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Arid soils of the Badia region of northeastern Jordan: Potential use for sustainable agriculture

(Trockengebiete der Badia-Region im Nordosten Jordaniens: Potenzielle Nutzung für nachhaltige Landwirtschaft)

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Abstract

Arid lands have always been important to the world's human populations, but their significance has increased over the past few decades because of population demographics and continued use of natural resources (Hoekstra & Shachak, 1999). Jordan is faced with increasing population pressure in its already settled areas; hence, it will have to utilize the underpopulated Badia, which forms 85% of Jordan's land surface, so that it can contribute to the economy in a sustainable way without damaging the fragile desert environments. This can be done by gaining a better understanding of the natural resource base and suggesting actions which will lead to the protection of the resources and to their sustainable usage for the long-term benefit of the local population. Azraq basin, about 12,750 km^2 in size, is located in the northeastern Jordanian Badia region (Shahbaz & Sunaa, 2000). To develop soil resources in the Azraq basin, research is needed to establish the best practices for their management, improvement, and maintenance. Four different areas in the Basin were investigated. The choice of these areas was based on geologic studies which showed the proximity of these areas to promising underground water resources. Most of the studied soils contain considerable amounts of carbonates. This leads to alkaline reaction of the soils with pH values mostly above 8, resulting in low availability of certain nutrients like phosphorus and micronutrients. If such soils are to be cultivated, proper management practices should be adopted to ensure the availability of those nutrients to crops. Analysis of the collected soil samples also showed that those soils contain soluble salts in the upper horizons in amounts enough to impede plant growth. Salts would have to be leached using good quality water before successful growing of crops can be carried out. Most of the studied soils have high erodibility and susceptibility to seal and crust formation. The soils in some of the studied areas contain high amounts of gypsum and carbonates and also very high content of soluble salts. Such areas would have to be excluded from any agricultural development. Reclaiming soils in such areas would be too expensive and not feasible economically. The use of organic amendments would be highly recommended to improve the physical and chemical characteristics of the Badia soils in order to achieve a sustainable agricultural production.

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Introduction

From ancient times to the present, humans tried to utilize the arid lands of the world with only marginal success. People have been more successful in their attempts to utilize semiarid lands. However, heavy use of semiarid lands has often led to a reduction in available moisture for vegetation and has initiated succession from semiarid types of vegetation toward arid types of vegetation. Such human-caused succession of vegetation from semiarid to arid or from arid to extremely arid is currently referred to as *desertification* (Dick-Peddie, 1991). Le Houerou (1986) used the term 'desertization' for this process in northern Africa and emphasized that the process is caused by human beings, not climate.

Physical properties that are suggested to be common to many arid and semiarid region soils include high erodibility, high runoff generation potential, susceptibility to seal and crust formation, poor water-holding capacity, profile hardening, structural instability, low clay content, low activity clay, high bulk density, and high surface temperatures in the summer months (El-Swaify *et al.*, 1984; Guthrie, 1982; Lal, 1985).

Soils developing in an arid environment tend to retain the alkaline earth and alkali cations to a great extent, and subsequently hydroxides of these cations form and alkaline pH ensues. The upward gradient of water movement, the retention of these cations by inorganic and organic colloids, and their reprecipitation as cationic constituents (like calcite, apatites, gypsum, and halides) promote their concentration (Knight, 1991).

Desert is the prevalent ecosystem in Jordan, covering over 80% of the country. Jordan is faced with increasing population pressure in its already settled areas; hence, it will have to utilize the underpopulated Badia so that it can contribute to the economy in a sustainable way without damaging the fragile desert environments. This can be done by gaining a better understanding of the natural resource base and suggesting actions which will lead to the protection of the resources and to their sustainable usage for the long-term benefit of the local population. Azraq basin is an important part of the Jordanian Badia region. To develop soil resources in the Azraq basin, research is needed to establish the best practices for their management, improvement, and maintenance. As a first step towards understanding the soil resource in the Azraq basin, the present work has been carried out.

Methods

Four different areas were investigated. A team studying the geology of the Azraq basin recommended several areas in the basin as potential development areas for agricultural production. Their recommendations were based on the probability of deep soils and the proximity of these areas to promising underground water resources. Profiles were dug and described in the field for physical characterization. Figure1 shows the location of the studied profiles. Morphology and classification of the studied soils is reported in a separate paper (Khresat *et al.*, 2001). Soil samples were collected from each profile and taken to the laboratory for chemical and physical analysis. The bulk soil samples were air dried, crushed with a mortar and pestle, and sieved to remove coarse ($>$ 2mm) fragments. Particle size distribution was determined by the hydrometer method (Gee & Bauder, 1986). Soil pH was measured on 1:1 soil:water suspensions (Thomas, 1996). Soluble salts were determined by measuring the electrical conductivity of 1:1 soil:water extracts (Rhoades, 1996); organic

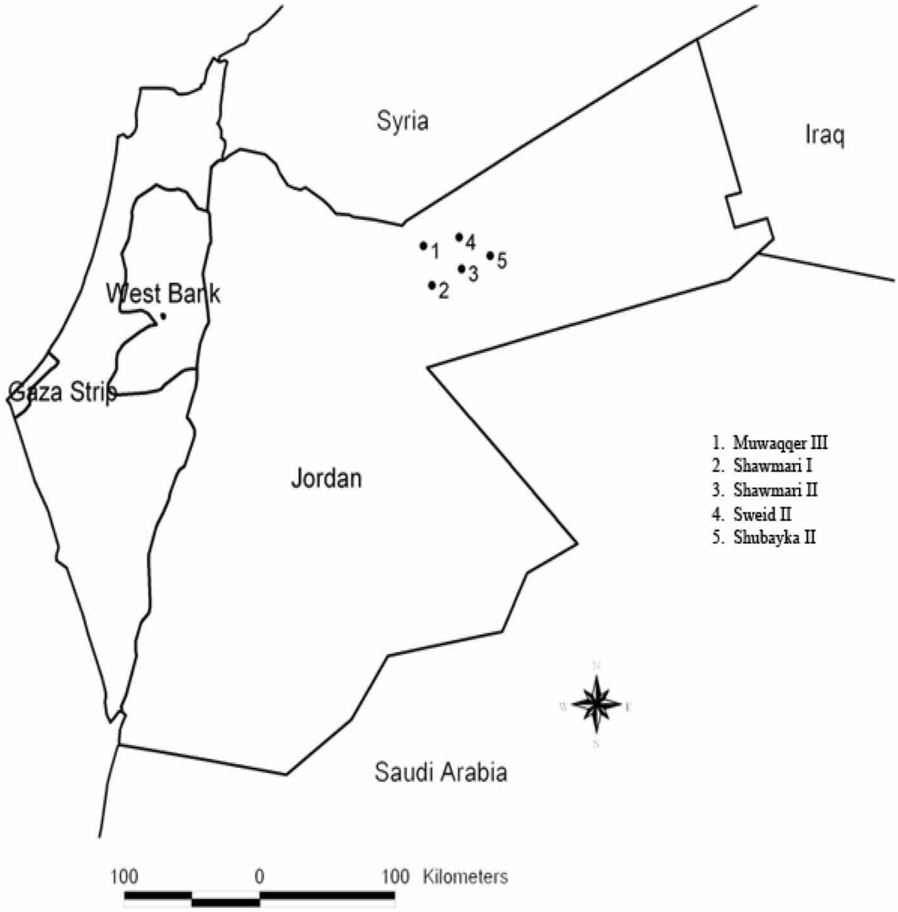

Figure 1. Map showing study area.

matter was determined using the Walkley-Black method (Nelson & Sommers, 1996); calcium carbonate equivalent values were obtained using the acid neutralization method (Richards, 1954). Nitrogen was determined by the Kjeldahl method (Bremner, 1996). Cation exchange capacity was determined by the sodium saturation method (Chapman, 1965). Available P was determined using the Olsen sodium bicarbonate extraction (Kuo, 1996). Potassium and calcium were extracted with ammonium acetate (Helmke & Sparks, 1996).

Results and discussion

Physical properties

Particle size analysis for the studied profiles is shown in Table I. The upper horizon of most of the profiles has more than 30% silt. Soil erodibility has been shown to be primarily a function of particle size distribution and various materials that bind particles together into aggregates and stabilize the aggregates. Wischmeier *et al.* (1971) developed a graphic solution to an equation for predicting soil erodibility in which increases in silt and very fine sand are

Table I. Particle size analysis of the studied profiles.

Sample	% Sand	% Silt	% Clay	Classification
Muwaqqer III Ap (0–8)	22.5	42.5	35.0	Xeric Haplocalcids
Muwaqqer III B (8–20)	12.5	37.5	50.0	
Muwaqqer III Bk1 (20–40)	10.0	35.0	55.0	
Muwaqqer III Bk2 (40–120)	3.8	41.2	55.0	
Shawmari I Av (0–4)	20.0	40.0	40.0	Typic Calcigypsids
Shawmari I A (4–20)	7.5	50.0	42.5	
Shawmari I By (20–60)	7.5	52.5	40.0	
Shawmari I Bky (60–100)	13.8	23.7	62.5	
Shawmari II A (0–4)	31.8	23.2	45.0	Typic Calcigypsids
Shawmari II Bk (4–20)	26.3	15.0	58.7	
Shawmari II Bky (20–75)	32.0	17.0	51.0	
Swaeid II A (0–20)	22.0	31.0	47.0	Typic Calciargids
Swaeid II Bk (20–55)	14.0	29.0	57.0	
Swaeid II Btk (55–140)	14.0	26.0	60.0	
Shubayka II Ap (0–10)	1.3	40.3	58.4	Typic Haplogypsids
Shubayka II Byl (10–35)	2.6	35.1	62.3	
Shubayka II By2 (35–90)	1.0	34.0	65.0	
Shubayka II Bty (90–140)	1.0	37.0	62.0	

predicted to increase soil erodibility. Other factors in the nomograph are soil organic matter, soil structure, and permeability of the least permeable horizon.

Water and wind erosion are both serious problems in these soils. Even though the region has very low rainfall, soils are subject to water erosion because they are bare and subject to the direct, although infrequent, impact of raindrops. Wind erosion is a constant hazard because the dry, unprotected soil surface is easily moved by wind. Throughout the arid and semiarid climate zone, wind erosion is a real or potential problem. In the Middle East, dust storms are a serious problem (Middleton, 1986).

Managing soil erosion in arid and semiarid areas requires careful water management, surface vegetation management, and control of wind speeds with wind breaks. Increasing surface roughness can decrease wind erosion as can the use of windbreaks to reduce the critical wind speed near the ground. Maintaining soil moisture during critical parts of the year with mulches can also contribute to lower erosion rates. Gupta *et al.* (1983) have shown that a three-row windbreak consisting of *Cassia siamea*, *Albizia lebbeck*, and *C. siamea*, when 4–5 m tall, was most effective in reducing wind velocity, wind erosion, and evaporative losses downwind from the shelterbelt.

The soils in this region would also tend to form slowly permeable seals and crusts that decrease infiltration and increase runoff, further contributing to soil erosion. Sealing and crusting and the low infiltration rate they produce may often be responsible for the low water availability of arid and semiarid region soils (Singer, 1991). Both forms of erosion can be controlled by careful choice of farming systems that are designed to maintain maximum cover on the soil surface during the periods of the year with the highest soil erosion potential.

Chemical properties

Relevant chemical properties of the studied profiles are shown in Table II. The data reveal a very wide range of variation in the properties for the different soil profiles representing Azraq basin. This would require different systems of management for the different regions of the

Table II. Relevant chemical analysis of the studied profiles.

Sample	% N	Organic C %	pH	EC (dS/m)	$CaCO_3$ %	CEC cmol(+)/kg soil
Muwaqqer III Ap (0–8)	0.062	1.92	8.59	1.005	28.0	21.7
Muwaqqer III B (8–20)	0.037	1.30	8.46	2.319	28.3	25.2
Muwaqqer III Bk1 (20–40)	0.035	1.28	8.02	7.36	31.4	
Muwaqqer III Bk2 (40–120)	0.018	1.20	7.92	18.05	30.6	
Shawmari I Av (0–4)	0.0099	1.07	7.79	36.3	28.9	21.0
Shawmari I A (4–20)	0.021	0.93	8.03	11.27	30.8	19.9
Shawmari I By (20–60)	0.0015	1.06	7.72	43.2	28.1	
Shawmari I Bky (60–100)	0.0015	1.17	7.75	46.1	29.8	
Shawmari II A (0–4)	0.02	0.98	8.83	1.146	30.5	18.3
Shawmari II Bk (4–20)	0.016	0.96	9.01	3.23	30.0	22.8
Shawmari II Bky (20–75)	0.012	0.91	8.04	17.28	30.4	
Swaeid II A (0–20)	0.0295	1.95	7.42	0.280	22.7	22.8
Swaeid II Bk (20–55)	0.0280	1.81	7.20	0.287	23.8	21.7
Swaeid II Btk (55–140)	0.019	1.04	7.41	0.329	21.5	
Shubayka II Ap (0–10)	0.0545	2.05	8.06	0.366	14.7	36.3
Shubayka II Byl (10–35)	0.0560	1.86	8.17	3.04	14.7	38.2
Shubayka II By2 (35–90)	0.0465	1.05	7.91	0.913	14.3	
Shubayka II Bty (90–140)	0.0580	1.64	7.90	1.154	14.6	

basin. Some common properties of the investigated soils include their alkalinity, content of carbonates, and low organic matter content. The ability of these soils to supply essential plant nutrient elements would be restricted not only by the availability of water directly, but by the solubility of controlling mineral phases. Stable mineral or amorphous phases can exert controlling influences on the availability of calcium, phosphorus, and micronutrients (e.g., iron, zinc, copper, and manganese). In Table III we can see the low concentration of extractable P, which would be expected for calcareous soils which are not cultivated and fertilized. The presence of soluble salts contributed to the adequate amounts of K and Ca for crop requirement (Table III). In regard to micronutrients and phosphorus nutritional limitations to plant growth, organic exudates of plant and microbial origin are important to the natural remedy of deficiencies. The evaporative gradient in arid regions can also promote the accumulation of trace elements toxic to plants and/or animals (i.e., boron, molybdenum, and selenium).

Accumulation of the organic matter in soils is a rather delicate balance between the rate of addition of biological residues and the rate of their decomposition, with both processes highly dependent on climate. In arid regions, moisture limits the amount of plant growth, the overwhelming contributor of the raw material for humus synthesis. Generally, under arid conditions vegetation is sparse and short and develops as individual plants. Organic matter accumulates slowly and often imperceptibly. Erosion, runoff, and evaporation seriously influence the effectiveness of rainfall in supporting plants and biodegradation. The accumulation of humus is low in desert soils compared with those of other climates, but the plant ash residues are higher. The organic matter of desert USSR soils, for example, was reported to be highly mineralized. Ponomareva (1956) emphasized the importance of humus on desert soil formation as exemplified by her statement: ''The mineral forms of biogenic carbon and generally plant ash compounds shape the profile and properties of desert soils''. Some of the more prominent functions of organic matter include: direct contribution of nutrients for plants, such as nitrogen, phosphorus, and micronutrients; indirect contribution

Table III. Some nutrients content of the studied profiles.

Sample	$NaHCO_3$-Extractable P(μg/g)	NH_4OAc-Extractable K(μg/g)	NH_4OAc-Extractable Ca(mmole/kg)
Muwaqqer III Ap (0–8)	13.5	910	115
Muwaqqer III B (8–20)	6.6	775	100
Shawmari I Av (0–4)	3.0	1242	217
Shawmari I A (4–20)	5.6	1144	119
Shawmari II A (0–4)	8.0	1095	94
Shawmari II Bk (4–20)	4.4	1070	84
Swaeid II A (0–20)	4.3	916	127
Swaeid II Bk (20–55)	4.0	1234	154
Shubayka II Ap (0–10)	12.8	699	161
Shubayka II Byl (10–35)	11.1	635	168

to plant nutrition by making soil elements more available; food and nutrient supply for microorganisms; soil structure development, and thereby water behavior and conservation, bulk density, infiltration, and reclamation of salt-affected soils; storehouse of elements attached to clay particles; and increased water-holding capacity. The organic C in the soils of the Azraq basin is shown in Table II.

Some of the studied profiles have very high electrical conductivity, reflecting high content of soluble salts. The fundamental concerns about salt-affected soils are salinity and sodicity. High salinity results in the reduction of the water potential of the soil solution, and the concentration of toxic ions that interfere with normal plant metabolism. Specific ion toxicities are associated with chloride, sodium, and boron (James *et al.*, 1982). High sodicity manifests itself in both the physical deterioration of the soil structure and in the potential for sodium toxicity to plants. Two profiles (Swaeid and Shubayka) represent mud flat areas formed due to erosion and deposition of soil material in low areas. These limited areas are cropped with wheat and barley where extra moisture is received from run-off from surrounding slopes.

Management

The locations of the studied profiles gave a fairly good idea about the basin. Certain general recommendations could be given to manage some areas so that sustainable agriculture could be practiced in parts of the basin. Some of the areas studied represent potential new lands provided adequate water supplies of good quality are available.

Organic matter is an essential component of intensive rehabilitation of arid lands and deserts, and therefore its application is a must, if a sustainable use of arid soils is to be accomplished. Organic matter content and composition in soils have received considerable attention because of the disproportionately favorable effect on the chemical, physical, microbiological, and morphological properties of soil compared with the mineral matter (Tucker & Fuller, 1971; Fuller & Tucker, 1977). Moreover, organic matter is the nitrogen carrier of soils. Continued soil productivity depends upon the replenishment and maintenance of some organic matter. The maintenance of a given, fixed level is often not practical, nor is it advised. The practice of incorporating readily available plant residues, manures, straw, leaves, composts, and municipal wastes and sludges into the soil is more important than the establishment of a fixed level. The mere addition of organic residues to soil is not sufficient to produce good structure. It is the continued decomposition of organic matter and residues, for example, by organisms with the formation of new products that is important. Beneficial microorganisms live in soils in sufficient abundance, ready to work on organic materials. To increase their activity, they require mainly an abundant energy source, such as plant residues, other organic matter, favorable moisture relationships, and freedom from toxic substances.

Tillage is widely used to control weeds; incorporate soil amendments, nutrients, herbicides, and insecticides; and modify soil physical conditions, thereby improving soil conditions for crop establishment, growth, and yield. Tillage is also used to conserve soil and water. The number of tillage operations used to produce a crop varies widely and depends on the crop grown; soil and climatic conditions; and the economic level, degree of mechanization used, attitudes, and management capability of the producer. The proper tillage system must be used under the specific production system to protect the soil from water and wind erosion and to maintain the level of organic matter in the soil. Although no-tillage systems have some good advantages, they also have some disadvantages that could make its application in this part of Jordan very difficult. Such disadvantages include high cost of herbicides, limited water for spraying, unavailability of suitable equipment (sprayers and planters), potential for greater pest problems (insects, diseases, and rodents), limited residues, increased soil compaction, and the need for greater managerial ability of producers.

Salinity is very high in some of the profiles studied making the utilization of those soils for agricultural production not recommended at all. In the areas where soluble salts content is reasonable, leaching of the salts with a good quality of irrigation water must take place before any successful plant production can be carried out.

Finally, the proper types of mineral fertilizers must be used. All soils examined are calcareous with alkaline reaction. Phosphorus and micronutrients availability to crops would be a real problem if not managed well.

Conclusion

The studied profiles in the Azraq basin in northeastern Jordan represent an attempt to evaluate the potential of utilizing this area for sustainable agricultural production. The locations of these profiles gave a fairly good idea about the areas which should be excluded from any attempt to utilize the basin for a viable agricultural production system. The utilization of the basin for crop production would depend on the proper management, especially leaching the soluble salts, before the initiation of any agricultural activities; the continual application of organic matter; and using the proper tillage systems to protect the soils from degradation.

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