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Soil Research in Oman: Opportunities and Priorities

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خلاصة : الأنتيسول، الأنسيبتسول والأريدوسول التي تغلب على أتربة عمان هي الأساس في دفع النمو الزراعي في السلطنة. هذه الورقة تراجع باختصار تصنيف ميزات هذه الأتربة ودراستها وتقييم صلاحيتها، وأحدث أبحاث الأسمدة. ولأهمية الماء القصوى في نمو النبات، فقد تم تقييم مساهمة الري في كفاءة استعمال الأسمدة. كما ألقت الضوء على مشاكل تحول الأمونيا إلى غاز، وتثبيت الفسفور في تربات السلطنة. كما أن أثر الأحياء الدقيقة في تثبيت النتروجين وديناميكية المواد العضوية قد تم نقاشها. وأخيرا. تم تحديد مشاكل الأبحاث وتقديم مقترحات للعمل المستقبلي.

ABSTRACT: The Entisols, Inceptisols and Aridisols which dominate the soils of Oman are the foundation of the drive to agricultural development in the Sultanate. This paper reviews briefly the classification and pedological characteristics of these soils, their land suitability assessment, and recent fertilizer research. Water is absolutely essential for the growth of plants and the contribution of irrigation practice to the efficient use of fertilizers is assessed. The problems of ammonia volatilization and phosphorus fixation in the soils of the Sultanate are highlighted and microbiological aspects of nitrogen fixation and soil organic matter dynamics are briefly discussed. Finally, research problems and ideas for future work are identified.

Many of the naturally evolving soils of the Middle East, especially those developing over sand-blown deposits, are commonly thought to be too light textured, too infertile and too permeable for successful cultivation. Furthermore, it is often believed that, returns from farming these soils would likely not be profitable because of the arduous conditions. Consequently, the development of agriculture in the Sultanate has focused on more easily manageable characteristics, such as accessibility to water supplies and a labour force. However, this approach fails to recognize that soil properties may be the governing factor that determines whether cultivation will be successful, provided water is applied correctly. Attempting to cultivate areas based only on accessible water supplies and a trained work force may eventually lead to costly mistakes. In the long run, it may be more profitable to develop an efficient water distribution system on soils with desirable characteristics, than to cultivate land with poor soil characteristics, but having accessible water and a nearby work force.

To help with the proper development of agriculture in the Sultanate, the Ministry of Agriculture and Fisheries Wealth is surveying the soils. Reconnaissance-level surveys have been completed, and the results are published in the form of maps. Detailed surveys of regions with soils with favourable characteristics have been, or are being, conducted; however, all of the results are not currently available to the public. A major task for soil scientists in the Sultanate will be to interpret these surveys and provide Government Agencies with strategies for developing the agricultural industry.

The objective of this paper is to discuss research needs in soil science in the Sultanate and to provide a description of some of the current conditions and problems.

Soil Types and Classification

The soils of the Sultanate of Oman, classified according to Soil Taxonomy (1975), can be grouped into 61 mapping units (Ministry of Agriculture and Fisheries, 1990). The soils composing these 61 units can be placed into three soil orders, which are broad classification units within Soil Taxonomy. The three soil orders are Entisols, Inceptisols, and Aridisols. The soils could be further grouped into eight smaller units. These units, which are more narrowly classified than soil orders, are called great groups. At the time of publishing the reconnaissance-level survey, the eight great groups were Psamments, Orthents, Fluvents, Tropepts, Salorthids, Gypsiorthids, Calciorthids, and Camborthids. After classifying the soils according to Soil Taxonomy, the names and definitions of some great groups of the Aridisol soil order have since been changed (Keys to Soil Taxonomy, 1994). This presents some problems because there is not a one-to-one correspondence between the old and new names. Many of the soils surveyed in the Sultanate will need to be reexamined and classified. However, the main pedogenic features of Omani soils are subsurface accumulations of gypsum (i.e., calcium sulphate), calcium carbonate, and soluble salts, often in cemented form.

Gypsum Accumulation

Accumulation of gypsum is characteristic of soils in areas where rainfall is too low to leach it out of the profile. In Oman, soils can contain in excess of 58% by weight of gypsum very close to the soil surface, e.g., less than 10 cm. The genesis of this condition warrants investigation.

Gypsum deposits can be of aeolian nature such as those in Tunisia (van Alpen and Rios, 1971), or may result from precipitation with clay, silt and sand after being transported great distances by rivers in a dissolved state (Kovda et al., 1979). Alteratively, gypsum can be weathered either from gypsiferous rocks of hydrated and anhydrite calcium sulphate, or from outcrops of gypsum-bearing Triassic, Jurassic and Cretaceous clays (van Alpen and Rios, 1971).

Gypsum frequently occurs in Omani soils as secondary deposits. Gypsum bearing groundwater probably rises in the profile due to capillary action, precipitating secondary (or hydrogenic) gypsum when evaporation rates are high. However, secondary gypsum may also develop, as in Georgia (Russia), by the co-precipitation of sodium sulphate and calcium carbonate (Sonnenfeld, 1983). Since Gypsum is so common in Oman it is important to understand the processes leading to all the different forms in which it is found - from highly crystalline through 'spongy' to very finely divided. The effect on crop growth of these different forms of gypsum in the soil is not known.

Calcium Carbonate Accumulation

Calcium carbonate can accumulate in a profile in a similar manner as gypsum, i.e., the rainfall is not sufficient to leach it from the soil. However, whereas gypsum does not affect the pH of a soil very much, calcium carbonate accumulation will strongly affect a soil's pH. In slightly alkaline soils, calcium precipitates from solution as a carbonate. The reaction, shown below, acts to prevent the soil pH from rising above 8.0-8.5.

$$Ca^{2+} + CO_2 + H_2O \rightarrow CaCO_3 + 2H^+$$

The release of protons helps to prevent the pH from rising too high. The presence of calcium carbonate in soils with pH values less than 8.5 is an indicator of suitability for potential cultivation.

In Oman, calcium carbonate can be as much as 90% of the soil by weight. It commonly exceeds 40% and is rarely less than 20% by weight, posing problems for cultivation because nutrients required for crop growth, such as phosphorus, may become limiting for crop needs (Booker Tropical Soil Manual, 1991). Studies are warranted that address the chemistry of the nutrients in Omani soils to help develop criteria for making interpretations from soil survey data.

Soil Salinity

As with the accumulation of gypsum and calcium carbonate, soluble salts accumulate in a soil when they are not leached from the profile. Soluble salts are easier to leach from a soil because they are more soluble than gypsum and calcium carbonate. When rainfall is low and evaporation transpiration demands are high, as they are in most regions of Oman, soluble salts can accumulate. Soluble salts in a soil will inhibit cultivation, unless the crops are very salt tolerant.

The nature of soil salinity and techniques of prevention are important topic of research in Oman. The Ministry of Agriculture and Fisheries Wealth is actively monitoring salinity levels in coastal soils and irrigation wells. A problem with soil salinity is that it can vary tremendously within a soil profile and from the location where irrigation water is supplied. Near where irrigation water is applied, a soil may be only slightly saline, as determined from electrical conductivity measurements. However, within 100 cm from that location, the salinity level and electrical conductivity measurement may be very high. Where there is enough water to leach the soluble salts from the soil, the salinity level can be controlled to be manageable. Where there is not enough water to leach the soluble salts, the salinity can suppress plant growth.

The application of irrigation water at one point can create a salinity problem where there was none before or make the problem more severe. By capillary action, some water, together with dissolved salts, will travel through the soil pores from where the irrigation water was applied to some distance from the site of application. The distance and amount of water that will move laterally by capillary forces is a function of the soil-pore sizes and their distribution. In the region of the soil where the water primarily is moving laterally and not downward, there will not be enough water to leach the salts from the profile. Therefore, soluble salts will accumulate in these areas. The application of irrigation water and soil properties will strongly affect resulting salinity levels in soils.

For example, traditional cultivation of date palms in coastal areas in Oman consists of planting the palm in circular excavated holes in the ground that are backfilled with soil to within 10-20 cm from the original ground surface forming a shallow basin. The size of the basin varies between farms because of factors such as availability of water, age of palm, and individual preference. Irrigation water is applied to the basin. Water imbibes in the soil and moves downward and outward. Along the perimeter of the hole where water is primarily moving only laterally, soluble salts will accumulate and will affect the growth of roots of the palms into these regions.

The following is a comparison of salinity problems among three date palm farms in a coastal area in Oman (see Figure 1). In farm number 1, irrigation was suppressing salinity buildup in the holes, i.e., irrigation basins, but soluble salts were accumulating on the soil surface. In neighbouring farm number 2, irrigation was not used for three years and salt was accumulating in the original irrigation basins. In farm number 3, which was approximately 1 km inland from the other two farms, the owner was maintaining salt-free soil inside the irrigation basin, but salt was accumulating outside of the basin.

These three conditions are a result of water flow patterns around the irrigation basins. Profitable farming in coastal areas is a continual process of preventing the build up of soluble salts. There is a need to develop sound scientific water management strategies to aid farmers in the Sultanate maintain their lands in good condition. Once problems develop, it is commonly more of an effort and an expense to correct the problem than it is to use sound management practices that are based on research investigations. Factors, such as irrigation basin size as a function of soil type, palm rooting patterns, and quality and quantity of irrigation water, need all to be investigated.

Land Suitability Classification

Besides surveying and classifying the soils, the Ministry of Agriculture and Fisheries Wealth has ranked soils in the Sultanate for their suitability for agricultural use. Factors that were considered are soil depth, rock fragment content, water retention properties, salinity, gypsum content, slope and landform position, hydraulic conductivity, depth to water table, drainage characteristics, and erosion and flooding hazards. The suitability rankings were based on the collective experience of the individuals who surveyed the soils. All of the 61 mapping units were grouped into three suitability categories. Class 1 was highly to moderately suitable, Class 2 was marginally suitable, and Class 3 was unsuitable. For Class 1 lands, the most common limitation to cultivation was doughtiness. For Class 2 lands, the limitations were

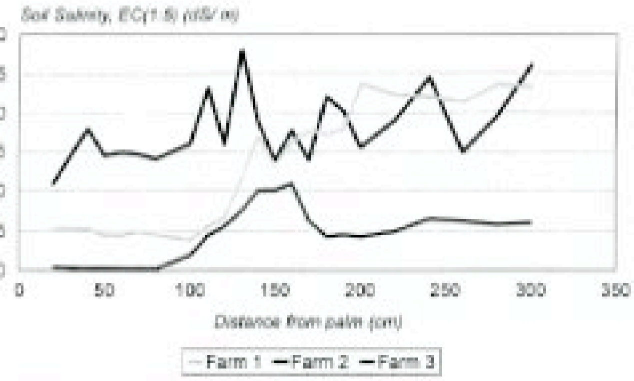

Figure 1. Variation of Soil Salinity around Date Palms.

high gravel content in 38%, doughtiness in 19%, high gypsum content in 15%, and poor drainage in 14% of the mapping units. Soil depth, rock fragment content, and low hydraulic conductivity were each listed as limitations for agricultural use in 5% of the Class 2 lands.

Of the total land area surveyed in the Sultanate, slightly over 7% or 2,000,000 hectares of land were categorized as Class 1 or 2. Of this land, approximately 800,000 hectares were categorized as Class 1. The soils typically found on Class 1 lands are deep, gently sloping, non- to slightly-saline, loamy Calciorthids and Torrifluvents. These soils can be productive for agriculture use, provided they are managed correctly. Given that lands were categorized in suitability classes based on personal experiences, research is warranted to evaluate the effect of soil factors on agricultural and other land usages for conditions existing in Oman. The combination of suitable soils, experienced work force, adequate supply of water via irrigation and nutrients via fertilization, and well-adapted crop varieties coupled with an expanding market can only lead to a prosperous agricultural industry, if the soils remain productive. Research can be a valuable asset for the future growth of the agricultural sector in the Sultanate.

Fertilization

For successful cultivation of crops in Oman, the nutrient needs of crops need to be satisfied as well as their water needs. The following section reports about fertilizer trials with Omani soils that have not been published in the open literature. From these reports, it can be understood that there is a need to conduct research to assess proper fertilization practices to optimize conditions for crop growth in Oman. Unfortunately, the fertility needs of each crop may be different and the effectiveness of the application of fertilizers may depend on specific site conditions. The effective use of fertilizers has contributed to the phenomenal growth in food production throughout the

Middle East in recent years (Mustafa et al., 1987).

High yield responses to nitrogen fertilizer have been reported from experimental stations and farms in the Sultanate. In a recent investigation (Cookson and Lepiece, in press) of cultivated soils in the Batinah region of Oman, the total soil nitrogen concentrations were measured to range between 0.001 and 0.09 percent by weight. This is very low considering that soils with total soil nitrogen concentrations in the range of 0.1 to 0.2 percent are classified as being low by the Booker Tropical Soil Manual (1991). In some regions of the United States, total soil nitrogen concentrations may exceed 1%. Therefore, it is not uncommon to expect significant yield response to nitrogen fertilization, if optimum growth conditions are maintained.

Grain yields of selected bread wheats (*Triticum aesticum* cv. W.Q.S. 160 and W.Q.S. 151), from the International Center for Agricultural Research in the Dry Areas (ICARDA) based in Syria, have been reported by the Ministry of Agriculture and Fisheries Wealth (Agricultural Research Annual Report, 1989a) to increase by 44.2% when supplied with 200 versus 50 kg N/ha of urea. Sweet Melon (*Citrullus lanatus* cv. Amco Sweet) has been reported to increase its yield in response to both larger and more frequent urea applications (Agricultural Research Annual Report, 1989b). Highest yields were obtained with 150 kg N/ha application rates. Okra *(Abelmoschus esculentus)* yield was increased 31% by applying 150 kg N/ha of urea compared to when no nitrogen fertilizer was applied (Agricultural Research Annual Report, 1989c). When the urea application rate was increased to 350 kg N/ha, the yield was significantly reduced. In a fertilizer trail with a bread wheat (*T. aestivum* cv. Yecoro Rojo) , a variety which is grown commercially in Saudi Arabia, there was no response to urea fertilization. It was concluded that Yecoro Rojo is too early maturing for conditions in Oman. This latter fertilizer trail serves to show that just by increasing fertilizer rates will not necessarily result in increased yields. Soil conditions and crop varieties are integral factors for optimizing yields.

In a comprehensive study on the application of nitrogen, phosphorus, and potassium fertilizers, the yields of Rhodesgrass *(Chloris gayana)*, Buffelgrass *(Cenchrus ciliaris)*, and Panicgrass *(Panicum sp.)* from 12 cuts taken during a 616 day period increased by 254, 310, and 306 percent, respectively, when 120 kg N/cut was applied compared to when no nitrogen was applied (Agricultural Research Annual Report, 1991). Rhodesgrass produced the highest yields of between 800-900 kg fresh matter/ha/day. Yields were higher and the response to nitrogen fertilizer was greater in the summer months than in the winter months. When phosphorus or potassium fertilizers were solely applied, the grass yields did not significantly increase. The high sodium bicarbonate-extractable phosphorus content of the soil, which was 18.02 ug/g soil, was proposed to be the reason for the negligible response. Because the fertility of a soil is an important factor in successful cultivation, whether natural or supplemented through the application of fertilizers, it is crucial that the physical, chemical, and biological processes that influence soil fertility be understood. The interaction of these physical, chemical, and biological processes in soils on plant growth and on fertilizer effectiveness is a ripe area for research in Oman. Few such investigations have been conducted. The following are discussions of some of the factors that affect fertilizer effectiveness in Oman and requirements for research.

Irrigation Practice

The importance of irrigation on agriculture in the Sultanate cannot be over-emphasized. In most areas, rainfall is inadequate for sustaining the water demands of crops. Extensive traditional irrigation methods have been in practice over many hundreds of years and are still being used successfully with date palm groves, (Travers Morgan (Oman), 1993). However, Oman is modernizing its agricultural practices. In the difficult period of inadequate knowledge of the new technologies which often follows modernization, inefficiencies, particularly in regard to meeting water demands of crops, can occur. If water is not effectively applied, then the application of fertilizer may have little benefit. To achieve increased yields that are economically profitable, both fertilizer and water applications need to help create optimal growth conditions.

Effective irrigation practice requires basic information on the ability of the soil to retain and transmit fluids, especially water. Information such as that measured by Abdulrahman et al. (1993), in which they characterized the ability of the soils in the Batinah region of Oman to retain water from gravitational forces, is essential to developing irrigation strategies that will maximize crop growth and fertilizer utilization and minimize salinity build up. Much more work in needed in Oman in characterizing the physical properties of soils as they relate to subsurface water behaviour. Much more work is needed in better understanding the results of irrigation practices on soil fertility and crop development in Oman.

Studies on barley *(Hordeum spp.)* in semi-arid regions of Syria (Shephard et al., 1987) suggest that increased nitrogen fertilizer application increase crop yields, but do not increase rates of water loss through evapotranspiration because the increased transpiration losses are balanced by the decreased evaporation losses.

Other studies in semi-arid West Africa (ICRISAT, 1985) have shown that small increases (i.e., 10%) in water use by pearl millet *(Pennisetum typhoides)* led to a three-fold increase in grain yield when crops were adequately supplied with nitrogen and phosphorus. Frequency of irrigation has been reported to affect the rooting structure of crops (Cooper et al., 1987), which will likely affect nutrient uptake. The interaction of irrigation practices on soil fertility and crop development are numerous. For successful cultivation in Oman, these interactions need to be understood as they apply to individual plant species and to conditions prevalent in Oman. Research is needed that investigates optimal fertilizer and irrigation regimes for specific crops on Omani soils. Fortunately, some of this type of work is being conducted by the Ministry of Agriculture and Fisheries Wealth (Agricultural Research Annual Report, 1992), as shown in Table 1, in which fertilizer requirements for a range of cereal and vegetable crops are listed.

Ammonia Volatilization

It is well know that ammonia may volatilize from soil surfaces that are drying and have a high pH (Stevenson, 1982). These conditions can cause a significant loss of nitrogen fertilizer, if improperly applied to soils. This was confirmed in laboratory studies at Sultan Qaboos University where 98% of applied ammonium was lost through volatilization. In Oman, the loss of nitrogen fertilizer via ammonia volatilization may be a problem because many soils have a high pH and will likely have drying surfaces. Techniques to reduce losses due to ammonia volatilization need to be investigated. One widely adopted solution is to irrigate immediately following nitrogen fertilizer applications so to leach the ammonium ions into the subsurface before the surface is allowed to dry. Although this practice is widely used, its effect on reducing ammonia volatilization is largely unknown for the soils in the Sultanate. Studies on the efficiency of fertilizers containing different forms of nitrogen in different soil types are needed.

The application of fertilizer to enhance soil fertility can be a relatively easy concept for farmers to understand. However, the physical and chemical processes that operate under the various conditions in Oman and how to utilize those processes to provide for optimal growth while minimizing any losses of fertilizers is not easily understood. Scientists can help to educate the agricultural community in the Sultanate by disseminating results of their investigations on fertilizer and irrigation requirements for different soil and crop types. Minimizing loss of nitrogen fertilizer because of inappropriate application is just one example of how research can make cultivation of crops more profitable in Oman.

TABLE 1

Recommended Fertilizer Requirements for Vegetable Production in the Sultanate of Oman.

Species	Fertilizer Requirements (kg/ha)		
	N	P_2O_5	K_2O
Tomato	240	100	100
Potato	300	70	400
Watermelon and Sweet Melon	130	23	225
Onion	160	70	160
Cabbage	150	92	100
Cauliflower	185	92	100
Okra	265	80	125
Carrot	240	115	365
Eggplant	100	90	150
Lettuce	90	70	75
Sweet and Hot Peppers	90	70	125

In addition, foliar applications of Zn,Mn,Fe and Cu are recommended.
Note: details are summarized from Department of Agriculture Research Annual Report (1992), Appendix 1. Ministry of Agriculture and Fisheries, Sultanate of Oman.

Phosphorus Fixation

Phosphorus is deficient in most soils of the Middle East. In an examination of 15 uncultivated soils of the Batinah region of Oman by Sultan Qaboos University, sodium bicarbonate extractable phosphate was found to vary between 1.4 and 5.9 ug/g soil. For a comparison, the Booker Tropical Soil Manual (1991) lists a medium range of phosphate concentrations of between 5 and 15 ug/g soil.

Phosphorus is present in various forms in soils with high pH, including inorganic phosphate ions, calcium phosphate precipitates, and organically-bound phosphorus. The conditions at which calcium phosphate precipitates in soils are important because the phosphorus is unavailable to plants in that form. When phosphorus becomes unavailable to crops, it is commonly called phosphorus fixation. Besides soil pH, other soil properties affect the fixation of phosphorus, such as the type of clay minerals present, the amorphous phosphorus content, and soil organic matter content (Sample et al., 1980).

In another investigation by Sultan Qaboos University of 13 soils of the Batinah region, it was found that fixation of orthophosphate fertilizer was highest in soils from As-Suwaiq. Between 23 and 76% of the phosphorus was fixed and unavailable to plants. The amount of phosphorus fixed was highly correlated to the silt content of the soils. At Wadi Quriyat Agricultural Research Station, a high rate of soil phosphorus fixation was suggested as the reason for poor responses of barley to phosphorus fertilizer applications found in field trials (Agricultural Research Annual Report, 1989d). The mechanisms involved in phosphorus fixation, particularly in regard to soil fertility, need to be further investigated in Oman because it is clear that Omani soils vary widely in their ability to fix phosphorus.

Micronutrient Deficiencies

Micronutrients are compounds that plants require for their existence, but they need only sparingly. Typically, micronutrient availability in soils are low. Their dominant role in plant growth is as activators for numerous enzyme systems (Miller and Donahue, 1990). Any process or condition that limits their availability further can adversely impact plant growth. A problem for Omani soils is that the solubilities of the micronutrients zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), and cobalt (Co) decrease as soil becomes more alkaline. In Oman, soil pH values are rarely less than 7.4 and are usually closer to 8.0; therefore, micronutrient solubility and availability to plants are likely to be deficient. Research is needed that investigates micronutrient availability to crops for conditions in the Sultanate. Furthermore, procedures for chemical analyses need to be developed which show close correlations between extractable micronutrients in soil and the micronutrient availability for crop growth.

Nitrogen Fixation

Nitrogen fixation is the conversion of atmospheric nitrogen (i.e., N_2) to ammonia (NH_3), which is then quickly converted to plant available forms in the soil (Miller and Donahue, 1990). This conversion is effected by symbiotic and nonsymbiotic microorganisms in soils. Nitrogen fixation by symbiotic is more prevalent than by nonsymbiotic microorganisms. In the group of symbiotic organisms are soil bacteria and actinomycetes that cause the formation of root nodules in certain plant species, which is the location of nitrogen fixation. Healthy nodules on field-grown alfalfa *(medicago sativa)* from experimental sites and farmers fields have been found to be actively fixing nitrogen by investigators from Sultan Qaboos University. However, measurements of annual nitrogen fixation rates were not attempted. Estimates of nitrogen fixation in grazed deserts of West Africa by Robertson and Rosswall (1986) were less than 1 kg N/ha/yr. The fact that root nodules have been found in some locations in Oman suggests that nitrogen fixation is occurring. Indigenious strains of nitrogen fixing microorganisms need to be collected and ways to successfully inoculate suitable crops investigated. The factors or conditions that resulted in productive indigenous nitrogen fixing bacteria becoming established in Oman should also to be determined so that management strategies can be developed to utilize nitrogen fixing microorganisms to supply crops with their nitrogen needs.

Soil Organic Matter Dynamics

In soil nitrogen is constantly mineralised from organic to inorganic forms to which are taken up (or immobilized) by plants and other soil organisms. The rate of this mineralisation / immobilization turnover (MIT) is governed by many soil factors, such as temperature, moisture, organic matter and also the activity of soil organisms and enzymes. Uncultivated desert soils are particularly low in organic matter (Shadfan and Husen, 1987) and, consequently, Omani farmers apply animal manure, usually at planting. The compositions and rates of release of nutrients from these decomposing manures need to be determined.

Organic matter decomposition has been subject to analysis using modelling techniques. A combined model incorporating major carbon and nitrogen transformations with water movement in soil would be useful in determining strategies for maintaining soil organic matter contents at adequate and prescribed levels. Such a model need not be developed in Oman, initially, but could be adapted from successful ones developed outside of the region. However, local validation of parameters and measurements of reaction rates remain necessary.

Soil microorganisms and enzymes are active in most of the reactions involved in soil organic decomposition. Bacterial populations in desert soils are, however, low. Uncultivated soils from Haima in the interior region of the Sultanate, for example, contain as low as 5 x 10^4 bacteria/gram of soil. Estimating reliably such low populations is a problem. The commonly employed methods of chloroform fumigation/incubation (Jenkinson and Powlson, 1976) to determine microbial bio-mass carbon and nitrogen have been found, at Sultan Qaboos University, to be insufficiently precise to give consistent results. Reliance on serial dilution techniques and plating on agar for counting is unsatisfactory because of all the uncertainties associated with extracting microorganisms by shaking in sterile water. A systematic comparison of different soil microorganism enumeration methods is required.

Soil bacterial and enzyme activities have on the other hand proven less difficult to determine, in the

Sultanate, than organism numbers. The dimethylsulphoxide (DMSO) reduction assay method for soil bacterial activity measurements (Alef and Kleiner, 1989) promises to be a relatively simple method for determining general activity in small (0.5g) soil samples. Trials at Sultan Qaboos university have shown Omani soils to be active reducers of DMSO, producing quantities of dimethylsulphide measurable by a sulphur-specific flame photometric detector fitted to a gas chromatograph.

Assays for measuring specific soil enzymes in Omani soils usually have to be modified by lengthening incubation times to allow sufficient end-product to accumulate for measurement. Cookson and Lepiece (in press) have shown that, in Oman, rates of urease activity vary between soils and are closely related to soil organic carbon concentration, salinity and texture. Essentially, increased soil organic carbon concentration promotes urease activity, while increased soil salinity inhibits activity. Such results have practical significant in Oman where the use of urea as a fertilizer is increasing.

Conclusions

In Oman, soil scientists are collecting information on soil types, fertilizer requirements, and irrigation scheduling. However, this information will not be enough to sustain an actively growing agricultural industry. Research is required to provide insights on how to best manage soils and water for successful, long-term cultivation. Crop yields are sensitive to changes in fertilization, irrigation, tillage, and other agricultural management practices. The time is now to develop sound scientific soil and water management strategies to prevent salinity problems and to provide Oman with its agricultural needs. Studies aimed toward understanding how the soil and crops respond to land management practices will be a valuable asset for the future development of the agricultural industry in Oman. Ministries of the Sultanate and researchers in Oman (e.g., Sultan Qaboos University) need to develop a strong research program in soil and water that will yield beneficial results for a long time in the future.

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