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IMPACTS OF LAND USE/COVER CHANGE ON SOIL PROPERTIES IN THE MEDITERRANEAN REGION OF NORTHWESTERN JORDAN

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ABSTRACT

This study was carried out to evaluate the effects of deforestation on physical and chemical properties of soils under native forest in the Mediterranean region of northwestern Jordan. Land use/cover maps of 1953, 1978 and 2002 were interpreted and analysed within GIS to quantify the shift from forest to rainfed cultivation. Six sites were sampled in a non-changed forest and in cultivated fields, three for each. Different soil properties of texture, bulk density, organic matter, total nitrogen, pH, cation exchange capacity (CEC), phosphorous and potassium were analysed. Results showed that many forests were changed into cultivated lands at a rate more than the reforestation. Subsequently, adverse effects on the studied physical and chemical properties were observed. The most affected properties were particle size distribution, bulk density of surface soil and subsoil. Organic matter and CEC decreased in cultivated soil as compared to the forest soil. Cultivated soils were found to exhibit a significantly lower status in physical and chemical soil properties as compared to forest soils. This general decline in the soil physical and chemical properties, in turn, contributed to soil erosion, reduction of soil fertility and land degradation.

There is an urgent need to improve soil quality by developing sustainable land use practices to reduce the rate of soil degradation and to ensure long-term sustainability of the farming system in the study area and in similar biophysical settings.

KEY WORDS: land use/cover change; forest; GIS; Jordan; Mediterranean

INTRODUCTION

Land degradation has been widely recognized as a major problem that threatens food production around the world. Among the major causes of land degradation are agricultural practices, shifts in land use, removal of natural vegetation, use of machinery and agricultural chemicals and modification of hydrological systems. The consequences of such practices have been wide-ranging in both on-site and off-site areas. Among these causes, land use change was shown to have the most important environmental consequences through its impacts on soil and water quality, biodiversity, methane emission and reduced CO_2 absorption; hence, land use widely contributes to land degradation (Lambin *et al*., 2000; Schneider and Pontius, 2001; Tilman *et al*., 2001). Many studies (Lal, 1996; Hajabbasi et al., 1997; Hartemink, 1998; Lumbanraja et al., 1998; Saikh et al., 1998; Wang and Gong, 1998; Nambiar et al., 2001; Arshad and Martin, 2002; Doran, 2002) have shown that land use change and conversion could lead to deterioration in the physical and chemical properties of soils and degradation of the land. Several experiments have demonstrated a rapid decline in soil chemical properties following de?forestation and intensive cultivation (Lal 1996).

In Jordan, land resources have been altered by rapid land use change accelerated by changeable socio-economic factors including high population growth, urbanization and agricultural intensification (Millington et al., 1999;

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Al-Bakri et al., 2001; Al-Bakri, 2005). Jordan, 8·9 million ha in size, contains only 0·7 million ha of arable land of which less than 1 per cent is under forest. A hundred years ago the area of forest in Jordan was estimated to be twice that of today. The area had decreased to 50 000 ha in the 1940s and 40 000 ha during the 1950s. Currently, the total area of forest is less than 20 000 ha and is mainly located in the northwestern parts of the country, particularly in Ajloun area (MoA, 1995; MoE, 2006). The forestlands face the greatest threat of over-cutting and deforestation for agriculture. The commonly cultivated varieties are olive orchards, grape vine, cereal, forage and fruit-nut crops (MoA, 1995). Agricultural practices are adopted by the local communities in these rural areas to increase income and to improve their livelihood. In areas like Ajloun, the conversion of forests into agricultural land can enhance soil degradation by modifying soil physical and chemical properties which, in turn, can accelerate soil erosion. The conversion of forest into cultivated lands would impact soil organic matter and nutrient contents, as well as physical properties with the greatest change occurring during the land clearing process (Olson, 1981; Brown and Lugo, 1990; Gimeno-Garcia *et al*., 2000). However, to understand the effects of land use/cover change on soil properties and quality, mapping and analysis of soil data in relation to this change is required.

Although, the consequences of converting forestland to agricultural land are well known, the magnitude of these effects, which vary from one region to another, is not well known. Unfortunately, basic data on land resources and soil quality in general are limited, particularly at detailed levels. Therefore, this study aimed to assess changes in soil properties in relation to land use/cover change and land degradation in this Mediterranean region. Specifically, the objective of the study was to assess the changes in the soil physico-chemical properties due to deforestation and cultivation of forested land. This would enable a better understanding of the relative susceptibility of soil properties to changes in land-cover in northwestern Jordan and similar environments.

MATERIALS AND METHODS

Study Area

The study area (Figure 1), located in Ajloun, has a sub-humid Mediterranean climate with an average annual rainfall of 560 mm. Precipitation occurs from November to April. The area is mountainous (altitudes of 1000–1250 m) and characterized by cool temperature in winter and mild temperature in summer. The highest temperature occurs in August. The mean maximum temperature is 34°C and the lowest temperature (occurring in January) is −4°C. Ajloun is dominated by steep slopes, valleys and numerous springs. Most of the soils in Ajloun are shallow with a low content of calcium carbonate. The dominant soil types (according to USDA classification system (Soil Survey Staff, 2003)) are: Lithic Haploxerepts, Lithic Haploxerolls and Lithic Haploxererts with true vertisols on flat sites (MoA, 1995).

Two areas were selected: an undisturbed forest and a completely deforested area which has been clear cut and cultivated for over 50 years. Forest species of the study area are *Quercus coccifera*, *Pistachio atlantica*, *Q. aegilops*, *Callipriou*s, *Q. infectoria* and *Pinus halepensis*. Neighbouring areas of forest and cultivated fields (cleared forest) were selected to study the differences from different land management and land use types.

Major crops grown in the area are wheat (*Triticum* spp.) and barley (*Hordeum* spp.) which are harvested once per year. Crop rotation of legumes/cereals is a common practice in Ajloun. Wild relatives of pistachio, apricot, almond, wheat and barley and ancient local cultivars of fruit trees and olives are grown in the area. Replacement of landraces and local varieties by improved cultivars is a common-widespread practice in the area. In addition, improper farming practices and uncontrolled expansion of urban and rural settlement is common practice in the area (Khresat *et al*., 1998).

Mapping of Land Use/Cover and Its Change

The method of land use/cover mapping, similar to Al-Bakri *et al*. (2001), was based on the interpretation of coloured aerial photographs of 2002 and black and white ones of 1953 and 1978 with scales of 1:25 000. The total mapped area was 58·3 km^2 (7·4 km × 7·9 km). The three sets of aerial photographs were interpreted, following a classification scheme (Table 1) of four classes that could be visually identified on all photographs using tone, shape

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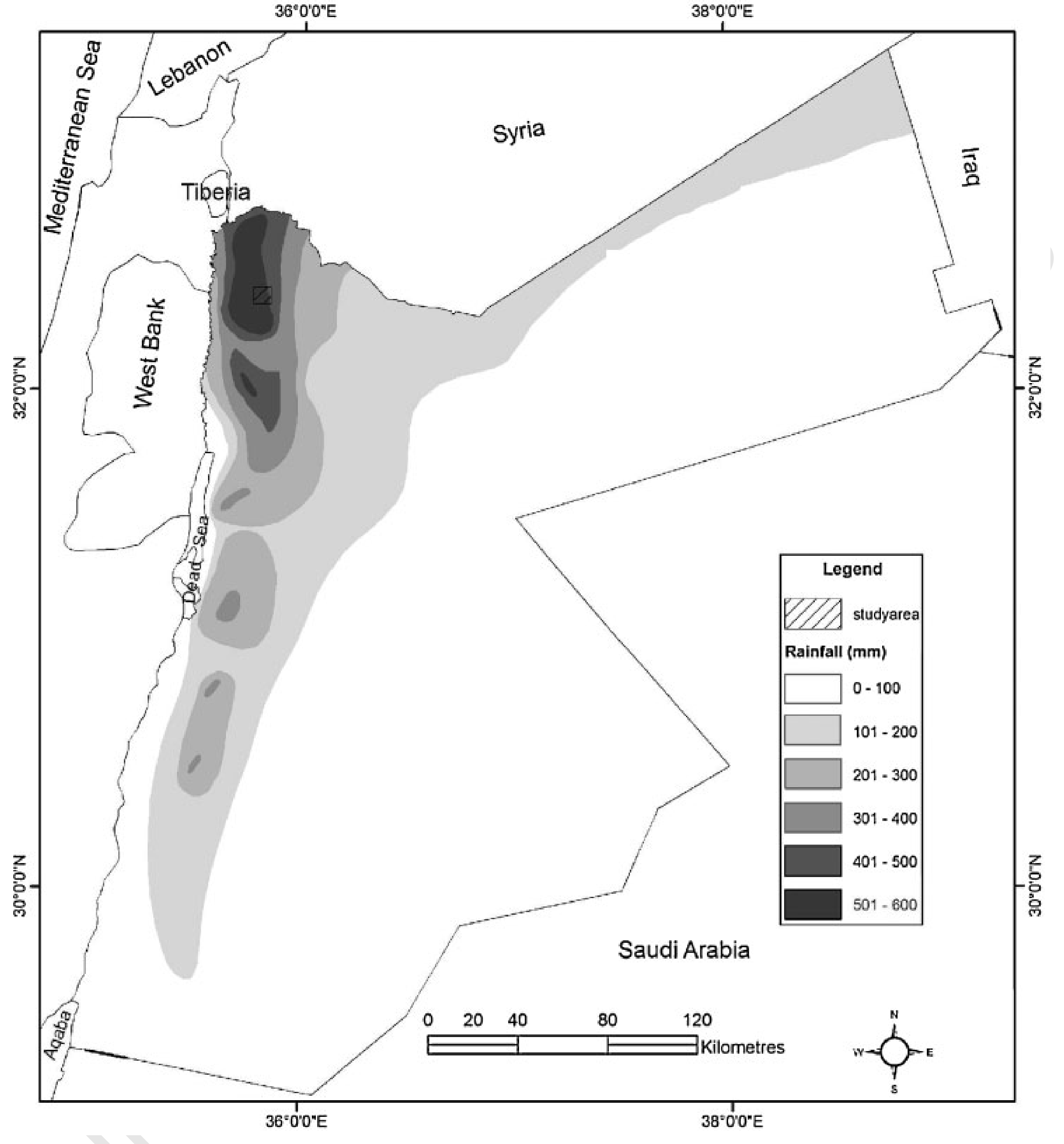

Figure 1. Location of the study area in Jordan.

and size. An interdependent interpretation procedure (FAO, 1996), which consisted of interpreting the first land use/cover map and then using this first delineation as a reference when interpreting the second map, was followed for delineating land use/cover parcels.

Results of the interpretation were verified by comparing ground reference points, collected by several field visits and aided by topographic maps and a global positioning system (GPS) and stratified according to class per cent in

Table 1. Summary of land use/cover classes and their per cents in 1953, 1978 and 2002

Class	Definition	Mapping accuracy	Per cent in 1953	Per cent in 1978	Per cent in 2002
Urban (U)	Continuous and discontinuous urban fabric of residential areas inside towns and villages	100% (4/4)[a]	0·4	1·6	5·5
Agricultural areas (AA)	Rainfed areas planted with one or more crop types of wheat, summer crops of chickpea, lentils and tobacco and rainfed fruit trees, olives and vine	87% (26/30)	18·3	29·7	50·0
Forest (F)	Deciduous and evergreen oaks and coniferous forest of mixed species. Most of the area is used for recreation while small areas are under protection as natural reserves	90% (18/20)	42·0	37·6	34·6
Open range (OR)	Non-cultivated areas of shrub and herbaceous rangelands including scattered and low density forests and cliffs where land is used for open grazing	83% (5/6)	39·3	31·1	9·9

[a] Numbers between parenthesis represent the correctly interpreted samples/ number of ground samples. The overall accuracy = 53/60 = 88·3%.

2002. The photo overlays were manually transferred onto drafting film overlays (transparencies) attached to topographic maps with scales of 1:25 000. This was carried out by tracing permanent roads in the aerial photographs onto the transparencies and shifting the land use/cover polygons according to them. The procedure was applied on the map grid (1 km × 1 km). The overlays of land use/cover maps, including roads, were scanned and digitized using an on-screen digitizing procedure. The maps were rasterized with an output grid cell size of 10 m.

An affine transformation (Bostald, 2005) was made for the 1978 and 1953 maps based on the 2002 map and using 10 points collected interactively between the 2002 and the 1953 and 1978 maps. Although the overlays were transferred using the topographic maps, this additional step of relative geometric correction was made prior to map overlay and analysis to reduce possible location error, which usually had the major contribution to overall uncertainty in change detection (Carmel *et al*., 2001). The output maps were resampled and registered with an overall residual mean square error (RMSE) of less than 16 and 18 m for the 1978 and 1953 maps, respectively. All maps were analysed within the GIS to determine the percentage of each land use/cover. False change polygons (slivers), which could result from positional errors, were removed using the epsilon band method (Mas, 2005). The method was applied by creating a buffer that extended by the RMSE in both directions around the polygon edges. Only the polygon that presented boundaries which deviated by an amount greater than the epsilon band width (2 × RMSE) was considered as true change and considered in the change detection results. The procedure was applied on the three maps with an attribute value of zero for the buffer area. The different land use/cover maps were cross-tabulated to quantify changes between the different periods of 1953–1978, 1978–2002 and the 1953–2002.

Soil Sampling and Analysis

Results from the previous stage were used to identify and collect 60 soil samples from a location that had changed from forest into agricultural land near Samta village. Another 60 soil samples were collected from nearby forests that remained unchanged between 1953 and 2002.

The soil was sampled at two different depths: 0–20 cm (surface layer) and 20–40 cm (subsurface layer). The surface layers coincided with A horizons and the subsurface layers were the upper parts of B horizons. Sixty soil samples from each location were collected, air-dried and passed through a 2 mm sieve. Undisturbed subsets of the samples were used for determining particle size distribution with the hydrometer. Soil bulk density was determined by cores of undisturbed samples. Soil pH was measured on a 1:1 soil to water ratio suspensions while organic matter was determined by the standard Walkley–Black method. Calcium carbonate ($CaCO_3$) equivalent values were determined by acid neutralization while cation exchange capacity (CEC) was determined by the sodium (Na)

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saturation method (Rhoades, 1982). Total nitrogen was determined by the Kjeldahl method (Bremner and Mulvaney, 1982) while available P was determined using the Olsen sodium bicarbonate extraction (Kuo, 1996). Ammonium acetate was used to extract and determine potassium content of the soil (Helmke and Sparks, 1996). One-way analysis of variance (ANOVA) was performed on each soil property of each soil layer to test significant changes in the soil properties ($p < 0{\cdot}05$).

RESULTS AND DISCUSSION

Land Use/Cover Change

Results showed that the land use/cover changes have altered the character of the study area over the period of 1953–2002. The main observed trends were the expansion of agricultural areas at the expense of forests and open range (Table 2). This was reflected on land use/cover maps (Figure 2). Results of land use/cover changes showed that forest area had decreased from 42 per cent in 1953 to 38 per cent in 1978, and reached 35 per cent by the year 2002. Intensive agricultural activities could be clearly seen as the area of the open range decreased from 39 per cent in 1953 to 31 per cent in 1978 and reached 10 per cent in year 2002. On the other hand, agricultural areas had increased from 18 per cent in 1953 to 30 and 50 in 1978 and 2002, respectively.

Results of cross-tabulation of land use/cover maps explained the type of change and showed that 31 per cent of the 1953 forests changed into agricultural lands by the year 2002 while 5 per cent forest changed into open range and less than 1 per cent of the forests were urbanized. The other important change was the conversion of 53 per cent of the open range into agricultural lands. Urbanization on the other hand was on the expenses of other land use/cover classes, particularly agricultural areas.

Although results of land use/cover change (Table 2) showed that 21 per cent of open range has changed into forest (reforestation), however this proportion was less than the magnitude of deforestation. This could be explained by converting the figures in Table 2 into per cents of the total area. For example, 31 per cent of the total area of forests in 1953 changed into agricultural areas. In terms of total area, the total area which had changed from forest to agricultural areas was 16 per cent (calculated by multiplying 31 per cent by 42 per cent). Similarly, the total area which had changed from open range to forests was 8 per cent. Therefore, the overall trends were the reduction in forest area and the increase in agricultural areas.

Table 2. Summary[Q1] of per cent land use/cover changes between 1953, 1978 and 2002

Q1

Land types	U	AA	F	OR	Total[a]
From 1953 to 1978					
U	97·9[b]	0·0	0·0	0·0	97·9
AA	2·3	60·8	5·2	21·0	89·3
F	0·0	12·5	63·9	11·7	88·0
OR	1·2	23·6	16·2	45·4	86·4
From 1978 to 2002					
U	97·6	0·0	0·0	0·0	97·6
AA	6·0	72·3	3·0	6·5	87·8
F	0·0	13·6	68·1	2·8	84·5
OR	3·2	54·0	11·5	16·9	85·7
From 1953 to 2002					
U	100·0	0·0	0·0	0·0	100·0
AA	9·4	54·0	7·7	14·9	86·0
F	0·8	31·0	49·0	4·8	85·5
OR	4·9	52·6	20·9	9·0	87·4

Figures are presented as class per cent in the row map.

[a] Difference between the total and 100% represents the per cent of false change (slivers within epsilon band width).

[b] Diagonal represents the unchanged proportion of the particular land use class between the two dates.

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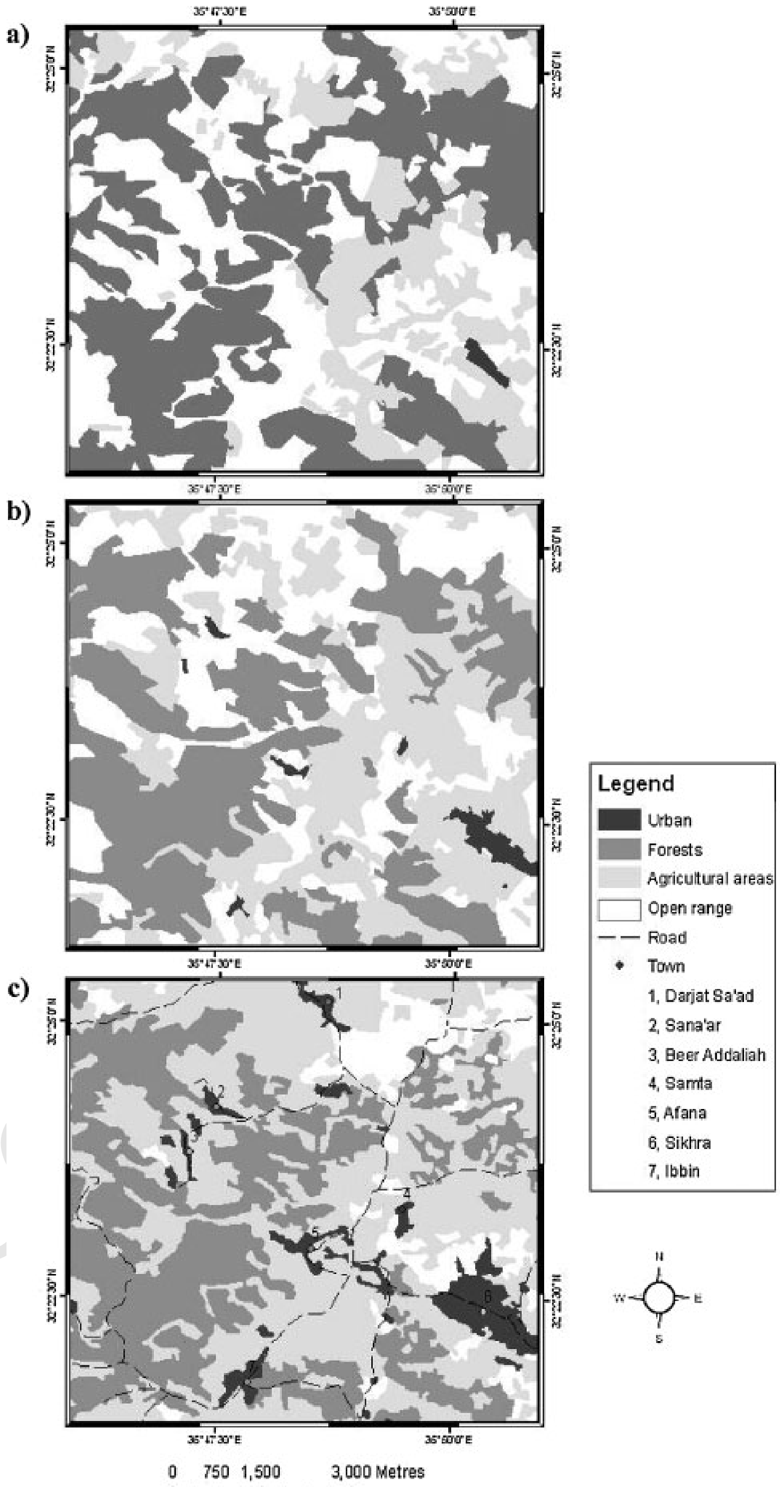

Figure 2. Land use maps of the study area in 1953 (a), 1978 (b) and 2002 (c).

Different findings could be drawn from the analysis of land use/cover maps and the cross-tabulation results for 1953–1978 and 1978–2002 periods. One could see that urbanization and agricultural activities were more intensive in 1978–2002 period than in the 1953–1978 period, while deforestation magnitude was nearly the same during the two periods. Visual inspection of the land use/cover maps showed that deforestation was more intensive in the eastern parts near the village of Sikhra (Figure 2) than in the western parts of the study area. This could be attributed to the intensive agricultural activities near the main settlements and to the steep slopes in the western parts which restricted agricultural activities. Finally, the conversion of agricultural areas into forest could be attributed to the agroforestry system in which the farmers illegally established the right to use and develop state (governmental) land by fencing, ploughing and planting small patches at the edges and inside the forests.

Impacts of Land Use/Cover Change on Soil Properties

Soil texture

Results showed that sand content decreased with soil depth while clay and silt contents increased with soil depth in all studied sites (Table 3). A trend of increased sand and decreased clay contents was observed for the samples of cultivated sites. This indicated that the clay fractions are likely to be eroded and migrated down the soil profile. This is evidenced by the higher clay content in the 20–40 cm soil layer in the cultivated sites.

There was more clay accumulation in the lower depths (20–40 cm) of the deforested sites which were cultivated (Table 3). This resulted from the effect of tillage practices and cultivation which caused the organic matter content to decrease and the aggregates to disintegrate. The clay particles were pushed downward; thus leaving the coarser particles at the surface (0–20 cm).

Particle size distribution showed no significant differences ($p > 0{\cdot}05$) in clay, sand and silt fractions for the 0–20 cm surface layer (Table 3). In that layer, the soil under the natural forest showed higher clay and lower sand and silt fractions than that for soils under cultivation (Table 3).

Since all particle size distributions in the sub-surface horizons and particularly the clay fraction of all the depths were fairly similar, it is concluded that soil conditions prior to conversion were similar. Thus, changes in soil properties observed on the farm fields compared to the soil conditions under the natural forest were interpreted as the effects of deforestation and subsequent cultivation.

Bulk density

There was a significant difference (at the 0·05 level of probability) for bulk density values between the forest and cultivated sites. Although, neither of these values are limiting factors for plant root growth (Table 3), the statistically higher bulk density of the deforested site could result in a lower soil quality as compaction could occur and result in non-favourable aeration.

Table 3. Mean values for particle soil distribution and soil Bulk density for the study area (forest and cultivated soil)

Property	Depth (cm)	Forest	Cultivated	ANOVA
Sand	0–20	15·2	17·1	n.s.[a]
	20–40	14·7	15·2	n.s.[a]
Silt	0–20	37·8	41·0	n.s.[a]
	20–40	36·0	36·1	n.s.[a]
Clay	0–20	47·0	41·9	n.s.[a]
	20–40	49·3	48·6	n.s.[a]
BD	0–20	1·09	1·23	*
	20–40	1·24	1·35	*

BD, soil bulk density.
*Significant at $p < 0{\cdot}05$.
[a]Not significant at $p < 0{\cdot}05$.

The increase of bulk density in cultivated land as compared to the forest soil is attributed to the reduction of organic matter, effect of compaction of machinery and human traffic through the forest clearing, and agricultural practices such as plowing and harvesting crops. In addition, the increased exposure of soil to direct temperature and precipitation effects may also have attributed to the increase in bulk density.

Organic matter

A trend of increased organic matter content of soils under forests was observed where both layers of soil significantly had higher amounts of organic matter for forest than the cultivated land (Table 4). Obviously, the conversion of forest into the cultivated land has led to a drop in soil organic matter contents. The effect of such conversion is two folds; first, it decreases the amount of fallout from vegetation and changes the quality of this fallout to a less resistant type to soil microbial mineralization. Second, it accelerates soil organic matter decomposition through providing better aeration to the cultivated soil layer.

The significant difference ($p < 0{\cdot}05$) in organic matter content between the forest and cultivated sites will lead to a reduction in the nutrient holding capacity of the soils. From an ecological perspective, this process of organic matter decomposition contributes to increased emission of CO_2 to the atmosphere (Hartemink *et al*., 2006).

Nitrogen

The distribution of total nitrogen content (Table 4) followed a similar pattern to organic matter distribution which was higher in the surface soil layer than in the subsurface layer. Such result is expected since most soil nitrogen is bound in organic matter. Generally, cultivation could result in high variations in soil content of nitrogen due to continuous cropping of the soils. Following clearing and crop harvests, the topsoil remains exposed, allowing for an increase in soil temperature and higher rates of microbial decomposition and nitrogen transformation.

The significant difference ($p < 0{\cdot}05$) in total nitrogen between the forest and cultivated sites is due to differences in soil organic matter content, intensities of erosion and intensity of cultivation. These results are similar to the results of Braimoh and Vlek (2006) who indicated that depletion of soil organic matter and nutrients was the dominant impact of continuous cultivation.

Soil pH

Regarding soil pH, there were significant differences ($p < 0{\cdot}05$) between the cultivated sites and forest sites. Soil pH value was slightly higher for cultivated soils compared to soils under forest. This is attributed to the reduction of organic matter and ploughing process of cultivated fields. In addition, the forest canopy could enhance more infiltration of rainfall water into soil as it reduced the impact raindrops by interception. This could result in more

Table 4. Mean values for selected chemical soil properties for the study area (forest and cultivated soil)

Property	Soil depth (cm)	Forest	Cultivated	ANOVA
pH	0–20	7·61	7·91	*
	20–40	7·92	8·08	*
CEC (cmol kg^{-1})	0–20	37·3	28·2	*
	20–40	33·4	26·1	*
OM (%)	0–20	1·16	0·81	*
	20–40	0·76	0·63	*
N (%)	0–20	0·30	0·19	n.s.[a]
	20–40	0·20	0·16	n.s.[a]
P (mg kg^{-1})	0–20	7·6	12·1	*
	20–40	4·3	6·4	*
K (mg kg^{-1})	0–20	798	565	n.s.[a]
	20–40	566	613	n.s.[a]

*Significant at $p < 0{\cdot}05$.
[a]Not significant at $p < 0{\cdot}05$.

leaching of soil bases and subsequent reduction in soil pH. For both forests and cultivated sites, the pH value increased with soil depth for all studied areas (Table 4), indicating the accumulation of carbonates with depth.

Cation exchange capacity

The total soil cations exchange capacity was high at the surface soil and decreased with soil depth for all studied areas. The cations exchange capacity of the studied soils was significantly ($p < 0{\cdot}05$) lower under cultivation than under forest. Although soil cations exchange capacity was higher in the forest than the cultivated area, this can be attributed to the relatively high organic matter content at the forest soil (Table 4). Usually it is expected that cations exchange capacity will increase because of increase in fertilizer use, but farmers in the area depend on native fertility and do not apply fertilizers unless there is an urgent need. The increasing population pressure on land resources make it almost impossible to restore soil fertility, especially with the current continuous cropping with little or no inorganic fertilizer.

Available phosphorus and exchangeable potassium

The higher available P content of cultivated fields than forest could be attributed to the higher phosphorus extraction by forest trees than that for the agricultural crops in the cultivated soil (Table 4). Also, it could be attributed to P immobility caused by higher microbial activity in the forest soil. This, however, should not enhance the continuous conversion of these forests into agricultural lands as other soil parameters were obviously deteriorated. Exchangeable potassium content was little affected by land use/cover changes (Table 4). Although soil potassium declined with soil depth under different land use/cover types, there was no significant difference in soil K between the forest and cultivated soil in either of the soil layers.

The overall long-term response of the soils to deforestation and land use/cover changes was a general decline in soil quality. This is consistent with other studies (Lal, 1996; Islam and Weil, 2000). In this study, the significant increase in soil bulk density and the decline in the soil organic matter content could have an adverse effect on the productivity of these soils. As an alternative to continuous clearing of forest for cultivation, the agroforestry system could be enhanced and expanded in Ajloun. This system, characterized by growing different species of woody perennials in association with field crops, could be practiced in the mountainous regions like Ajloun. According to previous studies (Muschler and Bonnemann, 1997; Garity, 2004), the agroforestry system could increase farmers' income while maintaining soil quality. Deforestation resulted in rapid and drastic changes in soil chemical properties in the cultivated sites. The capacity of soils to be productive depends not only on the plant nutrient stores but also on the physical characteristics of the soils such as bulk density and porosity. The rate of decline in soil chemical quality was consistent for most of the critical properties. These results confirm the conclusions from several other experiments (Ghuman and Lal, 1991).

CONCLUSIONS

The clearing of forested areas by farmers in the Ajloun area of northwestern Jordan for the establishment of orchards and farm based agricultural production systems has resulted in a general decline in the soil physical and chemical properties; which has, in turn, contributed to soil erosion, soil fertility degradation and land degradation.

The large and significant changes in organic matter, total N and CEC over time can also be interpreted in terms of degradation of forest soils during agricultural use. Cultivated soils were found to exhibit a significantly lower status in physical and chemical soil properties as compared to forest soils. This suggests that continuous cropping is primarily responsible for deterioration in soil quality in the study area.

This study indicated that there is an urgent need to improve soil quality by developing sustainable land use/cover practices to reduce the rate of soil degradation and to ensure long-term sustainability of the farming system. Restoration of soil organic matter content and improvements in plant nutrient reserves are crucial for achieving sustainability. National efforts are urgently needed to protect the remaining forests and to implement extension programmes to ensure sustainable use of lands and conservation of forested areas. As an alternative to continuous clearing of forest for cultivation, the agroforestry system could be enhanced and expanded.

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REFERENCES

Al-Bakri JT. 2005. Implementation of socio-economic aspects in sustainable land use planning in Jordan. In Zdruli, P., Trisorio Liuzzi, G. (eds), Promoting participatory management of the land system to enhance soil conservation. *Workshop proceedings*, Alexandria, Egypt 9–13 October 2004. MEDCOASTLAND publication 3. IAM Bari, Italy.

Al-Bakri JT, Taylor JC, Brewer TR. 2001. Monitoring land use change in the Badia transition zone in Jordan using aerial photography and satellite imagery. *Geographical Journal* **167**: 248–262.

Arshad MA, Martin S. 2002. Identifying critical limits for soil quality indicators in agro-ecosystem. *Agricultural Ecosystems and Environment* **88**: 153–160.

Bostald P. 2005. *GIS Fundamentals*, 2nd edn. Eider Press: White Bear Lake, Minnesota.

Braimoh AK, Vlek PLG. 2006. The impact of land-cover change on soil properties in northern Ghana. *Land Degradation and Development* **15**: 65–74.

Bremner JM, Mulvaney CS. 1982. Nitrogen—Total. In Page AL, Miller RH, Keeney DR (eds). *Methods of Soil Analysis. Part II*, 2nd edn. American Society of Agronomy: Madison, WI.

Brown S, Lugo AL. 1990. Effect of forest clearing and succession of the carbon and nitrogen content of soils in Puerto Rico and US Virgin Islands. *Plant and Soil* **124**: 53–64.

Carmel Y, Dean DJ, Curtis HF. 2001. Combining location and classification error sources for estimating multi-temporal database accuracy. *Photogrammetric Engineering and Remote Sensing* **67**: 865–872.

Doran JW. 2002. Soil health and global sustainability, translating science into practice. *Agricultural Ecosystems and Environment* **88**: 119–127.

FAO. 1996. Forest resources assessment 1990: Survey of tropical forest cover and study of change processes. Rome, Food and Agriculture Organization Forestry Paper No. 130.

Garity DP. 2004. Agroforestry and the achievement of the Millennium Development Goals. *Agroforestry Systems* **61**: 5–17.

Ghuman BS, Lal R. 1991. Land clearing and use in the humid Nigerian tropics. II. Soil chemical properties. *Soil Science Society of America Journal* **55**: 154–188.

Gimeno-Garcia E, Andreu V, Rubio JL. 2000. Change in organic matter, nitrogen, phosphorus and cations in soil as result of fire and water erosion in Mediterranean landscape. *European Journal of Soil Science* **51**: 201–210.

Hajabbasi MA, Jalalian A, Karimzadeh HR. 1997. Deforestation effects on soil physical and chemical properties, Lordegan, Iran. *Plant and Soil* **190**: 301–308.

Hartemink EA. 1998. Soil chemical and physical properties as indicator of sustainable land management under sugar cane in Papua, New Guinea. *Geoderma* **85**: 283–306.

Hartemink EA, Veldkamp A, Bai Z. 2006 Land cover change and soil fertility in tropical regions. *Proceedings IFA Agricultural Conference*, Kunming, China.

Helmke PA, Sparks DL. 1996. Lithium, sodium, potassium, rubidium, and cesium. In Sparks[Q2] DL et al. (eds). *Methods of Soil Analysis. Part III. Chemical Methods*. Soil Science Society of America and American Society of Agronomy: Madison, WI. Q2

Islam KR, Weil R. 2000. Land use effects on soil quality in a tropical forest ecosystem of Bangladesh. *Agricultural Ecosystems and Environment* **79**: 9–16.

Khresat SA, Rawajfih Z, Mohammad M. 1998. Land degradation in north-western Jordan, causes and processes. *Journal of Arid Environments* **39**: 623–629.

Kuo S. 1996. Phosphorus In Sparks[Q3] DL et al. (eds). *Methods of Soil Analysis. Part III. Chemical Methods*. Soil Science Society of America and American Society of Agronomy Madison, WI Q3

Lal R. 1996. Deforestation and land-use effects on soil degradation and rehabilitation in western Nigeria. II. Soil chemical properties. *Land Degradation and Development* **7**: 87–98.

Lambin EF, Rounsevell MD, Geist HJ. 2000. Are current agriculture land use models able to predict changes in land-use intensity? *Agricultural Ecosystems and Environment* **82**: 321–331.

Lumbanraja JT, Syam H, Nishide A, Mahi K, Utomo M, Kimura M. 1998. Deterioration of soil fertility by land use changes in south Sumatra, Indonesia, from 1970 to 1990. *Hydrological Processes* **12**: 2003–2013.

Mas JF. 2005. Change estimates by map comparison: A method to reduce erroneous changes due to positional error. *Transactions in GIS* **9**: 619–629.

Millington A, Al-Hussein S, Dutton R. 1999. Population dynamics, socio-economic change and land colonization in northern Badia, with special reference to the Badia research and development project area. *Applied Geography* **19**: 363–384.

MoA (Ministry of Agriculture, Jordan). 1995. *The Soils of Jordan: Semi-Detailed Level (1:50,000)*. The National Soil Map and Land Use Project, NSMLUP, Ministry of Agriculture, Amman, Jordan.

MoE (Ministry of Environment, Jordan). 2006. *National Action Plan and Strategy to Combat Desertification*. Ministry of Environment, Amman, Jordan.

Mulugeta[Q4] LK, Erik K, Mats O. 2005. Assessing soil chemical and physical property responses to deforestation and subsequent cultivation in smallholders farming system in Ethiopia. *Agricultural Ecosystems and Environment* **105**: 373–386. Q4

Muschler RG, Bonnemann A. 1997. Potentials and limitations of agroforestry for changing land-use in the tropics, experience from Central America. *Forest Ecology and Management* **91**: 61–73.

Nambiar KM, Gupta AP, Fu Q, Li S. 2001. Biophysical, chemical and socio-economic indicators for assessing agricultural sustainability in the Chinese coastal zone. *Agricultural Ecosystems and Environment* **87**: 209–214.

Olson GW. 1981. Archaeology, lessons on future soil use. *Journal of Soil and Water Conservation* **36**: 261–264.

Rhoades JD. 1982. Cation exchange capacity. In Page AL, Miller RH, Keeney DR (eds). *Methods of Soil Analysis. Part II*, 2nd edn. American Society of Agronomy: Madison, WI.

Saikh HC, Varadachari, Ghosh K. 1998. Changes in carbon, nitrogen and phosphorus levels due to deforestation and cultivation, a case study in Simlipal National Park, India. *Plant and Soil* **198**: 137–145.

DOI: 10.1002/ldr

Schneider LC, Pontius RG. 2001. Modeling land-use change in the Ipswich watershed, Massachusetts, USA. *Agricultural Ecosystems and Environment* **85**: 83–94.

Soil Survey Staff. 2003. Soil Survey Staff, Keys to Soil Taxonomy (9th edn), USDA-NRCS.

Tilman D, Fargione J, Wolff B, d'Antonio C, Dobson A, Howarth R, Schindler D, Schlesinger W, Simberloff D, Swackhamer D. 2001. Forecasting agriculturally driven environmental change. *Science* **292**: 281–284.

Wang X, Gong Z. 1998. Assessment and analysis of soil quality changes after eleven years of reclamation in subtropical China. *Geoderma* **81**: 339–355.

DOI: 10.1002/ldr

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