A Hundred Years of Research Towards the Conservation and Sustainable Management of South Africa's Land, Water and Climate Resources

ARC - Institute for Soil, Climate and Water: 1902-2002

The ARC-Institute for Soil, Climate and Water celebrated its Centenary during 2002. The oldest of the institutes of the Agricultural Research Council was established in 1902 as the Division of Chemistry in the Transvaal Department of Agriculture. In 1962 the Division was renamed the Soil Research Institute, and became the Soil and Irrigation Research Institute in 1971. The Institute adopted its present name upon the establishment of the ARC in 1992. This article proudly highlights some of the research achievements by the ARC-ISCW staff towards the conservation and sustainable management of our natural agricultural resources.

SOIL SURVEYS AND LAND EVALUATION FOR IRRIGATION

During the last 100 years the Institute has dealt with numerous investigations into salt-affected soils. At the first South African Irrigation Congress in 1909, concern was expressed at the extent of salt-affected soils, the sediment content of water supplies, the lack of suitable land for irrigation development and serious deficiencies in farm management. Even in those early days it was pointed out that for successful irrigation scheme development a careful soil survey must first be carried out; the volume of water which can be brought into the scheme must be known; and the irrigation scheme must proceed strictly along business lines. The same philosophy is still very relevant today.

The Institute was involved with the soil investigations and irrigation planning of all the major irrigation schemes in South Africa. More than 80 years ago, a Soil Survey Division was established whose main function was to examine proposed irrigation schemes. A review of such soil surveys reveals that soils free of limitations for irrigation are limited in their extent. However, it appears that waterlogging and salinisation affects only 13-18% of the area under regular irrigation, which, although still considerable, is lower than that experienced in many countries. Possible explanations for this relatively favourable state of affairs are the strict emphasis placed on the potential for waterlogging and its prevention in the Institute's selection criteria for irrigated soils, and the generally good water quality that has historically been available for irrigation. But with the salinity of South Africa's water resources on the increase due to mining, urban, industrial and agricultural developments, and the availability of water on the decrease, soil salinity due to deteriorating water quality is now on the rise.

The ARC-ISCW is presently involved in several studies on the use of poorer quality water for irrigation and to determine the effect of contamination of soils and water by industry and mining. Notably, the Blesbokspruit Wetland and adjacent farmland in Gauteng has been monitored on a monthly basis since 1996 to track the effect on soils and crops of irrigating with poor quality underground mine water. The uniqueness of this project lies not only in the amount of data generated but also in the fact that commercial farms use the water successfully. Through measuring soil salinity and other soil chemical properties at regular intervals, fluctuating trends in soil salinity and sodicity have been observed. Electrical conductivity values at the bottom of the root zone increased from 70 mS m^{-1} in 1996 (when mine water was first released) to 177 mS m^{-1} in 1999 (a dry year), but dropped to 95 mS m^{-1} in 2001 (a wet year). Long-term trends were masked by seasonal events such as high or low rainfall and irrigation demand, and the extent of winter irrigation.

Although the role of the Institute has now changed from primarily irrigation planning and development on the best soils to one of using poorer soils and waters in a sustainable manner, the fact that more than 3000 irrigation, salinity, drainage or waterlogging reports have been produced during the last century indicates the significant contribution the Institute has made to the knowledge base on the irrigability of South African soils.

The Water Research Commission has funded research into water management techniques in rainfed agriculture, conducted by the Institute at its experimental station at Glen, near Bloemfontein. *See article on p 17.*

CROP WATER-USE EFFICIENCY UNDER IRRIGATION

The WRC supported research on the water use of irrigated crops conducted by the ARC-ISCW over a period of more than 20 years. Much of this work was carried out at a field experimental station set up at Roodeplaat, near Pretoria. Considerable infrastructure was established including four weighing lysimeters and two rain shelters. The facilities were used from 1977-1989 in studies aimed at gaining a better understanding of the process of water movement through the soil-plant-atmosphere continuum and in particular on the effects of water stress on crop growth and water use. The field research trials used spring wheat as the test crop during the winter seasons and soybeans in the summer, and several international scientists participated in the detailed measurements of various plant physiological properties. This work culminated in a multi-disciplinary project conducted from 1990-94 that focussed on characterising the interactive effects of water and nitrogen on the growth, water use and yield of irrigated spring wheat. Guidelines were developed for farmers regarding the amount of irrigation water to apply and the optimal nitrogen application recommended for a specific target wheat yield in the warm irrigation regions of South Africa. For example, for spring wheat cultivars grown in a deep soil with a high clay content, in order to obtain a grain yield of 6 000-7 000 kg ha^{-1} a nitrogen fertiliser application rate of 135 kg N ha^{-1} was recommended. The field study indicated that a seasonal water use of approximately 550 mm would be required for this target yield if irrigation was applied weekly, but only 440 mm if it were applied once every two weeks. The efficiency of irrigation water could thus be improved if these guidelines are followed, and a higher yield produced per unit of irrigation water applied.

In the same project a significant contribution was made to the detailed monitoring of plant-water relations when the heat pulse system, which had previously been used only on plants with robust stems such as soybeans, was adapted for use with thin-stemmed wheat tillers. The technique was then calibrated and used successfully to make continuous measurements of single stem transpiration under field conditions. But perhaps the main legacy of the project was the large and comprehensive dataset that was generated. This was used to validate selected crop growth models and made available to other research institutions for the same purpose. Some of the data was subsequently included in the SWB irrigation scheduling model (developed at the University of Pretoria), which the Institute then also helped to validate.

In the late 1990s, in order to assist the many small-scale emerging farmers, the ARC-ISCW's research focus changed to determine the water requirements of vegetable crops grown in small flood-irrigated plots.

WATER HARVESTING UNDER RAINFED AGRICULTURE

The WRC has also funded research into water management techniques in rainfed agriculture, conducted by

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the Institute at its experimental station at Glen, near Bloemfontein. In-field rain water harvesting (IRWH), incorporating appropriate tillage and mulching practices, has proved to be a very effective method for enhancing rainfed crop production in marginal areas. IRWH techniques on clay soils, combining basin tillage, a bare no-till runoff strip and mulching, have resulted in both improved crop yields and precipitation-use efficiency (PUE: kg ha^{-1} grain yield divided by mm seasonal rainfall). Over a 4-year trial period the IRWH technique produced on average an additional 1.5 kg ha^{-1} grain per mm of rain in comparison to the PUE of 3.9 kg ha^{-1} mm^{-1} for conventional tillage. Even more impressive was the fact that the yields from the water harvesting techniques remained superior to those of conventional tillage irrespective of climatic conditions. Production conditions varied from very unfavourable during the 1998/99 season (401 mm rain) to very favourable in 1997/98 (633 mm). Grain yields varied from 0-3 133 kg ha^{-1} using a conventional tillage production system to 132-4 678 kg ha^{-1} when the water harvesting technique was used, with the average yield for IRWH being 810 kg ha^{-1} higher. The IRWH technique is more effective in converting water into food because it combines the advantages of water harvesting, no-till, basin tillage and mulching. The hydrological cycle is modified in such a way that more water is made available to the crop. Losses through runoff are prevented entirely and mulching further conserves water by enhancing the infiltration rate, allowing it to percolate deeper beyond the evaporation-sensitive zone.

CLIMATE MONITORING NETWORK AND DATABANK

The ARC-ISCW's climate monitoring network has expanded since its inception in 1940 to 250 mechanical and 270 automatic weather stations. An automatic weather station (AWS) is equipped with state-of-the-art communication technology which enables the provision of near real-time information for stress-sensitive crops, pests, diseases and crop production indices. Sixty percent of the stations are privately owned and incorporated into the monitoring network through maintenance and calibration service contracts. These contracts entail quality processing of data to facilitate *inter alia* early warning with respect to diseases. The climate monitoring network recently expanded to previously disadvantaged areas in the Eastern Cape where more than thirty AWSs have been established.

The climate databank includes information from the national networks of the ARC, the South African Weather Service and smaller monitoring institutions. It has recently been upgraded to provide numerous user-friendly agrometeorological applications. Currently under development is the accessibility of this databank via the Internet to provide clients with report and query application products.

During the 1980s much agrometeorological research was directed to producing climate zones to extrapolate point climate data, but recent advances in technology and computing facilities now make the generation of climate surfaces a preferable option. The development of 10-daily, monthly and annual long-term mean rainfall and temperature surfaces, which use a grid resolution of 1 km^2, was a significant one. These surfaces have numerous applications in the agricultural industry, including the successful delineation of crop production areas.

SOIL RESOURCE INFORMATION

During the last 30 years the Institute mapped the soil, terrain and climate resources of South Africa in a countrywide Land Type Survey. Over 7 000 land types were identi-

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fied and their properties inventorised on a total of 69 maps. Each land type differs significantly from those surrounding it in terms of its soils, terrain and macroclimate properties. As these properties are important in determining agricultural suitability, the land type maps and inventories have proved invaluable in assessing agricultural potential in South Africa, and have found numerous applications in the agricultural industry and the field of environmental quality.

LAND QUALITY INDICATORS

A healthy and productive soil resource base is essential to meet the needs and aspirations of present and future generations. Indicators of land and soil quality are being developed to monitor human impacts on land. The current condition of land in Mpumalanga was assessed for rainfed and irrigated crops, rehabilitated open-cast mined land and for rangeland in the grassland and savanna biomes. The recommended indicators to address future land quality were changes in land use, soil condition (chemical properties) and water quality, at monitoring intervals of 5, 2.5 and 0.5 years respectively.

Soil phosphorus (P) level was used as an indicator of land degradation in Gauteng. There was a unique relationship between soil P concentration and the intensity of degradation in terms of vegetative cover, whether it was for grassland or alien vegetation sites within the study area. The P concentration mostly increased with increasing degradation intensity and was generally higher for severely degraded sites compared to non-degraded sites. The implication here is that soil P could be used as an indicator of environmental degradation.

EROSION

The Instutute has been active in erosion studies for many years. Back in the 1930s these concentrated on the fundamental relationship between soil type, soil condition and rainfall erosivity, and on procedures to control erosion of natural grazing and cultivated land. Runoff plots and lysimeters were used to determine the magnitude of soil loss. Later, rainfall simulator and mini-flume investigations on a selection of soils evaluated the effect of a range of soil physical, chemical and mineralogical properties on the erosion process. In 1973, the Institute published a report on the vulnerability of South African soils to erosion. The effects of slope, water droplet energy, rainfall erosivity, soil stability, soil water infiltration, soil dispersion and crusting all received research prominence. Methods of reducing the soil dispersion and crust formation that lead to erosion, using soil amendments such as gypsum and polyacrylamide, were investigated in collaboration with Israeli scientists. The importance of soil mineralogy has improved our understanding of the erosion process; for example the mica content was identified as the single most dominant soil characteristic promoting interrill erodibility of Mollisols.

Later research provided opportunities for erosion assessment and prediction modelling at scales ranging from small catchments up to countrywide. Erosion models such as the Revised Universal Soil Loss Equation (RUSLE) produced estimates of soil loss under differing management systems. The significance of these studies is that estimated soil loss values could be displayed at either farm, district or provincial levels. The Lesotho Highlands Water Project served as a benchmark study to indicate land with potentially high or low erosion hazard. In a current WRC-funded project, models are being tested to assess their ability to predict the impact from various management practices typically used in our agricultural production systems.

The satellite-based Vegetation Index and Bare Soil Index have further enhanced capabilities in erosion research. The ARC-ISCW also maintains the South African database for the World Overview of Conservation Approaches and Technologies (WOCAT), aimed at evaluating soil and water conservation technologies.

SOIL DEGRADATION DUE TO STRIP MINING

Some of the most productive rainfed agricultural land in South Africa is found on the Mpumalanga Highveld. Stable land surfaces with gently rolling topography, receiving 750-800 mm annual rainfall, are occupied by moderately deep, highly weathered soils with favourable water-holding characteristics and response to fertilisation. Strip (opencast) mining became widespread in this area during the mid-1970s. Of a total of 2.7 million ha underlain by coal reserves in Mpumalanga, approximately 7% may ultimately be mined by strip mining methods. Guidelines for strip-mine rehabilitation were published and a growing awareness of the serious loss of agricultural potential and changes in soil hydrological properties resulting from this mining process led to a number of investigations.

The most widespread limiting soil property in rehabilitated strip-mined soils was found to be the high bulk densities induced by soil leveling operations using heavy rehabilitation equipment. Maize field trials conducted at representative rehabilitated sites produced a mean yield of only 2 400 kg ha^{-1}, about half the norm for the area and below the economic break-even yield for maize. Maize production was thus proven to be uneconomic if soil limitations are not corrected. Water extraction by maize and grass roots was limited in the cover soil where high bulk densities were present, despite evidence of water in deeper soil and spoil layers.

POLLUTION

Due to growing public concern and awareness of food quality, issues relating to trace elements in agricultural soils and chemical residues in agricultural produce have become increasingly important. Our health depends to a large extent on the supply of mineral nutrients in our daily diet, and deficiencies and toxicities are therefore critical. Since our food is produced mainly on the land, soil is the primary source of these mineral elements in the food chain. Ground-breaking work has been done in determining baseline concentrations of trace elements in South African soils. Areas with deficiencies or toxicities have been identified, whilst in Mpumalanga the influence of agricultural practices on the trace element content of soils has also been studied.

A related research field is the disposal of sewage sludge on land. Strict guidelines for sludge disposal on agricultural soils apply in South Africa. Most wastewater treatment plants dispose of their sewage sludge on dedicated land disposal sites. This is a quick and cheap but controversial practice. The impact on the environment is believed to be negative, but very little research has been done to determine the extent of the damage to the soil and water resources. A WRC-funded study to develop suitable management and environmental quality guidelines for waste disposal is presently in progress at the ARC-ISCW.

CARBON SEQUESTRATION

Global warming, caused by elevated levels of greenhouse gases in the atmosphere from human activities such as the burning of fossil fuels, is another issue of increasing concern. In particular it can have serious ramifications for agricultural production and food security, greatly affecting marginalised populations in rural areas. Carbon sequestration (the building up of carbon levels in the soil) is one way of counteracting this concern. To establish the potential for carbon sequestration in South African agriculture, the Institute derived the baseline carbon levels from over 2 000 soil profile analyses and produced maps to show the estimated distribution of carbon in South African soils. Although only an approximation, this unique approach illustrates the potential for building up carbon levels based on long-term soil and climate properties. Research indicates that carbon levels in cultivated land are generally about half of those in undisturbed grassland.

CONCLUSION

Much of the natural resources information collected by the ARC-ISCW over the last 100 years has been published in scientific journals, in reports or on maps which are archived at the Institute. Electronic dissemination of information has recently gained momentum, notably via the Agricultural Georeferenced Information System website (www.agis.agric.za). Readers are encouraged to consult this website or contact the Institute directly should they have any information requirements.

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