth(cm)	Soil profile description
Ap	0 - 10	Dull yellow orange (10YR6/4); dry; 10YR5/6 when moist; Sandy clay loam; weak fine subangular blocky; soft; slightly sticky, plastic; common fine roots; few fine pores; common gravels; shallow finger printing; clear smooth boundary to
BA	- 30	Yellowish brown (10YR5/6); moderately dry; Clay loam; moderate medium subangular blocky; soft; sticky, very plastic; common fine roots; common fine pores; few gravels; shallow finger printing; distinctive few fine carbonates; clear smooth boundary to
B1	- 63	Yellowish brown (10YR5/6); moderately dry; Clay loam; moderate medium subangular blocky; soft; sticky, very plastic; common fine roots; many fine pores; few gravels; no finger printing; distinctive common fine carbonates; gradual smooth boundary to
B2	- 86+	Bright brown (7.5YR5/6); moderately dry; Clay loam; moderate medium subangular blocky; soft; sticky, very plastic; few fine roots; few fine pores; few gravels; no finger printing; distinctive few fine carbonates.

Site ID 6 (Khazne rangeland)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;619850 Y;4036373)
Topography: South 70° East facing straight slope; gradient 2°
Parent material: limestone
Vegetation: *Artemisia herba-alba*, and Herbaceous species
Survey date: May 6, 1996
Soil sample: 6A, 6BA, 6B, 6BC

Hor.	Depth(cm)	Soil profile description
A	0 - 3	Dull orange (7.5YR6/4); dry; 7.5YR4/6 when moist; Sandy loam; moderate fine subangular blocky; soft; slightly sticky, plastic; many fine roots; common very fine pores; common gravels; no finger printing; clear smooth boundary to
BA	- 19	Dull yellowish brown (10YR5/4); moderately dry; Sandy clay loam; moderate fine subangular blocky; slightly hard ; sticky, plastic; common fine to medium roots; common fine pores; common gravels and pebbles; no finger printing; distinctive few fine carbonates; clear smooth boundary to
B	- 38	Brown (10YR4/6); moderately dry; Sandy clay loam; moderate medium subangular blocky; soft; sticky, plastic; common fine to medium roots; many fine pores; common pebbles; shallow finger printing; distinctive common fine carbonates; clear smooth boundary to
BC	- 70+	Brown (7.5YR4/4); moderately dry; Sandy clay loam; moderate fine subangular blocky; soft; sticky, very plastic; few fine roots; common fine pores; abundant pebbles; shallow finger printing; distinctive common fine carbonates.

Site ID 7 (Chair top grazed)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;630595 Y;4026577)
Topography: South 80° West facing straight slope; gradient 6°
Parent material: gypsum
Vegetation: Herbaceous species
Survey date: May 7, 1996
Soil sample: 7A, 7AC, 7C

Hor.	Depth(cm)	Soil profile description
A	0 - 1	Dull yellow orange (10YR7/3); dry; 10YR5/4 when moist; Sandy loam; weak fine subangular blocky; soft; slightly sticky, slightly plastic; common fine roots; few fine pores; many gravels; no finger printing; clear smooth boundary to
AC	- 8/10	Dull yellow orange(10YR6/3); dry; 10YR4/4 when moist; Sandy loam; weak medium subangular blocky; soft; slightly sticky, plästic; few fine roots; common fine pores; common gravels; no finger printing; abrupt smooth boundary to
R	- 16/35+	abrupt irregular boundary to
C	- 35+/-	Bright yellowish brown (10YR6/6); moderately dry; Loamy sand; weak medium subangular blocky; soft; slightly sticky, plastic; few fine roots; few fine pores; few pebbles; deep finger printing.

Site ID 8 (Chair bot grazed)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;630595 Y;4026577)
Topography: South 80° East facing straight slope; gradient 4°
Parent material: gypsum
Vegetation: Herbaceous species
Survey date: May 7, 1996
Soil sample: 8A, 8AB, 8BA, 8B1, 8B2

Hor.	Depth(cm)	Soil profile description
A	0 - 5	Dull yellow orange (10YR6/4); dry; 10YR4/4 when moist; Sandy loam; moderate fine subangular blocky; soft; slightly sticky, slightly plastic; abundant medium roots; few fine pores; common gravels; shallow finger printing; abrupt smooth boundary to
AB	- 19	Brown (10YR4/6); moderately dry; Clay loam; moderate fine subangular blocky; soft; sticky, plastic; common very fine roots; many fine pores; few gravels; no finger printing; clear smooth boundary to
BA	- 34	Brown (10YR4/6); moderately dry; Clay loam; moderate fine subangular blocky; soft; sticky, plastic; few fine roots; common fine pores; few gravels; shallow finger printing; distinctive few fine carbonates; clear smooth boundary to
B1	- 61	Brown (10YR4/6); moderately dry; Clay loam; moderate fine subangular blocky; soft; sticky, plastic; few very fine roots; many fine pores; few gravels; shallow finger printing; distinctive common fine carbonates; clear smooth boundary to
B2	- 80+	Yellowish brown (10YR5/8); moderately dry; Clay loam; moderate fine subangular blocky; soft; sticky, plastic; few very fine roots; common medium pores; common gravels; shallow finger printing; distinctive common fine carbonates.

Site ID 9 (Chair mid grazed)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;630595 Y;4026577)
Topography: South 80° West facing straight slope; gradient 4°
Parent material: gypsum
Vegetation: Herbaceous species
Survey date: May 7, 1996
Soil sample: 9A, 9AB, 9B

Hor.	Depth(cm)	Soil profile description
A	0 - 7	Dull yellow orange (10YR6/4); dry; 10YR4/4 when moist; Sandy loam; moderate very fine subangular blocky; soft; slightly sticky, plastic; many medium roots; few fine pores; common gravels; no finger printing; clear smooth boundary to
AB	- 18	Dull yellowish brown (10YR5/4); moderately dry; Sandy loam; moderate fine subangular blocky; soft ; slightly sticky, plastic; common fine roots; common fine pores; few gravels; shallow finger printing; clear smooth boundary to
B	- 40/48+	Dull yellowish brown (10YR5/4); moderately dry; Sandy loam; moderate medium subangular blocky; sticky, plastic; few very fine roots; common medium pores; many gravels; distinctive few fine carbonates; clear wavy boundary to
R	- 48+/	

Site ID 91 (Khazne2 top)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;617994 Y;4034557)
Topography: North 10° East facing straight slope; gradient 4°
Parent material: limestone
Vegetation: *Artemisia herba-alba*, and Herbaceous species
Survey date: September 17, 1996
Soil sample: 91A, 91BA, 91B, 91CB

Hor.	Depth(cm)	Soil profile description
A	0 - 5	Dull yellow orange (10YR6/4); dry; 10YR4/6 when moist; Sandy loam; moderate coarse granular; soft; slightly sticky, plastic; common fine roots; few fine pores; common pebbles; shallow finger printing; clear smooth boundary to
BA	- 20	Dull yellow orange (10YR6/4); dry; 10YR4/6 when moist; Sandy loam; moderate fine subangular blocky; slightly hard; sticky, plastic; common medium roots; common fine pores; common gravels; no finger printing; carbonates; gradual smooth boundary to
B	- 42	Dull yellowish brown (10YR5/4); dry; 10YR4/6 when moist; Clay loam; moderate fine to medium subangular blocky; slightly hard; sticky, plastic; few medium roots; common fine pores; many gravels; no finger printing; carbonates; clear smooth boundary to
CB	- 58+	Brown (7.5YR4/6); moderately dry; Clay loam; weak fine subangular blocky; soft; sticky, very plastic; common fine roots; few medium pores; abundant pebbles; no finger printing; carbonates.

Site ID 92 (Khazne2 middle)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;618317 Y;4035968)
Topography: North 10° East facing straight slope; gradient 4°
Parent material: limestone
Vegetation: *Artemisia herba-alba*, and Herbaceous species
Survey date: September 17, 1996
Soil sample: 92A, 92BA, 92B, 92CB

Hor.	Depth(cm)	Soil profile description
A	0 - 3	Dull yellowish brown(10YR5/3); dry; 10YR4/6 when moist; Sandy loam; weak medium subangular blocky; soft; slightly sticky, very plastic; common fine roots; few very fine pores; many gravels and pebbles; shallow finger printing; clear smooth boundary to
BA	- 28	Dull brown (7.5YR5/4); dry; 7.5YR4/4 when moist; Loam; moderate medium subangular blocky; hard; slightly sticky, very plastic; few medium roots; common fine pores; common pebbles; no finger printing; clear smooth boundary to
B	- 42	Yellowish brown (10YR5/6); dry; 10YR4/6 when moist; Clay loam; moderate medium subangular blocky; slightly hard; sticky, plastic; few medium roots; common fine pores; many pebbles; no finger printing; carbonates; abrupt smooth boundary to
CB	- 63+	Brown (10YR4/4); dry; 10YR4/6 when moist; Loam; strong fine subangular blocky; hard; sticky, plastic; few medium roots; few fine pores; abundant pebbles; no finger printing; carbonates.

Site ID 93 (Khazne2 bottom)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;618474 Y;4036495)
Topography: North 10° East facing straight slope; gradient 3°
Parent material: limestone
Vegetation: *Artemisia herba-alba*, and Herbaceous species
Survey date: September 17, 1996
Soil sample: 93A, 93BA, 93B, 93CB

Hor.	Depth(cm)	Soil profile description
A	0 - 5	Dull yellowish brown (10YR5/4); dry; 10YR4/6 when moist; Clay loam; moderate medium subangular blocky; soft; slightly sticky, plastic; many fine roots; few fine pores; common gravels; shallow finger printing; clear smooth boundary to
BA	- 16	Dull yellowish orange (10YR6/4); dry; 10YR4/6 when moist; Clay loam; moderate fine to medium subangular blocky; hard; sticky, plastic; few medium roots; many fine pores; common gravels; no finger printing; clear smooth boundary to
B	- 32	Yellowish brown (10YR5/4); dry; 10YR4/6 when moist; Clay loam; moderate medium subangular blocky; slightly hard; sticky, plastic; few medium roots; many fine pores; common gravels; no finger printing; carbonates; abrupt smooth boundary to
CB	- 47+	Yellowish brown (10YR5/6); moderately dry; 10YR 4/6 when moist; Loam; moderate fine subangular blocky; slightly hard; sticky, plastic; few fine roots; common fine pores; abundant pebbles; no finger printing; carbonates.

Site ID 94 (Badia top)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;601804 Y;4029048)
Topography: North 70° West facing straight slope; gradient 8°
Parent material: limestone
Vegetation: Herbaceous species
Survey date: September 18, 1996
Soil sample: 94A, 94BA

Hor.	Depth(cm)	Soil profile description
A	0 - 2	Dull yellowish brown (10YR5/4); dry; 10YR4/4 when moist; Sandy loam; moderate fine subangular blocky; soft; slightly sticky, slightly plastic; many fine roots; few medium pores; many pebbles; deep finger printing; clear smooth boundary to
BA	- 22	Yellowish brown (10YR5/6); moderately dry; 7.5YR4/6 when moist; Loam; moderate medium subangular blocky; slightly hard; slightly sticky, plastic; few fine roots; common very fine pores; many pebbles; finger penetrable; abrupt smooth boundary to
R	22 –	

Site ID 95 (Badia bottom)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;601670 Y;4029111)
Topography: North 70° West facing straight slope; gradient 4°
Parent material: limestone
Vegetation: *Salsola vermiculata*, and Herbaceous species
Survey date: September 18, 1996
Soil sample: 95A, 95BA, 95B, 95CB

Hor.	Depth(cm)	Soil profile description
A	0 - 5	Dull yellowish brown(10YR5/4); dry; 10YR4/6 when moist; Sandy loam; moderate fine subangular blocky; soft; slightly sticky, plastic; many medium roots; few fine pores; common gravels; shallow finger printing; abrupt smooth boundary to
BA	- 24	Dull yellowish brown (7.5YR5/4); dry; 10YR5/6 when moist; Clay loam; moderate medium subangular blocky; slightly hard; slightly sticky, plastic; common medium roots; common fine pores; common pebbles; no finger printing; few filamentous fine carbonates; clear smooth boundary to
B	- 60	Brown (10YR4/6); moderately dry; Clay loam; moderate fine subangular blocky; hard; sticky, plastic; few medium roots; few very fine pores; common pebbles; no finger printing; many filamentous fine carbonates; clear smooth boundary to
CB	- 72+	Brown (10YR4/6); moderately dry; Clay; weak fine subangular blocky; hard; sticky, plastic; few fine roots; few fine pores; abundant pebbles; no finger printing; common fine carbonates.

Site ID 96 (Amllad top)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;626082 Y;4023033)
Topography: North 30° East facing straight slope; gradient 10°
Parent material: gypsum
Vegetation: Herbaceous species
Survey date: September 19, 1996
Soil sample: 96A, 96CA

Hor.	Depth(cm)	Soil profile description
A	0 - 5	Dull yellowish brown (10YR5/3); dry; 10YR4/4 when moist; Sandy loam; moderate fine granular; slightly hard; slightly sticky, plastic; many fine roots; few fine pores; common gravels; no finger printing; clear smooth boundary to
BA	- 30/37+	Dull yellow orange (10YR7/3); dry; 10YR5/4 when moist; Sandy loam; moderate fine subangular blocky; soft; no sticky, slightly plastic; few very fine roots; few medium pores; common gravels; no finger printing ; few carbonates; abrupt wavy boundary to
R	- 37+/	

Site ID 97 (Amllad middle)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;626082 Y;4023033)
Topography: North 40° East facing straight slope; gradient 4°
Parent material: gypsum
Vegetation: *Noaea mucronata*, and Herbaceous species
Survey date: September 17, 1996
Soil sample: 97A, 97BA, 97B

Hor.	Depth(cm)	Soil profile description
A	0 - 5	Dull yellow orange (10YR6/4); dry; 10YR4/6 when moist; Sandy loam; moderate medium granular; soft; slightly sticky, plastic; common fine roots; few fine pores; common gravels; no finger printing; abrupt smooth boundary to
BA	- 29	Dull yellow orange (10YR6/4); dry; 10YR5/4 when moist; Sandy loam; moderate medium subangular blocky; hard; slightly sticky, plastic; few very fine roots; common very fine pores; few gravels; no finger printing; clear smooth boundary to
B	- 44	Dull yellowish brown (10YR5/4); moderately dry; 10YR4/6 when moist; sandy loam; weak fine subangular blocky; soft; slightly sticky, plastic; few very fine roots; many medium pores; few gravels; no finger printing; many carbonates; clear smooth boundary to
R		

Site ID 98 (Amllad bottom)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;626082 Y;4023033)
Topography: North 40° East facing straight slope; gradient 4°
Parent material: gypsum
Vegetation: *Noaea mucronata*, and Herbaceous species
Survey date: September 19, 1996
Soil sample: 98A, 98AB, 98B1, 98B2

Hor.	Depth(cm)	Soil profile description
A	0 - 5	Dull yellow orange (10YR6/4); dry; 10YR4/6 when moist; Sandy loam; moderate medium subangular blocky; hard; slightly sticky, plastic; many medium roots; few fine pores; common gravels; shallow finger printing; abrupt smooth boundary to
AB	- 15	Dull yellow orange (10YR6/4); dry; 10YR4/4 when moist; Clay loam; moderate medium subangular blocky; hard ; slightly sticky, very plastic; few fine roots; common fine pores; few gravels; no finger printing; clear smooth boundary to
B1	- 33	Dull yellowish brown (10YR5/4); moderately dry; 10YR4/6 when moist; Clay loam; moderate fine subangular blocky; slightly hard; sticky, plastic; few very fine roots; common fine pores; few gravels; no finger printing; few carbonates; clear smooth boundary to
B2	- 72+	Yellowish brown (10YR5/6); moderately dry; 10YR4/6 when moist; Clay loam; moderate fine subangular blocky; soft; sticky, very plastic; few very fine roots; many very fine pores; few gravels; no finger printing; many carbonates.

Site ID 99 (Naasri barley)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;632406 Y;4014198)
Topography: Flat
Parent material: limestone
Vegetation: cultivated barley
Survey date: September 20, 1996
Soil sample: 99A, 99AB, 99B1, 99B2

Hor.	Depth(cm)	Soil profile description
Ap	0 - 12	Dull yellow orange (10YR6/4); dry; 10YR4/6 when moist; Sandy loam; moderate medium subangular blocky; soft; slightly sticky, slightly plastic; many very fine roots; common medium pores; few gravels; shallow finger printing; clear smooth boundary to
AB	- 29	Yellowish brown (10YR5/6); dry; 10YR4/6 when moist; Clay loam; moderate fine subangular blocky; slightly hard ; sticky, plastic; common very fine roots; common fine pores; few gravels; shallow finger printing; few carbonates; abrupt smooth boundary to
B1	- 61	Brown (7.5YR4/6); moderately dry; 7.5YR4/4 when moist; Clay loam; weak fine subangular blocky; soft; sticky, plastic; common fine roots; many medium pores; few gravels; no finger printing; many medium carbonates; gradual smooth boundary to
B2	- 78+	Brown (7.5YR4/6); moderately dry; 7.5YR4/6 when moist; Clay loam; moderate fine subangular blocky; hard; sticky, plastic; common very fine roots; few very fine pores; few gravels; no finger printing; many medium carbonates.

Site ID 100 (Khabul wheat)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;630774 Y;4047897)
Topography: Flat
Parent material: limestone
Vegetation: Irrigated wheat
Survey date: September 21, 1996
Soil sample: 100Ap, 100B1, 100B2

Hor.	Depth(cm)	Soil profile description
Ap	0 - 23	Dull yellow orange (10YR6/4); dry; 10YR4/6 when moist; Loam; strong coarse subangular blocky; extra hard; slightly sticky, very plastic; many fine roots; common medium pores; few gravels; no finger printing; clear smooth boundary to
B1	- 49	Brown (7.5YR4/6); moderately dry; Loam; moderate medium subangular blocky; soft; sticky, very plastic; common fine and few medium roots; common fine pores; few gravels; shallow finger printing; common medium carbonates; clear smooth boundary to
B2	- 90+	Bright brown (10YR5/6); moist; distinctive many thin ped. cutan (10YR4/6); Clay loam; moderate medium subangular blocky; very friable; sticky, very plastic; few fine to medium roots; common medium pores; few gravels; deep finger printing.

Site ID 101 (Maghlooja forest)

Location: Abd Al-Aziz mountain, Hassakeh, Syria
(UTM coordinate: X;628827 Y;4034640)
Topography: North 10° West facing straight slope; gradient 3°
Parent material: limestone
Vegetation: Afforested pine
Survey date: September 21, 1996
Soil sample: 101A, 101AB, 101B1, 101B2

Hor.	Depth(cm)	Soil profile description
A	0 - 6	Brown (10YR4/4); dry; 10YR4/3 when moist; Sandy loam; weak medium crumb; soft; slightly sticky, slightly plastic; many medium roots; few medium pores; many gravels and pebbles; shallow finger printing; clear smooth boundary to
AB	- 17	Brown (10YR4/4); dry; 7.5YR3/2 when moist; Loam; moderate fine subangular blocky; soft; slightly sticky, plastic; many medium roots; common medium pores; many pebbles; no finger printing; clear smooth boundary to
B1	- 42	Dull yellowish brown (10YR5/4); dry; 7.5YR3/4 when moist; Loam; weak fine subangular blocky; soft; slightly sticky, slightly plastic; common medium roots; common fine pores; abundant pebbles; no finger printing; clear smooth boundary to
B2	- 64+	Brown (7.5YR4/3); moderately dry; Sandy loam; moderate fine subangular blocky; soft; slightly sticky, slightly plastic; common medium roots; many medium pores; many pebbles; no finger printing; many medium carbonates.

摘要

序論(第１章)および研究対象地域の概要(第２章)

世界の半乾燥地域では、降水量の年次変動が大きく、主たる生業である農業は脆弱な生産基盤の上に成り立ってきた。しかも、近年の著しい人口増加や一人当たりの食料消費量の増加によって土地をより集約的に利用せざるを得なくなり、土壌侵食の加速や土地生産力の低下といった土壌劣化が引き起こされていると言われている。本研究において対象地域としたシリア北東部のアブダル・アジズ山地周辺地域（年間降水量約 300mm）は従来、自然草地として利用されてきたが、1950 年代以降遊牧民が定着し、草地の耕地への転換を推進した結果、飼養頭数の増加や自然草地の減少による放牧圧の上昇、あるいは耕地の拡大という土壌劣化を引き起こし得る要因が現れてきている。従って、土地利用の集約化による土壌劣化一特に当地域においては降雨による土壌侵食一の促進という構図が容易に想起されるものの、この構図の妥当性はいまだ定量的に評価されていない。また、植生の後退を認識した政府は植林・禁牧地域を設定しているが、この政策の土壌侵食に対する影響も明らかとなっていない。

そこで本研究では、当地域（面積約 900km2）における持続的な土地資源の利用を進めるために、

１．当地域の主な土地利用である放牧と耕作が土壌侵食に及ぼす影響を、侵食発生に関わる因子ー特に、土壌・植生・地形ーの観点から解明する、

２．土壌侵食に関わる因子間の相互作用を理解する、

３．当地域全体で各因子について評価することにより土壌侵食危険度評価図を作成し、今後あるべき土地利用について指針を与える

ことを目的とした。

放牧と耕作が土壌侵食に及ぼす影響(第３章)

放牧と耕作が土壌侵食に及ぼす影響を、土壌・植生・地形の観点から解析するため、当地域内の３地点を選び、各地点において異なる土地利用を持ち、かつ隣り合う２ヶ所に土壌侵食観測用試験区を設置した(計６試験区)。地点１・２では放牧地と禁牧地に、地点３では放牧地とそれを開墾した耕作地に試験区を設置した。これら６試験区において、流失土壌量を 1994/95 と 1995/96 の雨季に観測した。土壌因子として団粒安定性、植生因子として植被率の季節変動、地形因子として斜度を調べた。

地点３において、耕作区の流失土壌量は放牧区に比べかなり多く、また耕作区では土壌有機物の選択的流亡が観察された。耕作による侵食の促進は、耕起による土壌表面の撹乱や、潅木の除去による土壌被覆の減少が原因と推察された。また草地の地点１・２では、流失土壌量は両季とも非常に少なく、かつ放牧区と禁牧区の差も小さかった。放牧の影響が顕著でなかった原因として植被が多かったことが考えられた。地点１・２の放牧区は斜度が大きいにもかかわらず、斜度の小さい地点３の放牧区とほぼ同量の流失土壌量を示したが、これは団粒安定性の違いにより説明できた。以上のことから山麓は潜在的に侵食の危険性が高く、草地から耕地への転換はその危険性を顕在化させることが示唆された。

地形と植生が土壌の団粒安定性に及ぼす影響(第４章)

上に述べた侵食試験の結果から、土壌の団粒安定性が流失土壌量を説明する上で有用であり、また山地に比べ山麓で団粒安定性が低いことが示された。この現象の普遍性について検討するため、当地域内のより広い範囲で、地形と植生が団粒安定性に及ぼす影響について解析した。耕地 18 地点において、団粒安定性・土壌特性値（ｐＨ・ＥＣ・有機炭素含量・炭酸塩含量・砂含量)・斜度を測定した。草地 55 地点においては、上記測定項目に加えて、土壌被覆率としてポイント・トランセクト法により、潅木・草本・リター・レキ・裸地の出現率

も記録した。

耕地においては、団粒安定性と測定項目の間には相関が無く、団粒安定性は土壌の諸性質よりむしろ耕起の程度に大きく左右されていることが示唆された。草地の団粒安定性は、主成分分析・重回帰分析の結果、被覆因子と斜度因子により説明された。被覆因子は、有機炭素含量・草本の出現率と正の相関が、裸地の出現率と負の相関が高く、被覆材が降雨の衝撃から土壌を守っていること、主な被覆材である植生が土壌有機物を増加させていることが、団粒の安定化を促進していると推察された。斜度因子は、斜度・レキの出現率と正の相関が、潅木の出現率と負の相関が高く、急傾斜面では不安定な団粒は崩壊後流失し、残存するのは安定な団粒であることを示唆した。従って、侵食試験で示唆された団粒安定性と地形・植生の関係は普遍的であり、団粒の安定化には、土壌被覆率を増加させることが、特に緩傾斜地において重要であることが明らかとなった。

土壌侵食危険度評価図の作成と持続的な土地利用法の提案(第5章)

当地域の今後あるべき土地利用について考察することを目的として、当地域全体で地形・土壌・植生因子を衛星画像と地理情報システムを用いて図化し、土壌侵食危険度を評価することを試みた。まず草地での土壌侵食に関わる因子として地形・土壌·植生因子を評価した。地形因子として、地形図から算出された斜度を３クラスに、土壌・植生因子として、それぞれ団粒安定性と土壌被覆率を衛星画像の教師付き分類により各３クラスに分類した。第３章で述べた侵食試験の結果をもとに、これら３因子の各クラスの組み合わせについて侵食危険度を算出し、３クラスの危険度に分類した。次に耕地では、画一的な栽培管理がなされていることから、土壌・植生因子は同一と考え地形因子のみにより３クラスの危険度に分類した。

土壌・植生因子は、教師付き分類の結果、それぞれ 81%・78%が正しく分類されていた。また、草地における各ピクセルが地形・土壌・植生の３因子についてどのクラスに分類されたかを検討したところ、植生が多いクラスほど、また地形が急なクラスほど、土壌団粒の安定なクラスに分類されているピクセルが多い傾向にあり、第 4 章で明らかとなった土壌・植生・地形の関係との整合性が確認された。作成した土壌侵食危険度評価図から、草地の 70%は危険度「小」に分類され、当地域全体としては、草地の土壌侵食危険度は高くないことが明らかとなった。また、禁牧地域には急傾斜地が多く、禁牧政策が侵食の軽減に有効であることが裏付けられた。一方、禁牧政策や草地の耕地への転換により、現在放牧に利用できる面積は当地域全体の半分に過ぎず、放牧の拠点となる村やテントも現在、放牧可能な地域に集中していることも明らかとなった。したがって、現在の放牧地における土壌侵食の危険性を高めないためには、禁牧地域内で侵食危険度が小さい場所での放牧を進める必要があると思われ、そのような地域を危険度評価図から特定することができた。一方、危険度の大きい耕地の拡大は、耕地に転換された土地の侵食危険性を高めるだけでなく、草地面積を減少させ草地での放牧圧を高める結果にもつながるので、抑制するべきであると考えられた。

まとめ(第6章)

1）侵食に対する放牧と耕作の影響を調べたところ、放牧の影響は顕著でなかったが、耕作による侵食の加速と侵食による有機物の選択的流亡が認められた。

2）地形と植生が団粒安定性に及ぼす影響を調べたところ、団粒安定性は斜度と土壌被覆に規定されていた。斜度の効果としては、傾斜による崩壊団粒の流亡が、土壌被覆の効果としては、有機物の供給・降雨の衝撃からの保護の２点が考えられた。

3）当地域全体の土壌侵食危険度を衛星画像・地理情報システムを用いて評価した。この評価図を用いて禁牧政策の有効性と限界を示すとともに、より持続的な土地利用について考察した。