# Management for Improved Water Use Efficiency in the Dry Areas of Africa and West Asia

OSWU

ICRISAT

International Crops Research Institute for the Semi-Arid Tropics
International Center for Agricultural Research in the Dry Areas

ICARDA

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# Abstract

This is a report of the 2002 workshop of the Optimizing Soil Water Use (OSWU) Consortium, held in Ankara, Turkey. It describes OSWU research in West Asia (Jordan, Syria, Turkey), North Africa (Morocco), Southern Africa (South Africa, Zimbabwe), and West Africa (Burkina Faso, Niger). The consortium aims at developing and disseminating effective and practical solutions for resource-poor farmers, being aware of the uncertainties of applying classical principles of soil-crop-water relations in arid and semi-arid environments.

Reports from Morocco, Turkey, Jordan and South Africa confirm the effectiveness of some existing technologies, including the use of mulches to reduce soil evaporation or runoff, sometimes combined with use of soil fertility inputs to improve water use efficiency. Other papers describe a new quality indicator to assess land degradation, the use of new decision support tools, and modeling techniques to improve research efficiency and increase the effectiveness of farmer participatory research. ICARDA and ICRISAT report on new developments within the international research centers that are now ready for testing by NARS partners in their environments.

Proposals for new work were presented and approved, with the emphasis on better transfer of methods to improve soil water use, and evaluating the impact of past research projects. In recognition of the current turbulent times, and the unlikelihood of increased resources for agricultural research in dry areas, OSWU partners developed a strategic plan to achieve greater impact; this plan is outlined.

# Résumé

Ce rapport de l'atelier 2002 du consortium OSWU (Optimizing Soil Water Use) tenu à Ankara, en Turquie, décrit les recherches d'OSWU en Asie occidentale (Jordanie, Syrie et Turquie), Afrique du Nord (Maroc), Afrique australe (Afrique du Sud et Zimbabwe) et Afrique de l'Ouest (Burkina Faso et Niger). Le consortium, conscient des doutes qui existent quant à l'application des principes classiques des relations sol-culture-eau dans les environnements arides et semi-arides, a pour objectifs le développement de solutions effectives et facilement accessibles et leur dissémination auprès des paysans pauvres.

Les rapports du Maroc, de la Turquie, de la Jordanie et de l'Afrique du Sud confirment l'efficacité de technologies existantes, telles l'utilisation du paillage pour réduire l'évaporation et le ruissellement, combiné par moment avec des intrants de fertilisation du sol pour améliorer l'usage de l'eau. Sont également décrits dans cet ouvrage un nouvel indicateur de qualité utilisable pour l'évaluation de la dégradation des terres, l'utilisation de nouveaux outils de prise de décision, et des techniques de modélisation pour améliorer l'efficacité des recherches et mieux capitaliser l'apport de la participation paysanne. L'ICARDA et l'ICRISAT exposent les nouveaux développements des centres internationaux de recherches prêts à être testés par les partenaires SNRA dans leurs environnements respectifs.

Des propositions de nouveaux travaux ont été présentées et approuvées, avec une attention particulière portée sur la qualité du transfert des méthodes d'amélioration de l'utilisation de l'eau et du sol et sur l'évaluation de l'impact des projets de recherche passés. Reconnaissant la conjoncture actuelle délicate et l'incertitude d'une amélioration des ressources de la recherche sur les milieux arides, les partenaires OSWU ont développé un plan stratégique pour de meilleurs impacts; ce plan est exposé.

# Management for improved water use efficiency in the dry areas of Africa and West Asia

**Proceedings of a workshop organized by the Optimizing Soil Water Use Consortium**
**Ankara, Turkey, 22-26 April 2002**

*Edited by*

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# Preface

The 2002 workshop of the Optimizing Soil Water Use Consortium, held in Ankara, Turkey, 22-26 April, was a pivotal event. It provided an opportunity to evaluate what progress had been made to date, and helped point the way for planning future activities that would maximize achievements possible with the remaining resources.

The objectives of the meeting were to review ongoing and completed OSWU activities, develop a new strategic plan for OSWU for the next few years, and plan activities for the next phase of work. In view of the limited resources available, future work will focus on activities with a high likelihood of impact, that would help small-scale farmers in dry areas. Therefore, emphasis was placed on integrated natural resource management, using a farmer-participatory approach in collaboration with other stakeholders. Where possible, new tools such as systems simulation and decision support tools would be used. Impact analysis was a key part of the completion of the work.

The workshop was coordinated by M Avci of the Central Research Institute for Field Crops, Ankara. Delegates from Burkina Faso, Jordan, Kenya, Morocco, Niger, South Africa, Syria, Turkey, and Zimbabwe contributed a breadth of knowledge and experience that led to the success of the discussions.

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**Session 6. New Proposals for OSWU Short-Term Funding**



**Session 7. Strategic Planning on Future of OSWU and Related Issues**

# Inaugural Session

# Welcome Address

**Huseyin Tosun**

*Director, Central Research Institute for Field Crops, Ankara, Turkey*

Mr Chairman and dear scientists,

On behalf of my institute, I would like to extend my warm welcome to all of you. We are honoured that Turkey has been selected as the host country.

We believe that optimized use of soil water is becoming very important, not only for semi-arid areas, but also for the world's humid areas that are affected by adverse environmental conditions such as global warming, climate change, and degradation of natural resources, particularly soil and water. Scientific information is the key to prosperity of all humanity. All nations, scientists and people should share it. It is not so important what research an institute specializes in - what is more important is whether or not this institute is willing to share this knowledge and experience with other institutes or scientists in similar environments. Now we are all gathered to share the information produced by each of us.

I would like to express my deep gratitude to the distinguished scientists Dr Mustafa Pala from ICARDA, Dr Bob Myers from ICRISAT, and Dr Danie Beukes from South Africa, and to all scientists from participating countries. We are ready to co-operate in joint programs for the development of agriculture in arid and semi-arid regions.

I will not take more of your valuable time. We are at all times at your disposal for making the meeting comfortable and successful.

I wish you a pleasant and memorable stay in Turkey and hope to benefit greatly from the discussions to be held at this workshop.

Thank you.

# Inaugural Address

**Dr Vedat Uzunlu**
*Deputy Minister and Undersecretary, Ministry of Agriculture, Ankara, Turkey*

Mr Chairman and distinguished guests

It is a pleasure for me to welcome you to this OSWU Workshop and Steering Committee Meeting. The prosperity and development of any nation depend largely on its land and water resources and their optimized use. These determine the level of human sustenance and, to a considerable degree, a nation's economic viability. With increasing population pressures throughout the world, it becomes increasingly important to improve and intensify agricultural production if food shortages and malnutrition are to be avoided. Our government has therefore allocated an ever-increasing priority to agricultural development.

Turkey made a great success of dryland agriculture during the mid-sixties and late seventies. In this success, improved summer fallow practices played a key role in increasing moisture availability at the time of wheat planting. During the 1980s, research and extension focused on optimizing use of rainwater during the fallow period; fallow areas were replaced mainly by food legumes. Although this practice slightly reduced wheat yield in the following rotation, production of food legumes greatly increased, and Turkey became a leading legume exporter. Now our objective is to seek sustainable crop and soil management technologies which permit more efficient water use and conservation.

The OSWU consortium has been a very important initiative in terms of more efficient use of soil water in farmers' fields. This is particularly important in view of a changing global climate that will adversely affect drylands. With diminishing rainfall and increase in drought, the pace of dryland degradation will increase.

Because this process strongly affects rural people in the world's dryland areas, collaborative research programs and sharing experiences among scientists from those areas have become vital to higher and more stable production. The OSWU has been playing a vital role to bring together scientists from national and international centers in dry areas of Africa and West Asia.

I would like to thank ICARDA and ICRISAT for pushing OSWU forward towards success. I wish you a pleasant stay in Ankara and success in your discussions.

# Session 2. Final Reports of Projects

# OSWU Projects in Jordan

**Mahmoud K Al-Akhras**
*NCARRT, Jordan*

## General Introduction

Jordan is a country with limited rainfed agricultural land, scarce water resources, and scanty and erratic rainfall. Research on optimizing soil water use is needed to increase the productivity of land through adoption of moisture conservation techniques such as tillage, crop rotations, supplementary irrigation, water harvesting, etc. This paper presents results from three projects undertaken by Jordan under the OSWU umbrella:

- Soil moisture content under different water harvesting techniques
- Effect of supplemental irrigation and N-fertilization on barley production under different irrigation systems
- Tillage, residue and nitrogen management in crop rotation.

## Project 1. Soil Water Content under Different Water Harvesting Techniques

*Researchers.* Abdelnabi A Fardous, NCARRT; Anwar M Battikhi, Jordan University of Science and Technology; Mahmoud Saleem, Mohamad A Mudabber, and Mahmoud K Al-Akhras (all NCARRT).

### Objectives

The objectives were to determine soil moisture storage and depletion (i) under compacted versus non-compacted soil, (ii) under different soil surface management such as soil surface disturbance, adding stones, and crop residue for mulching.

### Materials and methods

*Study location.* The experiment was conducted at Al Khanasri Research Station, in the northern region of Jordan. The annual rainfall is about 130 mm, characterized by rapid showers and irregular distribution. It is an ideal area to apply water harvesting techniques.

*Treatments and experimental design.* A diamond shape water harvesting technique was used. The diamond is a microcatchment unit, which is divided into a runoff area and a run-on area. Each plot had a catchment area of 4.29 $m^2$ with 1 $m^2$ as cultivated area. The plots were surrounded by earth ridges with infiltration pits in the lowest corner. The height of the ridges was 25-30 cm in order to avoid the risk of damage due to overtopping, and to ensure that all the runoff water infiltrates in the lowest part of the cultivated area.

There were two soil surface treatments in the catchment area: T1 - compacted soil surface, and T2 - untreated (natural) soil surface. Three soil surface treatments were applied to the cultivated area as follows: S1 - disturbed soil surface, S2 - covered with stones, and S3 - covered with crop residues. Thus there were six treatments: T1S1, T1S2, T1S3, T2S1, T2S2, T2S3. The treatments were replicated three times using an RCBD design.

## Measurement of soil physical properties

Bulk density was measured on soil cores (Blake and Hartge 1986) from normal, compacted and cultivated area at depths of 0-10, 10-20, and 20-30 cm. Three random samples were taken from each depth.

Infiltration rate was measured for normal, compacted, and cultivated area using the double ring infiltrometer method (Bower 1963).

Soil texture was determined as particle size distribution by the pipette method (Klute 1986) for soil depths of 0-10, 10-20, 20-30, 30-60, and 60-90 cm.

Soil moisture content was measured in each plot using Time Domain Reflectometry (TDR) (Sentry 200). PVC access tubes were installed in the-cultivated area where the harvested water is stored. Soil moisture was measured for the depths of 0-15, 15-30, 30-60, and 60-90 cm. Readings were taken after each rainfall event, or weekly when there was no rain. Soil moisture depletion and storage were calculated from the TDR readings. The calculations depend on the difference between every two readings from the beginning of the season till the end. Soil moisture storage is the change of water content ($\Delta S$), while soil moisture depletion is the negative change of soil moisture content ($-\Delta S$).

Since this study concentrated on water storage, no crop was grown. With the absence of crop, data for one year is believed to be enough to achieve the objectives of this study.

## Results

*Runoff area treatments.* There were no significant differences between T1 (compacted), and T2 (natural) treatments. Soil moisture storage and depletion were higher in TI than in T2. For example, storage was 362 mm and 338 mm under TI and T2 respectively; while depletion was 311 and 284 mm. During the early rainfall events, the compacted treatment performed much better than the natural treatment, because runoff was higher in the compacted treatment. Initial soil bulk density at the surface was 1.6 g $cm^{-3}$ for compacted, and 1.05 g $cm^{-3}$ for natural. Later on, both treatments started to behave similarly, probably because of crusts developing in both treatments. Raindrop impact probably formed the crusts, rapidly reducing infiltration. As a result, runoff on both treatments became similar.

*Run-on area treatments.* There were no significant differences between S1 (disturbed), S2 (stones), and S3 (crop residue). Soil water storage was 369 mm in S2, 342 mm in S1, and 339 mm in S3. Depletion was 313, 311 and 268 mm.

Soil surface cover with mulch of stones and crop residues affected some soil surface conditions. It protected the soil from rainfall impact, which could have reduced infiltration rate. Also mulch increased the resistance for vapor density, decreasing vapor flux from the soil surface.

Crop residue on the soil surface reduces the fluctuation of soil temperature profile, which decreases the gradient in vapor density, and consequently decreases vapor losses. The energy stored in the soil profile depends on the albedo, which is affected mainly by the type of mulch, soil color and soil moisture content.

Evaporation decreased during the first few days after rain. During this period, a highly reflective cover, such as stones or crop residue, decreased evaporation due to decreased net radiation.

Since crop residue is a complete mulch, it markedly altered evaporation during the final period. Also surface mulch affected the temperature and moisture regime of the surface horizon. The surface soil moisture content was almost always higher under the mulch. Surface mulch was added to further reduce surface water loss. Thus amounts of water conserved from evaporation remained high within the soil profile, and would have been available for plant use.

S2 (stones) and S3 (crop residue) performed well throughout the season with respect to moisture storage and depletion. The S3 treatment was the best at the end of the period, whereas the natural treatment S1 was, in general, the worst.

There were no significant differences in soil moisture depletion and storage between catchment and cultivated treatments. T1S2 (compacted with *stones) gave* the highest soil water storage (394 mm). T1S3 (compacted with crop residue) showed 286 mm soil water depletion, and T2S3 (natural with crop residue) had 251 mm.

*Total water content.* Initial soil moisture contents were determined before the winter season when the experiment started. Readings were then taken after 44.5 mm of rain during Nov and the first two weeks of Dec. The highest amounts of stored water were on 28 Jan and 4 March, due to high rainfall during these two periods (Fig 1).

Figure 1 shows the total water stored as affected by T1 (compacted) with cultivated treatments S1 (disturbed), S2 (stones), and S3 (crop residue). T1S2 and T1S3 were more efficient in storing water than T1S1. The amounts of water conserved were 152 mm in T1S1, 241 mm in T1S2, and 211 mm in TI S3 in the first readings. This was because evaporation from the soil surface was reduced by mulching. At the end of the season, there was 174 mm in T1S1, 260 mm in T1S2, and 280 mm in T1S3. The use of mulch conserved more water by increasing infiltration and decreasing evaporation. Stones or crop residue insulated the surface from severe climatic effects, especially temperature, where it reduced the energy absorption.

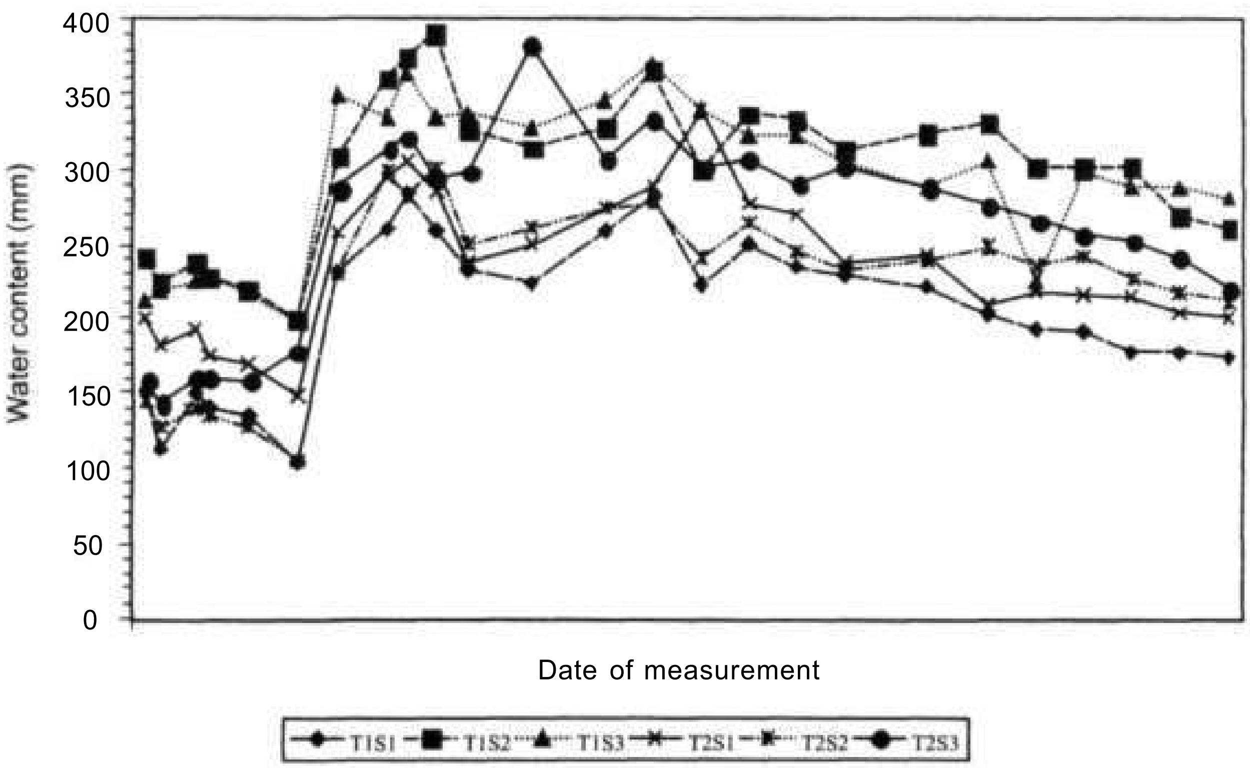


***Figure 1. Total amount of water (mm) in different treatments, 1996/97***

T1S2 (compacted with stones) conserved more water than T2S2 (natural with stones). The amount of water conserved during the few rainfall events was 241 mm in T1S2, and 145 mm in T2S2. This indicates that T1 (compacted) diverted much more water from catchment to cultivated area than T2 (natural). This was due to the higher bulk density for T I, which resulted from compaction, which reduced infiltration rate, which in turn increased run-off from catchment to cultivated area.

The water harvesting results indicated no significant differences in soil water storage and depletion for the different treatments, as affected by catchment and surface treatment. Water harvesting should be used in this area, considering amounts, duration and distribution of rainfall. At any time, infiltrated water did not reach more than 50-60 cm in depth. Therefore the results indicate that using MCWH (microcatchment water harvesting) is very useful, since water content in the normal sites was lower than where WHT was used (Table 1).

Soil surface management, whether in the catchment area or in the cultivated area, played a big role. The compacted treatment had less infiltration, and more runoff to cultivated area. Mulching with stones and crop residue influenced evaporation and infiltration, and thus the amount of water stored in the profile for a long time (Fig 1).

**Table 1. Total water depth (mm per 60 cm) in the runoff and run-on areas for T2S1 treatment (non-compaction and disturbed) in 1997**

| | Diamond (large size) | | Diamond (small size) | |
|---|---|---|---|---|
| Date of reading | Runoff area* (mm per 60 cm) | Run-on area (mm per 100 cm) | Runoff area (mm per 60 cm) | Run-on area (mm per 100 cm) |
| 26 Feb | 97 | 270 | 125 | 328 |
| 14 Mar | 115 | 338 | 113 | 264 |
| 26 Mar | 107 | 269 | 105 | 319 |
| 2 Apr | 96 | 238 | 116 | 300 |
| 14 Apr | 73 | 243 | 109 | 311 |
| 23 Apr | 64 | 208 | 113 | 302 |
| 30 Apr | 52 | 218 | 112 | 299 |
| 7 May | 51 | 215 | 114 | 300 |
| 14 May | 51 | 214 | 117 | 282 |
| 21 May | 50 | 203 | 126 | 277 |
| 30 May | 34 | 200 | 107 | 272 |

*No change in soil moisture content below 60 cm before and after the winter season

## Conclusions and recommendations

Water harvesting was very useful in the study area (annual rainfall 100-200 mm). There was no change in soil moisture content below 60 cm depth before and after the winter season. The amount of stored water in the catchment area did not exceed 115 mm per 60 cm, whereas in the cultivated area, the highest amount of stored water was 328 mm per 100 cm. Diamond shape water harvesting was efficient in collecting and storing rainfall up to 393 mm in the soil profile. Physical properties of the soil such as infiltration, texture and bulk density had a clear effect on runoff storage and water retention in the soil profile. Soil surface treatments played a big role in this.

The diamond shape water harvesting technique is applicable for trees and bushes. Under the experimental conditions, the technique doubled the amount of water stored in the profile. Using stones and crop residue as mulch is an effective, low cost water conservation method, and can be implemented without much effort.

# Project 2. Effect of Irrigation and N-Fertilizer on Barley Production under Different Irrigation Systems: (a) Sprinkler Irrigation

*Researchers.* Abdelnabi A Fardous, Naem Mazahrih, Luna Al-Hadidi, and Mohamad A Jitan, NCARRT, Jordan

## Objectives

To illustrate the effectiveness of supplemental irrigation and N-fertilizer on barley production, and to estimate the actual water consumptive use for barley.

## Materials and methods

This research was carried out for three seasons, 1995/96, 1996/97 and 1997/98, at Ramtha Station for Agricultural Research, located 10 km from Ramtha city, near the Jordan University of Science and Technology. Soil physical and chemical analysis is reported in Table 2. Bulk density using Blake method, EC (paste extract) using conductivity bridge, mechanical analysis (pipette method) and pH of the paste extract were also measured.

The experiment was laid out using a strip plot design. One sprinkler line was used to provide different levels of irrigation water in a vertical direction

**Table 2. Physical and chemical characteristics of the soil at the experimental location**

| Soil depth (cm) | Bulk density ($g\ cm^{-3}$) | Field capacity ($g\ kg^{-1}$) | Sand ($g\ kg^{-1}$) | Silt ($g\ kg^{-1}$) | Clay ($g\ kg^{-1}$) | Soil texture |
|---|---|---|---|---|---|---|
| 0-30 | 1.36 | 398 | 143 | 505 | 352 | SCL |
| 30-60 | 1.27 | 413 | 12 | 296 | 696 | Clay |
| 60-90 | 1.34 | 421 | 22 | 201 | 777 | Clay |

| Soil depth (cm) | pH | $CaCO_3$ ($g\ kg^{-1}$) | P ($mg\ kg^{-1}$) | K ($mg\ kg^{-1}$) | O.M. ($g\ kg^{-1}$) |
|---|---|---|---|---|---|
| 0-30 | 8.0 | 21.5 | 5.9 | 4310 | 11 |
| 30-60 | 8.3 | 28.9 | 3.9 | 3490 | 7 |
| 60-90 | 8.3 | 24.1 | 3.2 | 2790 | |

on the irrigation line. The highest amount was near the line and decreased gradually with distance from the line (Hanks 1976). The experimental plot was 30 x 30 m. Spacing between sprinklers was 6 m, and diameter of the wetting area was 24 m. Barley (Acsad 176) was sown at 100 kg $ha^{-1}$. Five N fertilizer levels, 0, 20, 40, 60, and 80 kg N $ha^{-1}$, were used as main treatment in four replications. The N fertilizer was applied half at sowing, and half at elongation stage with the first irrigation. To determine the amount of irrigation, 25 collecting cans were installed on one side of the irrigation line at 1.5, 4.5, 7.5, 10.5, and 13.5 m to represent five irrigation levels. Changes in soil moisture were measured using a neutron probe. Twenty-five access tubes were fixed near the collecting cans for one replicate. To determine the actual water consumptive use for barley, moisture readings were taken at six depths, and surface soil samples were taken every 10 days, or immediately before, and 48 hours after irrigation, or when rainfall exceeded 10 mm.

To calculate water consumption the following equation was used:

$$ET = I + R + AS$$

where ET = actual water consumptive use (mm), I = amount of water added (mm), R = rainfall (mm), and AS = change in soil moisture (mm). Runoff and deep percolation were assumed to be zero.

In the first season, 1995/96, the amounts of water applied were 0, 13, 31, 39, and 50 mm. Two irrigations were applied, at elongation and at flowering. A third irrigation was not given because of windy weather. In the second season, 1996/97, applied water was 0, 5, 9, 23, and 40 mm (Table 3). Two irrigations were applied - at elongation and at flowering. A third irrigation at grain filling was not given because of windy weather. In the third season,

| Table 3. Irrigation and rainfall (mm) at Ramtha station | | | |
|---|---|---|---|
| Treatment | 1st irrigation | 2nd irrigation | Rainfall + total irrigation |
| 1995/96 season, rainfall 162 mm | | | |
| I0 | 0.0 | 0.0 | 162 |
| I1 | 3.5 | 9.5 | 175 |
| I2 | 8.3 | 22.7 | 193 |
| I3 | 10.3 | 28.7 | 201 |
| I4 | 12.5 | 37.4 | 212 |
| 1996/97 season, rainfall 230 mm | | | |
| I0 | 0.0 | 0.0 | 230 |
| I1 | 5.0 | 0.0 | 235 |
| I2 | 7.0 | 2.0 | 239 |
| I3 | 15.0 | 8.0 | 253 |
| I4 | 27.0 | 13.0 | 270 |
| 1997/98 season, rainfall 283 mm | | | |
| I0 | 0.0 | | 283 |
| I1 | 1.0 | | 284 |
| I2 | 4.0 | | 287 |
| I3 | 14.0 | | 297 |
| I4 | 19.0 | | 302 |

1997/98, temperature and rainfall were higher. The water applied was 0, 1,4, 14, and 19 mm (Table 3). Only one irrigation was applied - the second was not given due to windy weather and high rainfall.

## Results and discussion

*Grain yield.* In the 1995/96 season N-fertilizer did not affect grain yield. The highest yield was 0.91 t ha$^{-1}$ when 60 kg N ha$^{-1}$ was added. When irrigation was combined with N fertilizer, yield increased to 1.67 t ha$^{-1}$ under 50 mm supplemental irrigation plus 20 kg N ha$^{-1}$. In the 1996/97season, there was a significant effect of treatments on grain yield. Yield was 1.78 t ha$^{-1}$ for the control, and 2.72 t ha$^{-1}$ with 40 mm irrigation without N fertilizer. In 1997/98, there was no effect of irrigation, N fertilizer, or combination of the two. The highest yield was 1.93 t ha$^{-1}$ for the control, and 2.19 t ha$^{-1}$ when 19 mm of irrigation was added without N fertilizer (Table 4).

*Biomass production (grain and straw).* N fertilizer caused no difference in biomass production in 1995/96 and 1996/97. The highest production was 4.09 t ha$^{-1}$ when 20 kg N ha$^{-1}$ was added, and 5.05 t ha$^{-1}$ for the control. In

| Table 4. Effect of irrigation and fertilizer levels on barley grain yield (t ha$^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|
| | N fertilizer (kg N ha$^{-1}$) | | | | | |
| Irrigation (mm) | 0 | 20 | 40 | 60 | 80 | Mean |
| 1995/96 season | | | | | | |
| 0 | 0.369 | 0.276 | 0.336 | 0.438 | 0.285 | 0.341 |
| 13 | 0.427 | 0.617 | 0.521 | 0.418 | 0.320 | 0.461 |
| 31 | 0.787 | 0.796 | 0.848 | 0.762 | 0.727 | 0.784 |
| 39 | 0.969 | 1.140 | 0.727 | 1.340 | 0.826 | 1.000 |
| 50 | 1.420 | 1.670 | 1.270 | 1.590 | 1.190 | 1.430 |
| Mean | 0.794 | 0.901 | 0.740 | 0.910 | 0.669 | |
| 1996/97 season | | | | | | |
| 0 | 1.15 | 1.11 | 1.17 | 1.09 | 0.943 | 1.09 |
| 5 | 1.29 | 1.39 | 1.27 | 1.27 | 1.17 | 1.28 |
| 9 | 1.66 | 1.53 | 1.63 | 1.47 | 1.33 | 1.52 |
| 23 | 2.10 | 1.81 | 1.94 | 1.71 | 1.87 | 1.89 |
| 40 | 2.72 | 2.55 | 2.59 | 2.66 | 2.29 | 2.56 |
| Mean | 1.78 | 1.68 | 1.72 | 1.64 | 1.52 | |
| 1997/98 season | | | | | | |
| 0 | 1.91 | 2.02 | 1.91 | 2.08 | 1.69 | 1.92 |
| 1 | 1.82 | 1.88 | 1.93 | 1.98 | 1.79 | 1.88 |
| 4 | 2.05 | 1.87 | 2.04 | 2.08 | 1.97 | 2.00 |
| 14 | 1.67 | 1.64 | 1.66 | 1.86 | 1.66 | 1.70 |
| 19 | 2.19 | 1.71 | 1.67 | 1.93 | 1.57 | 1.81 |
| Mean | 1.93 | 1.82 | 1.84 | 1.99 | 1.74 | |

contrast, biomass production was increased due to the combination of irrigation and N fertilizer. The highest production in 1995/96 was 6.04 t ha$^{-1}$ with 50 mm irrigation and 80 kg N ha$^{-1}$. In 1996/97, production increased to 7.36 t ha$^{-1}$ when 40 mm of irrigation was added without N fertilizer. In 1997/98, biomass production was increased by irrigation and N fertilizer. Production reached 7.86 t ha$^{-1}$ when 4 mm of supplemental irrigation with 60 kg N ha$^{-1}$ were added (Table 5).

The relationships between yield (seed, biological) and irrigation were determined as linear and quadratic equations. There was no difference between the linear and quadratic equations for biological yield (Table 6). Linear relationships between biological yield and irrigation under different levels of N fertilizer were obtained. For seed production, quadratic equations were obtained to describe the relation between yield and irrigation under different levels of N fertilizer (Table 7).

**Table 5. Effect of irrigation and fertilizer levels on barley biomass yield (t ha$^{-1}$)**

| | N fertilizer (kg N ha$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| Irrigation (mm) | 0 | 20 | 40 | 60 | 80 | Mean |
| 1995/96 season | | | | | | |
| 0 | 2.35 | 2.31 | 2.56 | 2.45 | 2.29 | 2.39 |
| 13 | 2.51 | 3.18 | 2.98 | 2.82 | 2.61 | 2.82 |
| 31 | 3.66 | 3.91 | 4.00 | 3.92 | 3.57 | 3.81 |
| 39 | 4.39 | 5.12 | 4.46 | 5.14 | 4.16 | 4.65 |
| 50 | 5.67 | 5.94 | 5.30 | 6.04 | 5.41 | 5.69 |
| Mean | 3.70 | 4.09 | 3.86 | 4.07 | 3.63 | |
| 1996/97 season | | | | | | |
| 0 | 3.77 | 3.54 | 3.59 | 3.83 | 3.76 | 3.70 |
| 5 | 3.73 | 3.879 | 4.38 | 4.17 | 4.19 | 4.07 |
| 9 | 4.73 | 4.32 | 4.22 | 4.34 | 4.79 | 4.48 |
| 23 | 5.54 | 5.20 | 4.94 | 4.80 | 534 | 5.16 |
| 40 | 7.46 | 6.63 | 6.95 | 7.13 | 6.71 | 6.98 |
| Mean | 5.05 | 4.71 | 4.81 | 4.85 | 4.96 | |
| 1997/98 season | | | | | | |
| 0 | 6.78 | 5.97 | 6.50 | 7.37 | 6.03 | 6.53 |
| 1 | 5.87 | 6.75 | 7.11 | 7.53 | 6.85 | 6.82 |
| 4 | 6.86 | 6.89 | 7.22 | 7.86 | 7.17 | 7.20 |
| 14 | 5.97 | 6.06 | 6.39 | 6.97 | 6.08 | 6.29 |
| 19 | 6.56 | 6.36 | 6.25 | 7.10 | 6.69 | 6.59 |
| Mean | 6.41 | 6.41 | 6.69 | 7.37 | 6.56 | |

**Table 6. Linear and quadratic relationships between biological yield (t ha$^{-1}$) and irrigation (mm) for barley under different fertilizer levels using sprinkler irrigation, Ramtha station, 1995, 1996,1997**

| Fertilizer level | A | B | C | $R^2$ | Error of Y estimation |
|---|---|---|---|---|---|
| | **Linear** | | | | |
| N1 | -2.2854 | 0.0304 | | 0.753 | 0.82851 |
| N2 | -1.3059 | 0.0264 | | 0.691 | 0.84062 |
| N3 | -2.0835 | 0.0299 | | 0.792 | 0.72818 |
| N4 | -2.9556 | 0.0348 | | 0.766 | 0.91246 |
| N5 | -2.534 | 0.0314 | | 0.840 | 0.65305 |
| | **Quadratic** | | | | |
| N1 | -6.6954 | 0.0693 | $-4*10^{-5}$ | 0.761 | 0.84811 |
| N2 | -3.1542 | 0.0427 | $-3*10^{-5}$ | 0.692 | 0.87250 |
| N3 | -1.3378 | 0.0233 | $1.4*10^{-5}$ | 0.792 | 0.75746 |
| N4 | -0.2798 | 0.0112 | $5*10^{-5}$ | 0.769 | 0.94499 |
| N5 | -5.4125 | 0.0568 | $-5*10^{-5}$ | 0.843 | 0.67204 |

| Table 7. Linear and quadratic relationships between grain yield (t $ha^{-1}$) and irrigation (mm) for barley under different fertilizer levels using sprinkler irrigation, Ramtha station, 1995,1996,1997 | | | | | |
|---|---|---|---|---|---|
| Fertilizer level | A | B | C | $R^2$ | Error of Y estimation |
| | **Linear** | | | | |
| N1 | -1.5755 | 0.0128 | | 0.752 | 0.34848 |
| N2 | -1.1174 | 0.0107 | | 0.686 | 0.34419 |
| N3 | -1.4367 | 0.0119 | | 0.744 | 0.33212 |
| N4 | -1.4135 | 0.0121 | | 0.757 | 0.32629 |
| N5 | -1.4959 | 0.0116 | | 0.785 | 0.2894 |
| | **Quadratic** | | | | |
| N1 | -6.2653 | 0.0541 | $-9*10^{-5}$ | 0.804 | 0.32252 |
| N2 | -7.0823 | 0.0633 | -0.0001 | 0.795 | 0.28947 |
| N3 | -6.5689 | 0.0571 | $-1*10^{-4}$ | 0.814 | 0.29414 |
| N4 | -5.1407 | 0.045 | $-7*10^{-5}$ | 0.794 | 0.31296 |
| N5 | -5.7365 | 0.049 | $-8*10^{-5}$ | 0.838 | 0.26119 |

**Table 8. Effect of different irrigation and fertilizer levels on 1000-seed weight (g)**

| | N fertilizer (kg N $ha^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| Irrigation (mm) | 0 | 20 | 40 | 60 | 80 | Mean |
| 1995/96 season | | | | | | |
| 0 | 25.2 | 23.4 | 23.9 | 23.4 | 21.4 | 23.5 |
| 13 | 25.8 | 24.7 | 25.3 | 23.9 | 22.8 | 24.5 |
| 31 | 29.6 | 26.4 | 26.8 | 26.0 | 246 | 26.7 |
| 39 | 30.6 | 29.0 | 30.4 | 27.5 | 27.0 | 28.9 |
| 50 | 34.5 | 32.8 | 33.6 | 33.2 | 33.0 | 33.3 |
| Average | 29.2 | 27.3 | 28.0 | 26.8 | 25.6 | |
| 1996/97 season | | | | | | |
| 0 | 21.8 | 21.5 | 22.3 | 24.9 | 23.4 | 22.8 |
| 5 | 24.8 | 24.8 | 22.8 | 24.1 | 24.2 | 24.2 |
| 9 | 24.4 | 25.9 | 26.9 | 24.2 | 24.5 | 25.2 |
| 23 | 26.0 | 26.6 | 25.5 | 25.3 | 24.9 | 25.7 |
| 40 | 29.4 | 28.0 | 30.1 | 30.6 | 29.1 | 29.4 |
| Mean | 25.3 | 25.3 | 25.5 | 25.8 | 25.2 | |
| 1997/98 season | | | | | | |
| 0 | 24.8 | 24.4 | 24.8 | 25.4 | 23.2 | 24.5 |
| 1 | 23.5 | 22.9 | 22.9 | 24.1 | 24.5 | 23.6 |
| 4 | 23.6 | 23.9 | 23.6 | 24.7 | 23.3 | 23.8 |
| 14 | 23.9 | 24.0 | 23.8 | 23.9 | 24.3 | 24.0 |
| 19 | 24.5 | 23.5 | 23.7 | 25.1 | 25.3 | 24.4 |
| Mean | 24.1 | 23.7 | 23.8 | 24.6 | 24.1 | |

*1000-seed weight.* In the three seasons, there was no effect of N fertilizer on 1000-seed weight (Table 8).

*Harvest index (HI).* HI is the percentage of grain in total production:

HI = grain yield / total biomass production x 100

In 1995/96, N fertilizer did not affect HI which ranged from 11.2% to 27.9%. In 1996/97, N fertilizer affected HI significantly and the highest value reached was 35.9% when 40 kg N $ha^{-1}$ was added. When irrigation was combined with N fertilizer, HI increased to 39.5% with 23 mm of irrigation plus 40 kg N $ha^{-1}$. In 1997/98, there was no effect of N fertilizer or irrigation on HI which ranged from 25.6% to 33.6% (Table 9).

*Water use efficiency (WUE) and Water benefit ratio (WBR).* WUE and WBR were calculated using the equations:

WUE = Seed production (kg $ha^{-1}$) / Water consumption (mm)

WBR = (Treatment production - Control production)/Total water added to treatment

**Table 9. Effect of different irrigation and fertilizer levels on barley Harvest Index (%)**

| | N fertilizer (kg N $ha^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| Irrigation (mm) | 0 | 20 | 40 | 60 | 80 | Mean |
| 1995/96 season | | | | | | |
| 13 | 16.2 | 19.4 | 164 | 14.4 | 12.4 | 15.7 |
| 31 | 20.7 | 19.5 | 20.3 | 18.6 | 20.4 | 19.9 |
| 39 | 21.9 | 22.4 | 14.8 | 25.4 | 19.5 | 20.8 |
| 50 | 25.4 | 27.9 | 24.2 | 26.5 | 21.7 | 25.1 |
| Mean | 20.1 | 20.1 | 17.7 | 20.6 | 17.2 | |
| 1996/97 season | | | | | | |
| 0 | 30.4 | 31.3 | 34.8 | 28.4 | 25.3 | 30.0 |
| 5 | 34.6 | 36.3 | 28.9 | 30.5 | 28.0 | 31.7 |
| 9 | 35.5 | 35.4 | 39.1 | 34.3 | 29.3 | 34.7 |
| 23 | 38.1 | 34.7 | 39.5 | 35.6 | 350 | 36.6 |
| 40 | 36.6 | 39.1 | 37.5 | 37.8 | 34.4 | 37.1 |
| Mean | 35.0 | 35.4 | 35.9 | 33.3 | 30.4 | |
| 1997/98 season | | | | | | |
| 0 | 29.00 | 34.3 | 29.9 | 27.7 | 28.1 | 29.8 |
| 1 | 31.2 | 28.1 | 27.4 | 26.2 | 26.5 | 27.9 |
| 4 | 30.0 | 27.5 | 28.1 | 26.8 | 27.6 | 28.0 |
| 14 | 28.0 | 27.3 | 25.6 | 26.7 | 27.3 | 27.00 |
| 19 | 33.6 | 27.6 | 26.6 | 27.2 | 23.4 | 27.7 |
| Mean | 30.3 | 29.0 | 27.5 | 26.9 | 26.6 | |

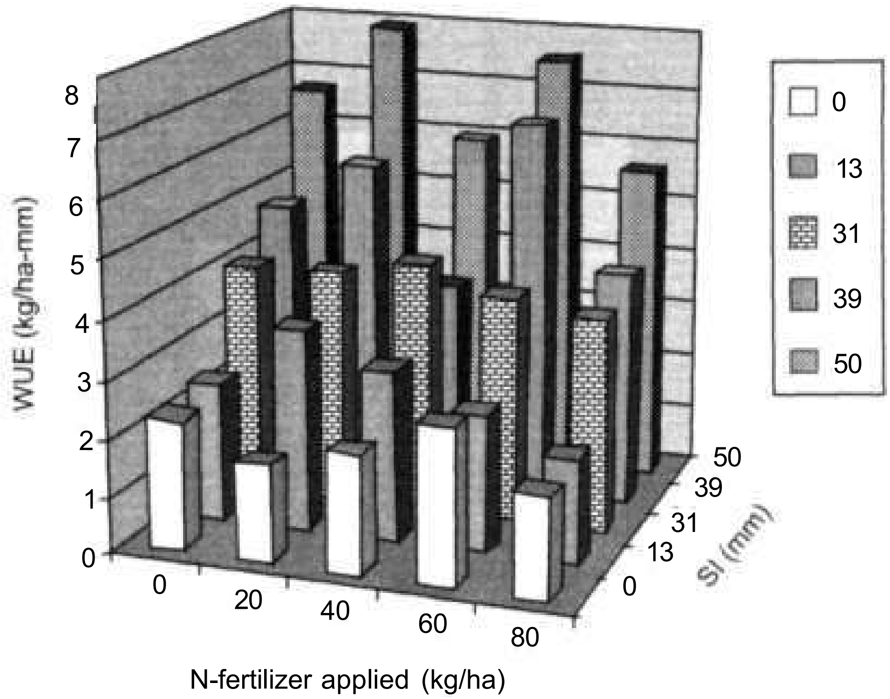


***Figure 2. WUE for rainfed, supplemental irrigation, and N-fertilizer application in producing grain yield, Ramtha station, 1995/96 (sprinkler irrigation)***

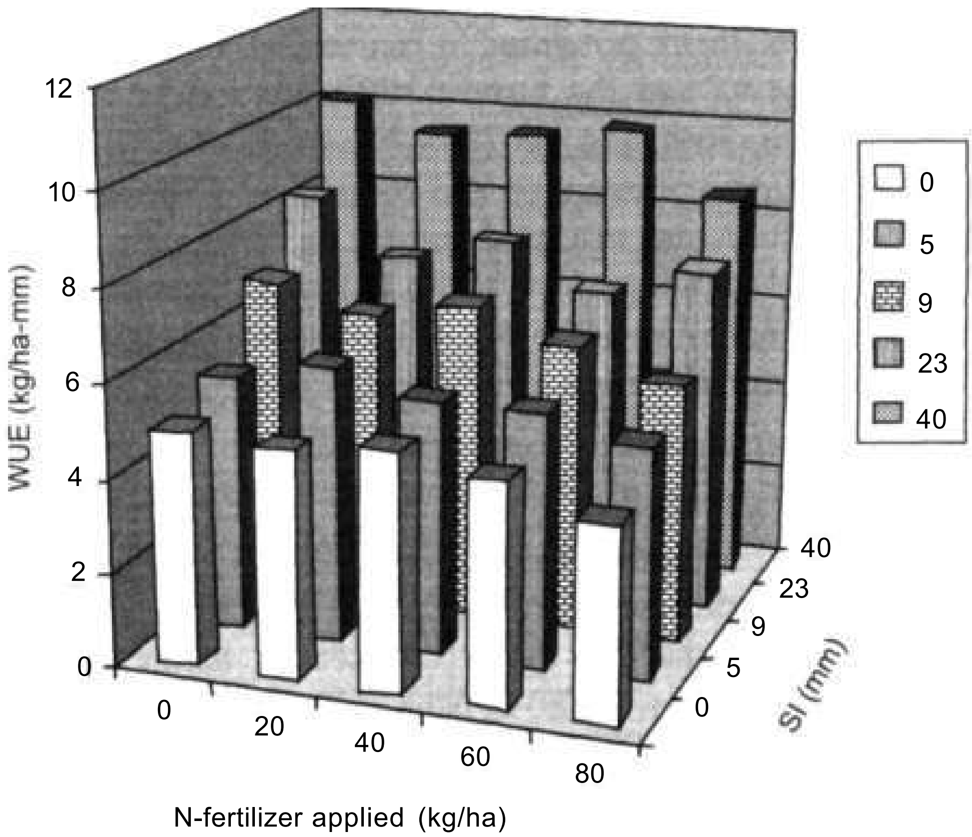


***Figure 3. WUE for rainfed, supplemental irrigation, and N-fertilizer application in producing grain yield, Ramtha station, 1996/97 (sprinkler irrigation)***

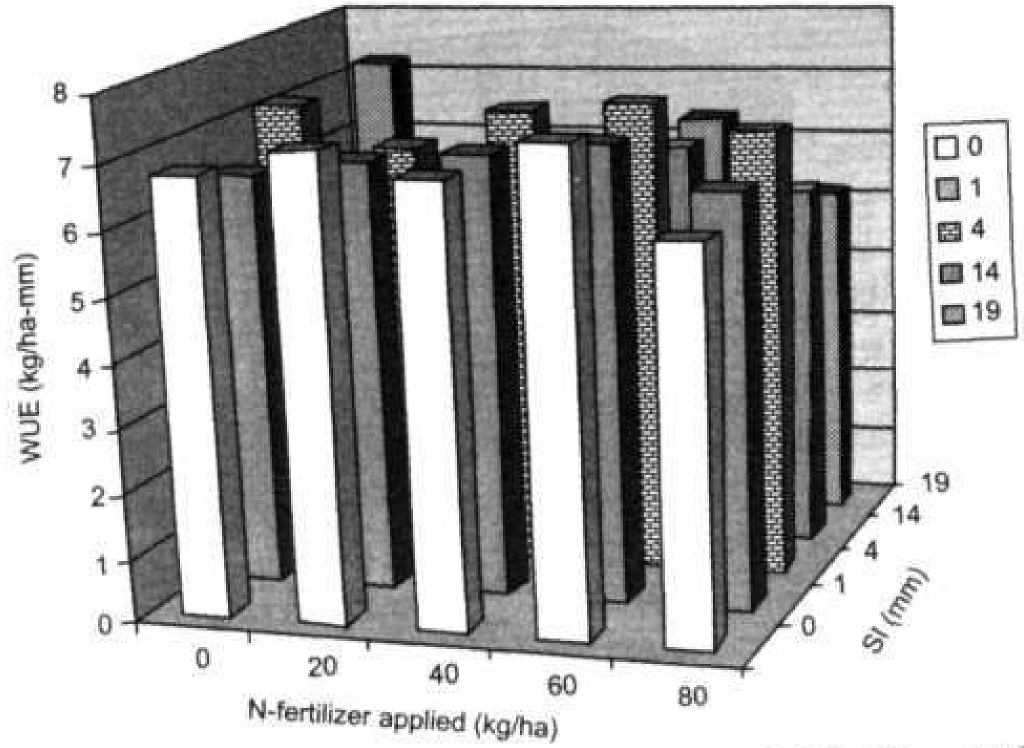


*Figure 4. WUE for rainfed, supplemental irrigation, and N-fertilizer application in producing grain yield, Ramtha station, 1997/98 (sprinkler irrigation)*

The results for WUE are presented in Figures 2-4. In 1995/96, the highest WUE was 0.92 kg $m^{-3}$ and the highest WBR was 2.8 kg $m^{-3}$. These were obtained with 50 mm irrigation and 20 kg N $ha^{-1}$. In 1996/97, WUE reached 1.15 kg $m^{-3}$ with 40 mm of irrigation and 60 kg N $ha^{-1}$. The highest WBR was 5.69 kg N $ha^{-1}$ with 9 mm irrigation and 80 kg N $ha^{-1}$. In 1997/98, WUE reached 3.45 kg $m^{-3}$ with 8 mm and 80 kg N $ha^{-1}$. WUE and WBR were also calculated in terms of biological yield. The highest WBR was 0.71 kg $m^{-3}$ when 80 kg N $ha^{-1}$ and 1 mm irrigation were added.

## Conclusions

In 1995/96, seed production ranged from 0.28 t $ha^{-1}$, for the control treatment with the addition of 20 kg N $ha^{-1}$, to 1.68 t $ha^{-1}$ with 50 mm irrigation and 20 kg N $ha^{-1}$. In the second season, barley seed production ranged between 0.94 t $ha^{-1}$ when 80 kg N $ha^{-1}$ was added without any fertilizer, to 2.72 t $ha^{-1}$ when 40 mm water was added without N fertilizer. In 1997/98, production ranged between 1.57 t $ha^{-1}$ with 19 mm irrigation and 80 kg N $ha^{-1}$, to 2.19 t $ha^{-1}$, with 19 mm irrigation and no N fertilizer.

In 1995/96, the highest WUE was 0.92 kg/$m^{-3}$, and the highest WBR 2.8 kg $m^{-3}$. In 1996/97, it was 1.15 kg $m^{-3}$ with 40 mm irrigation.

# Project 2. Effect of Irrigation and N-Fertilizer on Barley Production under Different Irrigation Systems: (b) Surface Irrigation

## Objectives

The objectives were to illustrate the effectiveness of supplemental irrigation and N-fertilizer on barley production, and to estimate the actual water consumptive use for barley.

## Materials and methods

This study was carried out in 1996/97 and 1997/98 at Ramtha Station, on barley (Acsad 176) as in the previous project. The experimental design was a complete randomized design in split plot, and the treatments were five N fertilizer rates (0, 20, 40, 60, and 80 kg N $ha^{1}$) as main treatments, with five irrigation schedules (0, 25, 50, 75, and 100% of field capacity) as sub-treatments. The experiment was divided into 2.5 m x 3 m plots with soil ridges of 30 cm height to prevent surface runoff to or from the plot. Half of the N fertilizer was added at sowing and the second half was added with irrigation. Neutron probe access tubes were installed in the middle of each plot for one replicate. To determine the actual water consumptive use for barley, moisture readings were made for six depths and surface soil samples were taken every 10 days, or immediately before irrigation; and 48 hours after irrigation or rainfall when it exceeded 10 mm. Water consumption was calculated by the equation:

ET = I + R + AS as above

Rainfall in 1996/97 was 230 mm, and three irrigations were applied through the critical growth stages of the crop. The first was through germination stage and beginning of tillering, the second was at flowering, and the third at grain filling. The applied amounts were 0, 25, 50, 75, and 100 mm for treatments 0, 25, 50, 75, and 100%, respectively. In 1997/98, rainfall was 283 mm, and two irrigations were added. The first was through germination stage and beginning of tillering, and the second was at grain filling. The amounts of water applied were 0, 22.3, 36.5, 49.3, and 65 mm for the treatments 0, 25, 50, 75, and 100%, respectively (Table 10). This was because rainfall distribution was uniform, and there were no large gaps between rainfall events.

**Table 10. Irrigation and rainfall (mm) at Ramtha Station**

| Treatment | $1^{st}$ irrigation | $2^{nd}$ irrigation | $3^{rd}$ irrigation | Rainfall + total irrigation |
|---|---|---|---|---|
| 1996/97 season, rainfall 230 mm | | | | |
| I0 | 0.0 | 0.0 | 0.0 | 230 |
| I1 | 6.2 | 7.5 | 11.2 | 245 |
| !2 | 12.5 | 15.0 | 22.5 | 280 |
| I3 | 18.7 | 22.5 | 33.7 | 305 |
| I4 | 25.0 | 30.0 | 45.0 | 330 |
| 1997/98 season, rainfall 283 mm | | | | |
| I0 | 0.0 | 0.0 | - | 283 |
| I1 | 6.3 | 16.0 | - | 305 |
| I2 | 12.5 | 24.0 | - | 320 |
| I3 | 17.3 | 32.0 | - | 332 |
| I4 | 25.0 | 40.0 | - | 384 |

## Results and discussion

*Grainyield.* In 1996/97, grain yield responded to N fertilizer giving 2.61 t ha$^{-1}$ when 20 kg N ha$^{-1}$ was added. Irrigation increased yield from 1.49 t ha$^{-1}$ for the control treatment, to 2.99 t ha$^{-1}$ with 100 mm irrigation; and 3.49 t ha$^{-1}$ with 100 mm irrigation plus 20 kg N ha$^{-1}$. In 1997/98, there was no effect of irrigation and N fertilizer on barley grain yield: 2.38 t ha$^{-1}$ for the control treatment (no irrigation, no N fertilizer) (Table 11).

**Table 11. Effect of irrigation and fertilizer levels on barley grain yield (t ha$^{-1}$)**

| | N fertilizer (kg N ha$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| Irrigation (mm) | 0 | 20 | 40 | 60 | 80 | Mean |
| 1996/97 season | | | | | | |
| 0 | 1.35 | 1.57 | 1.62 | 1.42 | 1.47 | 1.49 |
| 25 | 2.04 | 2.35 | 2.35 | 2.52 | 1.67 | 2.19 |
| 50 | 2.63 | 2.79 | 2.72 | 2.70 | 2.20 | 2.61 |
| 75 | 2.79 | 2.84 | 3.25 | 3.28 | 2.53 | 2.94 |
| 100 | 2.54 | 3.49 | 3.12 | 2.53 | 2.92 | 2.92 |
| Mean | 2.27 | 2.61 | 2.61 | 249 | 2.16 | |
| 1997/98 season | | | | | | |
| 0 | 2.49 | 2.37 | 2.41 | 2.23 | 2.39 | 2.38 |
| 22 | 2.26 | 2.23 | 1.92 | 2.26 | 2.23 | 2.18 |
| 36 | 2.33 | 2.09 | 2.24 | 2.14 | 2.20 | 2.20 |
| 49 | 1.81 | 1.97 | 1.94 | 2.32 | 2.01 | 2.01 |
| 65 | 2.05 | 1.98 | 2.26 | 2.19 | 2.06 | 2.11 |
| Mean | 2.19 | 2.13 | 2.15 | 2.23 | 2.18 | |

*Total biomass production* (*seed and straw*). In 1996/97 biomass production increased due to N fertilizer, irrigation, and the combination of both factors. The highest production was 7.19 t $ha^{-1}$ when 40 kg N $ha^{-1}$ was added; and it reached 7.53 t $ha^{-1}$ when 75 mm of irrigation was added. When using 75 mm irrigation with 60 kg N $ha^{-1}$, production increased to 8.65 t $ha^{-1}$. In 1997/98, there was no effect on biomass production from N fertilizer or irrigation (Table 12).

The relationship (linear, quadratic) between irrigation and yield under the different levels of N-fertilizer for the two seasons were also analyzed. There was no relationship between yield and irrigation under different levels of N fertilizer, except for some N levels with a quadratic relation (Tables 13, 14). There was a relationship (linear, quadratic) between irrigation and yield (grain and biomass) under different levels of N fertilizer for the two seasons.

*1000-seed weight.* Adding N fertilizer and irrigation in 1996/97 gave the highest 1000-seed weight of 29.8 g with 20 kg N $ha^{-1}$. Irrigation influenced seed weight: the treatments of 50, 75, and 100 mm gave higher seed weight than the control and 25 mm treatments. Weight reached 30.1 g for the 100 mm treatment. Applying N fertilizer and irrigation together gave a 1000-seed weight of 32.9 g with 75 mm irrigation and 20 kg N $ha^{-1}$. In 1997/98, there was no difference from adding N fertilizer. Irrigation increased 1000-seed

**Table 12. Effect of irrigation and fertilizer levels on barley biomass yield (t $ha^{-1}$)**

| | N fertilizer (kg N $ha^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| Irrigation (mm) | 0 | 20 | 40 | 60 | 80 | Mean |
| 1996/97 season | | | | | | |
| 0 | 4.53 | 5.08 | 604 | 5.29 | 5.36 | 5.26 |
| 25 | 5.07 | 5.92 | 6.43 | 6.52 | 6.61 | 6.11 |
| 50 | 6.24 | 6.47 | 740 | 7.06 | 7.09 | 6.85 |
| 75 | 6.33 | 7.17 | 8.11 | 8.65 | 7.40 | 7.53 |
| 100 | 6.48 | 7.99 | 7.99 | 7.02 | 7.45 | 7.38 |
| Mean | 5.73 | 6.53 | 7.19 | 6.91 | 6.78 | |
| 1997/98 season | | | | | | |
| 0 | 7.67 | 6.15 | 7.87 | 6.79 | 7.48 | 7.19 |
| 22 | 7.46 | 7.77 | 7.75 | 8.79 | 8.25 | 8.00 |
| 36 | 6.81 | 6.90 | 7.77 | 7.67 | 7.33 | 7.30 |
| 49 | 6.10 | 7.00 | 6.85 | 7.75 | 7.02 | 6.95 |
| 65 | 7.33 | 5.81 | 7.46 | 8.33 | 7.96 | 7.38 |
| Mean | 7.07 | 6.72 | 7.54 | 7.87 | 7.61 | |

**Table 13. Linear and quadratic relationships between seed yield (t ha$^{-1}$) and irrigation (mm) for barley under different fertilizer levels using surface irrigation, Ramtha station, 1996 and 1997**

| Fertilizer level | A | 6 | C | $R^2$ | Error of Y estimation |
|---|---|---|---|---|---|
| | **Linear** | | | | |
| N1 | 1.1047 | 0.0038 | | 0.115 | 0.4294 |
| N2 | 1.3495 | 0.0034 | | 0.058 | 0.5626 |
| N3 | 1.3139 | 0.0036 | | 0.071 | 0.5326 |
| N4 | 1.2997 | 0.0036 | | 0.085 | 0.4783 |
| N5 | 0.2278 | 0.0065 | | 0.372 | 0.3462 |
| | **Quadratic** | | | | |
| N1 | -19.36 | 0.1484 | -0.0003 | 0.718 | 0.2592 |
| N2 | -14.80 | 0.1176 | -0.0002 | 0.291 | 0.5219 |
| N3 | -12.69 | 0.1025 | -0.0002 | 0.263 | 0.5070 |
| N4 | -15.35 | 0.1212 | -0.0002 | 0.417 | 0.4080 |
| N5 | -12.88 | 0.0992 | -0.0002 | 0.642 | 0.2794 |

**Table 14. Linear and quadratic relationships between biological yield (t ha$^{-1}$) and irrigation (mm) for barley under different fertilizer levels using surface irrigation, Ramtha station, 1996 and 1997**

| Fertilizer level | A | B | C | $R^2$ | Error of Y estimation |
|---|---|---|---|---|---|
| | **Linear** | | | | |
| N1 | 1.093 | 0.0178 | | 0.465 | 0.7820 |
| N2 | 2.475 | 0.0139 | | 0.348 | 0.7803 |
| N3 | 3.896 | 0.0117 | | 0.411 | 0.5705 |
| N4 | 1.201 | 0.0208 | | 0.554 | 0.7622 |
| N5 | 2.586 | 0.0155 | | 0.568 | 0.5520 |
| | **Quadratic** | | | | |
| N1 | -25.68 | 0.2070 | -0.0003 | 0.653 | 0.6731 |
| N2 | -26.54 | 0.2190 | -0.0004 | 0.618 | 0.6382 |
| N3 | -22.52 | 0.1983 | -0.0003 | 0.790 | 0.3644 |
| N4 | -20.53 | 0.1743 | -0.0003 | 0.663 | 0.7086 |
| N5 | -17.70 | 0.1589 | -0.0002 | 0.743 | 0.4551 |

weight to 26 g with 65 mm irrigation. There was no benefit from combining N fertilizer with irrigation (Table 15).

*Harvest index* (*HI*). In the first season, N fertilizer, irrigation, and both factors together increased HI. HI reached 39.5% with 20 kg N ha$^{-1}$, 40.6% with 100 mm irrigation, and ranged between 23.8% with 80 kg N ha$^{-1}$ and 50 mm irrigation, to 44.3% with 80 kg N ha$^{-1}$ and 75 mm irrigation. In 1997/98, there was no benefit from N fertilizer, irrigation, or both factors together (Table 16).

**Table 15. Effect of different irrigation and fertilizer levels on 1000-seed weight (g)**

| | N fertilizer (kg N ha$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| Irrigation (mm) | 0 | 20 | 40 | 60 | 80 | Mean |
| 1996/97 season | | | | | | |
| 0 | 22.3 | 26.6 | 22.6 | 25.2 | 23.5 | 24.0 |
| 25 | 30.7 | 27.1 | 24.7 | 28.0 | 22.6 | 266 |
| 50 | 265 | 329 | 297 | 30.4 | 28.7 | 29.6 |
| 75 | 31.7 | 31.2 | 28.2 | 25.5 | 275 | 28.8 |
| 100 | 31.0 | 31.4 | 27.6 | 29.3 | 31.5 | 30.2 |
| Mean | 28.5 | 29.8 | 26.5 | 27.7 | 26.7 | |
| 1997/98 season | | | | | | |
| 0 | 28.6 | 29.1 | 25.5 | 26.5 | 25.6 | 27.1 |
| 22 | 27.7 | 26.9 | 25.7 | 26.1 | 27.4 | 268 |
| 36 | 280 | 25.5 | 25.7 | 26.3 | 26.0 | 26.3 |
| 49 | 25.9 | 25.6 | 26.0 | 25.0 | 25.7 | 25.7 |
| 65 | 26.3 | 22.4 | 27.1 | 28.2 | 277 | 26.3 |
| Mean | 27.3 | 25.9 | 26.0 | 26.4 | 26.5 | |

**Table 16. Effect of different irrigation and fertilizer levels on barley Harvest Index (%)**

| | N fertilizer (kg N ha$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| Irrigation (mm) | 0 | 20 | 40 | 60 | 80 | Mean |
| 1996/97 season | | | | | | |
| 0 | 28.3 | 319 | 27.8 | 26.9 | 27.2 | 282 |
| 25 | 39.8 | 39.6 | 36.3 | 38.2 | 23.8 | 356 |
| 50 | 42.1 | 43.1 | 361 | 38.4 | 31.1 | 38.2 |
| 75 | 44.3 | 38.9 | 39.7 | 37.6 | 34.2 | 38.9 |
| 100 | 39.7 | 44.0 | 39.4 | 40.7 | 39.1 | 40.6 |
| Mean | 38.8 | 39.5 | 35.7 | 36.4 | 31.1 | |
| 1997/98 season | | | | | | |
| 0 | 32.7 | 39.1 | 30.5 | 32.8 | 31.7 | 334 |
| 22 | 30.7 | 28.8 | 254 | 259 | 280 | 27.8 |
| 36 | 34.6 | 30.2 | 29.0 | 28.4 | 30.7 | 306 |
| 49 | 29.8 | 30.9 | 29.7 | 30.1 | 28.8 | 29.9 |
| 65 | 28.4 | 35.3 | 31.0 | 26.3 | 26.3 | 29.5 |
| Mean | 31.2 | 32.9 | 29.1 | 28.7 | 29.1 | |

*Water use efficiency and water benefit ratio.* In 1996/97, WUE reached 1.15 kg $m^{-3}$ with 50 mm irrigation and 80 kg N $ha^{-1}$. The lowest WUE value was 0.6 kg $m^{-3}$ with no N fertilizer and no irrigation. WBR was 4.37 kg $m^{-3}$ with 25 mm irigation and 80 kg N $ha^{-1}$. During 1997/98, the highest WUE was 0.82 kg $m^{-3}$ when 40 kg N $ha^{-1}$ was added without irrigation. The lowest WUE value was 0.58 kg $m^{-3}$ when 65 mm irrigation and 60 kg N $ha^{-1}$ were added. For biological yield, WBR reached 4.1 kg $m^{-3}$ when 22 mm of irrigation was added without N fertilizer.

## Conclusions

The highest WUE in 1996/97 was 1.15 kg $m^{-3}$ when 50 mm irrigation with 80 kg N $ha^{-1}$ were added. In 1997/98, WUE was 0.82 kg $m^{-3}$ when 40 kg N $ha^{-1}$ was added without any application of supplemental water.

WBR through 1996/97 was 4.37 kg $m^{-3}$ when 25 mm of irrigation and 60 kg N $ha^{-1}$ were added. In 1997/98, the highest WBR was 4.1 kg $m^{-3}$ when 22.3 mm of water was added without N fertilizer.

Barley production increased in 1996/97, from 1.35 t $ha^{-1}$ for control treatment to 3.49 t $ha^{-1}$ when 80 mm and 20 kg N $ha^{-1}$ were added. In 1997/98, barley production was not affected.

# Project 3. Tillage, Residue, and N Management in Crop Rotation

*Researchers.* Abdelnabi A Fardous, Marwan Suifan, and Fahed Al-Khatib, NCARRT.

## Goal and objectives

The main goal was to enable recommendations of soil and residue management techniques in crop rotation suitable for rainfed areas, which could reduce soil erosion, increase soil moisture capacity and soil fertility, and thus improve land productivity and net economic return. This will permit farmers to best utilize Jordan's limited land and water resources. The project aimed to:

- Select the most suitable method for soil plowing and preparation
- Determine the best management for wheat residue
- Make best utilization of N fertilizer in crop rotation
- Identify the best crop rotation in wheat planting areas

- Identify the proper sowing dates for field crops
- Quantify relationships between soil moisture and physical properties of Vertisols.

## Materials and methods

The study was carried out at Rabba Research Station, southern Jordan, Mushaqar Research Station, central Jordan, and Maru Research Station, northern Jordan.

*Treatments.* The following treatments were included in the three- and two-course rotations at the three locations:

- Tillage treatments:
  T1 Mouldboard and sweep early in the season before rain (early sowing, Nov)
  T2 Chisel and sweep early in the season before rain (early sowing, Nov)
  T3 Sweep late in the season after rain (late sowing, Dec)
- Residue management treatments (wheat phase only):
  R1 Bale straw and incorporate immediately after harvest
  R2 Bale straw, graze and incorporate early after harvest
  R3 Bale straw, graze and incorporate late after harvest
- N application treatments (wheat phase only):
  N1 no N fertilizer application
  N2 rate used traditionally by farmers in the area
  N3 50% higher than farmer's rate

Crop rotations were carried out as follows. Rabba: wheat/lentil, wheat/vetch. Mushaqar: wheat/lentil, wheat/vetch, wheat/lentil/summer crop. Maru: wheat/lentil/summer crop.

*Design.* Split plot with T and R randomized as main plots and fertilizer as subplot. Plot size was 10 x 45 m, subplot size was 10 x 15 m. The main plot treatments were T1R1, T1R2, T1R3, T2R1, T2R2, T2R3, T3R1, and T3R3.

## Measurements

*Crop measurements.* Biological yield from 0.5 $m^2$, grain yield from 0.5 $m^2$ and 25 $m^2$, straw yield from 0.5 $m^2$, plant number in 0.5 $m^2$, weed number in 0.5 $m^2$, numbers of tillers in 0.5 $m^2$ (for wheat only), plant height, 1000-grain weight, seed number in 0.5 $m^2$.

*Soil moisture.* Soil moisture measurements were taken at 7.5, 22.5, 45, 75, and 135 cm depth using a neutron probe (CPN 503 DR Hydroprobe) and galvanized steel access tubes (150 cm long, 5.08 cm inside diameter) installed in each treatment in two replicates. Crop evapotranspiration (Etc) and soil moisture storage from rainfall during the season (SMS) were calculated from changes in soil moisture content for the whole soil profile and different times of the season. Meteorological data was used to calculate the amount of moisture stored during the rainy days. Etc and SMS were calculated using the following equations:

$$Etc = ET + Etce$$

where ETce is total actual evapotranspiration, and ET is $\sum(\Delta S)$. $\Delta S$ is soil moisture depletion for the periods between neutron probe readings during the growing season which occurs due to crop consumptive use during those periods. Etce is total sum of actual crop water requirement during rainy days (when it is difficult to determine the depletion using neutron probe readings because of the inconvenience of working in the field during these days). It was estimated using the class A pan evaporation reading and FAO handbook method outlined in Doorinbos and Pruit (1974):

$$Etce = Ep * Kp * Kc$$

where Ep is the class A pan evaporation, Kp is the pan coefficient, Kc is the crop coefficient.

SMS and WUE were calculated by the following equations:

$$SMS = \sum(\Delta S) + Etce$$

$$WUE = \text{Grain or straw yield (kg/ha)} / Etc \text{ (mm)}$$

*Soil physical properties.* Aggregate size distribution, bulk density, infiltration rate and soil strength at 5, 10, 15, and 20 cm soil depths were taken for wheat/lentil rotation at different times.

## Results and discussion

The combined data analysis is presented in Tables 17-26. Table 17 shows that there was no effect of type of plowing on the grain yield of wheat in the wheat/lentil rotation. However, using the moldboard plow plus the sweep (T1) resulted in higher grain yield and WUE (Table 23). The combination of chisel plus sweep (T2) and residue management (R3) gave the best wheat yields in the wheat/lentil rotation.

Table 18a shows that using the sweep (T3) to till the land for the preparation for sowing lentil in lentil/wheat rotation with added N resulted in higher grain yield of lentil in contrast with using moldboard plus sweep (TI)

Table 17. Crop data for wheat in wheat/lentil rotation, Mushaqar, 1991-98 (8 years combined)

| Treatment | Plant number per 5 $m^2$ | Plant height (cm) | Grain yield (t $ha^{-1}$) | Harvest index | Biomass yield (t $ha^{-1}$) | Straw yield (t $ha^{-1}$) |
|---|---|---|---|---|---|---|
| T1 | 55a | 59.9 | 1.16 | 0.25 | 4.72 | 2.56 |
| T2 | 51b | 59.0 | 1.08 | 0.25 | 4.54 | 3.47 |
| T3 | 56a | 58.1 | 1.08 | 0.26 | 4.39 | 3.31 |
| R1 | 55 | 58.2 | 1.06 | 0.25 | 4.67 | 3.61 |
| R2 | 54 | 60.0 | 1.11 | 0.25 | 4.50 | 3.39 |
| R3 | 53 | 59.3 | 1.16 | 0.26 | 4.52 | 3.37 |
| T1R1 | 54 | 58.8 | 1.14abc | 0.24 | 4.92ab | 3.77ab |
| T1R2 | 56 | 61.4 | 1.23ab | 0.25 | 4.93ab | 3.70ab |
| T1R3 | 55 | 59.5 | 1.11cd | 0.26 | 4.31 bc | 3.20abc |
| T2R1 | 54 | 58.4 | 1.02d | 0.25 | 4.40abc | 3.38abc |
| T2R2 | 52 | 57.8 | 1.00d | 0.25 | 4.07c | 3.07bc |
| T2R3 | 49 | 60.0 | 1.24a | 0.26 | 5.22a | 3.98a |
| T3R1 | 57 | 57.6 | 1.01d | 0.25 | 4.69abc | 3.68ab |
| T3R3 | 56 | 58.5 | 1.11bcd | 0.27 | 3.99c | 2.87c |
| N0 | 51b | 58.0b | 0.99c | 0.9a | 3.63c | 2.64c |
| N1 | 55a | 59.5a | 1.12b | 0.24b | 4.63b | 3.51b |
| N2 | 56a | 60.0a | 1.21a | 0.23b | 5.46a | 4.25a |

In each group (eg T1T2T3), numbers not followed by letters are not significantly different at p=0.05

**Table 18a. Crop data for lentil in lentil/wheat rotation, Mushaqar, 1993-2000 (6 years combined analysis with nitrogen)**

| Treatment | Plant number per 5 $m^2$ | Plant height (cm) | Grain yield (t $ha^{-1}$) | Harvest index | Biomass yield (t $ha^{-1}$) | Straw yield (t $ha^{-1}$) |
|---|---|---|---|---|---|---|
| T1 | 74ab | 35.3 | 0.62b | 0.23 | 3.94 | 3.32 |
| T2 | 70b | 36.2 | 0.58b | 0.21 | 364 | 3.06 |
| T3 | 78a | 37.3 | 0.73a | 0.22 | 3.74 | 3.01 |
| R1 | 74 | 35.8 | 0.64 | 0.21 | 3.77 | 3.13 |
| R2 | 71 | 36.8 | 0.59 | 0.21 | 3.76 | 316 |
| R3 | 74 | 36.0 | 066 | 0.23 | 3.80 | 3.14 |
| T1R1 | 74 | 34.3 | 0.58 | 0.20 | 3.92 | 3.35 |
| T1R2 | 77 | 369 | 0.59 | 0.22 | 4.01 | 3.42 |
| T1R3 | 71 | 34.7 | 0.700 | 0.27 | 3.89 | 3.19 |
| T2R1 | 72 | 36.5 | 0.58 | 0.22 | 355 | 2.97 |
| T2R2 | 66 | 367 | 0.59 | 0.21 | 3.51 | 2.91 |
| T2R3 | 71 | 35.3 | 0.57 | 0.21 | 3.87 | 3.30 |

*Continued*

**Table 18a.** *Continued.*

| Treatment | Plant number per 5 $m^2$ | Plant height (cm) | Grain yield (t $ha^{-1}$) | Harvest index | Biomass yield (t $ha^{-1}$) | Straw yield (t $ha^{-1}$) |
|---|---|---|---|---|---|---|
| T3R1 | 76 | 36.7 | 0.75 | 0.22 | 3.83 | 3.08 |
| T3R3 | 79 | 37.9 | 0.70 | 0.2a | 3.64 | 2.94 |
| NO | 74 | 35.8 | 0.65 | 0.21 | 3.80 | 3.15 |
| N1 | 73 | 35.9 | 0.63 | 0.23 | 3.88 | 3.25 |
| N2 | 74 | 36.7 | 0.62 | 0.22 | 3.65 | 3.03 |

In each group (eg T1T2T3), numbers not followed by letters are not significantly different at p=0.05

**Table 18b. Crop data for lentil in lentil/wheat rotation, Mushaqar, 1991-2000 (8 years combined analysis without nitrogen)**

| Treatment | Plant number per 5 $m^2$ | Plant height (cm) | Grain yield (t $ha^{-1}$) | Harvest index | Biomass yield (t $ha^{-1}$) | Straw yield (t $ha^{-1}$) |
|---|---|---|---|---|---|---|
| T1 | 79 | 32.4 | 0.79 | 0.28 | 4.03 | 3.23 |
| T2 | 77 | 33.0 | 0.76 | 0.24 | 4.08 | 3.32 |
| T3 | 87 | 34.9 | 0.91 | 0.24 | 3.90 | 2.99 |
| R1 | 79 | 32.7 | 0.76 | 0.24 | 3.94 | 3.18 |
| R2 | 76 | 32.9 | 0.76 | 0.24 | 3.80 | 3.04 |
| R3 | 85 | 34.0 | 0.90 | 0.28 | 4.23 | 3.33 |
| T1R1 | 81 | 31.5 | 0.69 | 0.23 | 3.95 | 3.27 |
| T1R2 | 77 | 32.7 | 0.76 | 0.25 | 4.00 | 3.23 |
| T1R3 | 79 | 32.9 | 0.93 | 0.36 | 4.12 | 3.20 |
| T2R1 | 76 | 32.7 | 0.73 | 0.26 | 3.85 | 3.13 |
| T2R2 | 74 | 33.1 | 0.75 | 0.23 | 3.60 | 2.84 |
| T2R3 | 81 | 33.2 | 0.80 | 0.23 | 4.78 | 3.97 |
| T3R1 | 80 | 34.0 | 0.86 | 0.24 | 4.01 | 3.15 |
| T3R3 | 94 | 35.9 | 0.97 | 0.25 | 3.79 | 2.82 |

In each group (eg T1T2T3), numbers not followed by letters are not significantly different at p=0.05

and chisel plus sweep (T2). This is due to the higher WUE obtained in T3 (Table 24).

None of the residue management methods had an effect on grain yield.

Table 19 shows that there was no effect of plow type on the grain yield of wheat in wheat/vetch rotation. Adding N resulted in higher yield, and the rate of 20 kg N $ha^{-1}$ was as good as using 30 kg N $ha^{-1}$. Residue management method had no effect on the yield.

**Table 19. Crop data for wheat in wheat/vetch rotation, Mushaqar, 1991-98 (8 years combined)**

| Treatment | Plant number per 5 $m^2$ | Plant height (cm) | Grain yield (t $ha^{-1}$) | Harvest index | Biomass yield (t $ha^{-1}$) | Straw yield (t $ha^{1}$) |
|---|---|---|---|---|---|---|
| T1 | 57a | 58.6a | 1.02 | 0.29 | 3.73 | 2.71 |
| T2 | 51b | 57.6b | 097 | 0.27 | 3.84 | 2.88 |
| T3 | 53b | 56.5c | 0.97 | 0.26 | 3.76 | 2.78 |
| R1 | 54 | 57.7 | 0.95 | 0.28 | 3.60 | 2.65 |
| R2 | 54 | 58.3 | 1.05 | 0.26 | 4.25 | 3.20 |
| R3 | 53 | 57.4 | 0.98 | 0.28 | 3.65 | 2.66 |
| T1R1 | 59 | 57.8 | 0.98 | 0.28 | 3.73b | 2.75b |
| T1R2 | 57 | 58.7 | 1.07 | 0.27 | 3.88b | 2.82b |
| T1R3 | 55 | 59.3 | 1.02 | 0.29 | 3.57b | 2.55b |
| T2R1 | 50 | 58.1 | 0.91 | 0.28 | 3.44b | 2.53b |
| T2R2 | 51 | 57.9 | 1.04 | 0.26 | 4.61a | 3.57a |
| T2R3 | 52 | 57.0 | 0.95 | 0.28 | 3.49b | 2.54b |
| T3R1 | 55 | 57.2 | 0.96 | 0.26 | 3.63b | 2.67b |
| T3R3 | 53 | 55.8 | 0.91 | 0.26 | 3.88b | 2.90b |
| NO | 53 | 56.4b | 0.90b | 0.32a | 2.97b | 2.07b |
| N1 | 55 | 58.2a | 1.01a | 0.25b | 4.19a | 3.17a |
| N2 | 54 | 58.6a | 1.05a | 0.25b | 4.18a | 3.12a |

In each group (eg T1T2T3), numbers not followed by letters are not significantly different at p=0.05

**Table 20a. Crop data for vetch in vetch/wheat rotation, Mushaqar, 1993-2000 (6 years combined analysis with N)**

| Treatment | Plant number per 5 $m^2$ | Plant height (cm) | Grain yield (t $ha^{-1}$) | Harvest index | Biomass yield (t $ha^{-1}$) |
|---|---|---|---|---|---|
| T1 | 59 | 73b | 0.25 | 3.00b | 2.28b |
| T2 | 59 | 75b | 0.25 | 3.20b | 2.45b |
| T3 | 65 | 85a | 0.27 | 3.60a | 2.75a |
| R1 | 62 | 79 | 0.26 | 3.20 | 2.41 |
| R2 | 58 | 74 | 0.26 | 3.11 | 2.37 |
| R3 | 61 | 76 | 0.25 | 3.33 | 2.57 |
| T1R1 | 59 | 71 | 0.26 | 2.87c | 2.15 |
| T1R2 | 58 | 77 | 0.26 | 3.29ab | 2.52 |
| T1R3 | 61 | 69 | 0.25 | 2.85c | 2.16 |
| T2R1 | 62 | 75 | 0.24 | 3.12bc | 236 |
| T2R2 | 58 | 70 | 0.26 | 2.92bc | 2.22 |
| T2R3 | 59 | 79 | 0.25 | 3.56a | 2.76 |

*Continued*

**Table 20a.** *Continued.*

| Treatment | Plant number per 5 $m^2$ | Plant height (cm) | Grain yield (t $ha^{-1}$) | Harvest index | Biomass yield (t $ha^{-1}$) |
|---|---|---|---|---|---|
| T3R1 | 66 | 89 | 0.28 | 3.61a | 2.71 |
| T3R3 | 64 | 80 | 0.26 | 3.59a | 2.79 |
| NO | 62 | 78 | 0.26 | 3.27 | 2.49 |
| N1 | 61 | 77 | 0.25 | 3.24 | 2.47 |
| N2 | 60 | 73 | 0.26 | 3.16 | 2.42 |

In each group (eg T1T2T3), numbers not followed by letters are not significantly different at p=0.05

Table 20b shows that using the sweep alone late in the season (T3) with N resulted in significantly higher grain yield of vetch in vetch/wheat rotation, in contrast to using moldboard plus sweep (T1), or chisel plus sweep (T2). No effect of residue management method was shown on the grain yield.

Table 21 shows that using the moldboard plow plus the sweep (TI) to prepare land for wheat planting in wheat/lentil/melon rotation resulted in higher grain yield of wheat compared with using chisel plus sweep (T2). Adding N produced higher grain yield than no N.

**Table 20b. Crop data for lentil in lentil/wheat rotation, Mushaqar, 1991-2000 (8 years combined analysis without N)**

| Treatment | Plant number per 5 $m^2$ | Plant height (cm) | Grain yield (t $ha^{-1}$) | Harvest index | Biomass yield (t $ha^{-1}$) |
|---|---|---|---|---|---|
| T1 | 76 | 0.85 | 0.25b | 3.28ab | 2.43 |
| T2 | 70 | 0.86 | 0.28a | 3.11b | 2.25 |
| T3 | 78 | 0.96 | 0.30a | 3.76a | 2.80 |
| R1 | 75 | 0.88 | 0.28 | 3.13 | 2.25 |
| R2 | 73 | 0.87 | 0.27 | 3.33 | 2.46 |
| R3 | 74 | 0.89 | 0.27 | 3.55 | 2.66 |
| T1R1 | 78 | 0.78 | 0.24 | 3.03 | 2.25 |
| T1R2 | 74 | 0.93 | 0.26 | 3.69 | 2.76 |
| T1R3 | 76 | 0.84 | 0.25 | 3.12 | 2.28 |
| T2R1 | 69 | 0.88 | 0.27 | 2.93 | 2.05 |
| T2R2 | 72 | 0.81 | 0.27 | 2.96 | 2.16 |
| T2R3 | 69 | 0.88 | 0.28 | 3.44 | 2.56 |
| T3R1 | 79 | 0.97 | 0.31 | 3.43 | 2.46 |
| T3R3 | 78 | 0.95 | 0.28 | 4.09 | 3.14 |

In each group (eg T1T2T3), numbers not followed by letters are not significantly different at p=0.05

**Table 21. Crop data for wheat in wheat/lentil rotation, Mushaqar, 1991-98 (8 years combined)**

| Treatment[ | Plant number per 5 m² | Grain yield (t ha⁻¹) | Harvest index | Biomass yield (t ha⁻¹) | Straw yield (t ha⁻¹) |
|---|---|---|---|---|---|
| T1 | 54 | 1.80a | 0.30a | 6.46 | 4.66 |
| T2 | 52 | 1.68b | 0.27b | 6.17 | 4.49 |
| R1 | 54 | 1.73 | 0.29 | 6.57 | 4.83 |
| R2 | 54 | 1.72 | 0.28 | 6.21 | 4.49 |
| R3 | 50 | 1.77 | 0.29 | 6.17 | 4.40 |
| T1R1 | 52b | 1.77 | 0.29 | 6.77 | 5.00 |
| T1R2 | 56ab | 1.79 | 0.3 | 6.17 | 4.38 |
| T1R3 | 54ab | 1.84 | 0.29 | 6.44 | 4.60 |
| T2R1 | 57a | 1.70 | 0.28 | 6.37 | 4.67 |
| T2R2 | 53ab | 1.65 | 0.27 | 6.25 | 4.60 |
| T2R3 | 46c | 1.69 | 0.28 | 5.90 | 4.21 |
| NO | 51 | 1.69b | 0.30a | 5.76b | 4.07b |
| N1 | 54 | 1.76ab | 0.28ab | 6.42a | 4.66a |
| N2 | 54 | 1.78a | 0.27b | 6.77a | 4.99a |

In each group (eg T1T2T3), numbers not followed by-letters are not significantly different at p=0.05

**Table 22a. Crop data for lentil in lentil/wheat/melon rotation, Mushaqar, 1993-2000 (6 years combined analysis with N)**

| Treatment | Plant number per 5 m² | Grain yield (t ha⁻¹) | Harvest index | Biomass yield (t ha⁻¹) | Straw yield (t ha⁻¹) | Treatment |
|---|---|---|---|---|---|---|
| T1 | 80 | 32.8 | 0.59 | 0.22 | 3.10 | 2.51 |
| T2 | 75 | 33.4 | 0.59 | 0.22 | 2.92 | 2.33 |
| R1 | 79 | 33.1 | 0.62 | 0.23 | 2.99 | 2.37 |
| R2 | 76 | 33.0 | o.59 | 0.22 | 3.12 | 2.53 |
| R3 | 79 | 33.4 | 056 | 0.21 | 2.93 | 2.36 |
| T1R1 | 81 | 32.9 | 0.59 | 0.22 | 2.95 | 2.37 |
| T1R2 | 79 | 32.3 | 0.60 | 0.22 | 3.37 | 2.77 |
| T1R3 | 81 | 33.2 | 0.59 | 0.22 | 2.99 | 2.417 |
| T2R1 | 77 | 33.1 | 0.65 | 0.23 | 3.03 | 2.38 |
| T2R2 | 72 | 33.5 | 0.58 | 0.22 | 2.87 | 2.29 |
| T2R3 | 77 | 33.5 | 0.54 | 0.21 | 2.86 | 2.32 |
| NO | 77 | 33.4a | 0.05 | 0.22 | 3.08 | 2.48 |
| N1 | 79 | 32.7b | 0.58 | 0.22 | 2.96 | 2.37 |
| N2 | 80 | 33.2ab | 0.58 | 0.22 | 3.00 | 2.42 |

In each group (eg T1T2T3), numbers not followed by letters are not significantly different at p=0.05

**Table 22b. Crop data for lentil in lentil/wheat/melon rotation, Mushaqar, 1991-2000 (8 years combined analysis without N)**

| Treatment | Plant number per 5 $m^2$ | Grain yield (t $ha^{-1}$) | Harvest index | Biomass yield (t $ha^{-1}$) | Straw yield (t $ha^{-1}$) | Treatment |
|---|---|---|---|---|---|---|
| T1 | 96 | 30.7 | 0.712 | 0.24 | 3.05 | 2.34 |
| T2 | 90 | 30.8 | 0.682 | 0.24 | 2.88 | 2.20 |
| □ | □ | | | | | □ |
| R1 | 96 | 30.8 | 0.743a | 0.25 | 2.97 | 2.23 |
| R2 | 89 | 30.6 | 0.679b | 0.23 | 3.03 | 2.35 |
| R3 | 94 | 30.9 | 0.669b | 0.24 | 2.89 | 2.22 |
| □ | □ | | | | | □ |
| T1R1 | 99 | 31.0 | 0.716 | 0.25 | 2.88 | 2.17 |
| T1R2 | 94 | 30.3 | 0.706 | 0.24 | 3.30 | 2.59 |
| T1R3 | 95 | 30.8 | 0.714 | 0.24 | 2.96 | 2.25 |
| T2R1 | 93 | 30.7 | 0.771 | 0.25 | 3.07 | 2.30 |
| T2R2 | 83 | 30.8 | 0.652 | 0.22 | 2.76 | 2.11 |
| T2R3 | 94 | 30.9 | 0.625 | 0.24 | 2.83 | 2.20 |

In each group (eg T1T2T3), numbers not followed by letters are not significantly different at p=0.05.

**Table 23. Crop and soil moisture data (6 years combined) for wheat in wheat/lentil rotation at Mushaqar**

| Treatment | Etc (mm) | Grain yield (kg $ha^{-1}$) | Straw yield (kg $ha^{-1}$) | WUE grain (kg $ha^{-1}$ per mm) | WUE straw (kg $ha^{-1}$ per mm) |
|---|---|---|---|---|---|
| T1 | 275b | 1.34a | 3.66 | 4.7a | 13.1a |
| T2 | 269c | 1.16b | 3.22 | 4.1ab | 11.7ab |
| T3 | 284a | 1.09b | 3.04 | 3.5b | 10.2b |
| R1 | 281 a | 1.21 | 3.58 | 4.0 | 12.5 |
| R2 | 272b | 1.22 | 3.36 | 4.2 | 12.1 |
| R3 | 271b | 1.21 | 3.08 | 4.3 | 11.0 |
| T1R1 | 284 | 1.37 | 3.99 | 4.5 | 13.7 |
| T1R2 | 275 | 1.43 | 3.83 | 4.9 | 13.3 |
| T1R3 | 266 | 1.22 | 3.17 | 4.7 | 12.2 |
| T2R1 | 273 | 1.21 | 3.32 | 4.3 | 11.9 |
| T2R2 | 269 | 1.00 | 2.90 | 3.6 | 11.0 |
| T2R3 | 265 | 1.28 | 3.43 | 4.4 | 12.2 |
| T3R1 | 286 | 1.05 | 3.44 | 3.3 | 11.8 |
| T3R3 | 283 | 1.14 | 2.63 | 3.7 | 9.0 |

In each group (eg T1T2T3), numbers not followed by letters are not significantly different at p=0.05

**Table 24. Crop and soil moisture data (5 years combined) for lentil in lentil/wheat rotation, Mushaqar**

| Treatment | Etc (mm) | Grain yield (kg ha$^{-1}$) | Straw yield (kg ha$^{-1}$) | WUE grain (kg ha$^{-1}$ per mm) | WUE straw (kg ha$^{-1}$ per mm) |
|---|---|---|---|---|---|
| T1 | 239b | 0.837 | 2.97 | 3.0 | 11.4 |
| T2 | 246b | 0.830 | 3.03 | 2.9 | 11.3 |
| T3 | 257a | 1.006 | 3.05 | 3.5 | 11.1 |
| R1 | 255a | 0.835 | 3.18 | 2.9 | 11.6 |
| R2 | 242b | 0.770 | 2.76 | 2.7 | 10.5 |
| R3 | 240b | 0.991 | 3.01 | 3.5 | 11.5 |
| T1R1 | 250 | 0.708 | 2.99 | 2.5 | 11.1 |
| T1R2 | 236 | 0.762 | 2.79 | 2.8 | 10.8 |
| T1R3 | 232 | 1.044 | 3.31 | 3.8 | 12.3 |
| T2R1 | 251 | 0.844 | 3.32 | 2.9 | 12.1 |
| T2R2 | 248 | 0.777 | 2.72 | 2.6 | 10.2 |
| T2R3 | 239 | 0.868 | 3.05 | 3.1 | 11.5 |
| T3R1 | 263 | 0.951 | 3.23 | 3.4 | 11.6 |
| T3R3 | 250 | 1.060 | 2.86 | 3.7 | 10.6 |

In each group (eg T1T2T3), numbers not followed by letters are not significantly different at p=0.05

**Table 25. Crop and soil moisture data (6 years combined) for wheat in wheat/lentil/melon rotation at Mushaqar**

| Treatment | Etc (mm) | Grain yield (kg ha$^{-1}$) | Straw yield (kg ha$^{-1}$) | WUE grain (kg ha$^{-1}$ per mm) | WUE straw (kg ha$^{-1}$ per mm) |
|---|---|---|---|---|---|
| T1 | 297 | 2.01 | 4.83 | 7.0 | 17.1 |
| T2 | 275 | 1.88 | 4.71 | 6.7 | 17.2 |
| R1 | 281 | 1.96 | 4.68 | 6.8 | 16.6 |
| R2 | 275 | 1.93 | 4.75 | 6.9 | 17.2 |
| R3 | 276 | 1.95 | 4.88 | 6.9 | 17.6 |
| T1R1 | 283 | 1.97 | 4.84 | 6.8 | 16.9 |
| T1R2 | 278 | 2.09 | 4.73 | 7.4 | 17.0 |
| T1R3 | 277 | 1.98 | 4.91 | 6.9 | 17.4 |
| T2R1 | 279 | 1.94 | 4.53 | 6.8 | 16.3 |
| T2R2 | 272 | 1.78 | 4.77 | 6.4 | 17.5 |
| T2R3 | 275 | 1.92 | 4.84 | 6.9 | 17.9 |

In each group (eg T1T2T3), numbers not followed by letters are not significantly different at p=0.05

**Table 26. Crop and soil moisture data (5 years combined) for lentil in lentil/melon/wheat rotation at Mushaqar**

| Treatment | Etc (mm) | Grain yield (kg ha$^{-1}$) | Straw yield (kg ha$^{-1}$) | WUE grain (kg ha$^{-1}$ per mm) | WUE straw (kg ha$^{-1}$ per mm) |
|---|---|---|---|---|---|
| T1 | 266 | 0.753 | 2.50 | 2.6 | 8.9 |
| T2 | 266 | 0.714 | 2.29 | 2.4 | 8.2 |
| | 261 | 0.753 | 2.28 | 2.6 | 8.3 |
| R1 | 269 | 0.730 | 2.52 | 2.5 | 9.1 |
| R2 | 287 | 0.717 | 2.37 | 24 | 8.3 |
| T1R1 | 260 | 0.760 | 2.15 | 2.7 | 7.9 |
| T1R2 | 271 | 0.751 | 2.87 | 2.6 | 10.2 |
| T1R3 | 269 | 0.748 | 2.45 | 2.5 | 8.6 |
| T2R1 | 263 | 0.748 | 2.40 | 2.6 | 8.6 |
| T2R2 | 268 | 0.710 | 2.17 | 2.4 | 79 |
| T2R3 | 268 | 0.687 | 2.29 | 2.3 | 8.0 |

In each group (eg T1T2T3), numbers not followed by letters are not significantly different at p=0.05

**Table 27. Aggregate size distribution (mean weighted diameter, mm) for wheat-lentil rotation at Rabba, Mushaqar, and Maru stations**

| Treatment | Rabba | Mushaqar | Maru |
|---|---|---|---|
| T1 | 0.65 | 0.55a | 0.61a |
| T2 | 0.80 | 0.45ab | 0.52ab |
| T3 | 0.57 | 0.39b | 0.44b |
| R1 | 0.63 | 0.46 | 0.49 |
| R2 | 0.75 | 0.54 | 0.53 |
| R3 | 0.70 | 0.44 | 0.59 |
| T1R1 | 0.50b | 0.59 | 0.42bc |
| T1R2 | 0.51b | 0.55 | 0.57b |
| T1R3 | 0.93a | 0.51 | 0.85a |
| T2R1 | 0.89a | 0.39 | 0.52bc |
| T2R2 | 0.98a | 0.52 | 0.48bc |
| T2R3 | 0.54b | 0.43 | 0.57b |
| T3R1 | 0.49b | 0.41 | 0.53b |
| T3R3 | 0.64ab | 0.38 | 0.35c |

In each group (eg T1T2T3), numbers not followed by letters are not significantly different at p=0.05

Table 25 shows that WUE for grain was not affected by treatments. Tables 22a and b show that the type of plow used to prepare the land for sowing lentil in the lentil/melon/wheat rotation did not influence grain yield. Therefore, the use of the chisel plus the sweep (T2), which is the least expensive, should be sufficient. Table 26 shows that WUE did not differ for the different plows. Residue management treatment (R1) resulted in higher yield than R2 and R3.

## Recommendations

In the three-course rotation, wheat/lentil/melon at Maru, it is recommended to use the moldboard plow plus sweep (TI) for land preparation to sow wheat after melon.

However, it is recommended to use the chisel plus sweep (T2) for land preparation to sow lentil after wheat. The sweep (T3) may be recommended whenever TI was used in the previous season, ie, use T3 for lentil sowing if the previous wheat had used T1.

In the two-course rotation, wheat/lentil at Mushaqar, no preference on the type of plow could be given for land preparation to sow wheat after lentil. However, it is recommended to use the sweep (T3) to prepare the land for lentil sowing after wheat. In the wheat/vetch rotation at Mushaqar, any type of plow could be used to prepare the land for wheat sowing. However, the sweep is recommended for plowing the land for vetch sowing after wheat. In the three-course rotation, namely wheat/lentil/melon, it is recommended to use moldboard plus sweep to prepare the land for sowing wheat after melon. Any type of plow could be used to prepare the land to sow lentil after wheat.

In the two-course rotation, wheat/lentil at Rabba, it is recommended to use moldboard plus sweep to prepare the land for wheat sowing. Any type of plow can be used for preparing the land for lentil sowing after wheat; or for wheat sowing after vetch in the wheat/vetch rotation. It is recommended to use the chisel plow plus sweep to prepare the land for vetch sowing after wheat.

In general, it appears that incorporation of wheat crop residues immediately or shortly after harvesting and baling or grazing will produce the best grain yield.

It is recommended to use 30 kg $ha^{-1}$ N fertilizer added to the soil in doses when wheat is sown in any of the rotations.

In Mushaqar, it is recommended to follow the three-course rotation wheat/lentil/melon. But if the farmer desires to use the two-course rotation, then wheat/lentil or wheat/vetch may be used.

In Rabba, a two-course rotation is recommended, either wheat/lentil or wheat/vetch.

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# *Evaluation* of Soil Phosphorus as a *Quality* Indicator to Assess Degradation of Natural Land in Gauteng Province, South Africa

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## Introduction

Land degradation has an impact on soil quality through adverse changes in its physical, chemical and biological attributes. Soil quality has been defined as "the capacity of the soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health" (Doran and Parkin 1994). The degree to which the soil's functions are sustained depends on the integrity of internal nutrient cycles, energy flows, plant community dynamics, an intact soil profile and stores of nutrients and water (National Research Council 1994). The concept of soil quality is clear, but remains difficult to measure operationally because soil and its functions are ecologically complex.

Several soil physical, chemical and biological attributes can be used as indicators of sustainability, land condition, soil degradation, soil health and quality for a variety of land uses (Arshad and Coen 1992, Doran and Parkin 1996, Nell et al. 2001). There are well-documented specifications to which' indicators of the above-mentioned parameters must conform. In short, indicators must be sensitive to environmental stress and to temporal and spatial changes, focus on risk of degradation, be related to ecosystem function, and be predictable, measurable and interactive. An indicator of soil quality must be sensitive enough to reflect the influence of climate on long-term changes in soil quality, but not be so sensitive that it is influenced by short-term weather patterns (Doran and Parkin 1996).

It would be impossible and unnecessary to monitor changes in all of the soil attributes that relate to ecosystem function. It is, therefore, useful to select attributes that can serve as indicators of change in land condition. Currently there is no consensus on a definitive data set for soil quality monitoring, nor on how the indicators should be interpreted (Shipper and Sparling 2000).

Plant-available soil phosphorus (P), in combination with other soil properties, is widely used as an indicator of soil quality for agriculture

(National Research Council 1993). Phosphorus is an essential plant nutrient and its concentration in the soil thus provides an estimate of crop productivity. Several research studies have also focused on the quantification of P sorption saturation of agricultural soils and its environmental implications (eg Kleinman 1999, Hesketh 2000). The concentration of P in soil may thus provide an indication of the risk of environmental pollution, eg eutrophication of rivers. Little is, however, documented about the usefulness of P as a soil quality indicator for non-agricultural natural land.

Natural land usually refers to all areas covered by indigenous plant communities which have not yet been transformed to another form of land cover. These systems differ from agricultural systems in many ways. When considering soil quality, both inherent and dynamic soil characteristics are important. Inherent soil characteristics are those determined by the basic soil forming factors: climate, parent material, topography, time and vegetation (Jenny 1941). In contrast to inherent soil quality, dynamic soil quality reflects the changes associated with current or past land use and anthropogenic management decisions (Karlen et al. 2001). Although non-point source pollution of P from agricultural, industrial or domestic practices may influence the quality of soils of nearby natural land (Tilman 1999), inherent soil characteristics will mostly influence soil quality of natural systems.

A further difference between natural and agricultural land is that measurable pools of nutrients are often small, and nutrient cycling rather than pool size is a major determinant of annual productivity and the levels and kinds of biological activity (Cole et al. 1977). Critical soil P levels that were developed for sustainable crop production can thus not be used for measuring biological productivity of natural ecosystems.

Studying nutrient cycling presents many difficulties not only because of the lack of sufficient time to observe substantial gains or losses from the system, but also in terms of costs. It can be hypothesized that the plant-available soil P fraction of an undisturbed ecosystem, evaluated on a relatively short time scale, may give an indication of P cycling, since no substantial P gains or losses from the system are expected and the system observed is, therefore, under an equilibrium situation. Phosphorus concentrations in soils are less influenced by seasonal variations in rainfall, or episodic rainfall events, than most other nutrients and may provide a reliable measure of nutrient deterioration over a period of time.

The usefulness of one single attribute as an indicator of soil quality or land condition is limited and may be meaningless, since soil attributes are often highly correlated, which makes it difficult to interpret the significance of changes in single indicators of soil quality. Inherent soil differences are also the reason why there can be no single value or expression that describes soil quality (Karlen et al. 2001). This is especially true when soil quality assessments are made on a provincial scale, ranging over a wide variety of climatic, geologic and topographic conditions. Any attempt to evaluate the significance of soil P as a quality indicator should thus try to understand the system as a whole to enable sound interpretation guidelines to be made and put into practice.

## Objectives

The objective was to evaluate the use of soil P as an indicator to investigate the impact of various forms and intensities of degradation of natural land on soil quality in Gauteng Province, South Africa. The effect of the principal soil-forming factors on soil P status of natural land was also evaluated. Natural land in this study was as defined above, whereas soil P refers to the plant-available fraction.

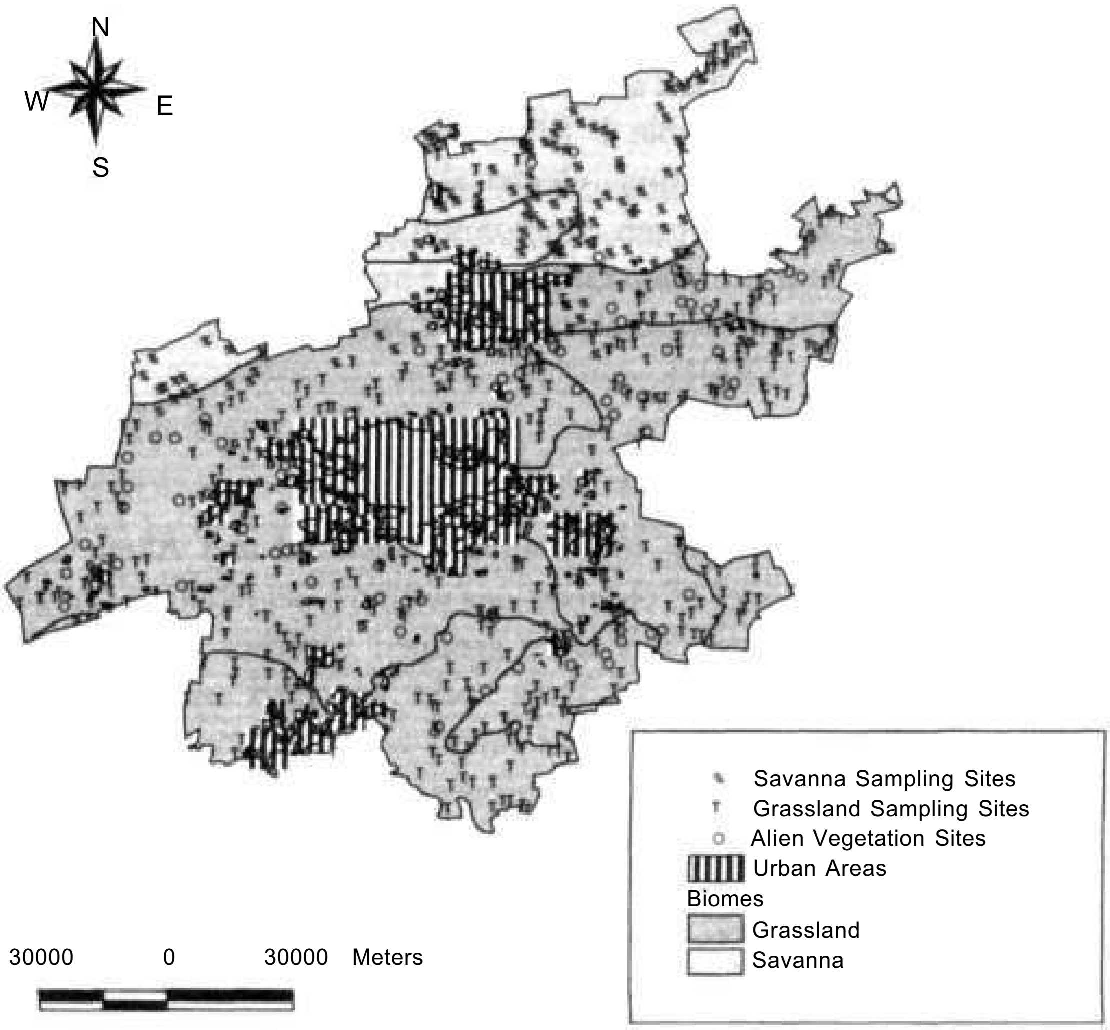
## Methods

### Field sampling

The methods for soil sampling are described by Wessels et al. (2001). Soil samples were collected from the top 250 mm of the profile. Soil samples from the Grassland and Savanna Biomes were collected between 28 Mar and 20 Apr 2000. One hundred sites invaded by alien vegetation were sampled throughout Gauteng Province in order to provide more detailed information on alien species and their on-site degradation impacts. Samples of the alien vegetation study were collected during 22-29 Mar 2001. The location of the 342 grassland, 149 savanna and 100 alien vegetation sample points is shown in Map 1.

### Degradation assessment

The degradation assessment procedures employed in this study are described by Wessels et al. (2001) in the section on Field Surveys. These entailed the subjective evaluation of different forms and intensities of natural land degradation. The forms of degradation that were investigated for the




***Map 1. Location of grassland, savanna, and alien vegetation sites in Gauteng Province***

Grassland and Savanna Biomes were: vegetation cover degradation, biomass degradation, negative species change, soil erosion, bush encroachment, and overall degradation. The forms of degradation assessed for the alien vegetation survey included: vegetation cover degradation, negative species change, soil erosion, and overall degradation.

The severity of negative species change was evaluated based on the expected condition of a site in good condition. Overall degradation was assessed as an estimate of the combined impact of all the above-mentioned forms of degradation.

The intensity of degradation was categorized as follows: 1 - no degradation, 2 - light degradation, 3 - moderate degradation, 4 - high degradation, and 5 - severe degradation.

Attributes such as crusting, type of soil erosion (sheet, rill and gully), wind erosion, stream bank erosion and landslides were also documented.

## Laboratory analysis

The soil samples were air-dried and passed through a 2-mm screen. They were analysed for Bray 1-extractable P (Bray and Kurtz 1945). Organic carbon (OC), particle size distribution, electrical conductivity of the saturation extract, pH($H_2O$), total nitrogen, ammonium acetate extractable Ca, Mg, K and Na, CEC and saturation percentage were analyzed according to standard methods (Non-Affiliated Soil Analysis Work Committee 1990) as part of the study by Wessels et al. (2001).

## Statistical analysis

Data were divided according to Savanna, Grassland and Alien vegetation regions. Where the number of observations within a degradation category was too low, the adjacent categories were grouped together in order to make statistically sound comparisons. Data were analysed using GenStat for Windows (2000). As the soil analysis values were not normally distributed, often extremely skew and with heterogeneous variances, the differences between primary degradation indicators were tested using the method known as generalized linear modeling (GLM) (Dobson 1990) with the gamma distribution. Fisher's protected t-test for Least Significant Difference (LSD) was then applied to test for pairwise statistically significant differences.

The on-site degradation impacts of alien species on soil quality were investigated by testing for differences between means of soil attributes of grassland and alien sites of similar soil forms and on similar terrain units at the $p=0.05$ level of significance.

## Spatial representation of data

Inverse Distance Weighting (IDW) that interpolates between sampling points was used to form polygons that predict the distribution of soil P between the sampling points. Urban areas were masked out during interpolation. Long-term mean annual precipitation data and mean minimum/maximum temperatures were obtained from the National AgroMet Climate Databank, which consists of data obtained from rainfall stations recording data for more than 20 years and temperature stations recording data for more than 5 years. The geological formation of each sampling point was obtained from a 1:250,000 Geology map of Gauteng, and altitude data from a digital elevation model.

# Results and Discussion

## Soil P status of Gauteng

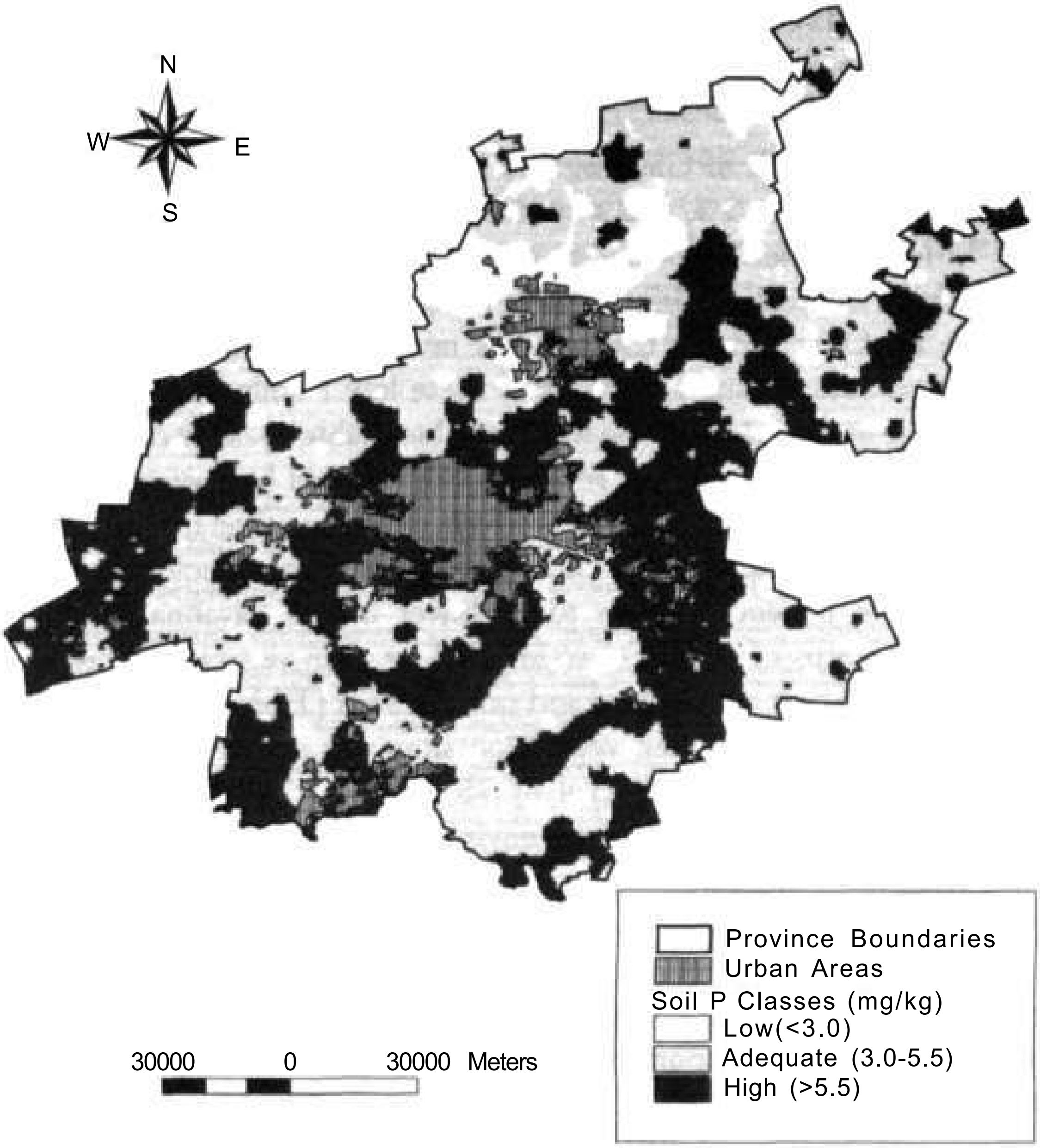
The P status of the soils of Gauteng determined by IDW of sample points is presented in Maps 2 and 3, and a summary of the statistics is presented in Table 1. When classified according to norms given for soils from natural land (Table 2), most soil samples investigated were adequate (44%) or high (30%) in P (Map 2). Only 26% of the samples investigated were low in P with concentrations below 3 mg $kg^{-1}$. Most of these low P soils were taken in the Savanna Biome as indicated by the median value (Table 1). This could indicate that P cycling by organic matter return via above- and belowground litter is less effective in replenishing soil P in the Savanna Biome than in the Grassland Biome. Other abiotic factors, like climate, topography and geology, could also have caused the P concentration to be lower in the Savanna Biome (see below). The P status of soils at sites invaded by alien vegetation was several orders higher than that of grassland and savanna soils (Table 1). The maximum soil P concentration from alien vegetation sites was still far lower than the environmentally upper critical level of 75 mg $kg^{-1}$ given by Sibbesen and Sharpley (1998), indicating that little environmental risk, like eutrophication of rivers or dams, is present.

Phosphorus concentrations were classified according to norms given for agricultural soils (FSSA 1986; Rehm et al. 1994) for the sake of comparison (Map 3). Eighty-two percent of the soils were low in P, and 12% had sufficient P. This emphasizes the importance of interpreting soil P results within the context of the intended land use.

According to Cole et al. (1977) measurable pools of P are small and P cycling rather than pool size will be the major determinant of annual productivity of natural ecosystems. The results of this investigation can

**Table 1. Summary of statistics for Bray 1-P (mg $kg^{-1}$) concentrations in soils for different vegetation areas in Gauteng**

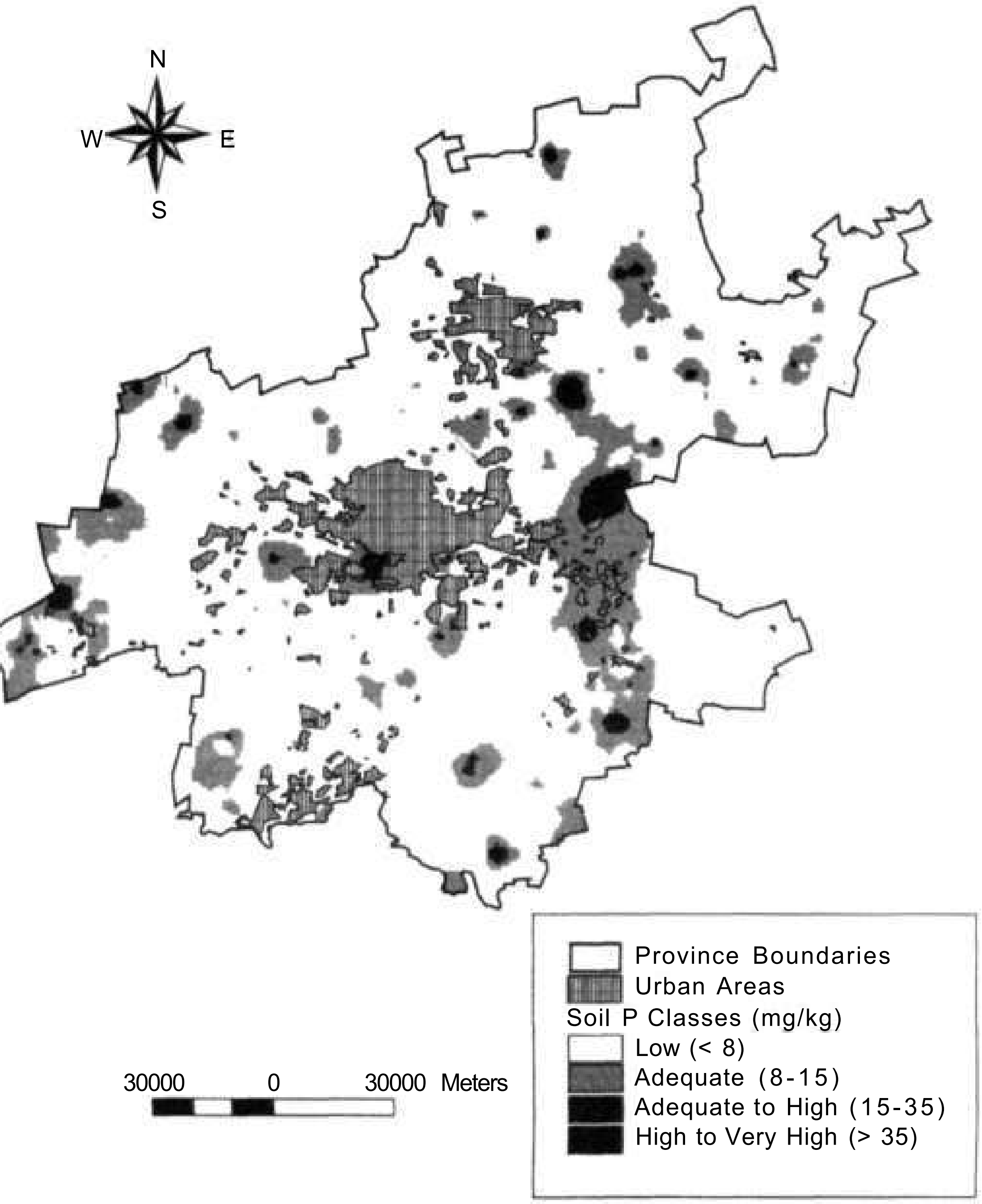
| | Grassland | Savanna | Alien vegetation |
|---|---|---|---|
| Mean | 5.71 | 4.48 | 7.59 |
| Median | 4.01 | 2.98 | 5.43 |
| Minimum | 1.35 | 1.34 | 2.62 |
| Maximum | 27.6 | 24.9 | 44.4 |
| Standard deviation | 4.47 | 4.18 | 6.00 |
| Coefficient of variation (%) | 78.2 | 93.3 | 36.0 |




***Map 2. Soil P map for Gauteng Province constructed by IDW of sample points. Phosphorus concentrations were classified according to norms for soils from natural land (Table 2)***

**Table 2. Common ranges for Bray 1-extractable P concentrations in soils of natural land (Venter et al. 1998)**

| Low | Adequate or good | High |
|---|---|---|
| <3.0 | 3.0-5.5 | >5.5 |




***Map 3. Soil P map for Gauteng Province constructed by IDW of sample points. Phosphorus concentrations were classified according to norms given for soils from agricultural land (FSSA 1986, Rehm et al. 1994)***

therefore, be regarded as points on the annual P cycle. In general the majority of natural soils in Gauteng have adequate P concentrations to sustain plant vigor and productivity.

## Effect of soil-forming factors on P status

The P status of a specific soil results from the combined effects of climate and biotic activity (plants and animals) acting upon parent material, as conditioned by topography over periods of time. Climate and parent material are the most important factors influencing the P status of soils since these factors determine the overall weathering rate and the balance between P loss and retention (Cross and Schlesinger 1995). Topography is also an important factor that controls the movement of P within landscapes. Only these three factors will, therefore, be discussed.

## Climate

Low temperature and high rainfall characterize the Grassland Biome, while high temperature and low rainfall characterize the Savanna Biome. Soils with P concentrations >5.5 mg $kg^{-1}$ generally occur in the high rainfall areas, while soils with adequate or low P concentrations occur in the low mean rainfall areas. Likewise, soils with P concentrations >5.5 mg kg"[1] occur at a low mean minimum temperature, and those with low P at high minimum temperature. The same trends were found for maximum temperature (Table 3). Phosphorus mineralization, immobilization, sorption, desorption and fixation processes are important in controlling soil P bioavailability in the soil-plant continuum. All these processes are controlled by water availability and temperature of soils. Drying of soils increases the capacity of a soil to adsorb P and would decrease its availability (Chepkwony et al. 2001), while elevated soil temperatures will also increase P retention and decrease its availability (Morgan 1998). Phosphorus release from organic matter by mineralization will further be higher in warm, moist soils than in cool, dry soils. Rainfall also plays an important role in P release through weathering and this could further explain the increase in plant-available P with increasing rainfall.

**Table 3. Climatic parameters for samples in P classes**

| | Low P | Adequate P | High P |
|---|---|---|---|
| Long-term mean rainfall (mm) | 648 | 655 | 659 |
| Long-term mean min temperature (°C) | 15.9 | 15.4 | 15.2 |
| Long-term mean max temperature (°C) | 24.7 | 24.1 | 23.9 |
| Mean altitude (m) | 1375 | 1480 | 1505 |

## Geology

The geology of Gauteng Province consists of a wide variety of parent materials ranging from ultramafic igneous gabbro, dolerite and norite to acidic granite and rhyolite through to highly siliceous quartzite. Weathering of the geological materials of Gauteng Province parent rock resulted in diverse textural and chemical characteristics of the soils (Table 4). The wide range of P concentration of soils from different parent materials is indicative of the large number of environmental factors, such as rock type, particle size, temperature and water quality, which influence the weathering rate. The mean P concentration of soils derived from the different geological materials increased with increasing acidity (Fig 1), as a result of the greater P extraction ability of the acid Bray

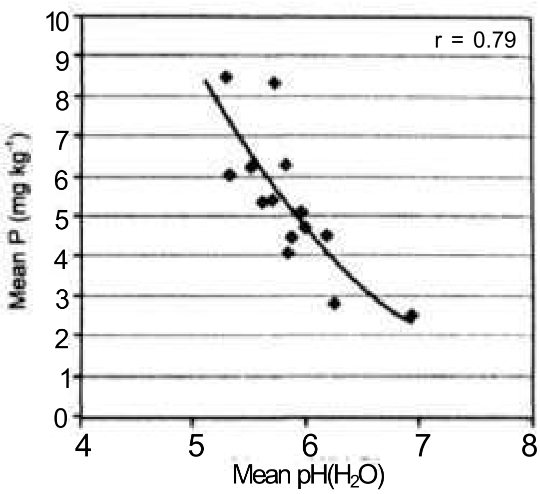



***Figure 1. Correlation between P and pH($H_2O$) of soils derived from different geological materials***

**Table 4. Textural and chemical properties of soils derived from different geological materials**

| | Mean | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Ammonium acetate extractable ($cmol_c$ $kg^{-1}$) | | | |
| Geology | Sampling distribution % | Clay % | OC % | pH ($H_2O$) | Bray I-P mg $kg^{-1}$ | K | Ca | Mg | Na |
| Shale | 203 | 22.4 | 1.82 | 5.61 | 5.36 | 0.38 | 2.30 | 1.88 | 0.14 |
| Arenite | 17.5 | 17.8 | 1.51 | 5.71 | 5.41 | 047 | 3.49 | 2.52 | 0.19 |
| Andesite | 11.3 | 22.2 | 2.12 | 5.87 | 4.48 | 053 | 3.50 | 2.19 | 0.16 |
| Dolomite | 9.9 | 19.7 | 1.41 | 5.32 | 605 | 0.22 | 1.96 | 1.63 | 0.15 |
| Dolerite | 7.2 | 248 | 220 | 6 17 | 4.49 | D.44 | 6 42 | 4.48 | 0.21 |
| Granite | 6.8 | 134 | 1.01 | 5.99 | 4.71 | 0.33 | 1.60 | 0.76 | 0.26 |
| Quartzite | 5.8 | 16.4 | 1.39 | 5.50 | 6.24 | 0.25 | 2.04 | 1.33 | 0.17 |
| Sedimentary rock | 5.8 | 204 | 1.01 | 5.95 | 5.09 | 0.38 | 3.31 | 2 97 | 0.42 |
| Gneiss | 4.0 | 133 | 1.02 | 5.82 | 6.27 | 0.24 | 1.26 | 0.43 | 0.11 |
| Rhyolite | 3.4 | 14.0 | 1.23 | 5.84 | 4.05 | 0.45 | 1.63 | 0.77 | 0.12 |
| Tillite | 3.0 | 17.9 | 1.20 | 5.72 | 8.35 | 0.29 | 3.52 | 2.48 | 0.24 |
| Lutaceous arenite | 2.2 | 18.2 | 1.52 | 5.29 | 8.48 | 0.26 | 1.92 | 1.19 | 0.23 |
| Gabbro | 1.4 | 39.3 | 149 | 6.94 | 2.48 | 0.51 | 16.99 | 8.71 | 0.38 |
| Syenite | 1.2 | 13.3 | 1.65 | 6.25 | 2.80 | 0.58 | 2.95 | 1.45 | 0.14 |

1-ammonium fluoride extracting solution in acid soils compared to more neutral or alkaline soils. Soils derived from gabbro, syenite and dolerite had high pH, while those derived from lutaceous arenite, dolomite and quartzite were most acidic. The P concentrations of soils derived from dolomite, quartzite, gneiss, tillite and lutaceous arenite were high.

### Topography

The altitude of Gauteng ranges from 950 m in the north to 1740 m asl in the center of the province. Most of the province has flat rolling terrain, with almost half the area having a gradient of less than 3%. Median P concentration in soils decreased gradually from crests to footslopes, being 3.3, 3.65 and 4.2 mg $kg^{-1}$ on footslopes, midslopes and crests respectively. This was also confirmed when the mean altitude was plotted as a function of the number of samples within a P class (Table 3). Soils with high P occurred at higher elevations than those with low P. Although this trend was observed when the data were evaluated on a provincial scale, and may differ for specific micro-sites, it may indicate that Gauteng Province is generally not eroded, since an opposite trend would be expected in eroded landscapes. Surface runoff and water erosion are serious loss mechanisms of plant-available P, causing P losses on crests and midslopes in sloping areas with insufficient vegetation cover. At the same time, P gains can be expected on footslopes and valley bottoms.

Soil pH increased from crests to footslopes. Median pH was 5.54, 5.80 and 5.88 being 3.3, 3.65 and 4.2 on crests, midslopes and footslopes respectively. The net effect of pH on P availability is difficult to assess, since the pH regulates the ratio of $HPO_4$ :$HPO_4^{2-}$ in the soil solution and Ca-phosphate precipitation. Generally phosphate is most available in the weak acid range, with maximum availability at a pH of 5.5 (Mengel and Kirkby 1987). This may explain why the P concentration in soils of crests was the highest, with median pH near 5.5. Increasingly more P will also be extracted in more acid soils with the acid Bray I-ammonium fluoride extracting solution than in less acid or neutral soils.

## Degradation Status of Gauteng Province

The sample distribution of different intensities of degradation of the vegetative cover, biomass production, erosion, negative species change and overall degradation in the grassland, savanna and alien vegetation regions is presented in Figures 2-4. Figures 2 and 3 show that most of the grassland and

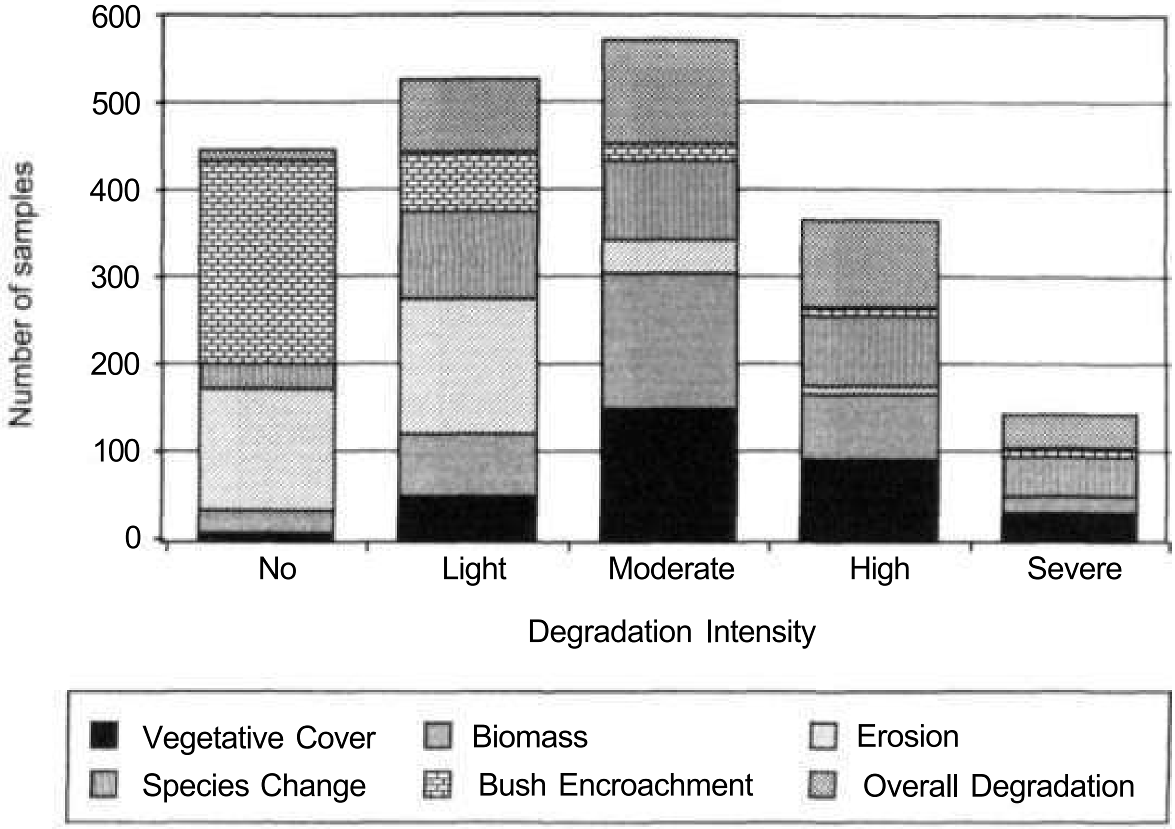



***Figure 2. Distribution of samples in each degradation form and category for the Grassland Biome***

savanna sampling sites investigated were moderately degraded, while Figure 4 indicates that most of the alien vegetation sampling sites were severely degraded. Presenting the results in a different way, Wessels et al. (2001) revealed that 42% of sites were highly degraded and 25% of sites severely degraded in terms of vegetative cover and biomass degradation. Four percent of the sites evaluated in this study were highly eroded, while soil crusting was observed in 4.3% of the soils investigated in the Grassland and Savanna Biomes. Forty-three percent of all sites investigated were highly or severely degraded in terms of negative species change, while 5% were degraded in terms of bush encroachment. Forty-seven percent of the sites investigated were overall highly and severely degraded.

## Response of soil P to degradation of natural land

GLM analyses revealed relationships between form of degradation and soil P concentrations for the grassland and savanna biomes, with some strong tendencies (p=0.085; 0.108) for alien vegetation (Appendix la). Appendix 1 b shows that differences exist when making pairwise comparison of intensity of degradation in terms of soil P. A summary of the data is given in Appendix

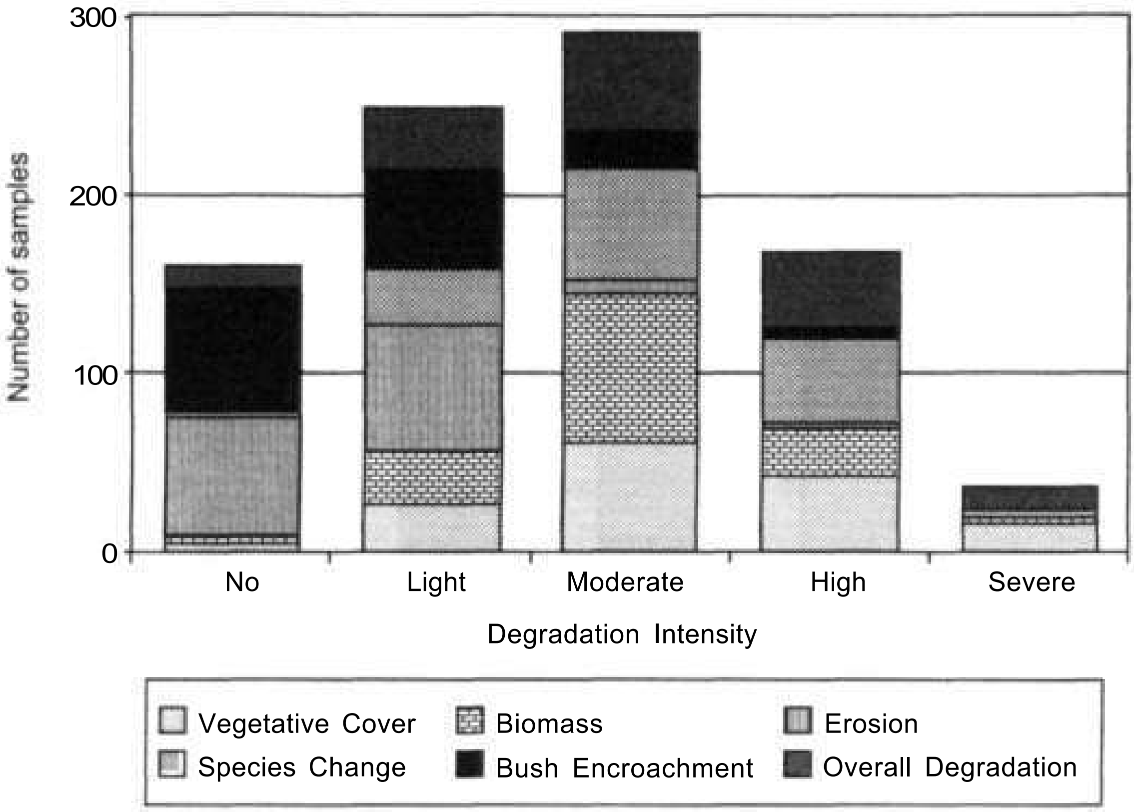



***Figure 3. Distribution of samples in each degradation form and category for the Savanna Biome***

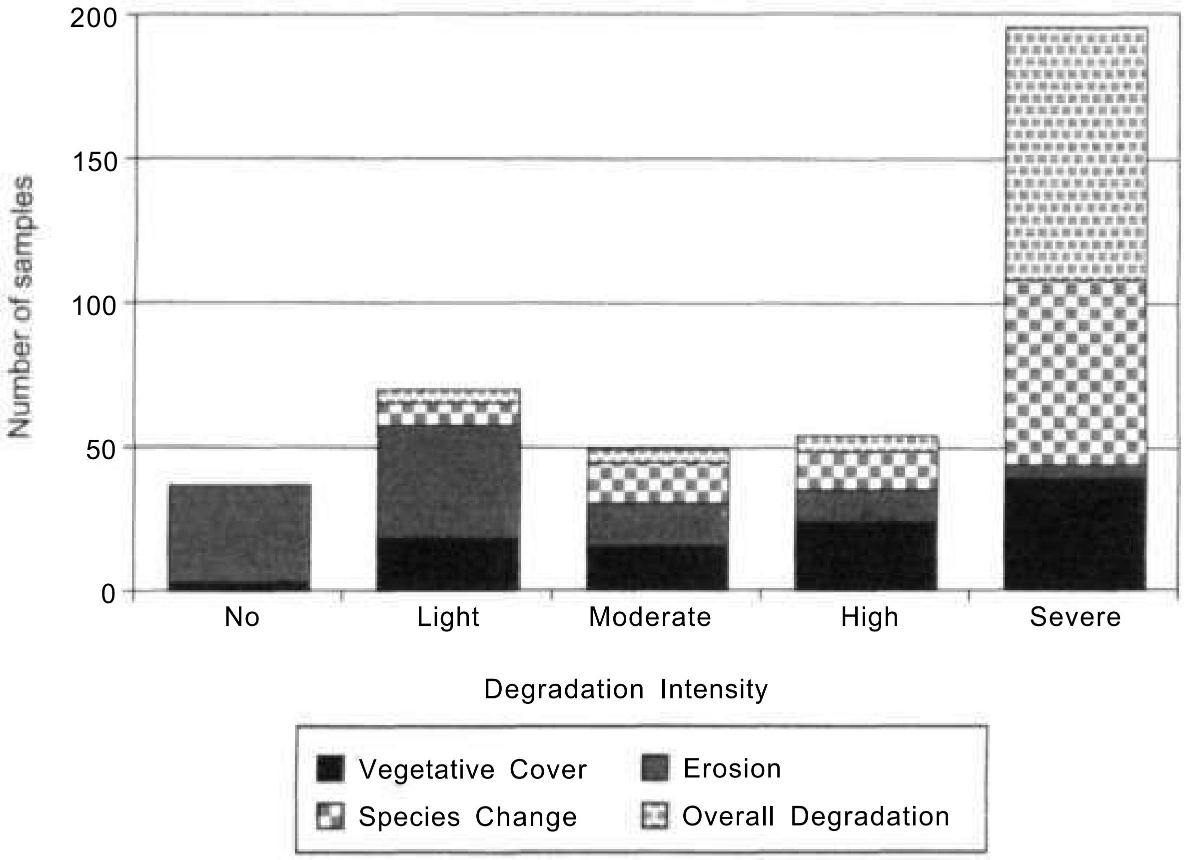



***Figure 4. Distribution of samples in each degradation form and category for the alien vegetation area***

1c for those parameters that tested statistically significant. A detailed discussion of the results of the analysis follows.

Plant-available P in soils of grassland and alien vegetation sites mostly increased with increasing degradation of vegetative cover (Table 5). Grassland sites that were not degraded had lower soil P than sites that were highly or severely degraded, while alien vegetation sites that were not degraded also had lower P than sites that were moderately, highly and severely degraded. The mean P of severely degraded grassland sites was also higher than highly degraded sites. This is exceptional, since it would be expected that degradation, especially in terms of vegetation condition, would be associated with deterioration of soil fertility. Several reasons might explain this. Firstly, the lower P concentration of plant-covered soils relative to exposed soils could be due to higher P removal rates from soils by plant uptake. A large proportion (usually more than 85%) of the net annual vegetation uptake of P from the soil is, however, returned to the soil, mainly in organic debris, and plant uptake can thus not fully explain the significant difference in P concentration between degraded and healthy grassland and alien vegetation sites (Table 5). Secondly, in their study, Wessels et al. (2001) found that basic cations were lower at degraded sites than at non-degraded sites. This caused the pH of degraded sites to be mostly lower than for non-degraded sites, which probably caused more P to be extracted in soil from degraded sites by the acid Bray 1 -extracting solution than in less acid soils from non-degraded sites.

Another important aspect relating to pH is that unlike most soil nutrients, P is very immobile in acid soils, since it is retained in Al- and Fe-phosphates and is not leached from open soil patches. The mean soil pH($H_2O$) of the grassland is 5.7, and of the alien vegetation sites is 5.0, which indicates that these soils are quite acidic.

Thirdly, because evapotranspiration of grasses is greater than evaporation from bare soil, there is greater cooling of soil at non-degraded sites by loss of

**Table 5. Mean soil P status (mg $kg^{-1}$) of grassland sites and alien vegetation sites as affected by increasing intensity of vegetative cover degradation**

| | Degradation intensity | | | | |
|---|---|---|---|---|---|
| | No | Light | Moderate | High | Severe |
| Grassland sites | 3.4 a | 5.4 bc | 5.0 ab | 6.4 c | 8.3 d |
| Alien vegetation sites | 5.7 a | 5.7 a | 7.3 ab | 7.8 ab | 8.6 b |

At each site, figures with different letters are different at p = 0.05

latent heat. Degradation of the vegetative plant cover thus increased surface albedo, which caused an increase in plant-available P through the process of mineralization of organically bound P. It can be expected that the P concentration of these degraded soils will eventually decrease as the organic matter decomposes and the organically bound P-pool is depleted.

Although care was taken during the selection of sites not to sample previously tilled, fertilized land or animal watering sites, high soil P at degraded sites could have been caused by localized animal excretal deposition that concentrated nutrients in watering and resting areas. These areas are usually degraded because of animal trampling. Other animals and insects, like termites, could also have caused concentration of P in localized degraded patches.

Soil P concentrations were positively correlated with sand content, and negatively correlated with clay, silt, OC content, K, Ca, Mg, CEC and water saturation percentage when degradation of the vegetative cover of grassland sites was considered. Similarly, Wessels et al. (2001) found relationships between soil properties and degradation intensity, eg the clay, silt, OC content, K, Ca, Mg, CEC and water saturation percentage decreased with increasing degradation. The correlation results of the present study must be interpreted against this background.

No relationship was found between P and pH, and it is possible that the extracting solution is not more effective at lower, compared to higher, soil pH in this situation. The negative correlation between P and organic C indicates that the higher surface albedo promotes higher decomposition of organic C for degraded sites, which then causes the plant-available P to increase (Fig 5). The data points in Figure 5 are the mean P concentrations of the degradation intensity categories.

When investigating the possibility of animal excretal deposition that caused higher soil P concentrations at degraded sites, it would be expected that the greatest differences in soil nutrient levels between low- and high-dung areas, will occur in descending order, for exchangeable K, followed by extractable P, exchangeable Ca and Mg, and total N (West et al. 1989). The K, Ca, Mg, and N concentrations will thus increase with increasing P concentration in soils where there is high dung. The negative correlations that were found between P and Ca, P and K, and P and Mg in this study (Fig 5) do not support this hypothesis.

The P concentration in grassland soils at sites where severe negative species change was recorded, was higher than at other sites (Table 6).

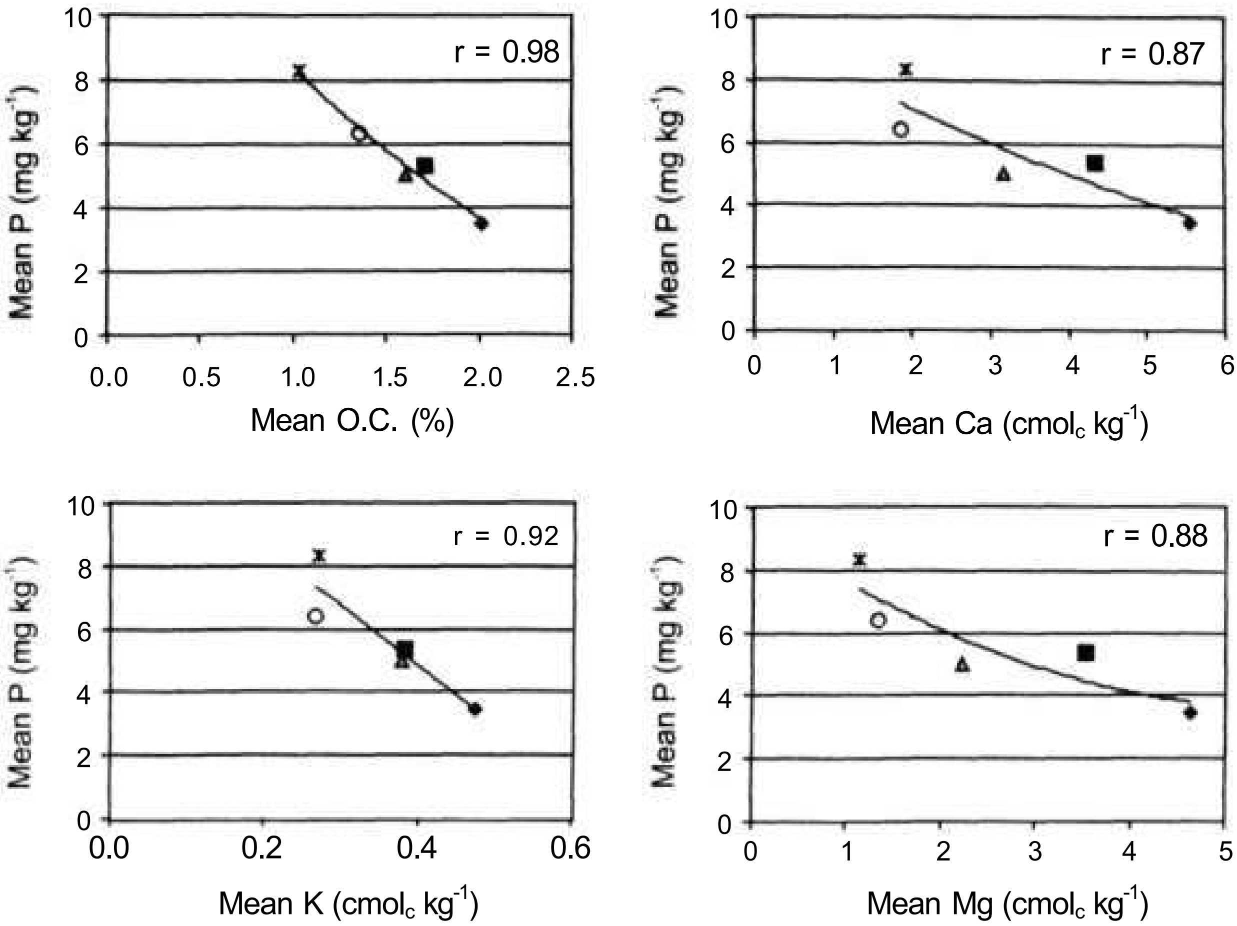



***Figure 5. Relationship between P and other soil properties when degradation of the vegetative cover of grassland sites was considered***

The mean P concentration of soils of alien vegetation sites was also higher than in soils on similar terrain units from natural grassland, 7.7 versus 5.9 mg $kg^{-1}$. It is not clear if higher P concentrations resulted from the invasion of alien plants, or if high P concentrations caused alien plants to invade. High P concentrations could have resulted from nearby agricultural practices such as fertilization and intensive livestock farming, sewage pollution or even from inputs of detergents in upstream sources. The National Research Council

**Table 6. Mean soil P status (mg $kg^{-1}$) of grassland sites as affected by increasing intensity of negative species change**

| | Degradation intensity | | | | |
|---|---|---|---|---|---|
| | No | Light | Moderate | High | Severe |
| Soil P | 5.2 a | 5.18 a | 5.6 a | 5.5 a | 8.2 b |

Figures with different letters are different at p = 0.05

(1993) reported that relatively small annual additions of P may cause a build-up of soil P. Plant invasions are known to occur after the chemical characteristics of a habitat have changed (Cronk and Fuller 1995, Palmer et al. 1999). Certain veld grass species, such as *Themeda triandra, Heteropogon contortus, Setaria sphacelata* and some *Eragrostis* species might never return if soil nutrient levels are built up (Breytenbach 2000).

It is possible that unnaturally high P concentrations in soils create growing conditions favorable for alien plant invasion. Neal (1973), on the other hand, reported that the presence of invader plants significantly increased soil phosphatase enzyme activities. This will increase the turnover of organic P and therefore also increase the plant-available soil P The higher P status of soils from degraded sites can also possibly be attributed to a lower vegetative cover on sites where alien vegetation occurred. Less vegetative growth probably resulted in a lower P uptake by plants. The plant-available P concentration in soils further increased with decreasing soil organic C content when species change was considered. This negative correlation also, as in the case of a low vegetation cover, indicates that a higher surface albedo and subsequent higher decomposition rate of organic C caused the plant-available P to be higher at degraded sites.

When comparing grassland sites that were moderately degraded versus sites that were highly and severely degraded, the mean P concentration differed significantly (Fig 6). Although not statistically significant, P concentration in highly and severely degraded soils did not differ from that in non-degraded or lightly degraded soils (Fig 6).

Soil crusting caused increases in the P concentration at grassland sites. Mean P was 5.7 mg $kg^{-1}$ in soils without crusts, and 8.3 mg $kg^{-1}$ in soils with crusts. These crusts, which are hard and compact, prevent water from infiltrating into soils or removing soil particles during rainstorms. Phosphorus is associated with the mineral fraction of soils which is transported in runoff. Soils without crusts can also sustain higher plant productivity, causing higher P uptake, and hence lower P concentration, than soils with crusts.

There were no differences in soil P between healthy sites and sites that were degraded in terms of biomass production and bush encroachment (data not included). Soil erosion is an important mechanism by which P moves as particulate or dissolved P within the landscape and it would be expected that eroded sites would have a lower bioavailable P status and clay concentration than healthy sites. No difference in soil P between eroded and non-eroded sites was found in this investigation.

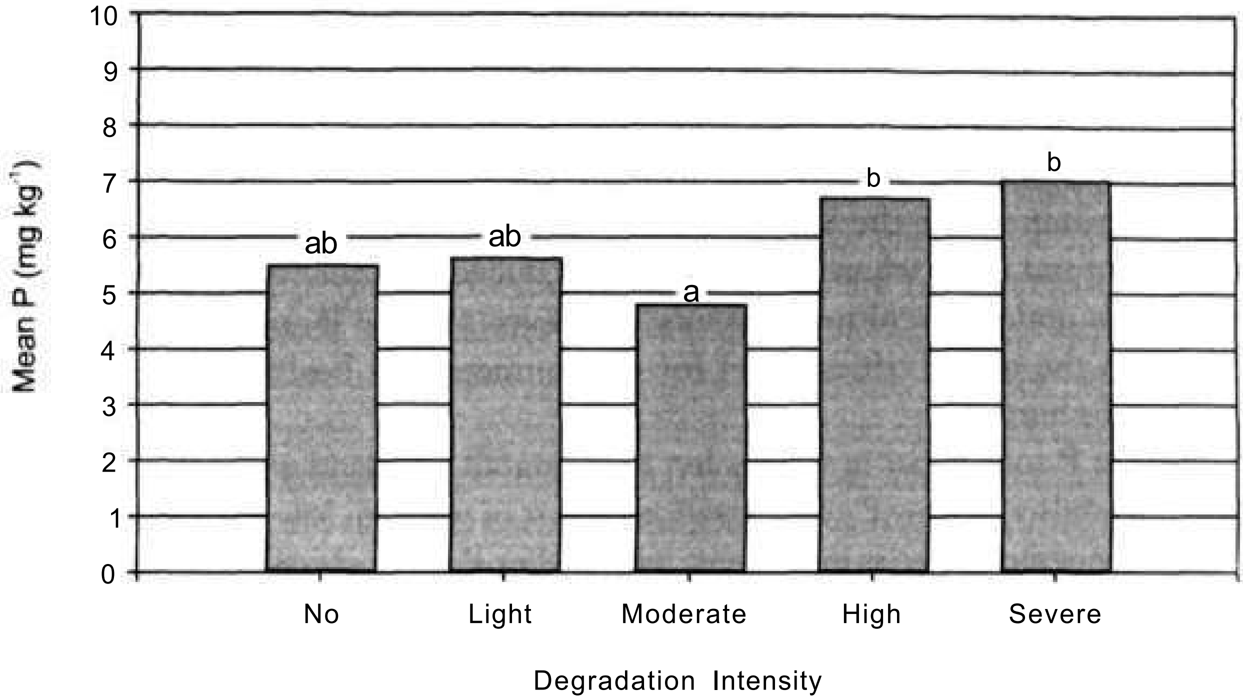



***Figure 6. Mean soil P status of grassland sites as affected by increasing intensity of degradation, bars with different letters are significant by different at p = 0.05.***

The P status of soils for highly degraded savanna sites differed from sites that were slightly, moderately and severely degraded (Appendix 1). No differences in P status were observed for degraded versus non-degraded savanna sites. Soil properties that were also affected by degradation of grassland sites, but not by degradation of savanna sites, were the water saturation percentage, organic C, and sand, silt and clay contents (Wessels et al. 2001). The Savanna Biome is characterized by a grassy field layer and a distinct upper layer of woody plants, while grasslands have a single structural layer (trees are absent). Soil under grass plants differs from soil under individual trees and woody plants by having higher total and mineralizable C, and higher microbial biomass and mineralizable N (Vinton and Burke 1995).

Grassland ecosystems show a fine-scale distribution of soil constituents (Schlesinger et al. 1996), while it can be expected that savanna ecosystems will show a coarse-scale distribution. Patterns of plant growth and nutrient uptake will thus differ between the savanna and grassland ecosystems. Another possible reason why no significant differences in soil P concentrations were found between healthy and degraded savanna sites could be that the number of observations made in each degradation category was not sufficient to allow statistically sound comparisons.

## Conclusions and Recommendations

Analysis of the use of soil P as an indicator of soil quality of natural, undisturbed land in Gauteng Province, South Africa, indicates that the majority of soils on natural land had adequate or high P concentrations. P concentration within the 3.0-5.5 mg $kg^{-1}$ range indicates a productive, healthy soil in natural land, whereas it can mean reduced soil quality and crop yield reduction under agricultural systems. However, the soil P concentrations are less than the upper critical level for environmental or health risk to plants, animals or humans.

Higher P soils occur in the cooler, high rainfall grassland areas of Gauteng, whereas soils with low P concentrations occur in warmer, low rainfall, savanna areas. Topography also is important, with higher P concentrations occurring on crests and higher altitudes. Relatively acid conditions are natural for the Grassland Biome due to the climate and geology. The positive correlation between the P concentration of soils derived from the different geological materials, and the acidity of soils in this study could be due to the enhanced extraction ability of the Bray 1-extracting solution at lower soil pH.

Gauteng Province was mostly degraded in terms of species change and vegetative cover. Soil P concentration was related to the intensity of degradation in terms of vegetative cover on both grassland or alien vegetation sites within the study area. Soil P concentrations were also related to intensity of negative species change, soil crusting and overall degradation of natural grassland sites. The response of soil P to degradation differed from other nutrients investigated in the study by Wessels et al. (2001) in that P concentration generally increased with increasing degradation. This is surprising since soil fertility would be expected to decline with increasing degradation. The P status of severely degraded sites was mostly higher than for non-degraded sites. This was mainly ascribed to superior plant growth on non-degraded sites, which led to higher P uptake rates compared to degraded sites. A higher mineralization rate of organically bound P could also have increased plant-available soil P of sites that were degraded in terms of vegetative cover, since the P increased with decreasing organic C in these soils. It is not clear from this investigation if the higher P concentrations in soils that were degraded in terms of negative species change, resulted from the invasion of alien plants, or if high P concentrations caused invasion by alien plants.

There were no differences in soil P between non-degraded and degraded savanna sites, or between sites that were non-degraded and degraded in terms of biomass production, bush encroachment and soil erosion.

We conclude that soil P can be used as an indicator of specific forms and intensities of environmental degradation of grassland and alien vegetation intrusion. Concentrations of P in soils are less influenced by seasonal variations in rainfall, or episodic rainfall events, than most other nutrients and may provide a reliable measure of nutrient deterioration or enrichment in soils of natural land over a period of time. Caution should be exercised when interpreting or putting into practice the findings of this study since soil quality evaluations were here at a provincial scale and are general and lack precision.

Spatial and temporal heterogeneity in the distribution of soil resources may be indicative of degradation and may further prove to develop most rapidly for the elements that are typically the most limiting to plant growth (Schlesinger et al. 1996). Much remains to be learnt about the spatial distribution of soil P in relation to degradation of natural land and it is recommended that intensive studies be conducted on a localized scale to investigate this matter. Despite clear perceptions about the relation of soil P and land quality in agricultural systems, it is evident that much uncertainty remains about how increased soil P concentrations will impact the structure of food chains, species diversity, composition, and functioning of remaining natural ecosystems.

Since the emphasis is on the change of the indicator with time, we recommend that soil P concentrations of long-term reference sites be monitored to determine the rate of changes and the possible long-term effects if changes were to occur. Baseline P concentrations are now available on a provincial scale against which changes can be evaluated in a monitoring process.

## Acknowledgments

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# Appendix 1. Results of GLM Analyses for Soil P in Biomes

**(a) Deviance ratios (F-values) and probabilities (in brackets)**

| Form of degradation | Alien | Grassland | Savanna |
|---|---|---|---|
| Overall degradation | 2.03 ns | 5.04*** | 4.66*** |
| | (0.108) | (<0.001) | (<0.001) |
| Soil crusting | nd | 5.89* | 0.01 ns |
| | | (0.018) | (>0.25) |
| Soil erosion | 0.74 ns | 0.69 ns | 0.39 ns |
| | (>0.25) | (>0.25) | (>0.25) |
| Species change | 1.07 ns | 5.15*** | 1.30 ns |
| | (>0.25) | (<0.001) | (>0.25) |
| Vegetative cover | 2.42 ns | 7.26 *** | 1.29 ns |
| | (0.085) | (<0.001) | (>0.25) |

**(b) t Probabilities of pair-wise differences**

***Alien vegetation***

| Form of degradation | Intensity of degradation | 1-2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Overall degrad'n | 2 | - | | | |
| | 3 | 0.018* | - | | |
| | 4 | 0.325 | 0.123 | - | |
| | 5 | 0.086 | 0.112 | 0.627 | |
| Vegetative cover | 1-2 | - | | | |
| | 3 | 0.174 | - | | |
| | 4 | 0.055 | 0.723 | - | |
| | 5 | 0.007*** | 0.365 | 0.539 | - |

***Savanna biome***

| Form of degradation | Intensity of degradation | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Overall degrad'n | 1 | | | | | |
| | 2 | 0.600 | | | | |
| | 3 | 0.816 | 0.634 | | | |
| | 4 | 0.091 | 0.002 ** | 0.002** | | |
| | 5 | 0.131 | 0.187 | 0.087 | 0.000*** | - |

*Continued*

**Appendix 1.** *Continued.*

***Grassland biome***

| Form of degradation | Intensity of degradation | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Vegetative cover | 1 | | | | | |
| | 2 | 0.031 * | | | | |
| | 3 | 0.053 | 0.487 | - | | |
| | 4 | 0.002** | 0.107 | 0.003 ** | - | |
| | 5 | 0.000*** | 0.002** | 0.087 | 0.000*** | - |
| Overall degrad'n | 1 | | | | | |
| | 2 | 0.924 | | | | |
| | 3 | 0.470 | 0.074 | - | | |
| | 4 | 0.316 | 0.056 | 0.000*** | - | |
| | 5 | 0.252 | 0.067 | 0.001 *** | 0.702 | |
| Species change | 1 | | | | | |
| | 2 | 0.938 | | | | |
| | 3 | 0.704 | 0.494 | - | | |
| | 4 | 0.766 | 0.580 | 0.910 | - | |
| | 5 | 0.003** | 0.000*** | 0.001 *** | 0.000*** | - |
| Soil crusting | 0 | | | | | |
| | 1 | 0.023* | * | | | |

**(c) Summary of data**

| Intensity of degradation | No. of observations | Mean P (mg $kg^{-1}$) | Standard error of mean |
|---|---|---|---|
| *Alien vegetation: overall degradation* | | | |
| 2 | 4 | 2.506 | 1.310 |
| 3 | 4 | 12.164 | 3.535 |
| 4 | 5 | 6.629 | 1.723 |
| 5 | 85 | 7.553 | 0.476 |
| *Alien vegetation: vegetative cover degradation* | | | |
| 1-2 | 21 | 5.602 | 0.703 |
| 3 | 15 | 7.313 | 1.086 |
| 4 | 24 | 7.822 | 0.918 |
| 5 | 39 | 8.675 | 0.790 |

*Continued*

**Appendix 1.** *Continued.*

| Intensity of degradation | No. of observations | Mean P (mg $kg^{-1}$) | Standard error of mean |
|---|---|---|---|
| *Grassland: vegetative cover degradation* | | | |
| 1 | 11 | 3.447 | 0.645 |
| 2 | 52 | 5.382 | 0.463 |
| 3 | 151 | 5.021 | 0.253 |
| 4 | 95 | 6.398 | 0.407 |
| 5 | 31 | 8.302 | 0.925 |
| *Grassland: negative species change* | | | |
| 1 | 27 | 5.210 | 0.629 |
| 2 | 97 | 5.155 | 0.328 |
| 3 | 90 | 5.489 | 0.363 |
| 4 | 82 | 5.430 | 0.376 |
| 5 | 44 | 8.209 | 0.777 |
| *Grassland: overall degradation* | | | |
| 1 | 11 | 5.427 | 1.027 |
| 2 | 82 | 5.532 | 0.384 |
| 3 | 115 | 4.702 | 0.275 |
| 4 | 95 | 6.634 | 0.427 |
| 5 | 37 | 6.950 | 0.717 |
| *Grassland: soil crusting* | | | |
| 1 | 326 | 5.597 | 0.198 |
| 2 | 14 | 8.327 | 1.420 |
| *Savanna: overall degradation* | | | |
| 1 | 11 | 5.427 | 1.027 |
| 2 | 82 | 5.532 | 0.384 |
| 3 | 115 | 4.702 | 0.275 |
| 4 | 95 | 6.634 | 0.427 |
| 5 | 37 | 6.950 | 0.717 |

nd = Not determined, ns = Statistically not significant at probability level (P) - 0.05
*, **, *** Statistically significant at P = 0.05, P = 0.01, P < 0.001 respectively

# On-Farm Evaluation of Pearl Millet Performance and Water Use in Zai, a Traditional Land Rehabilitation Technique in the Sahel

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## Introduction

An estimated 16-38% of the world's total cropland has been degraded by human activity during the past half century (Oldeman et al. 1990), and 65% of the cropland in Africa is degraded to some extent. In the Sahelian zone of West Africa, land degradation is a major threat to sustainable agricultural production (Roose et al. 1993). Due to increasing population pressure, and the resulting increase in cropped area, fertility restoration through the fallow system is becoming inefficient (Ssali et al. 1985). The limited availability of fertile land is increasing the use of marginal or degraded lands for agricultural production. Zai is a technique that can restore degraded lands. In this method, small pits are dug at a regular spacing on a field, and about two handfuls of organic amendments such as crop residue, manure, or their composted form, are placed in each pit.

The zai pits are 20-40 cm in diameter and 10-15 cm deep, dug into the degraded, crusted soil. Decomposition of the organic material releases nutrients required for crop growth. Biological activity, and especially the action of termites, favor the development of soil macroporosity that improves water infiltration. Besides the supply of valuable nutrients for crop growth, the zai pits promote better infiltration of water locally. Since this water infiltrates deeper than usual, zai ensures that a sizable fraction of the water percolates to depths where evaporation losses are reduced. The zai technique is labour intensive. About 60 working days (average 5 hours per day) are needed to dig 1 ha of zai (Ouedraogo et al. 1996). Since the zai pits can be dug during the dry season, this limitation may not be important.

Studies on zai have been conducted in Burkina Faso, Mali and Niger. Hassan (1996) reported millet yields of 400 kg $ha^{-1}$ with zai in low rainfall years, compared to zero yield without zai treatment. The technique combines water harvesting as well as nutrient management practices, which helps to minimize the diversion of water to where it is unproductive, and ensures that its utilization by the crop is as efficient as possible. Only locally available material is used, and it can deal with the limited availability of organic amendments in the Sahel (Williams et al. 1995, Baidu-Forson 1995). Zai therefore has the potential to be adopted by small-scale farmers, who are the major food producers in the region (Roose et al. 1992).

Resource use efficiency in zai has not been investigated previously. This project was conducted on farmers' fields at two sites with contrasting soil characteristics and rainfall regime in Niger (Damari and Kakassi) during the rainy seasons of 1999 and 2000. It aimed at understanding the interactions between water and nutrient management in the zai technique. The following hypothesis was investigated: The benefits of the zai technique depend on both water catchment area and organic amendment input. Optimizing the ratio of water catchment to various sources or types of organic amendment will provide the best return on investments in amendment and labor. This study examines the effect of different pit sizes and nutrient management techniques on the performance of millet.

# Materials and Methods

## Site description

Experiments were conducted during a two-year period at two locations in Niger: Damari and Kakassi. Damari (13°12'N, 2°14'E) is 45 km SW of Niamey, and 10 km W of the ICRISAT experimental station at Sadore. The long-term average annual rainfall at this site is 550 mm. Kakassi (13°50' N, 1°29' E) is 80 km NW of Niamey. It has a long-term average annual rainfall of 450 mm. The two sites have contrasting drought hazard. Lower rainfall and low soil permeability at Kakassi cause a higher drought risk than at Damari. The experimental sites had been previously used for millet production, but had not been cropped for several years as a result of loss of productivity. They presented clear signs of degradation, such as crust formation, wind/water erosion signs, and hardpan formation.

## Soil and vegetation

At Damari, the experimental field was on an upper glacis, eolian sand over laterite, severely eroded by wind and water. Soil depth to the laterite ranged from 45 cm to 2 m. It is classified as Kanhaplic Haplustult (Soil Survey Staff 1998). The vegetation was open bush with scattered trees. The selected field had been fallow for 3 years prior to the experiment. Except for small patches of loose sand deposits, which were cropped by the farmer, the field presented large patches of bare soil, which were selected for installing the experimental plots. The soil is acidic with relatively high Al saturation and high sand content (Table 1).

The experimental field at Kakassi was on an extended plateau, severely eroded by wind and water. The soil is classified as Vertic Haplustept (Soil Survey Staff 1998). The vegetation is open bush with scattered trees. It was bare soil in a fallow, with scattered patches of cropped areas less affected by erosion. The field had been uncultivated fallow for more than 10 years prior to the experiment. The soil has almost neutral reaction and no exchangeable Al, and relatively high clay content (Table 1). The soil at Kakassi was more fertile than at Damari, although both sites represent degraded land mostly bare of native vegetation.

**Table 1. Initial soil properties (0-20 cm depth) of the Damari and Kakassi fields**

| Soil characteristics | Damari | Kakassi |
|---|---|---|
| pH($H_2O$) | 4.2 | 6.4 |
| pH (KCl) | 3.9 | 5.4 |
| Exch cations, cmol $kg^{-1}$ | 1.7 | 7.9 |
| Exch acidity, cmol $kg^{-1}$ | 1.1 | 0.04 |
| ECEC, cmol $kg^{-1}$ | 2.8 | 7.9 |
| Al saturation, % | 29 | 0 |
| Base saturation, % | 61 | 99 |
| Extr PO4 Bray, mg $kg^{-1}$ | 2 | 08 |
| Organic C, % | 0.2 | 0.2 |
| Total N, mg $kg^{-1}$ | 116 | 169 |
| Bulk density, mg $m^{-3}$ | 1.6 | 1.8 |
| Sand % | 84 | 69 |
| Silt % | 3 | 6 |
| Clay % | 13 | 25 |

ECEC = Effective cation exchange capacity

## Characterization of the organic amendments

*Crop residue.* Millet stems and leaves were collected each year at ICRISAT's research station at Sadore. In 1999, this straw was cut manually into small pieces of about 10 cm, while in 2000 it was done mechanically. They were sun dried before weighing.

*Compost.* Compost preparation was done as suggested by Attikou (1998). In 1999, we used only crop residues and soil mixed with urine from the barn at ICRISAT as a source of micro-organisms. Due to the low quality of the compost of 1999, we decided to use cattle manure as a source of micro-organisms in 2000, but in the same proportion as the barn soil used in 1999. Two holes 80 cm deep, 2.5 m long and 1.5 m wide were used to prepare the compost. The holes were filled at the end of January with successive layers of crop residues and soil or manure from the barn at ICRISAT. The proportion of straw to soil (1999) or cattle manure (2000) was 4/5 to 1/5. Each layer was well irrigated before the next layer was added. The holes were covered with plastic sheets. They were irrigated twice a week with 200 L of water for three months. The compost was mixed 2 and 6 weeks after installation, and 2 weeks before the end of the composting period.

*Cattle manure.* Cattle faeces were collected from the barn at the ICRISAT research station at Sadore in both years, and sun dried before weighing.

*Carbon and nitrogen content.* The C:N ratio of the crop residue was high compared with that of the compost and manure (Table 2). Though the C:N ratio of the compost and manure were similar in 1999, the N content of manure was twice that of either crop residue or compost. The nutrient content of the amendment used was higher in 2000 than in 1999.

**Table 2. Characteristics of organic amendments used in 1999 and 2000**

| Organic amendment | %N | %P | %K | C:N |
|---|---|---|---|---|
| 1999 | | | | |
| Crop residue | 0.83 | 0.10 | 0.98 | 50 |
| Compost | 0.82 | 0.08 | 0.15 | 23 |
| Manure | 1.74 | 0.82 | 0.86 | 20 |
| 2000 | | | | |
| Crop residue | 1.18 | 0.10 | 1.57 | 50 |
| Compost | 1.04 | 0.10 | 0.23 | 32 |
| Manure | 2.53 | 0.94 | 1.72 | 21 |

## Experimental layout

The objective was to quantify the effect of different pit sizes and nutrient management techniques on the performance of pearl millet *Pennisetum glaucum.* There were 3 sowing techniques (traditional flat planting, zai pits of 25 cm and pits of 50 cm diameter), and 3 types of amendments (crop residues, compost and cattle manure), and a control without amendment. Plot size was 6 m x 6 m. In both years, zai pits were dug on 12 May at Damari, and

| Table 3. Dates of operations, 1999 and 2000 seasons | | | | |
|---|---|---|---|---|
| | Damari | | Kakassi | |
| | 1999 | 2000 | 1999 | 2000 |
| Amendment application | 24 May | 7 June | 4 June | 12 June |
| Sowing | 29 June | 26 June | 1 July | 1 July |
| Resowing missing hills | 14 DAS* | 10 DAS | 15 DAS | 13 DAS |
| Plant thinning | 22 DAS | 22 DAS | 22 DAS | 20 DAS |
| Harvest | 26 Oct | 23 Oct | 21 Oct | 31 Oct |

* Days after sowing

29 May at Kakassi. Important dates are listed in Table 3. In both years at Damari, plant growth was retarded. In 1999, there were heavy rains (sand covered the young seedlings in the zai), and in 2000 there were dry spells at the beginning of the rainy season.

The experiment was a factorial RCB design with 4 replications. A local pearl millet variety was sown at 10,000 hills $ha^{-1}$ at both sites (Sadore local at Damari, and Darinkoba at Kakassi). In all experiments, 300 g amendments were applied per hill.

## Observations

*Plant sampling.* To study nutrient uptake during plant growth, whole plants were sampled from 2 hills in the border rows 3 times during the cropping period. The samples were collected from 3 replications out of 4. The first samples were collected approximately 3 weeks after sowing. Afterwards, samples were taken approximately 9 weeks after sowing, and at harvest (Table 4)".

**Table 4. Observations made at Damari and Kakassi, 1999 and 2000**

| | Phenological observation | Plant sampling (DAS) | Observations at harvest |
|---|---|---|---|
| Damari 99 | Days to emergence<br>Plant no. at emergence | 26,76,119 | No. of hills, tillers<br>Straw, head and grain weight<br>1000-seedmass |
| Damari 2000 | | 25,67,122 | " |
| Kakassi 99 | Not done because of remoteness of the site | 22,65,113 | " |
| Kakassi 2000 | | 20,63,123 | " |

Soil sampling was initially at both sites and both seasons, at 20 cm depth

*Plant sample preparation and analysis.* Plant samples were cleaned and dried at 65°C for 48 hours, then weighed and ground to pass a 1 mm mesh size sieve. A 5 g sub-sample was analyzed for total N, P and K. Total N was determined using the colorimetric method based on the Bertholet reaction, after digesting using the Kjeldahl method with $H_2SO_4$, salicylic acid, $H_2O_2$, and selenium. Total P was determined with the colorimetric method based on the phosphomolybdate complex, reduced with ascorbic acid. Total K was determined with flame emission spectrophotometry (all methods based on Houba et al. 1995).

*Soil samples.* Prior to the trial layout, soil samples (0-20 cm depth) were collected to determine the soil characteristics at the sites. They were analyzed for pH($H_2O$) (1:2.5), pH(KCl) (1:2.5), and exchangeable acidity ($H^+$ + $Al^{3+}$) by extraction in IM KCl and titration with 0.025 M NaOH (Van Reeuwijk 1993). Exchangeable cations ($Na^+$, $K^+$ $Ca^{2+}$, $Mg^{2+}$) were determined by extraction in 0.01M AgTU (silver thiourea complex cation) and atomic absorption spectrophotometry (Van Reeuwijk 1993); except for $K^+$, which was determined by flame emission spectrophotometry (Houba et al.1995). Extractable P was determined with the Bray-1 method using extraction with a combination of 0.025N HCl and 0.03N $NH_4F$, and the colorimetric method of the phosphomolybdate complex, reduced with ascorbic acid (Van Reeuwijk 1993). Organic C was determined with the method of Walkley and Black (1934). The soil was digested with a mixture of $H_2SO_4$ and $K_2Cr_2O_7$ (potassium dichromate), and then the remaining $K_2Cr_2O_7$ was titrated with ferrous sulphate ($FeSO_4.2H_2O$) (Van Reeuwijk 1993). For soil texture determination, the samples were oxidized with $H_2O_2$, and then dispersed with a solution of sodium hexametaphosphate. Particles greater than 50 mm were separated by sieving and then weighed. Those less than 50 mm were determined with the pipette method (Van Reeuwijk 1993). ECEC was calculated as the sum of exchangeable base and exchangeable acidity.

*Water balance.* Measurements were made weekly using a neutron probe (Didcot Instrument Company; Station Road, Abingdon, Oxon OX14 3 LD). Two 48 mm diameter aluminum access tubes were installed in each plot. One tube was installed between the hills, and one was installed in/on the hole or hill close to the plant. At Damari the shallowest tube was at 45 cm, while the deepest reached 200 cm. At Kakassi, the shallowest tube was 100 cm, and the deepest was 165 cm. The probe was calibrated in situ against gravimetric determinations. Regression equations derived from the neutron probe calibration were used to calculate the volumetric water content from the weekly readings.

*Data processing and statistical analysis.* Data processing was done with Excel, and the statistical analysis was done by ANOVA using Genstat 5 release 4.1. Due to the large differences between the amended plot and the controls in terms of total dry matter and grain yield, the statistical analysis was done only on data from amended plots. Data from the control plots was analyzed separately. Almost no significant interactions were observed between the treatments in the individual experiment, but wherever any were observed, all of the treatment combinations were reported.

## Results and Discussion

In both years at Damari, rainfall was above the long-term average of 550 mm (Fig 1). At Kakassi, it was 397 mm in 1999, and 490 mm in 2000, compared to the long-term average of 450 mm. Despite a small amount of rain in early June at Kakassi in both years, rainfall adequate for planting was received only at the end of June. Grain yield at both sites was reduced by intermittent dry spells (more than one week without rain) in both years. This is typical of the rainy season in Niger (Sivakumar 1986) (Fig 2).

## Total dry matter and grain yield

Yield data from the control and amended plots are discussed separately as per the statistical analysis, because of the very high difference in yield response. Interaction effect of the treatments was observed on these parameters only at Damari, except for seed yield in 1999. The main treatment effects are therefore presented for both sites, and following that the combined effect of zai and amendment type are discussed.

## Effect of non-amended zai

Millet TDM and grain production on flat-planted, un-amended control plots remained very low, irrespective of the site and year, reflecting the strongly degraded status of the land (Tables 5, 6). Whereas un-amended zai pits did not significantly increase yields compared with the flat control plots at Damari, relatively high yields were produced in the non-amended zai at Kakassi in both years. Except for the extractable P, soil fertility at Kakassi was much higher than at Damari (Table 1). Water harvesting by the zai pits may therefore have

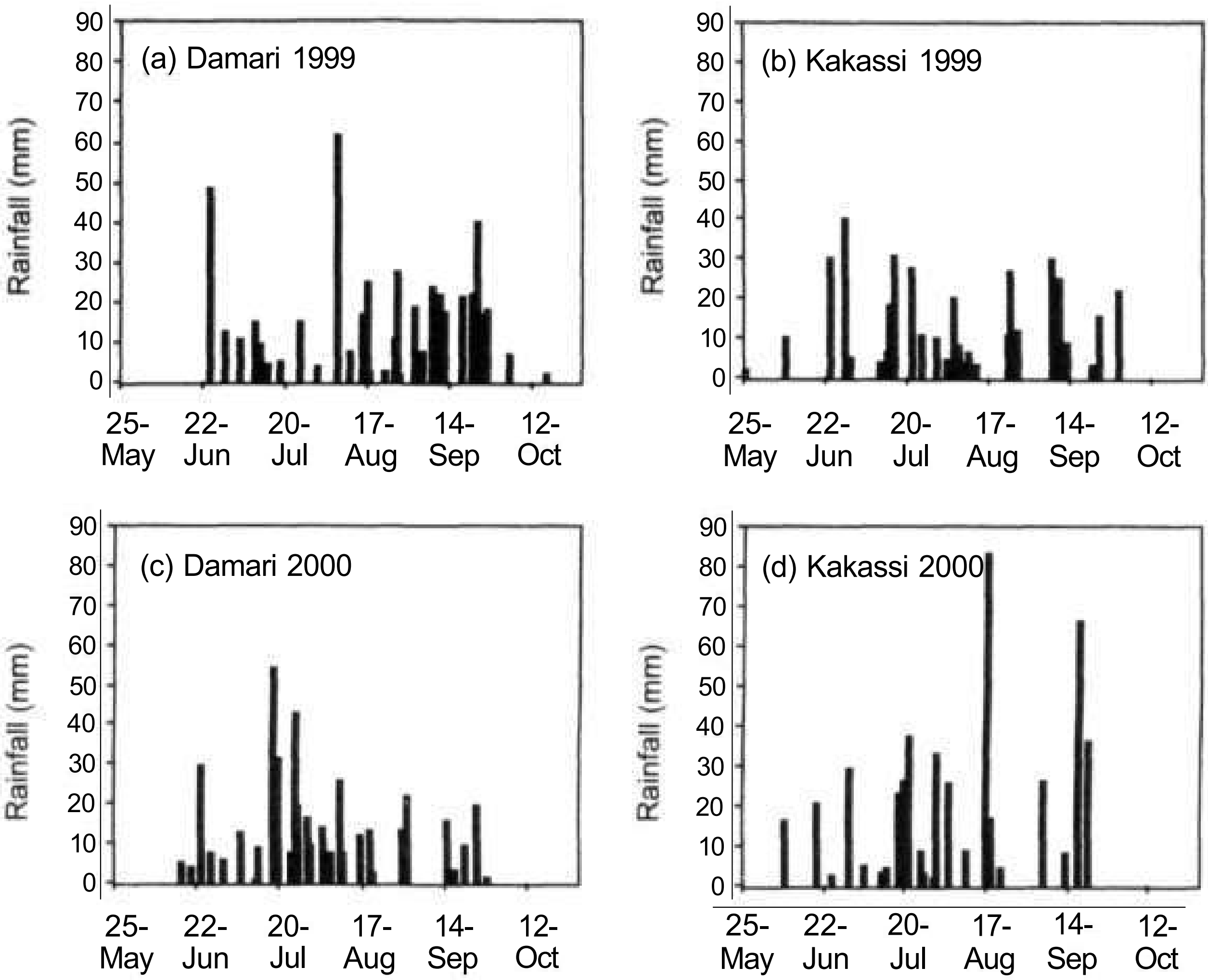


***Figure 1. Daily rainfall distribution at Damari and Kakassi, 1999 and 2000 cropping seasons***

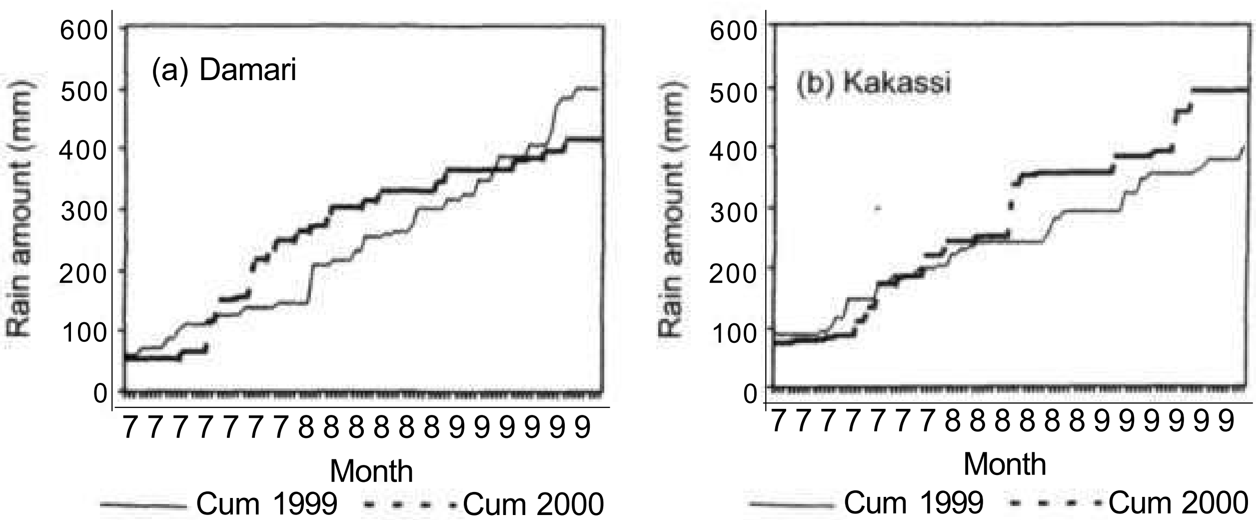


***Figure 2. Cumulative rainfall at Damari and Kakassi during the two cropping seasons. Dry spells visible as horizontal lines***

**Table 5. Effect of sowing techniques (zai versus flat) on millet TDM yield (total dry matter, kg ha$^{-1}$) in control plots at Damari and Kakassi, 1999 and 2000**

| | Damari 99 | Kakassi 99 | Damari 2000 | Kakassi 2000 |
|---|---|---|---|---|
| Zai, 25 cm | 303 | 2125 | 213 | 1938 |
| Zai, 50 cm | 280 | 2775 | 193 | 1415 |
| Flat | 96 | 752 | 101 | 768 |
| $LSD_{0.05}$ | 221 | 795 | 172 | 855 |

$LSD_{0.05}$ = least significant difference at 0.05 probability level

**Table 6. Effect of sowing techniques (zai vs flat) on millet grain yield (kg ha$^{-1}$) in control plots at Damari and Kakassi, 1999 and 2000**

| | Damari 99 | Kakassi 99 | Damari 2000 | Kakassi 2000 |
|---|---|---|---|---|
| Zai, 25 cm | 17 | 434 | 19 | 388 |
| Zai, 50 cm | 8 | 526 | 19 | 260 |
| Flat | 1 | 118 | 6 | 94 |
| $LSD_{0.05}$ | 12 | 203 | 27 | 262 |

overcome the primary constraint for crop production at Kakassi. However, in both years at this site, the zai pits filled up almost completely with wind-blown sand and plant debris before sowing, which may have provided an additional nutrient source to millet.

In this report the tables and figures of 1999 are presented, as the treatment effects are similar for both years in most cases, but the eventual differences are mentioned.

## Effect of amendment type

In Figures 3 and 4, the average effect of zai is reported as no significant differences were observed between the zai pit sizes (25 cm and 50 cm diameter). At both sites in both years, manure application increased TDM and grain yield, compared to the control and the other amendments. Compared treatment by treatment, TDM production under zai was higher than under flat planting, except for the low quality amendments at Damari. At both sites, TDM production with manure was 2-25 times higher than in the un-amended control, both in flat and zai planting. In 2000, the TDM produced with manure was less than in 1999 at both sites, but the trends of the treatment effects were similar to 1999. The TDM produced at Kakassi with compost and crop residue was higher than at Damari in both years (Fig 3).

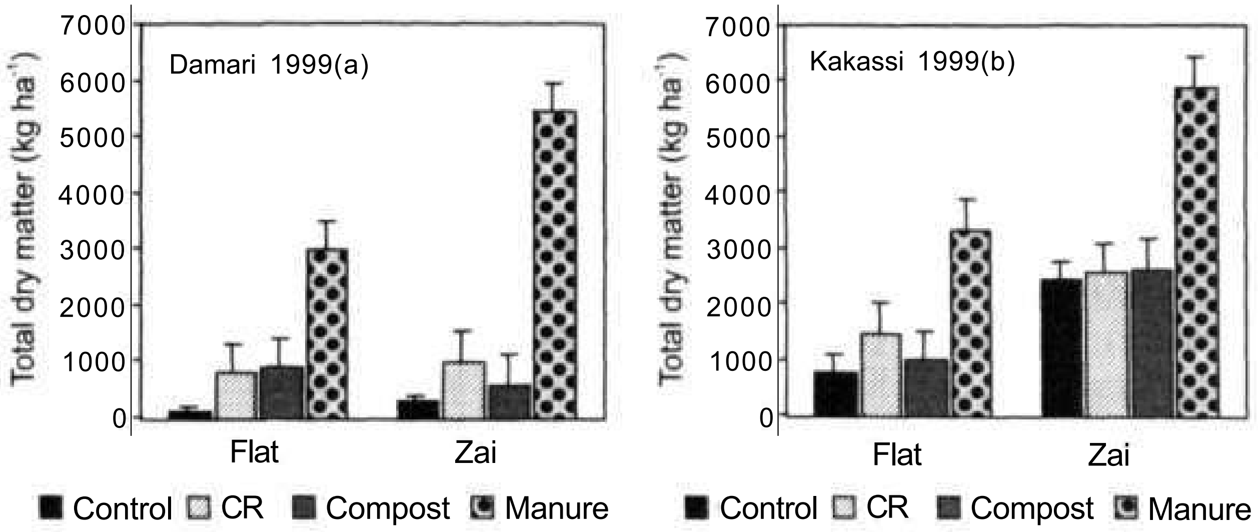


***Figure* 3. *Millet TDM as affected by sowing technique (zai vs flat) and amendment type, at Damari and Kakassi, rainy season 1999. CR = crop residue. Error bars are standard error of difference between means***

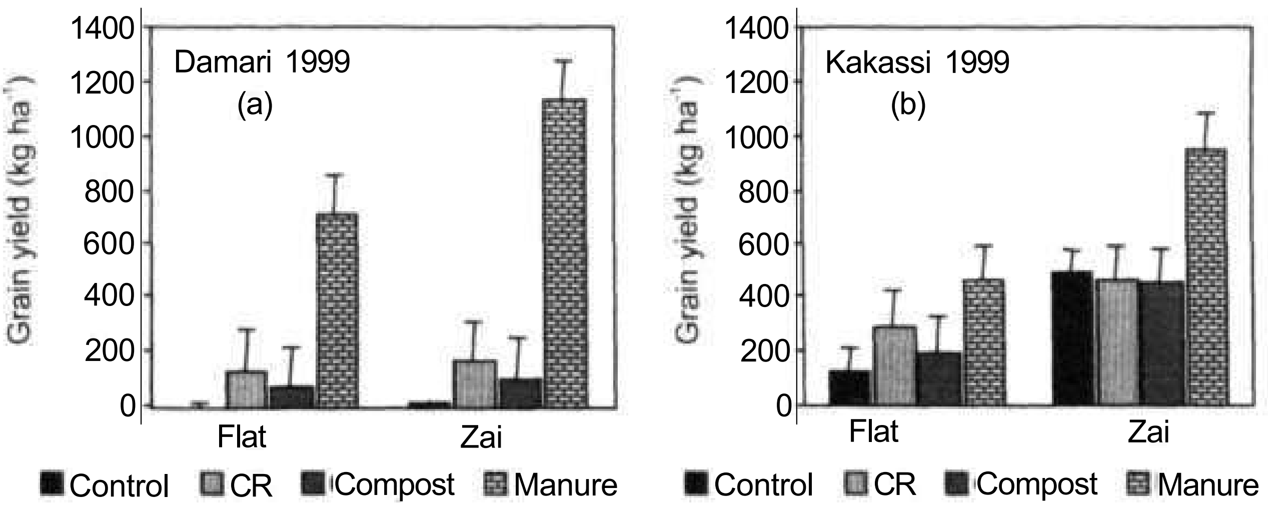


***Figure 4. Millet grain yield as affected by sowing technique (zai vs flat) and amendment type at Damari and Kakassi in rainy season 1999. CR - crop residue. Error bars are standard error of difference between means***

At Damari in 1999, manure application increased the seed yield 90-750 times (both in the zai and flat planting) compared to the control, and 11 and 7-fold compared to crop residues and compost, respectively. At Kakassi in 1999, the grain yield increase was 2 to 4-fold compared to the control and the other amendments (Fig 4). This shows that even on highly degraded soils, high quality organic amendment such as manure can provide good yields. Ganry et al. (1994) reported substantial millet TDM production (3500 kg ha$^{-1}$) on a sandy soil in Senegal with manure application. Pichot et al. (1981), Cisse

(1988), Rani (1988), Bationo et al. (1991), and van Duivenbooden et al. (1993) also reported a millet yield increase due to manure application.

The low grain and TDM yields obtained with crop residue and compost at both sites (Fig 4) resulted from the low nutrient content of these amendments, especially in terms of N and P (1% and 0.1% for crop residues, and 0.9% and 0.1% for compost, compared to 2% and 0.9% for cattle manure). The lowest yields with crop residue and compost were at Damari, suggesting that at Kakassi, the relatively higher native soil fertility compensated for the lower nutrient content of the amendments.

A similar effect was observed in 2000, but the overall grain yield was lower than in 1999. Michel et al. (1995b), Bationo et al. (1991), Hafner et al. (1993), and Buerkert et al. (1996) reported a positive effect of crop residue application on millet grain and TDM yield (residue applied as mulch). Incorporation of material with high C:N ratio and low initial N content leads to N and P immobilization (Tian et al. 1992, Thomas et al. 1993, Seligman et al. 1986, Watkins et al. 1996, Hood et al. 1999). This produced an asynchrony between plant requirement and nutrient release that may have caused the low yields with crop residue and compost.

Millet grain yield response to manure was more pronounced at Damari than at Kakassi. This better relative response may be explained by the soil characteristics. In the acidic soils of Damari, the organic amendment may have helped to bind the aluminum in the soil and thereby reduce P fixation (Bationo et al. 1989, Kretzschmar et al. 1991). Thus, P availability to millet at Damari may have been increased by the addition of manure.

A treatment interaction effect on grain yield was significant only in 2000. A possible explanation is that during the frequent dry spells that year, the zai could secure water, and therefore increased the effect of the amendment, particularly cattle manure. Increased effectiveness of manure resulted in TDM increases of 83 and 78%, and grain yield increases on average of 60% at Damari and 100% at Kakassi in 1999, compared to flat planting (Fig 4). This could be due to the combined effect of the readily available nutrients from the nutrient-rich manure and the water harvested in the zai pits. A more pronounced effect of zai combined with cattle manure on grain yield (90% increase on average for both sites) compared to flat amended was observed in 2000. There was no significant effect of pit size on millet grain yield at either location.

## Nutrient uptake

Zai increased N, P and K uptake by a factor of 2 to 3 compared to flat planting (Tables 7, 8). This increase was greatest in plots amended with manure. Nutrient uptake increased mainly at harvest at both sites and in both years ($P<0.05$). No significant interaction effect was observed between the main treatments, except for nutrient uptake at harvest due to the combined effect of zai and manure application. Zai pit size did not have any effect.

At both sites and in both years, manure application increased N, P and K uptake compared to the other treatments throughout the cropping period (Tables 9, 10). In most cases N, P and K uptake was increased by a factor of 3 due to manure application. At both sites and years, N, P and K uptake of millet amended with crop residues and compost was higher than the uptake in the control plots.

Increased nutrient uptake in the zai, particularly in plots amended with manure, might result from the better timing of nutrient release and the higher nutrient content of the manure. Zai might have favored root development and thereby increased the volume of soil explored. The initial N and P levels in crop residues and compost were low Even though most of the nutrients from

**Table 7. Effect of planting techniques (zai vs flat) on millet N, P, and K uptake (kg ha$^{-1}$), Damari, rainy season 1999**

| | 36 DAS | | | 76 DAS | | | 119 DAS stover | | | 119 DAS grain | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | N | P | K | N | P | K | N | P | K |
| Zai, 25 cm | 1.21 | 0.11 | 1.80 | 19.9 | 4.25 | 23.8 | 14.0 | 3.26 | 23.6 | 7.75 | 1.04 | 2.19 |
| Zai, 50 cm | 1.45 | 0.11 | 2.15 | 17.5 | 3.12 | 18.8 | 18.5 | 3.65 | 27.1 | 8.60 | 1.05 | 2.25 |
| Flat | 1.55 | 0.08 | 2.09 | 21.4 | 5.00 | 27.1 | 11.0 | 2.34 | 17.4 | 4.92 | 0.63 | 1.25 |
| LSD | 0.48 | 0.03 | 0.72 | 12.3 | 3.21 | 15.0 | 4.6 | 1.04 | 9.2 | 3.75 | 0.52 | 0.97 |

**Table 8. Effect of sowing techniques (zai vs flat) on millet N, P and K uptake, Kakassi, rainy season 1999**

| | 22 DAS | | | 65 DAS | | | 113 DAS stover | | | 113 DAS grain | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | N | P | K | N | P | K | N | P | K |
| Zai, 25 cm | 0.77 | 0.08 | 1.18 | 42.9 | 7.3 | 57.2 | 22.1 | 9.1 | 45.1 | 14.1 | 2.7 | 3.5 |
| Zai, 50 cm | 0.59 | 0.05 | 0.93 | 33.1 | 5.4 | 42.9 | 29.3 | 11.8 | 57.7 | 15.4 | 2.8 | 3.8 |
| Flat | 0.28 | 0.03 | 0.45 | 20.4 | 3.3 | 26.3 | 14.4 | 5.3 | 26.3 | 7.2 | 1.3 | 1.8 |
| $LSD_{0.05}$ | 0.33 | 0.04 | 0.50 | 14.4 | 2.5 | 20.6 | 6.9 | 2.1 | 9.9 | 3.6 | 0.7 | 0.9 |

**Table 9. Effect of organic amendment type on millet N, P and K uptake, Damari, rainy season 1999**

| | 36 DAS | | | 76 DAS | | | 119 DAS stover | | | 119 DAS grain | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | N | P | K | N | P | K | N | P | K |
| Control | 0.60 | 0.03 | 0.64 | 3.6 | 0.50 | 3.3 | 3.6 | 0.53 | 3.2 | 0.2 | 0.02 | 0.06 |
| Crop residues | 1.38 | 0.07 | 1.88 | 15.8 | 2.95 | 18.8 | 8.6 | 1.74 | 13.2 | 3.1 | 0.39 | 0.76 |
| Compost | 0.79 | 0.03 | 0.96 | 6.0 | 0.96 | 6.1 | 7.6 | 1.50 | 11.0 | 2.1 | 0.27 | 0.57 |
| Manure | 2.86 | 0.27 | 4.57 | 53.0 | 12.1 | 64.8 | 38.1 | 8.56 | 63.4 | 22.9 | 2.95 | 6.19 |
| $LSD_{0.05}$ | 0.56 | 0.04 | 0.83 | 14.2 | 3.71 | 17.3 | 5.3 | 1.20 | 10.6 | 4.3 | 0.60 | 1.12 |

**Table 10. Effect of organic amendment type on millet N, P and K uptake, Kakassi, rainy season 1999**

| | 22 DAS | | | 65 DAS | | | 113 DAS stover | | | 113 DAS grain | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *N* | P | K | N | P | K | N | P | K | N | P | K |
| Control | 0.24 | 0.02 | 0.35 | 20.8 | 3.2 | 27.4 | 15.4 | 5.4 | 29.7 | 9.4 | 1.7 | 2.3 |
| Crop residues | 0.44 | 0.04 | 0.64 | 20.7 | 2.9 | 28.9 | 17.3 | 6.5 | 32.4 | 9.9 | 1.9 | 2.5 |
| Compost | 0.52 | 0.03 | 0.78 | 24.1 | 4.0 | 33.4 | 15.6 | 6.4 | 33.0 | 8.3 | 1.5 | 2.0 |
| Manure | 0.97 | 0.12 | 1.64 | 62.9 | 11.2 | 78.9 | 39.6 | 16.6 | 77.1 | 21.4 | 3.9 | 5.4 |
| $LSD_{0.05}$ | 0.37 | 0.05 | 0.58 | 16.6 | 2.9 | 23.7 | 8.0 | 2.4 | 11.4 | 4.1 | 0.08 | 1.0 |

these sources may be released, the amount released might not have met the full requirements of the plant. Slower nutrient release might also have brought about an asynchrony between plant needs and nutrient release.

## Water balance - volumetric water content

At both sites in both years, the wetting front moved faster in zai than in flat planting (data not presented). This was more pronounced at Damari, where at sowing in 1999, the wetting front was below 150 cm depth, probably due to the sandy nature of the soil and its low organic matter content. Almost no progress of the wetting front was observed in plots not treated with zai and amended with manure.

Soil water was not measured at Kakassi in 1999 before sowing. At this site, the volumetric water content in the upper 60 cm increased more in the zai than under flat sowing (data not presented). On flat-sown plots, and mainly those amended with manure, the water content below the upper 30 cm soil layer did not change much.

Similar treatment effects were observed in 2000. Except for the increased water content in the plots with 50 cm diameter zai pits, the trends were similar to the plots treated with 25 cm diameter zai pits (Fatondji 2002). Soil water content in the profile decreased markedly towards harvest, which suggests important transpirational and evaporative use induced by increased biomass production, particularly in plots amended with cattle manure.

## Plant available water

In both years and at both sites, almost all the plant available water (PAW) was consumed at harvest, more so on plots amended with manure (Fig 5). At Kakassi in both years, PAW was regularly fully depleted (particularly in 2000) on plots amended with manure. At this site, both seasons started with a period of water shortage, which occurred again in the period between 60 and 80 DAS in 2000. From 90 DAS to harvest, PAW was exhausted in both years, but water shortage did not cause any drastic grain yield loss, as is the case when water shortage occurs during flowering and grain filling (Fussell et al. 1980). Nevertheless, grain filling may have been affected in flat-sown plots amended with cattle manure, if the plants ran out of water during grain filling.

Penning de Vries and Djiteye (1982) and Breman and de Wit (1983) maintained that nutrient (but not water) availability was the most important limiting factor for agricultural production in the Sahel. However, Bationo et al. (1990) reported poor response of millet to N application in dry years, and Payne et al. (1995) argued that the nutritional aspect of agriculture in the Sahel could not be considered without the water component. Many studies have shown that a strong interaction exists between the availability of water and plant nutrients, and that changing one factor can greatly affect response to the other. Increased water supply not only directly enhances fertilizer response, but may also affect native nutrient availability and utilization efficiency. Plants grown with an adequate nutrient supply extend roots deeper than if the soil is deficient in one or more nutrients (Payne et al. 1995). Increased root proliferation increases the potential water use, thus reducing the probability of plant growth being restricted by intermittent periods of drought. Therefore, it is imperative to promote technologies that combine both factors and consequently help rehabilitate degraded lands. The study showed that zai enhanced soil water storage and increased PAW, but on soils with low water holding capacity like at Damari, most of this water can be lost. The use of high-quality organic amendment, which promotes rapid and deep root growth, helps limit this loss as well as the associated nutrient loss.

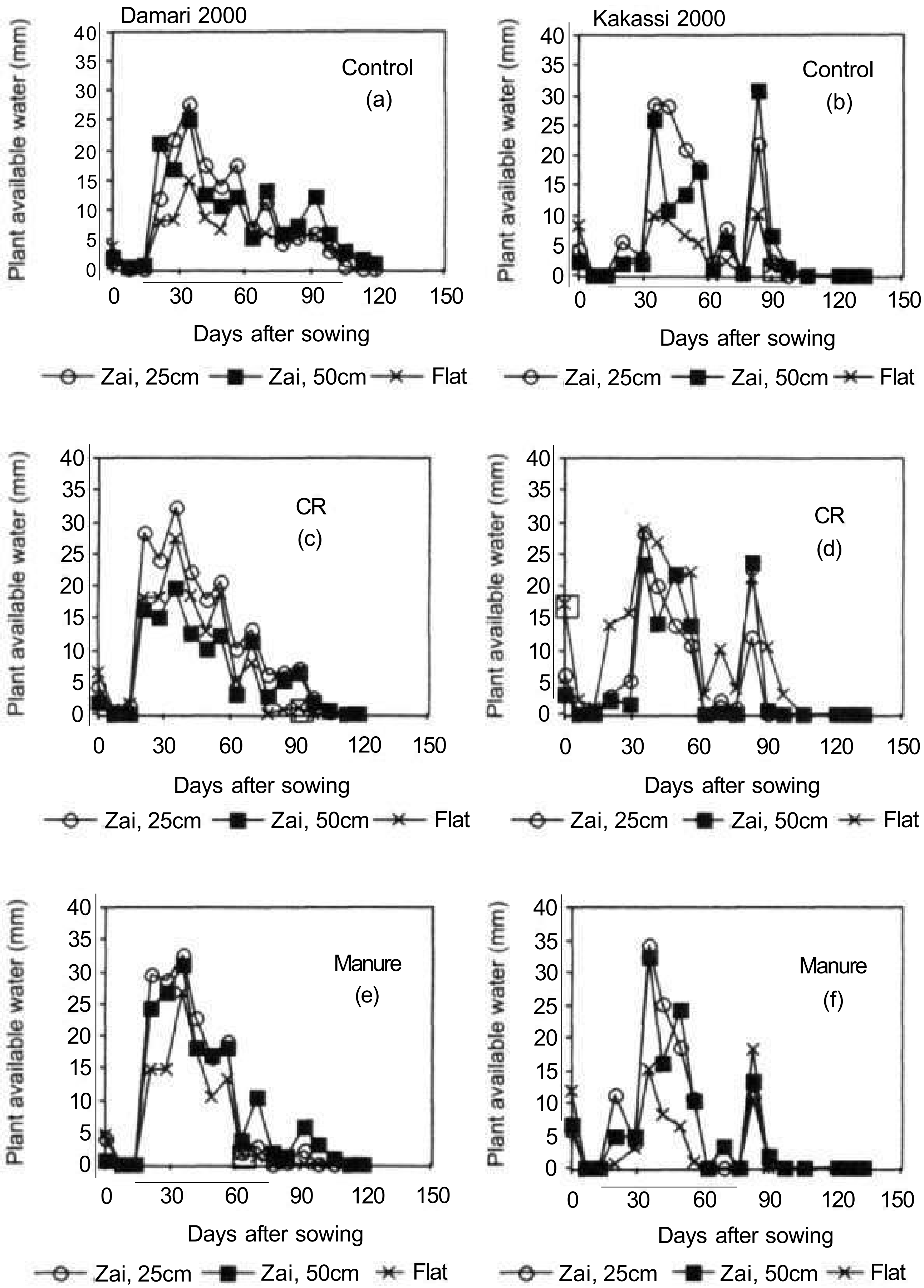


***Figure 5. Plant available water as affected by planting technique and amendment type, Damari and Kakassi, 2000***

At the end of the growing period, most of the PAW was consumed in all planting techniques and at all sites, particularly in plots amended with manure. On plots with good plant development, this was possibly a result of increased shoot development, whereas on the other plots, a large fraction of this water might have evaporated, or percolated into deeper soil layers.

## Summary

Millet productivity remained very low on flat-planted un-amended control plots, particularly on the highly degraded soils at Damari. The yield recorded with the application of the organic amendments, showed that the amendment was crucial, but good quality amendments like the manure used in our experiment is needed to produce high yields. On soils with better native fertility (as at Kakassi), the yield gains by using zai without amendment are important. The physical loosening of the soil by digging the zai and the run-off water collected have removed the main barrier to crop production at this site. It appears that here the importance of zai lies mainly in its ability to secure the crop during short dry spells. The high yield recorded at both sites with the application of cattle manure points to an interaction between the water and nutrient aspects of zai. As this was more prominent on highly degraded sandy soils, farmers should always apply zai when planting under these conditions, but if they have access to better soil fertility, zai only pays off if dry spells are to be expected.

The progress of the wetting front, as well as the pattern of the changes in the plant available water through the season, show that under both soil conditions, zai can provide the crop with water through the season. This was not evident in flat planting, where the plants may even suffer water shortage, particularly at Kakassi. It appeared that on the highly degraded sandy soils at Damari, a sizable part of the runoff water collected in the zai pit could percolate to a deeper layer to feed the underground water table.

## Conclusions and Recommendations

From this study the following conclusions can be drawn:

- On soils with moderate native fertility, substantial yield could be produced with zai, reflecting the importance of the water collection aspect of zai. Under these conditions, the efficiency of zai is more reflected when dry spells occur.

- Increased TDM and grain yield is possible when using zai technique in the Sahel, particularly on highly degraded sandy soils, where more than 1000 kg $ha^{-1}$ millet grain yield was obtained when the zai pit was amended with cattle manure at 3 t $ha^{-1}$.
- The yield gains in zai compared to flat planting, point to the importance of zai pits under high and low soil fertility conditions, particularly when good quality amendment is used.
- A good quality organic amendment is essential on highly degraded soils. The scarcity of animal manure might be a constraint to the use of zai. However, farmers are able to prepare good quality compost using all kinds of domestic waste, weeds and leguminous residues before and during the onset of the rainy season. In this study, such quality compost was not available, which resulted in the low grain and straw yields recorded with this amendment.
- The zai pit enhances run-off water collection and infiltration. On soil with low water-holding capacity and low organic matter content, high quality organic amendments that assure good plant growth, need to be used to make use of this water, and limit the losses through drainage and evaporation.

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# Session 3. Progress Reports of OSWU Projects

# Zero and Minimum Tillage as Alternatives to Conventional Cultivation in Dryland Fallow/Wheat and Annual Cropping Systems in Central Anatolia

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## Introduction

In Turkey, 16 million ha of land within land use classes I, II, III and IV has been under cultivation without conservation measures, although the need for increased conservation practices increases as the class number increases. About 5 million ha in classes VI and VII has been used for dryland agriculture although it is better suited for grazing land or forest (Topraksu 1980). At present, there is no possibility of re-allocating this 5 million ha for pasture and grazing or reforestation. There is severe or very severe water erosion on 53% of Turkish land; and medium class erosion on another 23%. Wind erosion affects 0.6% of land. Most of the affected land is in Central Anatolia. (Topraksu 1980).

Clean fallow (compared to retained crop residue) is more vulnerable to soil and water loss through erosion. This is a problem in most of the Central Anatolian plateau, particularly in steep sloping areas. In the wheat/ fallow system, retention of stubble on the soil surface results in 36% less water runoff, 29% less soil loss, and 23% greater wheat yield than when stubble is burnt (Ayday 1980). Sayin (1983) demonstrated that burning of stubble resulted in 24% more water runoff, and 100% more soil loss in a fallow/wheat system. Higher wheat yields were also obtained with stubble retained than when stubble was burnt.

The tillage practiced by farmers in annual cropping systems increases susceptibility to soil and water loss as it removes residues from the surface of the seedbed. Wheat stubble on the field after harvest is usually burnt for easy seeding of the following legume crop. Legumes are harvested by hand, and all the crop biomass is removed from the field.

In the Central Anatolian plateau, crop management research programs have so far focused on tillage in the fallow/wheat system, with limited or no consideration to other systems such as no tillage or minimum tillage (Avci

1998). No tillage and minimum tillage systems which retain crop residue, might play a role in water conservation, preventing soil loss, increasing yield and sustaining long-term production.

One of the primary benefits of zero or reduced tillage is lower production cost compared to conventional systems. The ratio of cost of soil cultivation to total production cost varies with the socioeconomic conditions of farmers. Generally small-scale farmers rent tillage equipment from rich farmers. The cost ratios of soil cultivation were 24% for rich farmers and 32% for poor farmers in fallow/wheat production systems in Central Anatolia (Kabakci and Anderson 1994). This ratio can be higher in annual cropping systems than in fallow/wheat since one more moldboard plowing and successive disk or sweep operations are needed. The ratios in both systems can be substantially reduced by introducing minimum tillage, or better still, zero-tillage systems.

A systematic effort is required to (i) assess no-tillage and reduced tillage systems in terms of water economy, (ii) compare the tillage systems in terms of crop yields, and feasibility for production economy, weed, pest and disease control.

## Materials and Methods

The experiment was conducted at Haymana Research Farm near Ankara (39° 40' N, 32°39' E, altitude 1055 m). Long-term rainfall average is 332 mm with high variability. On average 34% of total rainfall occurs in spring, 13% in summer (first half of June), 18% in autumn, and 35% in winter (mostly snow). The site has a typical dry continental climate. Soil is poor in organic matter (1-2%) and high in $CaCO_3$ (24%). The 0-20 cm layer contains about 23% sand, 37% silt, and 40% clay; and has a pH of 7.8.

Three treatments were used: fallow-wheat, chickpea-wheat and continuous wheat. The experiment had four replications.

## Fallow-wheat system

*Conventional fallow-wheat/barley system.* The fallow phase consists of a series of tillage operations to create a soil mulch, to combat weeds, and for final seedbed preparation. The tillage operates in the following scheme:

- First tillage (primary tillage) after wheat harvest in July/Aug: Time - spring, whenever the soil becomes workable. Implement - moldboard plow. Depth 18-20 cm.

- Follow up operations: Time - after the solstice (20-21 June), when soil crust has formed and weeds occupy the field. Implement - sweep + spike harrow combination. Depth 8-10 cm at first operation, 6-8 cm on succeeding operations.
- As a no-till alternative to the conventional system, a chemical fallow - wheat treatment was introduced in the trial. Contact herbicides were used to control weeds that emerged during the fallow phase. Like the conventional system, there are two phases - chemical fallow and chemical wheat.

### Chickpea-wheat system

In the chickpea-wheat system, in which fallow is eliminated, no till and minimum tillage (which is actually conventional tillage) are compared.

*Minimum tillage.* For chickpea: as early in spring as is feasible, broadcast the seed into the field with wheat stubble and cover with moldboard plow, followed by a trunk (roller) to press down the seed and smooth the surface. For wheat: after the chickpea harvest around August, one pass of sweep + harrow or offset disk.

*Zero-tillage.* For chickpea: as early in spring as is feasible, seed into wheat stubble with no-till drill, and spray with a pre-emergence herbicide. For wheat: sow wheat with no-till drill without tillage in late Sep or early Oct.

### Continuous wheat (wheat-wheat)

In the wheat-wheat cropping system, no tillage and minimum tillage are compared. Direct seeding is done into wheat and barley stubble.

## Climatic Data

Total precipitation was 216, 403 and 375 mm, during 2000/01, 2001/02 and 2002/03 seasons respectively (Table 1). The long-term average precipitation in the area, for the growing period, is 332 mm. In terms of monthly average temperatures, 2000/01 was hotter throughout the growing season, 2001/02

**Table 1. Monthly and seasonal precipitation (mm) for Haymana Research Farm.**

| | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2000/01 season | 9 | 23 | 13 | 36 | 0 | 23 | 24 | 23 | 65 | 0 | 216 |
| 2001/02 season | 11 | 5 | 3.6 | 98.1 | 113 | 34 | 2 | 47 | 82 | 7.5 | 403 |
| 2002/03 season | 63 | 15 | 18 | 23 | 53.5 | 56.9 | 18 | 75 | 53 | 0 | 375 |
| Long term average | 15 | 27.5 | 32.4 | 41.9 | 39.7 | 28.1 | 31.5 | 43.8 | 47.6 | 24.0 | 332 |

was average, 2002/03 was colder in winter than the long-term average.

## Results and Discussion

### Weeds

As the seasons in the project area were moist, weeds were a problem, especially in continuous wheat plots, whether direct or normal seeded. Cheat grass (*Bromus tectorum*) was the dominant weed. These plots were a source of cheat grass seed, permitting spread to neighboring plots which became infested with weeds. Because of emergence of cheat grass with early rains, it was necessary to eliminate these weeds using paraquat (gramoxone) at 1000 g $ha^{-1}$ dosage.

### Soil moisture

Soil moisture was measured before seeding and after harvest.

*Fallow-wheat system.* In 2001, accumulated soil moisture in upper and deeper

**Table 2. Wheat pre-seeding soil moisture (mm) under chemical-no-tillage (NT) and conventional tillage (CT) in fallow-wheat cropping system.**

| | | Soil depth (cm) | | | | |
|---|---|---|---|---|---|---|
| | Type of fallow | 0-10 | 10-30 | 30-60 | 60-90 | 0-90 |
| 2001 | Chemical (NT) | 6.7b | 73.5 | 127.4 | 125.1b | 332.6 |
| | Clean (CT) | 18.3a | 70.8 | 135.4 | 159.3a | 383.9 |
| 2002 | Chemical (NT) | 17.4 | 64.3 | 104.8 | 117.1 | 303.6 |
| | Clean (CT) | 18.1 | 66.7 | 110.4 | 126.4 | 321.6 |
| 2003 | Chemical (NT) | 15.1 | 73.5 | 139.2 | 151.8 | 379.6 |
| | Clean (CT) | 13.4 | 70.5 | 134.4 | 148.6 | 367.0 |

**Table 3. Wheat post-harvest soil moisture (mm) under chemical-no-tillage (NT) and conventional tillage (CT) in fallow-wheat cropping system.**

| | | Soil depth (cm) | | | | |
|---|---|---|---|---|---|---|
| | Type of fallow | 0-10 | 10-30 | 30-60 | 60-90 | 0-90 |
| 2001 | Chemical (NT) | 7.6b | 32.8 | 48.5 | 45.7 | 134.6 |
| | Clean (CT) | 16.6a | 33.6 | 56.8 | 62.5 | 169.4 |
| 2002 | Chemical (NT) | 18.2 | 67.3 | 132.7 | 143.9 | 362.0 |
| | Clean (CT) | 21.8 | 74.1 | 146.8 | 136.1 | 378.7 |
| 2003 | Chemical (NT) | 13.9 | 53.9 | 101.5 | 116.6 | 285.9 |
| | Clean (CT) | 14.0 | 59.6 | 99.0 | 120.9 | 293.5 |

**Table 4. Wheat post-harvest soil moisture (mm) under no-tillage and conventional tillage in chickpea-wheat system.**

| | | Soil depth (cm) | | | | |
|---|---|---|---|---|---|---|
| | Type of fallow | 0-10 | 10-30 | 30-60 | 60-90 | 0-90 |
| 2001 | Conventional | 7.6 | 35.0 | 56.5 | 54.4 | 153.6 |
| | No-tillage | 6.0 | 34.3 | 57 0 | 54.6 | 151.8 |
| 2002 | Conventional | 9.4 | 31.4 | 51.6 | 59.5 | 151.9 |
| | No-tillage | 11.1 | 34.3 | 53.6 | 37.5 | 136.5 |
| 2003 | Conventional | 6.7 | 25.8 | 48.6 | 54.7 | 135.8 |
| | No-tillage | 6.5 | 32.7 | 49.7 | 52.8 | 141.7 |

zones at time of wheat planting was more with clean fallow than with chemical fallow. In other years, there were no significant differences (Table 2). After harvest of wheat, there were no significant differences in soil moisture between the two fallow systems, except in the surface layer, 0-10 cm (Table 3).

*Chickpea-wheat system.* Soil moisture results showed no noteworthy differences between conventional tillage versus no-till (Table 4).

*Continuous wheat system.* No-till provided more soil moisture value at wheat planting than conventional minimum tillage. It was statistically significant in 2002 (60-90 cm and profile total) and 2001 (only 60-90 cm) (Fig 1).

Wheat yields under no-till versus conventional clean tillage, were equal in 2001.But over the 3 seasons, conventional clean tillage gave slightly higher yield (Fig 2). With respect to stand establishment, the number of plants/$m^2$ was higher with clean tillage than with no-till (Fig 3).

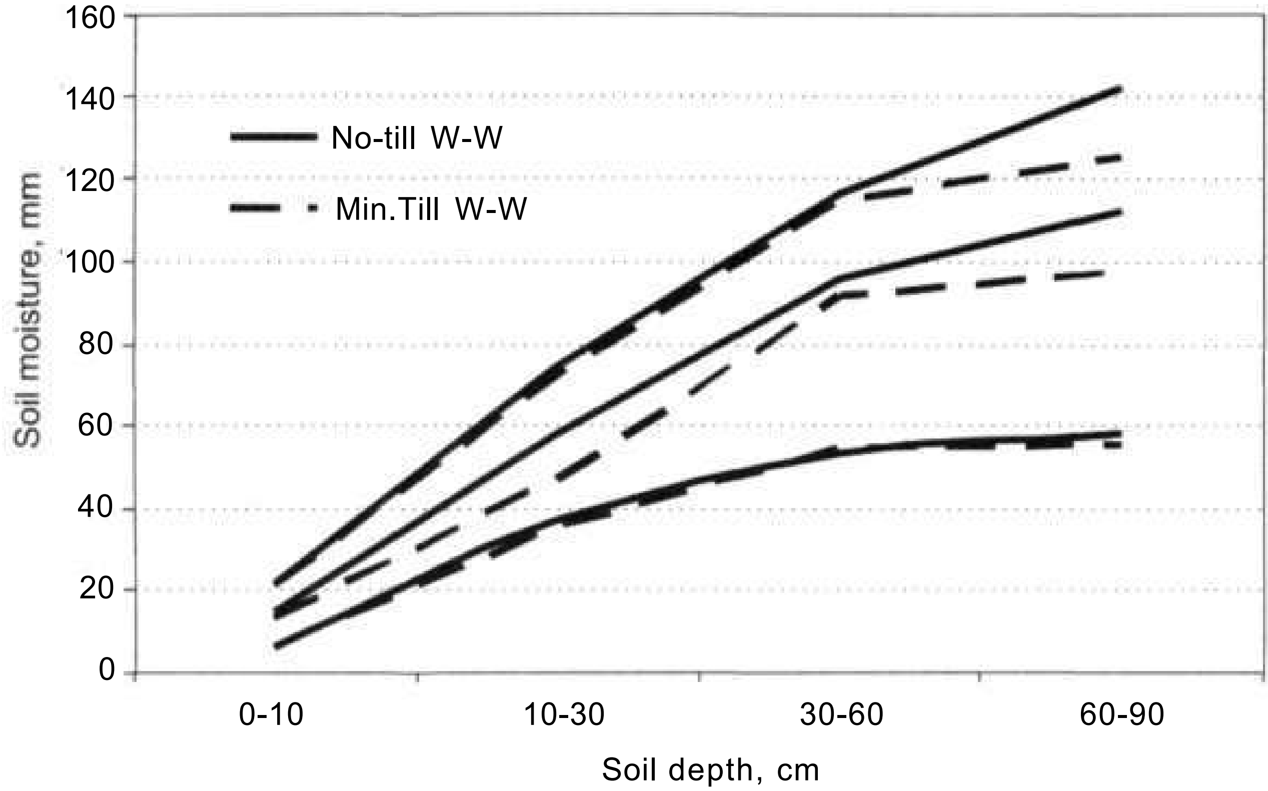


***Figure 1. Effects of no-tillage and conventional minimum tillage on moisture (mm) in soil profile in continuous wheat system.***

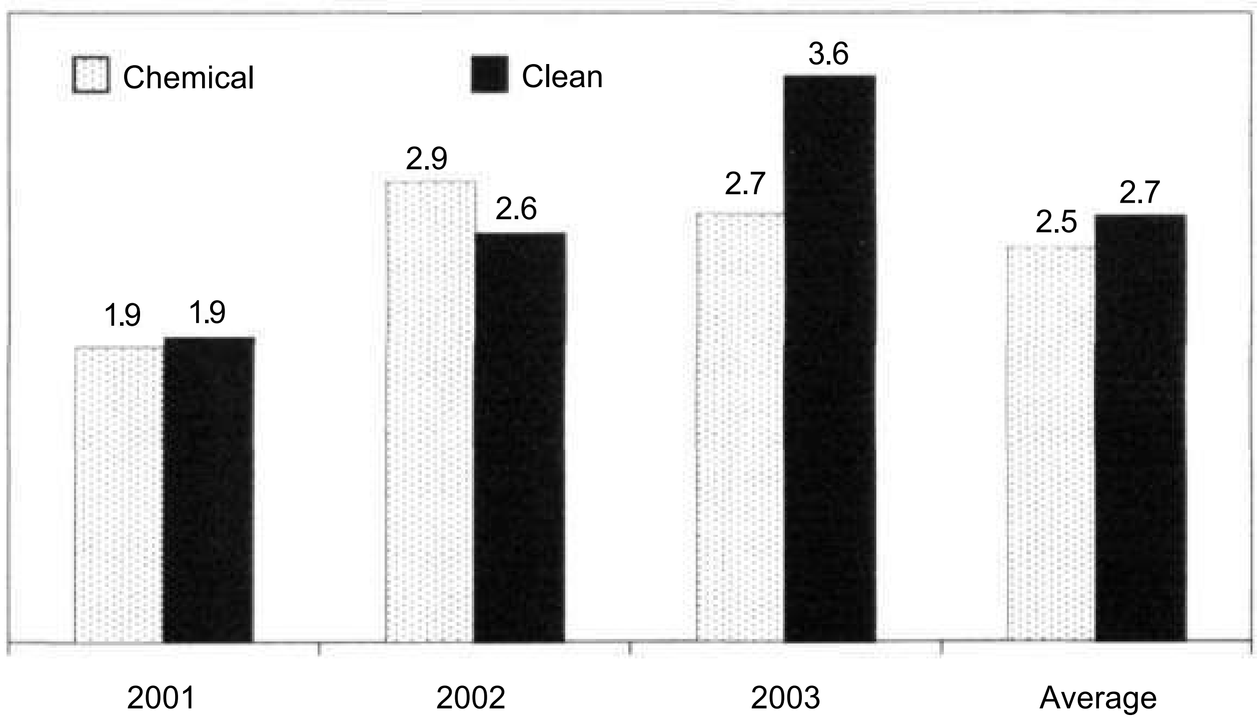


***Figure 2. Effects of no-tillage (chemical fallow) and conventional clean tillage on wheat yields (t ha$^{-1}$) in fallow-wheat cropping system***

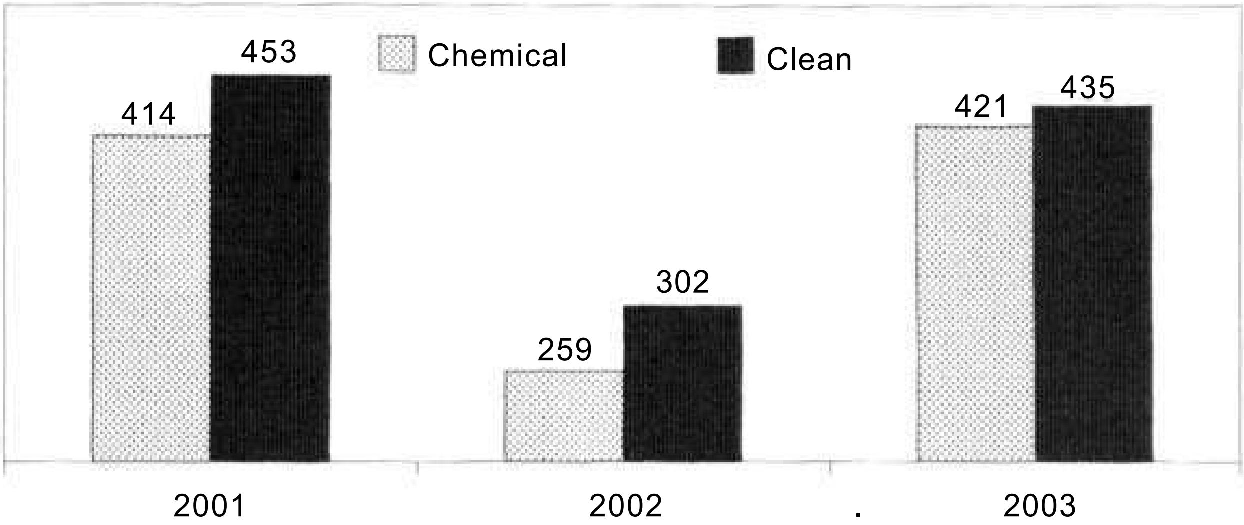


***Figure 3. Effects of no-tillage (chemical fallow) and conventional clean tillage on wheat emergence (plant/m²) in fallow-wheat cropping system***

## Wheat and chickpea yields under chickpea-wheat system

In 2001 and 2002, wheat yield was slightly higher under no-till compared to conventional tillage. However, in 2003 there was a large advantage in wheat yield, favor of conventional tillage (Fig 4). Stand establishment was strikingly more than conventional with no-tillage wheat except for 2001 (Fig 5).

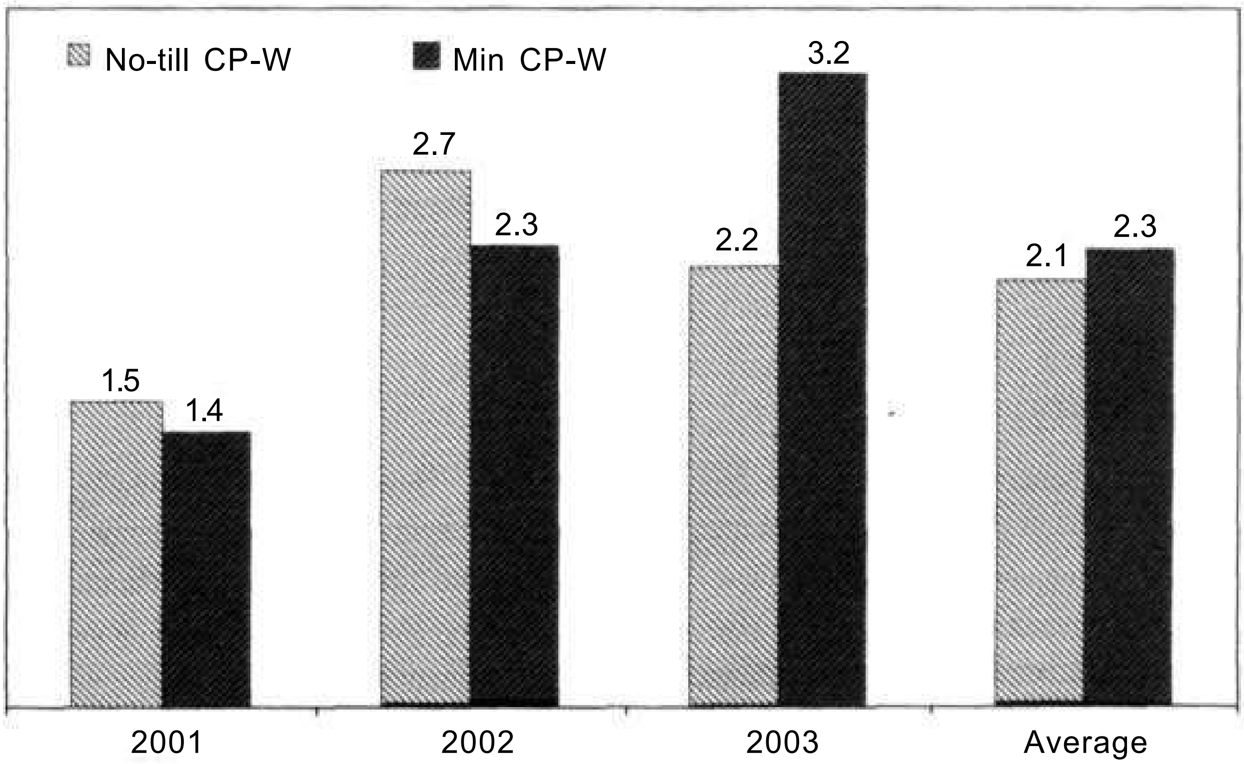


***figure 4. Effects of no-tillage and conventional tillage on wheat yields in chickpea- wheat system (CP-W)***

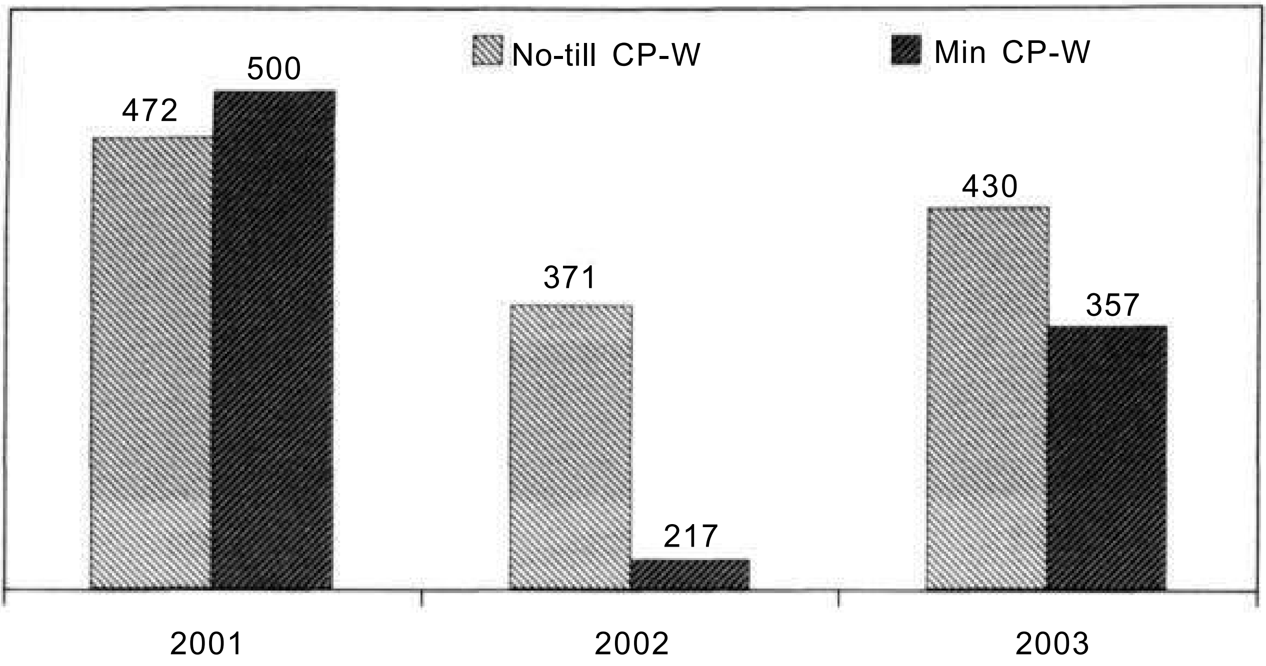


***Figure 5. Effects of no-tillage and conventional tillage on wheat emergence (plant/m²) in chickpea-wheat system (CP-W)***

For the first two years, chickpea yields were similar. Unfortunately we could not measure chickpea yields due to massive damage to the plots by rabbits.

## Yield under continuous wheat system

The picture was the same as the previous cropping systems. In 2001 and 2002 there was not much yield difference between conventional versus no-till treatments. In 2003, the conventional minimum tillage system gave significantly higher yield (Fig 6). Stand establishment was better under no-till, in all three years (Fig 7).

## Discussion

Better emergence rates with clean fallow than chemical fallows imply that good seedbed preparation was obtained with this system. However, except for 2001, there were no differences between the two fallowing methods in 0-10 cm soil moisture. In 2001, the difference may stem from good seed-soil contact and relatively more moisture in clean fallow below 10 cm.

There was a remarkable yield advantage with minimum tillage and clean fallow over no-tillage methods, for all three cropping systems in 2003. This

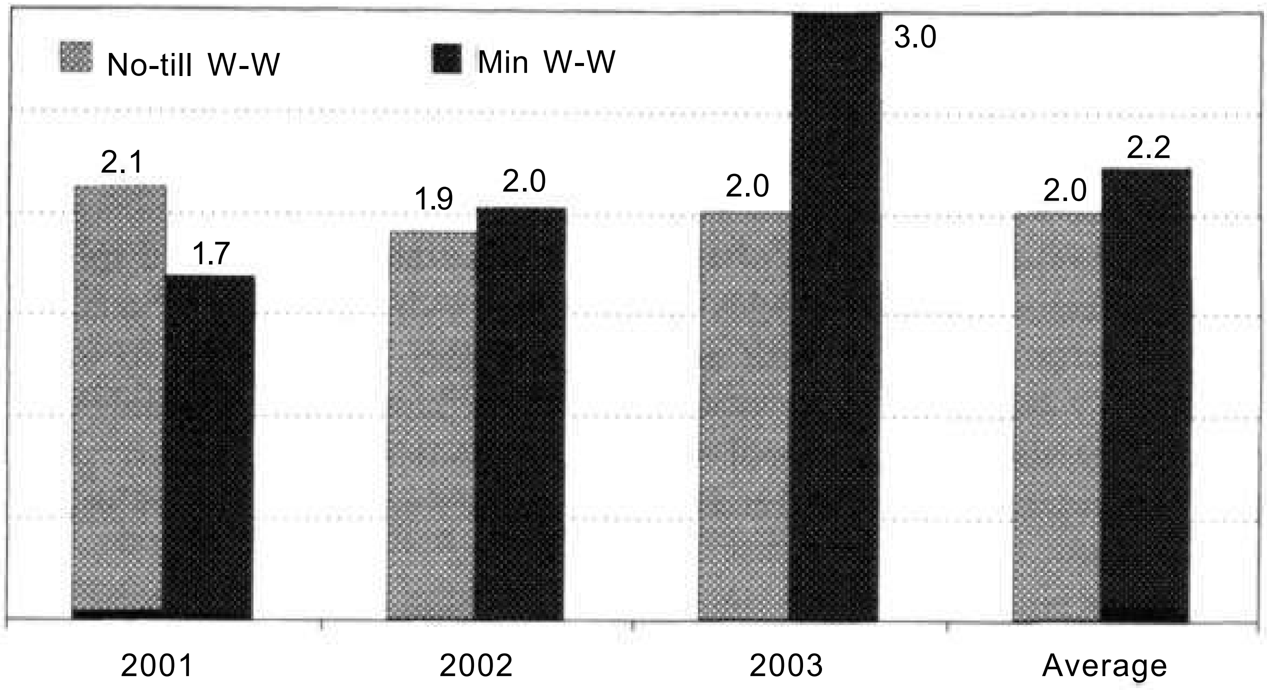


***Figure 6. Effects of no-tillage and minimum tillage on wheat yields (t ha$^{-1}$) in continuous wheat system***

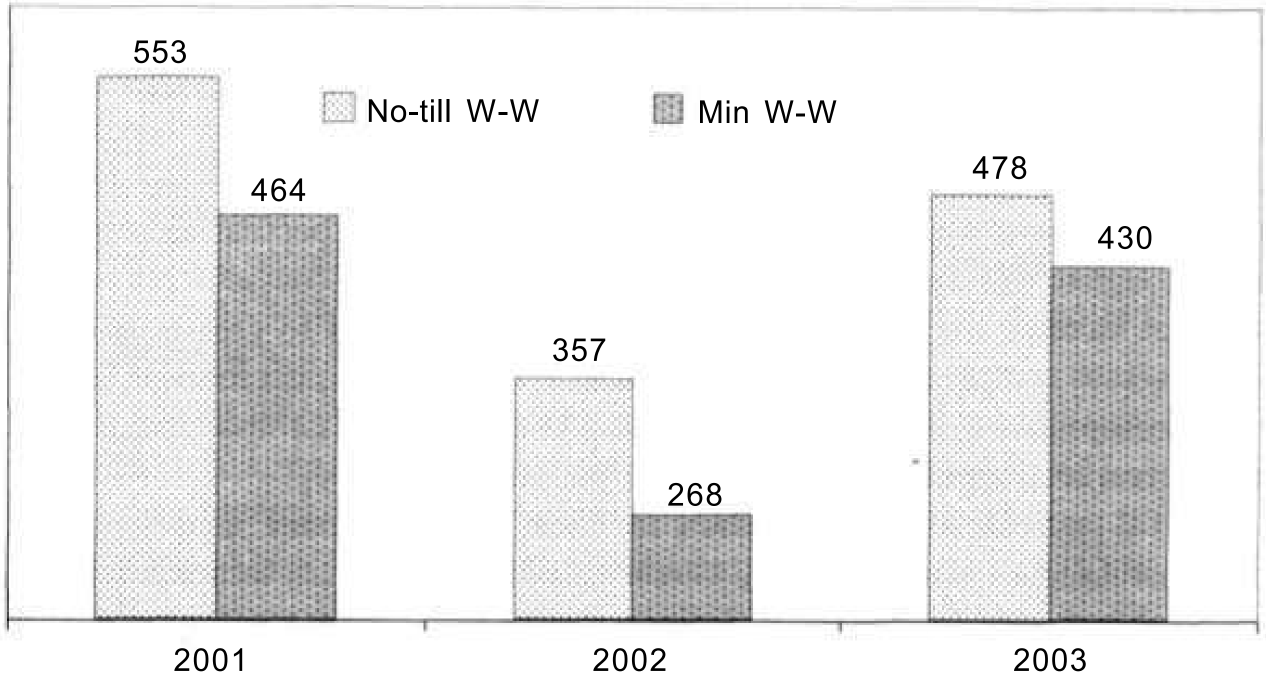


***Figure 7. Effects of no-tillage and minimum tillage on emergence (plant/m$^2$) in continuous wheat system***

may have resulted from unusual pre-planting rainfall in mid-Sep, which enabled deep tillage and burying the stubble deep enough for good seedbed preparation, and planting in wet soil. In the continuous wheat system, accumulation of more moisture under no-till compared to minimum tillage, may be due to breaking of continuity of capillarity in the soil by minimum tillage and resultant decrease of water infiltration during winter and spring. Thus, one can expect higher yields with no-tillage in drought years, as in 2001.

Better crop emergence with no-till system may be attributed to more moisture (9.2%) in the upper 0-30 cm soil layer. Low emergence cannot be ascribed to the improper seedbed of tillage methods because very good seedbed was prepared in 2003 and emergence rate was still lower - not higher, as expected.

Another problem with minimum tillage system in continuous wheat, was the difficulty of seedbed preparation. Wheat stubble and straw complicate tillage practice and seeding operations. In high residue years, disc tools were used in place of sweep. Farmers generally burn the wheat stubble in annual cropping to eliminate tillage and planting problems created by residue. Because stubble burning is illegal, some farmers use high speed vertical and horizontal rotary hoes to eliminate the residue and prepare a good seedbed. However, this type of equipment harms the soil structure and also consumes large quantities of fuel.

In the chickpea-wheat system, pre-emergence herbicides play important role, particularly in no-till. If good control cannot be achieved, hand weeding is inevitable. This involves additional costs and time. Conventional tillage resulted in lower weed population, but in most years the population was not low enough to eliminate the need for weeding. Besides this, conventional tillage was not suitable for mechanical harvesting because it led to greater surface roughness as compared to no-till. The rolling after planting was a solution to the roughness problem, but this caused another problem of soil compaction, which prevents a good seedbed preparation for the next wheat crop.

No-till increased the infestation of cheat grass (*Bromus tectorum*). In chemical fallow - wheat system, weeds including cheat grass were controlled by Total herbicide (glyphosphate); there was no cheat grass population in the system during the 3 years of experiment. However, in the third year, weeds occurred at higher than expected density. The main reason for this infestation was cheat grass seeds drifting with the wind, from continuous wheat and chickpea-wheat plots to the chemical fallow plot. The standing stubble in chemical fallow facilitates trapping wind-borne cheat grass seeds. In large scale production, this might be a problem.

If cheat grass can be controlled at reasonable cost, farmers would prefer continuous wheat because it is totally mechanized. The new herbicides (commercial names Monitor and Attribute) need careful application and do not kill but stop the growth of the cheat grass. In our research, Attribute was applied and suppressed the wheat seedling until the herbicide showed its effect. At later stages, weeds could not grow further and stayed at short stature but the crop was totally suppressed out.

In the chickpea-wheat system an effective herbicide was needed to control weeds, particularly grassy weeds in chickpea. In spring, pre-sowing application of glyphosphate successfully controlled all weeds during the growing period of chickpea. Hence, spring legume - wheat system will be practiced successfully. The direct planting machine used in our study was not the recommended version, but modified from an ordinary drill. Therefore we could test the difference between our modified drill and the drill specifically manufactured for no-till. However, the modified drill produced adequate stand establishment and plant growth.

For large scale production, there is need to study how to modify farmers' drills into a direct drill.

## Conclusions

The following conclusions can be drawn from the results obtained from 4 years of research:

- If chemical weed control is performed well and on a timely basis in fallow areas, then chemical fallow will be a good alternative to clean fallow. In particular, it will reduce tillage cost.
- Continuous wheat increased cheat grass infestation. No-till aggravated this problem. In spite of these drawbacks, no-till seemed economically superior and gave better water conservation and erosion control. With an efficient herbicide to control cheat grass, no-till continuous wheat can give adequate yields.
- Past experience and a huge amount of research worldwide, have shown that shows that no-till or reduced tillage systems are a prerequisite for sustainable agriculture. Therefore the research in this area should be intensified in Turkey.

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# New Decision Support Tool: Farmer Survey for Optimizing Soil Water Use in the Anatolian Plateau

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## Introduction

When they are well prepared, questionnaires provide accurate results, are easily applied by interviewers, and readily evaluated. Surveys on technical issues such as water use or tillage can provide more realistic results than surveys on socioeconomic issues, because farmers can supply misleading responses to questions directly or indirectly related to tax, government support or incentives.

Each farmer can be a representative of an agricultural system. When the farm area and farming types increase, information gathered from farmers may not reflect reality. However, in the case of smallholder farmers and dryland agriculture, questionnaire responses probably reflect the real situation due to more uniform environment and crop management. Most Central Anatolian farmers do not have large farms, and they have limited types of agricultural activities. Therefore it can be expected that surveys on the plateau are likely to produce accurate and informative results.

In dryland farming, water plays a key role. Evaluation of agricultural water must consider very important factors like precipitation, crop water use (ET), climatic drought, plant available water and surface runoff in the water cycle. Based on this evaluation, the technologies to be adopted (or their order of importance) will change. Determining the proper technologies will speed up the process of adoption.

The objectives of this study are to (i) evaluate the water budget in order to define constraints to the availability of water, (ii) make decisions on technologies which solve the main constraints defined.

## Materials and Methods

We prepared a questionnaire which aimed to:

- Determine the level of rainfall-crop requirement satisfaction (RCS)

- Understand the degree of climatic drought risk (CDR)
- Understand the edaphic drought risk in terms of plant available water (PAW) and runoff potential (RP).

The questionnaire is reproduced in Appendix 1. Appendix 2 describes analysis of results and explains the reasoning behind the questions.

Eight questions relate to whether precipitation adequately meets the crop water requirement (RCS). A score of 11-30 was considered as deficient, whereas 30-39 was sufficient.

Six questions were to evaluate climatic drought risk (CDR). A score of 5-16 for this was considered as risky, whereas 17-21 was non-risky. There were two questions on the extent of PAW A score of 1-5 was considered as insufficient, and 6-8 was considered sufficient. One question was used to evaluate the runoff potential of soil in the farmer's area. High runoff potential had a score of 3-4, and low runoff potential had a score of 1-2.

A total of 39 farmers were interviewed using the questionnaire - 28 farmers from northern transitional areas (Cankiri, and (Jorum provinces), 10 from the eastern part (Yozgat and Sivas), and one farmer from Central.

## Results and Discussion

The responses to the first section (RCS) indicate that all areas except for one, suffer from deficiency of rainfall. The scores stayed below 30 (Tables 1 and 2).

Drought (CDR) was a common risk for all farmers, except for one farmer in (Jorum province. In this section, the score for each farmer was near the score for non-risky, implying moderate risk of climatic drought for the area concerned. This was particularly true for farmers from (Corum and Sivas provinces, confirming current observation and past experience from those provinces (Tables 1 and 2).

PAW was not a problem for nearly half the farmers. These farmers seemed to be distributed randomly, and were not concentrated in any province. This was probably because PAW is mostly related to soil conditions, which are more variable than weather factors.

RP was low in 60% of farmers' fields. Forty percent was considered high water runoff potential (Tables 1 and 2).

The farmers were divided into two groups, high PAW and low PAW (Tables 1 and 2). The high PAW group was classified into four sub groups. Only one farmer (2.5% of total) had sufficient RCS, high CDR and low RP. For this farmer, new crops or a better adapted crop variety should be recommended.

**Table 1. Survey responses and scores in terms of water status in some provinces of Central Anatolia (high PAW group).**

| Province | Town | District | Section 1 | Section 2 | Section 3 | Section 3 PAW | Section 3 RP | RCS | CDR | PAW | RP |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sivas | Hafik | Qukur | 16 | 11 | 11 | 8 | 3 | Deficient | High | High | High |
| Sivas | Gurun | | 17 | 9 | 10 | 7 | 3 | Deficient | High | High | High |
| Qorum | Mecitozu | Kuyuca | 18 | 16 | 11 | 7 | 4 | Deficient | High | High | High |
| Qorum | Fakahmet | | 17 | 13 | 11 | 7 | 4 | Deficient | High | High | High |
| Qorum | Kargi | | 12 | 12 | 11 | 7 | 4 | Deficient | High | High | High |
| Qorum | Oguzlar | | 15 | 11 | 9 | 6 | 3 | Deficient | High | High | High |
| Qorum | Merkez | | 17 | 17 | 10 | 6 | 4 | Deficient | Low | High | High |
| Yozgat | Yerkoy | | 16 | 9 | 10 | 7 | 3 | Deficient | High | High | High |
| Cankiri | Merkez | | 17 | 13 | 9 | 6 | 3 | Deficient | High | High | High |
| Qankiri | Merkez | | 16 | 13 | 10 | 7 | 3 | Deficient | High | High | High |
| Qankiri | Yaprakli | | 17 | 11 | 10 | 6 | 4 | Deficient | High | High | High |
| Cankiri | Merkez | | 16 | 9 | 10 | 6 | 4 | Deficient | High | High | High |
| Qankiri | Merkez | | 16 | 10 | 12 | 8 | 4 | Deficient | H.gh | High | High |
| Ankara | Haymana | | 16 | 13 | 10 | 6 | 4 | Deficient | High | High | High |
| Sivas | Nerkez | Dedeli | 22 | 12 | 8 | 7 | 1 | Sufficient | High | High | Low |
| Qorum | Alaca | Akoren | 17 | 10 | 8 | 6 | 2 | Deficient | H.gh | High | Low |
| Qorum | Alaca | | 15 | 16 | 8 | 6 | 2 | Deficient | H.gh | High | Low |
| Qorum | U.Dag | | 15 | 10 | 8 | 6 | 2 | Deficient | High | High | Low |
| Qorum | Sugurlu | | 11 | 13 | 7 | 6 | 1 | Deficient | High | High | Low |
| Qankiri | Ilgaz | | 15 | 11 | 8 | 7 | 1 | Deficient | High | High | Low |
| Qankiri | Merkez | | 15 | 15 | 7 | 6 | 1 | Deficient | High | High | Low |

In the second sub group (28% of total), 15% of the farmers had rainfall deficiency (RCS), high CDR, and sufficient PAW, but low RR This group could be recommended to try water conservation technologies, variety and crop selection, and crop management technologies because weather conditions were more stable. In the third sub group (33% of total) had deficient RCS, high CDR, and sufficient PAW, but high RP. This group, in addition to the technologies for the second group, could be recommended technologies for modifying soil surface conditions, such as terracing, contour tillage and seeding, seeding in stubble (direct seeding), and increasing infiltration rate. The fourth sub group (2.5% of total) had deficient rainfall satisfaction, low CDR, and sufficient PAW, but high RP. Water conservation techniques, and/or variety and crop selection, and/or crop management technologies with surface modification technologies, can be recommended to this group.

The farmers with low PAW all had rainfall deficiency and high CDR, and were divided into two sub groups, low and high RP. The sub group with low RP (44% of the low PAW group, and 20.5% of the total) could be recommended

**Table 2. Survey responses and scores in terms of water status in some provinces of Central Anatolia (low PAW group).**

| Province | Town | District | Section 1 | Section 2 | Section 3 | Section 3 PAW | Section 3 RP | RCS | CDR | PAW | RP |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sivas | Merkez | Beypazari | 15 | 12 | 6 | 4 | 2 | Deficient | High | Low | Low |
| Sivas | Merkez | | 15 | 12 | 6 | 4 | 2 | Deficient | High | Low | Low |
| Sivas | Merkez | | 19 | 9 | 6 | 4 | 2 | Deficient | High | Low | Low |
| Corum | Yskilip | Cukurkoy | 13 | 12 | 6 | 4 | 2 | Deficient | High | Low | Low |
| Yozgat | Saraykent | | 14 | 10 | 7 | 5 | 2 | Deficient | High | Low | Low |
| Yozgat | Kadisehir | | 16 | 13 | 7 | 5 | 2 | Deficient | High | Low | Low |
| Cankir | Yaprakli | | 16 | 9 | 4 | 3 | 1 | Deficient | High | Low | Low |
| Cankir | Merkez | | 16 | 12 | 7 | 5 | 2 | Deficient | High | Low | Low |
| Sivas | Hafik | Cukurbelen | 17 | 14 | 8 | 5 | 3 | Deficient | High | Low | High |
| Corum | Bayat | | 15 | 13 | 9 | 5 | 4 | Deficient | High | Low | High |
| Corum | Merkez | | 14 | 11 | 7 | 3 | 4 | Deficient | High | Low | High |
| Cankiri | Merkez | | 16 | 12 | 9 | 5 | 4 | Deficient | High | Low | High |
| Cankiri | Kizilirmak | | 16 | 12 | 9 | 5 | 4 | Deficient | High | Low | High |
| Cankiri | Merkez | | 15 | 11 | 7 | 3 | 4 | Deficient | High | Low | High |
| Cankiri | Yaprakli | | 16 | 12 | 8 | 5 | 3 | Deficient | High | Low | High |
| Cankiri | Merkez | | 17 | 10 | 9 | 5 | 4 | Deficient | High | Low | High |
| Cankiri | Merkez | | 13 | 12 | 8 | 5 | 3 | Deficient | High | Low | High |
| Cankiri | Merkez | | 16 | 12 | 6 | 3 | 3 | Deficient | High | Low | High |

water conservation and agronomic technologies based on high stability, long term research, and positive interaction of concerned technologies, with the technologies for increasing water holding capacity of soil, eg organic matter increase, chemical soil amendments, and deep tillage. The sub group with high RP (56% of the low PAW group, and 26% of the total) could be recommended technologies to modify soil surface, in addition to the technologies recommended for the first sub group.

## Conclusions

Nearly all farms had deficient rainfall compared to crop requirement (RCS). There was high climatic drought risk (CDR). The main sources of variation for agricultural water in the farms were PAW and RP. About half the farms had sufficient PAW, and 38% of the farms had low RP.

For the area, water conservation and crop management technologies, and variety and crop selection are recommended. There should be positive interaction of the concerned technologies, and there is a need for additional long term research. Technologies to increase PAW or to reduce RP were considered almost equally important for the area.

# Appendix 1. Questionnaire for farmer survey for optimizing water use

1. Name ____________ Province ____________ Town ____________ Village ____________

Section 1. Farmer satisfaction with rainfall and water requirement

2. When is the starting date of rainfall in your area?
   a) Sep b)Oct c)Nov c)Dec

3. Which are the more rainy months?
   1 2 3 4 5 6 7 8 9 10 11 12

4. Do you have snow? If yes, when does it fall ?
   a) Oct b)Nov c)Dec d)Jan e)Feb

5. When does the snow melt?
   a) Shortly after falling b) Stays 15 days c) Stays 1 month d) Stays 2 months

6. When does rainy period end?
   a) end of May b) mid June c) end of June d) mid July

7. Is freeze frequent and soil freeze?
   a) Frequent, soil freezes b) Frequent, soil does not freeze c) No freeze d) Not frequent, soil freezes

8. When do wheat and barley start growing after winter?
   a) beginning of March b) mid March c) end of March d) beginning of April e) end of April

9. When does the wheat crop start maturing ?
   a) end of June - beginning of July b) beginning of July - mid July c) mid July - end of July
   d) End of Jury - beginning of Aug e) beginning of Aug - mid Aug

10. Dryland wheat yields in your area?
    Wheat Barley Lentil Chickpea
    Sunflower Vetch

Section 2. Climatic drought risk

1. How often does drought occur ?
   a) Every year b) Once in 2 years c) Once in 3 years d) Once in 4 years
   e) Once in 5 years f) Very seldom

2. Which is the best growing crop in your area?
   a) Wheat b) Barley c) Chickpea d) Sunflower e) Vetch

3. Is wheat grown continuously? What about yield?
   a) Grown, very good b) Grown, good c) Grown, moderate d) Grown, bad e) Not grown

4. Is wheat irrigated? Why?
   a) Irrigated - if not irrigated yield drops          b) Irrigated - for high yield
   c) Irrigated - because plenty of water available          d) No irrigation

5. How much benefit of doing fallow?
   a) Very much          b) Moderate          c) Not much          d) Very little

6. Do you till the fallow field in summer when the field is covered with weed?
   a) Yes          b) No          c) If it is very weedy

Section 3. Edaphic drought risk

1. Your soil texture is?
   a) Clayey          b) Sandy          c) Near clayey          d) Near sandy          e) Between sandy and clayey

2. When your field is tilled deep or dug 50 cm, do one or a group of lime, gravel, sand or stone come out from the soil?
   a) Yes from all soils          b) Seldom          c)No          d) Sometimes from all soils

3. After heavy rainfall in spring, does flood and/or outflow occur in streams?
   a) Yes, very much          flood          b) Yes, stream water increases
   c) Less flood, less stream water          d) No or seldom

# Appendix 2. Scoring system and explanation of questions

*Underlined numbers indicate score given for each answer. Text in italics explains why the question was asked.*

**Section 1. Farmer satisfaction with rainfall and water requirement**

*Questions 2-10 relate to satisfaction with respect to rainfall and crop water requirement*

2. When is the starting date of rainfall in your area? (*If starting date is earlier, the growing period will probably be longer and availability of rainfall higher*)

| a) Sep | b)Oct | c)Nov | c)Dec |
|---|---|---|---|
| 4 | 3 | 2 | 1 |

3. Which are the more rainy months? *(Months 4, 5 and 6 are the active growing months, so rainfall in these months will be most efficient)*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 4 | | | 4 | | 3 | |

4. Do you have snow? If yes, when does it fall? (*Snow helps the good distribution of rainwater during growing period*)

Falls 2 Does not fall 1

5. When does the snow melt? (*Questions 5-7 relate to water intake and crop growth*)

a) shortly after falling 1 b) stays 15 days 2
c) stays one month 3 d) stays two months 4

6. When does rainy period end?

a) end of May 1 b) mid June 2
c) end of June 3 d) mid July 4

7. Is freeze frequent? Does the soil freeze?

a) Frequent, soil freezes 1 b) Frequent, soil does not freeze 2
c) No freeze 3 d) Not frequent, soil freezes 4

8. When do wheat and barley start growing after winter? *(Questions 8-9 relate to duration of active growing period)*

a) Onset of March 5 b) Mid-March 4 c) End of March 3
d) Onset of April 2 e) End of April 1

9. When does wheat crop start maturing ?

a) end of June -beginning of July 1 b) beginning of July - mid-July 2
c) mid July - end of July 3 d) end of July-beginning of Aug 4
e) beginning of Aug - mid Aug 5

10. Dryland wheat yields in your area? (*To obtain results and data*)

**Section 2. Climatic drought risk**

1. How often does drought occur? *(This was asked because the season had been extremely dry, and farmers already have an understanding of drought)*

a) Every year 1  b) Once in 2 years 2  c) Once in 3 years 3
d) Once in 4 years 4  e) Once in 5 years 4  f) Very seldom 5

2. Which is the best growing crop in your area? *(Wheat - relatively high rainfall areas. Barley - dry areas. Chickpea - moderate rainfall areas where livestock production is not common. Sunflower - rainy places particularly under summer rains. Vetch - moderate rainfall, livestock areas)*

a) Wheat 2  b) Barley 1  c) Chickpea 3
d) Sunflower 4  e) Vetch 5

3. Is wheat grown continuously? What about yield? *(Continuous wheat cropping, and yield levels, indicate wetness)*

a) Grown, very good 5  b) Grown, good 4  c) Grown, moderate 3
d) Grown, bad 2  e) Not grown 1

4. Is wheat irrigated? Why? *(Efficiency of irrigation is related to drought level)*

a) Irrigated - if not irrigated yield drops 2  b) Irrigated - for high yield 3
c) Irrigated - because plenty of water available 1  d) No irrigation 1

5. How much benefit of doing fallow? *(Much of the contribution of fallow to yields can be linked to dryness of the area)*

a) Very much 1.  b) Moderate 2  c) Not much 3  d) Very little 4

6. Do you till the fallow field in summer when the field is covered with weeds? *(Related to previous question. Benefit of fallow is proportionally related to summer tillage. This is asked to elaborate fallow benefit, and therefore is equally scored)*

a) Yes 2  b) No 2  c) If it is very weedy 1

**Section 3. Edaphic drought risk**

*Questions 1-2 relate to plant available water, question 3 relates to runoff)*

1. Your soil texture is? *(Indicates water intake and water-holding capacity)*

a) Clayey 1  b) Sandy 1  c) Near clayey 4
d) Near sandy 2  e) Between sandy and clayey 3

2. When your field is tilled deep or dug 50 cm, do one or a group of lime, gravel, sand or stone come out from the soil? *(Related to water-holding capacity)*

a) Yes from all soils 1  b) Seldom 3
c) No 4  d) Sometimes from all soils 2

3. After heavy rainfall in spring, does flood and/or outflow occur in streams? *(Indicates surface runoff potential)*

a) Yes, very much flood 1  b) Yes, stream water increases 2
c) Less flood, less stream water 3  d) No or seldom 4

**Evaluation of answers**

If total score for section 1 is:
11-30: Crop water requirement cannot be met by rainfall
30-39: Amount of rainfall is sufficient for or exceeds the crop need.

If the total score for section 2 is:
5-16: Risk of climatic drought
17-21: No climatic risk

If the total score for section 3 questions 1 and 2 is:
1-5: PAW is not sufficient
6-8: PAW is sufficient

If the total score for section 3 question 3 is:
3-4: Little runoff
1-2: More runoff

# Optimizing Soil Water Use Through Sound Crop Management Practices in a Semi-Arid Region of Morocco

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**PROJECT 1. EFFECT OF PLANTING PATTERN ON YIELD AND WATER USE EFFICIENCY OF BREAD WHEAT IN SEMI-ARID REGIONS OF MOROCCO**

## Justification

The semi-arid regions of Morocco have low and erratic rainfall, with most rain in winter (El Mourid and Watts 1993) during the early growth of wheat, when the soil is not well covered by vegetation. Considerable rainwater is lost through evaporation. El Mourid (1988) estimated soil evaporation losses during the cropping season at 38-47% of the total evapotranspiration. Grain yield of wheat is related to the amount of water transpired by the crop. This can be increased if the proportion of water lost by evaporation in the evapotranspiration process is reduced.

Most farmers usually broadcast seed and cover it with an offset disk. Thereby, they use high seeding rates to compensate for germination and emergence failures due to the heterogeneous seeding depth and distribution (Karrou 1998), and to decrease weed growth (Tanji and Karrou 1992). Early research recommended the use of drills to improve crop establishment and reduce seed loss. However, the row space of 25-30 cm that has been advised allows loss of soil water through evaporation during early crop growth. One way to reduce early season evaporation is by early soil covering. Water could then be conserved for later stages, and reduce the effect of terminal drought, which is very common in arid and semi-arid areas. Many researchers have reported the benefits of this strategy, either through development of species and varieties or technologies that stimulate soil shading and reduce soil evaporation (Siddique et al. 1989).

*Objectives.* The main objective was to assess how a planting pattern change through variation of seeding rate and seeding method can affect bread wheat production and water use efficiency, under semi-arid conditions in Morocco.

## Cropping Season 2000-01

### Materials and methods

The research was conducted at two sites in the Chaouia area of central occidental Morocco, on Jemaa Riah Experiment Station, and a nearby farm. Bread wheat (*Triticum aestivum*) was used; variety Arrihane on the experiment station and variety Achtar on the farm. Factors studied were seeding methods (broadcast and row spacing with 12 cm and 24 cm), and seeding rate (200 and 400 kernels $m^{-2}$). Different levels of the two factors were combined in six treatments: P1R1 (12 cm + 200 kernels $m^{-2}$), P1R2 (12 cm + 400 kernels $nr^{2}$), P2R1 (24 cm + 200 kernels $m^{-2}$), P2R2 (24 cm + 400 kernels $m^{-2}$), P3R1 (broadcast + 200 kernels $m^{-2}$), and P3R2 (broadcast + 400 kernels $m^{-2}$).

At the experiment station, weed control was added to the seeding treatment. Each treatment was split into two subplots: weedy (w) and weed free (wf).

The soil type at the experiment station is a Chromoxert with pH 7. This soil has 25% volumetric water content at field capacity, and 12% at wilting point. The profile depth is around 60 cm. The soil type at the farm is an alkaline Calci Argixeroll with 33% water content at field capacity, and 17% at wilting point. The profile depth is more than 100 cm.

Sowing dates were 11 Nov at the farm and 18 Nov at the experiment station. Preceding the experiment, both sites were bare fallowed. Fertilizers were applied at 40 kg $ha^{-1}$ of nitrogen and 60 kg $ha^{-1}$ of phosphorus. Soil moisture was not measured, therefore only rainwater use efficiency was calculated (RWUE), assuming that all water received during the growing season was used:

RWUE = Grain yield/Rainwater, kg/ha/mm.

Statistical analysis was by GLM and LSD when appropriate (SAS program).

### Climatic conditions

The 2000 cropping season had a severe drought. Total rainfall was 220 mm with an irregular distribution (Fig 1), which was much less than the region's long term average of 390 mm. Most rain was during the early season (Oct-Jan), when there was 209 mm. Thus the early season was favorable and allowed good stand establishment. Drought started in Feb and continued until

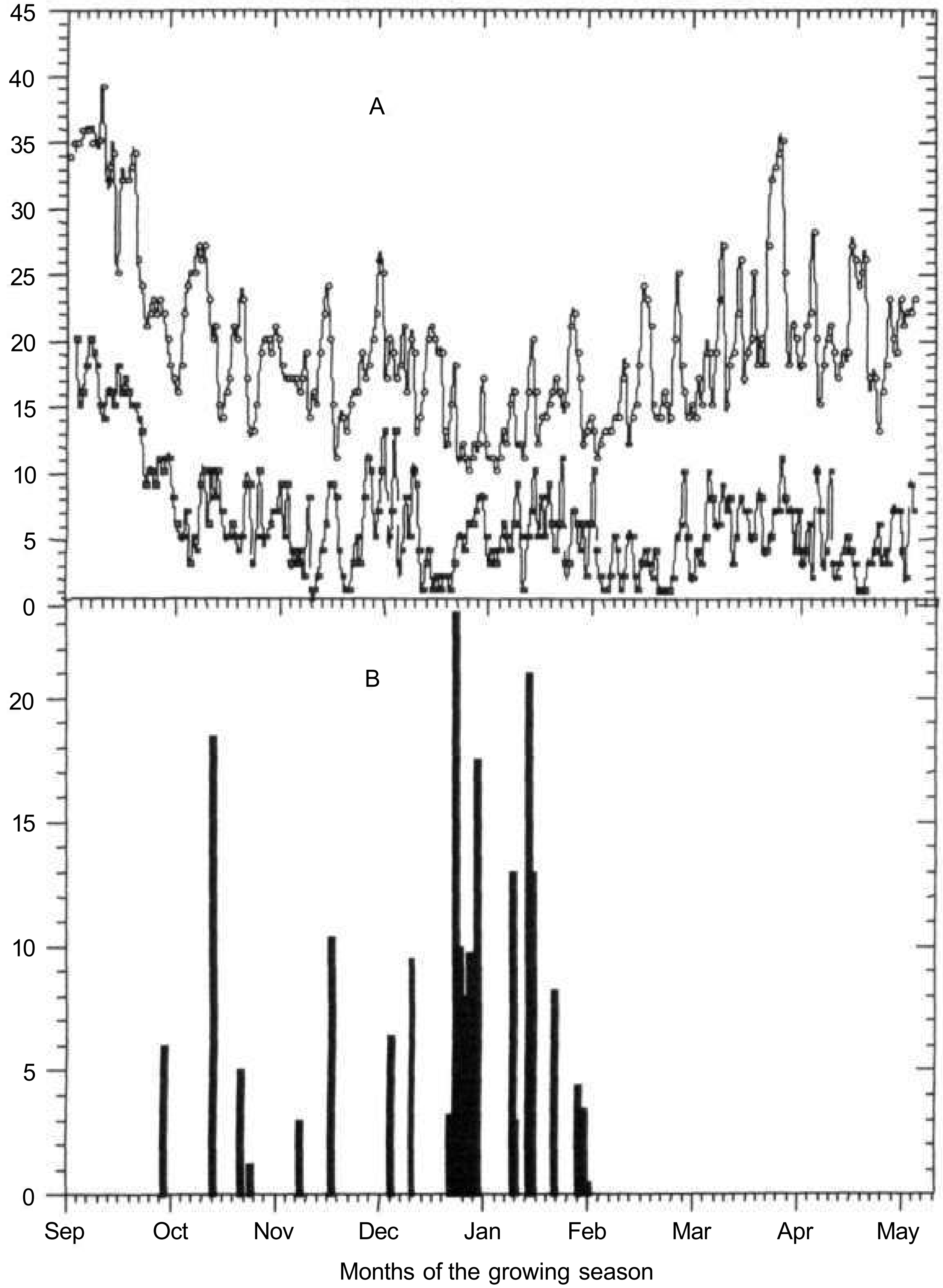


***Figure 1. Daily maximum and minimum temperature (A) and rainfall (B) at Sidi El Aydi, 2000-01 season***

May. The 10 mm in May came too late to save winter-grown cereals and legumes. In terms of cumulative rainfall and distribution, the 1999/2000 cropping season was one of the poorest experienced in the Settat region.

Temperature showed a low amplitude with 37°C as the highest maximum, and 1°C the minimum. The temperature regime did not show any major change except in March when an unusual increase was registered.

## Results and discussion

Under dryland conditions, increasing vegetative cover early in the growing season by changing row spacing in wheat crops appears attractive as a strategy. The idea is to reduce evaporation rate and save water for later stages when water deficit and high temperature are experienced, and thus increase grain

**Table 1. Grain yield and biomass (t $ha^{-1}$) and RWUE (kg $ha^{-1}$ $mm^{-1}$) at experiment station, 2000-01**

| | Grain yield | | Biomass yield | | RWUE | |
|---|---|---|---|---|---|---|
| Treatment | WF | W | WF | W | WF | W |
| P1R1 | 1.51 | 1.13 | 4.32 | 3.95 | 6.7 | 5.3 |
| P1R2 | 1.78 | 1.40 | 4.98 | 4.83 | 8.0 | 6.3 |
| P2R1 | 1.49 | 1.12 | 4.49 | 3.87 | 6.7 | 5.3 |
| P2R2 | 1.42 | 1.05 | 4.73 | 4.04 | 6.3 | 4.7 |
| P3R1 | 1.56 | 1.03 | 4.27 | 3.52 | 7.3 | 4.7 |
| P3R2 | 1.66 | 1.40 | 4.97 | 4.53 | 7.7 | 6.3 |
| Mean | 1.57 | 1.19 | 4.63 | 4.12 | 7.1 | 5.4 |
| Significance | PR * W* | | PR ns W* | | PR*W* | |

W = weedy, WF = weed free

**Table 2. Grain yield and biomass (t ha[1]) on farmers field, 2000-01**

| Treatment | Grain yield | Biomass |
|---|---|---|
| P1R1 | 1.65ab | 4.33ab |
| P1R2 | 1.75a | 5.47a |
| P2R1 | 1.17c | 3.94b |
| P2R2 | 1.37bc | 4.38ab |
| P3R1 | 1.19bc | 3.94ab |
| P3R2 | 1.30c | 4.38ab |
| Mean | 1.41 | 4.41 |

Treatments with the same letter are not significantly different yield. Tables 1 and 2 show that, although the average yield was low, narrow row spacing gave higher grain yields at both sites. There was an increase in biomass in the experiment on the farm, but not at the experiment station. Rainwater use efficiency for grain showed the same trend as grain yield. The best planting pattern was a 12 cm row spacing with 400 kernels $m^{-2}$. The effect of seeding rate was not significant. The broadcasting treatment gave better yield than 24 cm spacing when combined with 400 kernels $m^{-2}$, which again shows the benefit of early vegetative soil coverage.

Water saving can be also achieved by decreasing weed infestation. Weed-free plots had higher grain yield than weedy plots (Table 1), and this is supported by the yield increase that occurred when weed biomass was reduced with the narrow row spacing of wheat (Fig 2).

These results show that under rainfed conditions and where water is limiting, wheat production can be improved and weed infestation reduced with narow spacing. This reduces evaporation and saves water for later stages when moisture deficit occurs frequently in this environment.

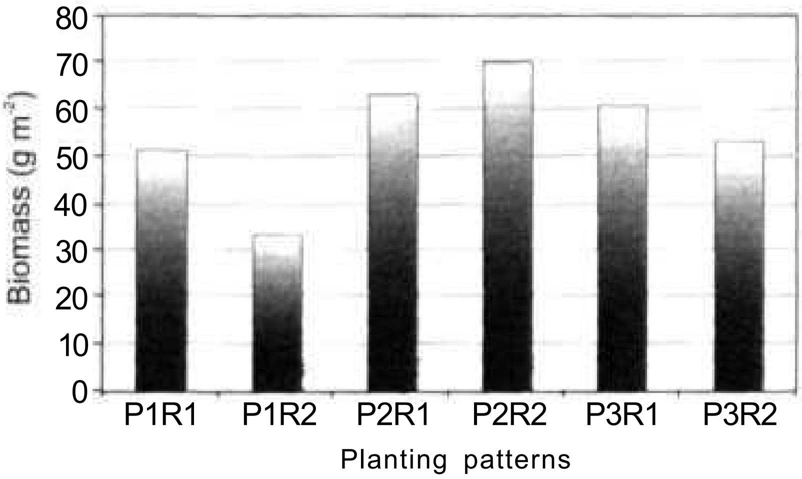


***Figure 2. Weed biomass under different planting patterns***

# Cropping Season 2001-02

## Materials and methods

The research was conducted at two sites in the Chaouia area, on Sidi E1 Aydi Experiment Station, and a nearby farm. Bread wheat was used, variety Arrihane on the experiment station. Factors studied were seeding methods and seeding rate, using six treatments as in the previous season. At the experiment station, weed control was added to the planting treatment. Each treatment was split into two subplots: weedy (w) and weed free (wf).

Soil characteristics and fertilizer application were as in the previous season. Sowing dates were 16 Nov at the farm and 15 Nov at the experiment station. Preceding the experiment, both sites had a period of bare fallow. Soil moisture was measured at emergence and maturity.

## Climatic conditions

Total rainfall was 308 mm (ie less than the long term average), with an irregular distribution (Fig 3). Almost half the rain was received during Dec. Thus the early season was favorable and there was good stand establishment. Jan and Feb were dry. March and April received 113 mm (37% of the annual total). In terms of cumulative rainfall and its distribution, the 2001-02 season was about the 50% probability level for the Settat region.

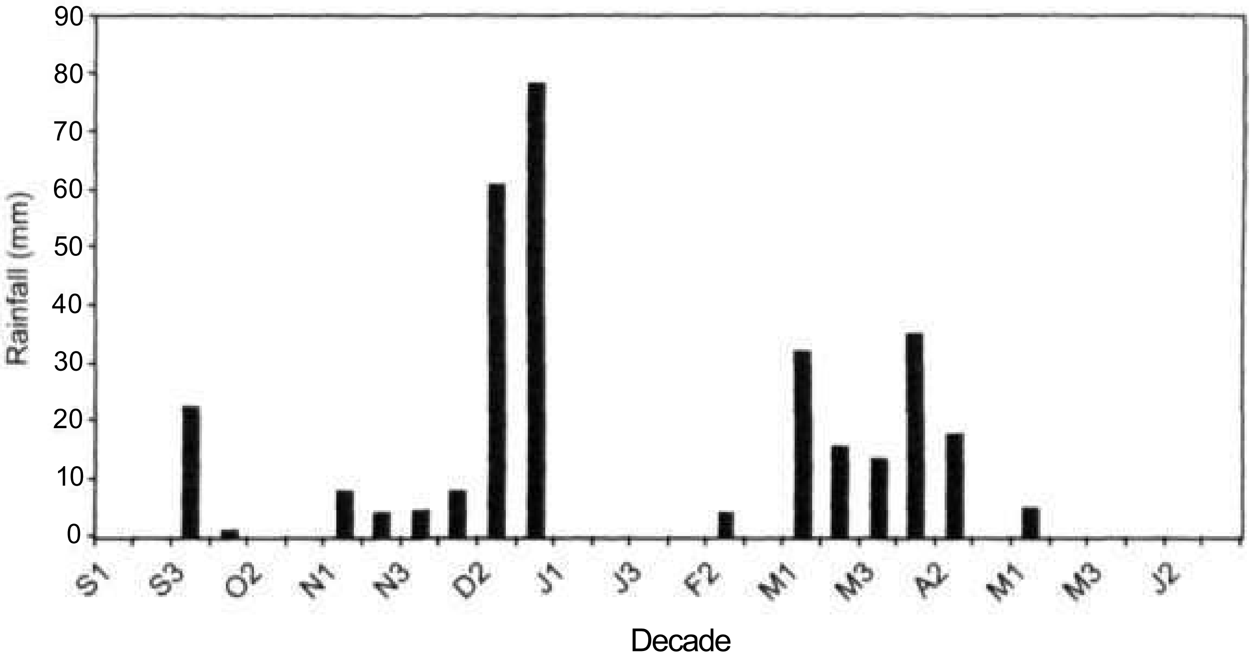


***Figure* 3. *Rainfall at Sidi ElAydi, 2001-02 season***

Temperatures showed a high amplitude with 31°C as the highest maximum, and 1°C as minimum. The temperature regime did not show any major change except in March and April where an unusual increase was registered (Fig 4).

## Results and discussion

Grain yield, biomass and WUE for grain are shown in Table 3 for the experiment station, and Table 4 for the farmer's trial. The average yield is satisfactory for the region. There were significant differences in grain, biomass and WUE which are related to planting pattern and weed control.

**Table 3. Grain yield and biomass (t ha$^{-1}$) and WUE (kg ha$^{-1}$ mm$^{-1}$) at experiment station, 2001-02**

| | Grain yield | | Biomass yield | | RWUE | |
|---|---|---|---|---|---|---|
| Treatment | WF | W | WF | W | WF | W |
| P1R1 | 1.64 | 1.29 | 5.02 | 3.74 | 5.7 | 4.5 |
| P1R2 | 2.00 | 1.80 | 5.27 | 5.22 | 7.0 | 6.3 |
| P2R1 | 1.57 | 1.28 | 4.05 | 3.17 | 5.4 | 4.4 |
| P2R2 | 2.01 | 1.68 | 5.84 | 4.55 | 7.0 | 5.8 |
| P3R1 | 1.92 | 1.47 | 4.56 | 3.80 | 6.6 | 5.1 |
| P3R2 | 2.01 | 1.54 | 5.47 | 3.98 | 7.0 | 5.3 |
| Mean | 1.86 | 1.51 | 5.04 | 4.08 | 6.5 | 5.3 |
| Significance | PR***D*** | | PR***D*** | | PR*D* | |

**Table 4. Grain yield and biomass (t ha$^{-1}$) at farm level, 2001-02**

| | Grain yield | | Biomass yield | |
|---|---|---|---|---|
| Treatment | WF | W | WF | W |
| P1R1 | 1.65 | 1.03 | 4.63 | 2.98 |
| P1R2 | 2.06 | 1.24 | 5.01 | 3.21 |
| P2R1 | 1.56 | 1.03 | 4.03 | 257 |
| P2R2 | 1.75 | 1.15 | 4.92 | 3.12 |
| P3R1 | 1.36 | 0.89 | 3.66 | 2.31 |
| P3R2 | 1.54 | 1.10 | 4.37 | 3.12 |
| Mean | 1.65 | 1.08 | 4.44 | 2.89 |
| Significance | PR***D*** | | PR*'** D *** | |

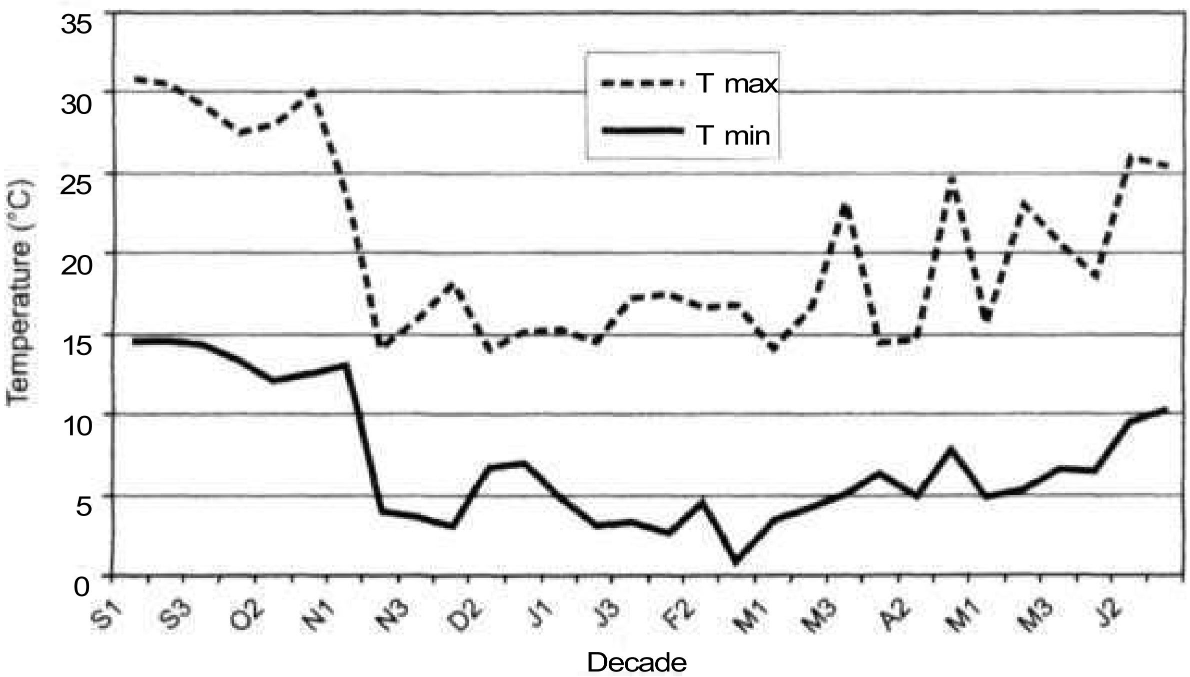


***Figure 4. Daily maximum and minimum temperatures at Sidi el Aydi, 2001-02 season***

Chemical weed control increased yield by 23% at the station and 54% at the farm site. The difference between the two sites is essentially due to a higher infestation rate at the farm, and higher average yield at the experiment station. On the other hand, with the weedy treatment at both sites, the best yield was obtained with the closer planting pattern (narrow spacing and high seeding rate, P1R2).

Planting pattern affected grain yield, biomass and WUE in both experiments. On the station, where seedbed preparation and sowing conditions were optimal, and weed competition was low, with favorable weather conditions, yield increased mainly as a result of planting rate. On the farm, planting space had more effect, and the best planting pattern was 12 cm row spacing and 400 kernels $m^{-2}$.

Conclusions on the benefits of weed control and narrow spacing are the same as in the previous season.

**PROJECT 2. SEASON DISPLACEMENT, PHOSPHATE FERTILIZATION, AND WEED CONTROL EFFECTS ON CHICKPEA IN DRYLAND REGIONS OF MOROCCO**

## Introduction

Water is a major constraint to increasing chickpea production in the semi-arid areas of Morocco. The crop is spring-sown, grown on residual soil moisture, and experiences progressively increasing terminal drought.

Season displacement, phosphate fertilization, and weed control are management options to meet our goal of soil and water conservation. They considerably influence crop productivity and water use efficiency. Research has demonstrated the benefits of advancing chickpea sowing from spring to winter (Dahan 1988, 1996, Dahan and Elhadi 1996, Kamal and Dahan 1996, Ali et al. 1997). The mean increase of productivity over years and locations in Morocco was 87%. The effect was more pronounced at locations where rainfall was low. Phosphate fertilization in chickpea effectively maximizes the use of available water resources for grain production in these areas. Weed control is essential to reduce direct competition for water and nutrients. Many herbicides have been tested in chickpea, and highly selective herbicides are available, but the high cost limits their use (Elbrahli 1987, 1996, Dahan 1988, Dahan et al. 1987).

Although significant advances have been made in developing suitable conservation techniques for dryland crop production, more needs to be done to make these techniques more widely adaptable. An integrated approach involving season displacement, phosphate fertilization and weed management at farmer level within a systems approach, would improve implementation of proven principles of good agronomic management and technology transfer, and develop new ways to enhance water use and water use efficiency at lower cost and with low risk of failure.

The specific objectives of this work are to:

- Evaluate different combinations of management options on yields of chickpea
- Determine the potential of winter vs. spring sowing in terms of productivity under the management options tested
- Evaluate weed infestation and biomass.

# Cropping Season 2000-01

## Materials and methods

The experiment was conducted on a farmer's field in a randomized complete block design with three replications. The treatments consisted of two planting seasons of chickpea (winter vs spring), two phosphate applications (nil versus 26.2 kg P $ha^{-1}$), and two levels of herbicide application (Igran at 2 and 4 L $ha^{1}$). The total area of the plot was 1 ha. The cultivar used was Rizki. Planting dates were 9 Jan for winter and 28 Feb for spring-sown chickpea.

The observations and measurements consisted of meteorological data, yields and yield components. Meteorological data were recorded at weather stations neighboring the farmer site. The yield components were measured by harvesting four samples of two rows of 2 m per treatment at every location. The number of plants was counted. Total weight was determined for biomass yield. The pods were then detached and their number per plant was counted. Samples were then threshed and the seed weight, seed number and seeds per pod were determined. The total biological yield and grain yield were determined by harvesting larger plots of 25 $m^2$.

Data analysis was carried out using SAS (Statistical Analysis System) procedures (SAS Institute). All parameters measured, counted or calculated were analyzed statistically using the analysis of variance procedure. Treatment means were compared by the least-significant difference method at the 0.05-

probability level. Pearson's rank correlation coefficients were calculated among yield and yield components to determine any association.

## Results and discussion

*Climatic conditions.* The total seasonal rainfall was approximately 280 mm, mostly concentrated between 22 Dec and 31 Jan. Temperatures were relatively high during March, sometimes exceeding 30°C (Fig 5). These conditions were accentuated by hot, dry winds (sirocco) for more than three days in March.

*Advancing date of sowing.* Table 5 summarizes yields under different management options. Average grain yields were 493 kg $ha^{-1}$ for winter-sown, and 133 kg $ha^{-1}$ for spring-sown chickpea. Straw yields were 622 kg $ha^{-1}$ for winter-sown and 414 kg $ha^{-1}$ for spring-sown chickpea. The yield advantage of winter vs spring sowing is 270% for grain yield and 50% for straw yield. These results re-emphasize that substantial yield gains can be obtained by advancing the date of sowing (Kamal and Dahan 1996, Ali et al. 1997).

Winter-sown chickpea can be more stable and productive than the conventional spring-sown crop. The main reason is that the winter-sown crop has a more favorable thermal and moisture regime during its reproductive phase than the spring-sown crop, which develops during a period of increasing moisture and thermal stress.

**Table 5. Effect of different herbicide (Igran) levels, 2000-01**

| | Winter | | | Spring | | |
|---|---|---|---|---|---|---|
| Herbicide dosage | Zero P | P22.6 kg $ha^{-1}$ | Average | Zero P | P22.6 kg $ha^{-1}$ | Average |
| Grain yields, kg $ha^{-1}$ | | | | | | |
| 1 kg a.i. $ha^{-1}$ | 439 | 495 | 467 | 121 | 139 | 130 |
| 2 kg a.i. $ha^{-1}$ | 494 | 543 | 519 | 136 | 137 | 137 |
| Average | 466 | 519 | 493 | 128 | 138 | 133 |
| Straw yields, kg $ha^{-1}$ | | | | | | |
| 1 kg a.i. $ha^{-1}$ | 626 | 594 | 610 | 333 | 359 | 346 |
| 2 kg a.i. $ha^{-1}$ | 605 | 663 | 634 | 431 | 533 | 482 |
| Average | 616 | 628 | 622 | 382 | 446 | 414 |
| Weed biomass, g $m^{-2}$ | | | | | | |
| 1 kg a.i. $ha^{-1}$ | 8.7 | 8.1 | 8.4 | 38.9 | 48.3 | 43.6 |
| 2 kg a.i. $ha^{-1}$ | 8.0 | 13.5 | 10.7 | 34.0 | 28.6 | 31.3 |
| Average | 8.3 | 10.8 | 9.6 | 36.4 | 38.4 | 37.4 |

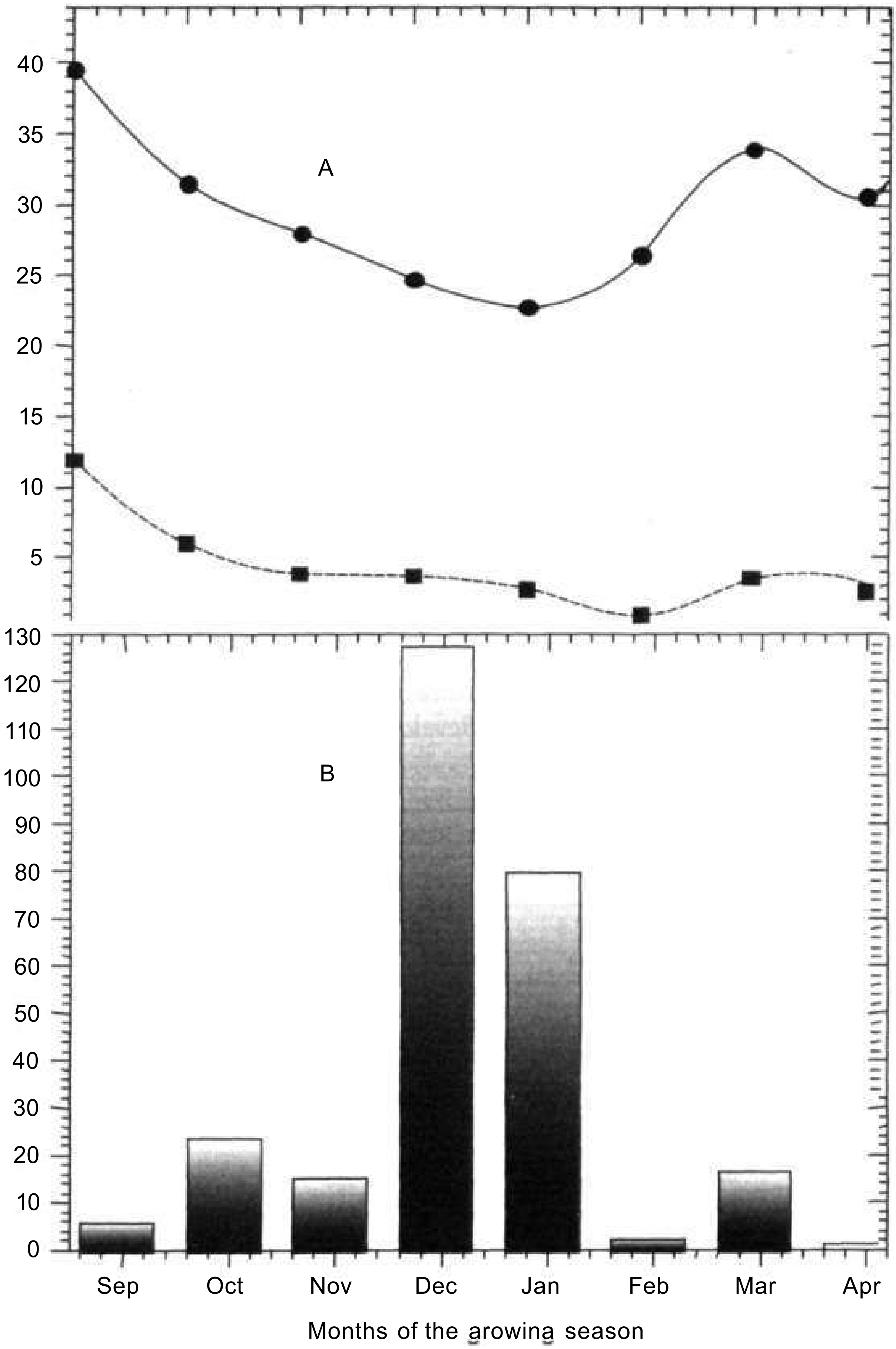


***Figure 5. Monthly maximum and minimum temperature (A) and rainfall (B) at Ain Nzagh, 2000-01 season***

*Phosphate fertilization.* P fertilizer had no significant effect on yields (Table 5). Adequate mineral nutrition is important to meet chickpea requirements, especially for phosphorus. Previous research has demonstrated that growth and yield could be substantially restricted by phosphorus deficiency, particularly in soil with available phosphorus content of 2.5 mg P $kg^{-1}$ (Dahan 1988).

*Weed control.* Herbicide use at two different rates had no significant effect on yields (Table 5). Early sown chickpea was heavily infested by both broadleaves (*Scolymus maculatus, Vaccaria pyramidata, anagallis foemina, Torilis nodosa, Galium tricornutum, Centaurea diluta, Scolymus maculates, Redolfia segetum, Arisarum vulgare, Anchusa azurea* and *Convolvulus althaeoides*) and grasses (*Bromus rigidus* and *Avena sterilis*). Both rates of Igran gave good control of annual broadleaves up to 60 days after treatments. Late emerging weeds *Chenopodium album, Amaranthus blitoides* and *Polygonum aviculare* were more observed in spring chickpea plots, and they were poorly controlled. Also grasses and perennial weeds such as *Convolvulus althaeoides, Anchusa azura* and *Arisarum vulgare* escaped completely from herbicide control. Even though weed infestation was lower in spring than in winter chickpea, lack of moisture led to poor weed control and emerged weeds had a significant effect on yield.

Cropping Season 2001-02

## Materials and methods

The experiment was conducted on a farmer's field in a randomized complete block design with four replications. Plot area, treatments and cultivar used were as in the previous season. Planting dates were 6 Dec for winter and 15 Feb for spring-sown chickpea.

## Results and discussion

*Climatic conditions.* The total seasonal rainfall was approximately 293 mm. Figure 6 shows the distribution of rainfall per decade over the growing season. Most of it was concentrated between 10-25 Dec (159 mm) and March/April (115 mm). Figure 7 shows temperature conditions during the season. Maximum and minimum temperatures were relatively mild, except during the last decades of March and April, when maximum temperatures exceeded 30°C.

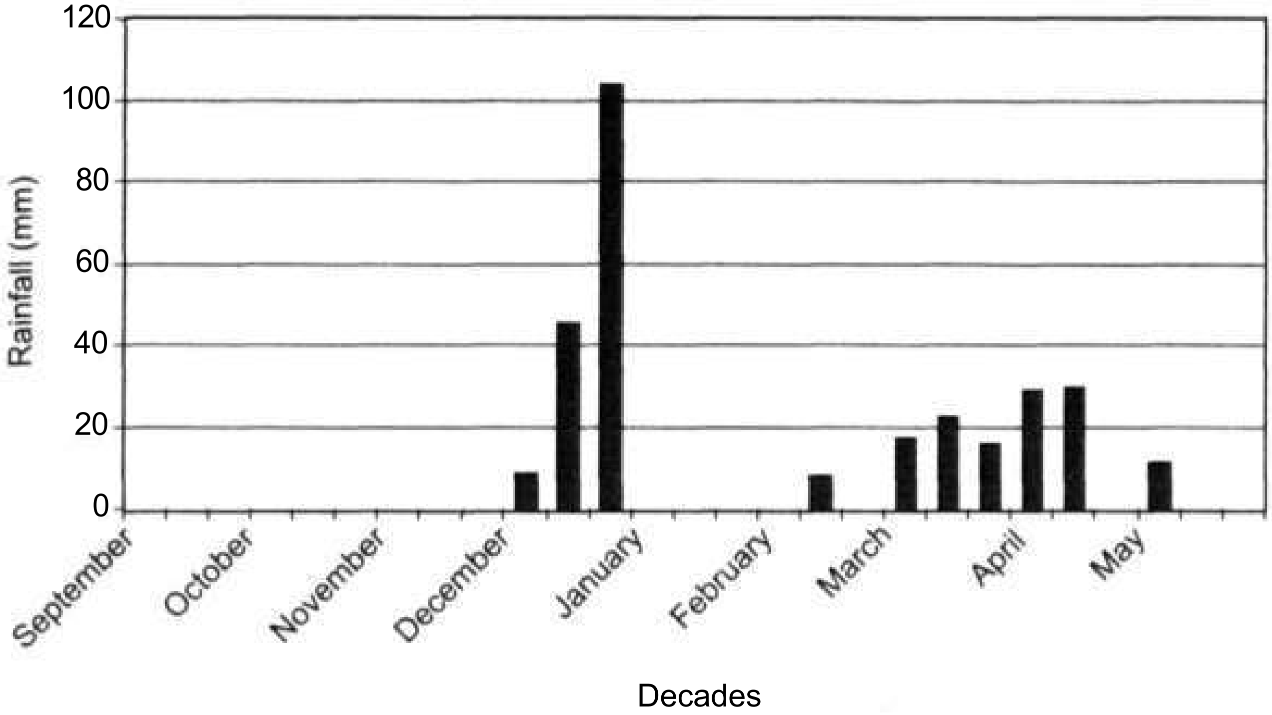


***Figure* 6. *Rainfall at Marchouch, 2001-02 season***

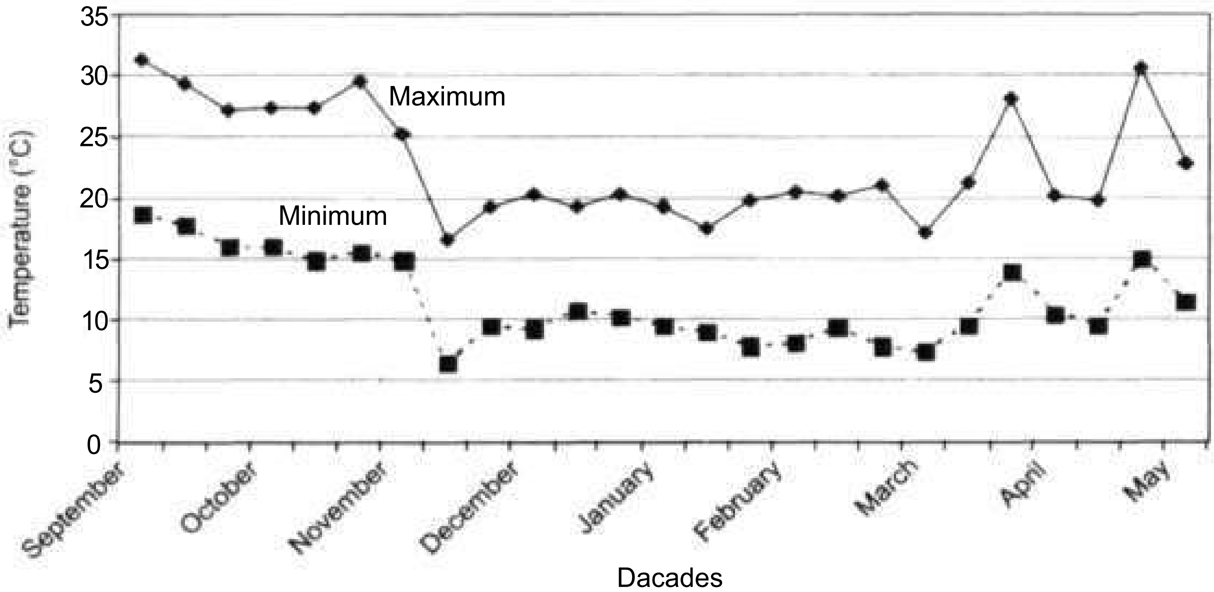


***Figure 7. Maximum and minimum temperatures at Marchouch, 2001-02 season***

*Advancing date of sowing.* Table 6 summarizes grain and biomass yields for different management options. Average grain yields were 2.1 t $ha^{-1}$ for winter-sown, and 1.35 t $ha^{-1}$ for spring-sown chickpea. Straw yields were 5.6 t $ha^{-1}$ for winter-sown, and 3.8 t $ha^{-1}$ for spring-sown chickpea. The yield advantage of winter vs spring sowing was 57% for grain yield and 60% for straw yield.

*Phosphate fertilization.* The phosphorus fertilizer had no significant effect on yields (Table 6). This is attributed to both available P status in the soil, and moisture supply. Winter-sown chickpea is more responsive to P application than spring-sown chickpea. Yield increases due to fertilizer use within any given herbicide treatment for both planting seasons are presented in Figures 8 and 9. For winter-sown chickpea, grain yield increases are 4% for low rate and 15% for high rate of herbicide use. Straw yield increases are 22% for low rate and 12% for high rate. For the spring-sown crop, grain yield increases are 2.5% for low rate and 7.3% for high rate; straw yield increases are 7% for low rate and 6% for high rate of herbicide use.

*Weed control.* The effects of herbicide use at two different rates on yields are reported in Table 6. Both rates of herbicide use gave good control of annual broadleaves. Late emerging weeds were more common in spring-sown

**Table 6. Effect of different herbicide (Igran) levels on grain and biomass yield, 2001-02**

| | Winter | | | Spring | | |
|---|---|---|---|---|---|---|
| Herbicide dosage | Zero P | P 22.6 kg $ha^{-1}$ | Average | Zero P | P 22.6 kg $ha^{-1}$ | Average |
| Grain yields, kg $ha^{-1}$ | | | | | | |
| 1 kg a.i. $ha^{-1}$ | 1.8b | 1.9b | 1.8 | 1.2a | 1.3a | 1.2 |
| 2 kg a.i. $ha^{-1}$ | 2.2ab | 2.5a | 2.3 | 1.4a | 1.5a | 1.4 |
| Average | 2.0 | 2.2 | 2.1 | 1.3 | 1.4 | 1.3 |
| Yield increase % | 22.2 | 31.6 | 26.9 | 16.7 | 15.4 | 16.0 |
| LSD (0.05) | | 0.5 | | | 0.4 | |
| Total biomass yields, kg $ha^{-1}$ | | | | | | |
| 1 kg a.i. $ha^{-1}$ | 4.6b | 5.6ab | 5.1 | 2.9b | 3.1b | 3.00 |
| 2 kg a.i. $ha^{-1}$ | 5.7a | 6.4a | 6.05 | 4.5a | 4.8a | 4.65 |
| Average | 5.15 | 6.0 | 5.6 | 3.7 | 3.95 | 3.82 |
| Yield increase % | 23.9 | 14.3 | 18.6 | 55 | 54.8 | 55 |
| LSD (0.05) | | 1.05 | | | 0.86 | |

Treatments with the same letter are not significantly different

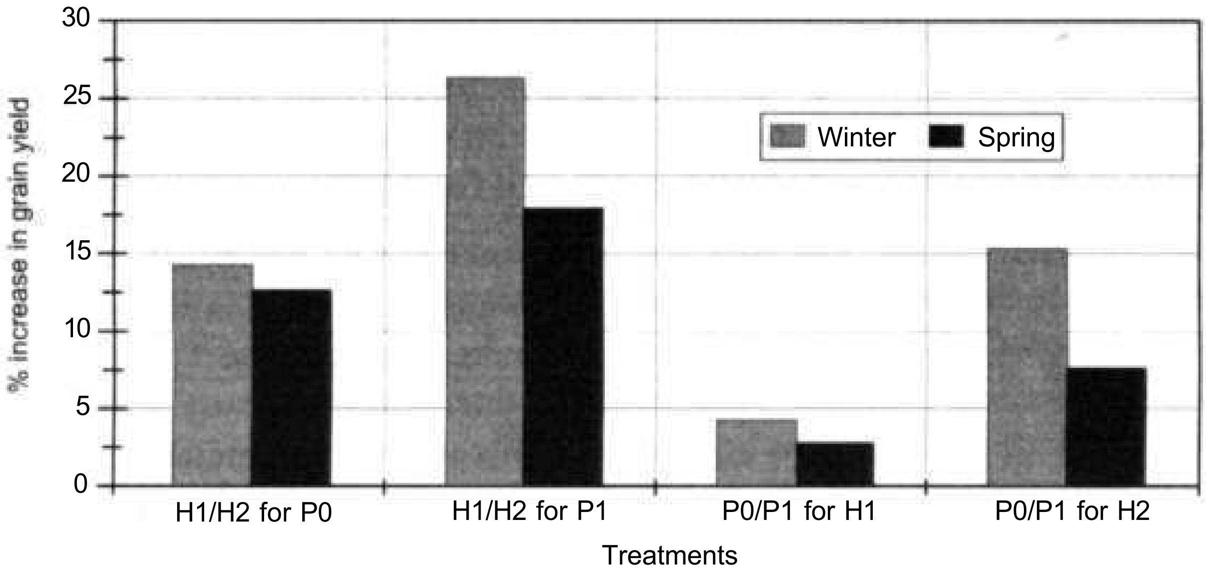


***Figure 8. Increase in grain yield due to herbicide and phosphorus use on winter and spring chickpea***

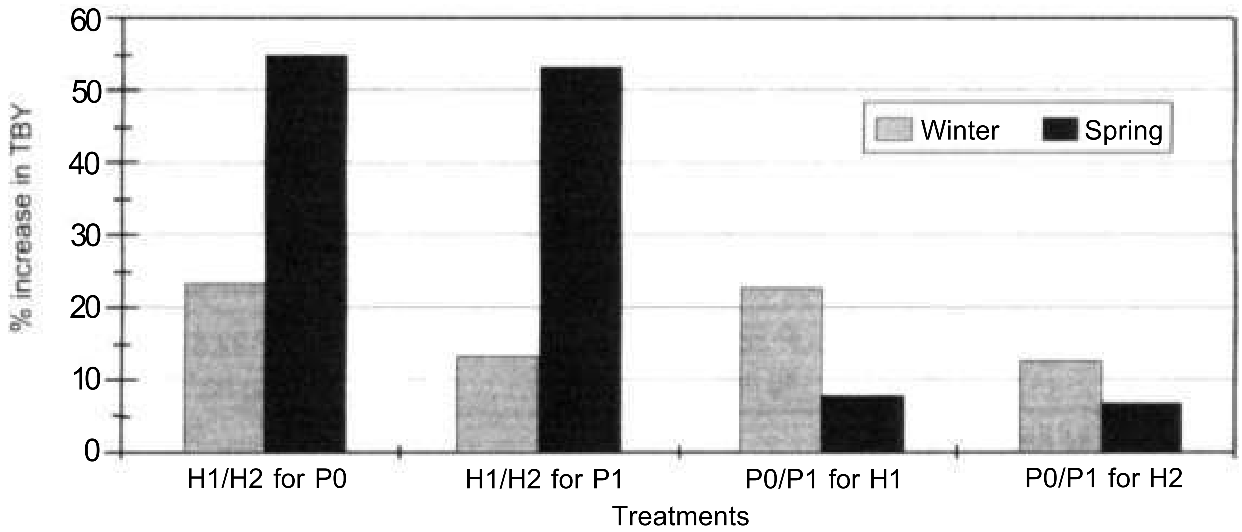


***Figure 9. Increase in biological yield due to herbicide and phosphorus use on winter and spring chickpea***

chickpea, and they were controlled effectively. The higher rate gives better yields in all treatments. Grain and straw yields increased 17-20% for winter sowing and 17-53% for spring sowing.

Yield increase due to higher herbicide use (within any given P treatment) is presented in Figures 8 and 9. For winter-sown chickpea, grain yield increased by 14% without P and by 26% with P. Straw yield increased by 23% without P and 13% with P. For the spring-sown crop, grain yield increases were 12.3% without P and 17.6% with P. Straw yield increased by 54.3% without P and 52.6% with P. Thus, most gains in both seasons came from herbicide use, especially when the spring season is relatively wet.

## Conclusions

Advancing the date of planting improved the performance of winter-sown chickpea due to the relatively more favorable thermal and moisture regime during its vegetative and, more importantly, reproductive phases, compared to conventional spring-sown chickpea. Phosphorus fertilization is advantageous mainly in soils where available P is low. Weed control using a pre-emergence herbicide, can be effective when environment conditions are favorable for its absorption.

There is a need for further studies in different parts of the region on these agronomic options and other aspects that take full advantage of existing environments.

### PROJECT 3. WEED MANAGEMENT IN LENTIL

## Introduction

Lentil is very susceptible to weed competition. Complete crop loss can occur if weeds are not controlled (El Brahli 1994). Hand weeding accounts for an estimated 19% of the total production cost (Zimdahl et al. 1992). This factor has contributed to the decline in lentil area from 90,000 ha to less than 57,000 ha (El Khayari 1992). Weed control and mechanization are the main constraints to lentil crop improvement. In dryland areas, where rainfall is low and variable, weed control is essential to reduce direct competition for water and nutrients. Chemical options are limited, and precautions are required to minimize yield loss. Some selective herbicides have been identified but high cost and ineffectiveness limits their use (El Brahli 1987).

Development of an early crop canopy by the use of narrower row-spacing and higher seed rate can improve the ability of the crop to compete with weeds. Use of pre-emergence herbicides can also give some control of annual weeds. Combining these options would increase the effectiveness of weed control and, hence productivity and WUE. However, there is still a need to identify more efficient selective herbicides for use with lentil.

*Objectives.* The objectives were to:

- Evaluate various management options to control weeds in lentil
- Evaluate pre-emergence herbicides, and identify the most effective ones
- Identify the best strategy for weed control in lentil.

## Materials and Methods

The experiment was conducted at Sidi El Aydi experimental station of INRA during the 2000-01 cropping season. It tested two levels of row spacing as main plots (30 cm and 60 cm), and eight weed control options as sub-plots. T1: Gesatope 0.25 kg a.i. $ha^{-1}$, T2: Gesatope 0.50 kg a.i. $ha^{-1}$, T3: Igran 0.75 kg a.i. $ha^{-1}$, T4: Igran 1 kg a.i. $ha^{-1}$, T5: Karmex 0.25 kg a.i. $ha^{-1}$, T6: Karmex 0.50 kg a.i. $ha^{-1}$, T7: weedy check, T8: hand weeding. The design was a split plot with four replicates. The lentil cultivar used was Bakria. The total area of the experiment was 0.2 ha.

Observations were made on weed infestation (species, density and biomass), yield and yield components, and meteorological data.

## Results and Discussion

Temperatures and rainfall during the 2000-01 season at Sidi E1 Aydi are presented in Figure 1. The weather conditions were dry, and the crop experienced drought and temperature extremes at all growth stages.

Table 7 summarizes yields for different management options. The effect of row spacing was highly significant. However, there were no significant effects of herbicides, or herbicide by row spacing interactions.

With the narrower row spacing, grain yield increased by 28%, and straw yield by 38%, compared with the wider spacing. The herbicides Igran (terbutryn) at 0.75 or 1 kg a.i. $ha^{-1}$, and Karmex (diuron) at 0.50 kg a.i. $ha^{-1}$ gave best weed control and yields (Table 7), compared to weedy check and hand weeding. Wider spacing combined with Karmex gave better yields and weed control.

The weeds on the lentil plots were exclusively broadleaves, with the dominant species *Amaranthus blitoides, Chenopdium album, Centaurea diluta, Papaver rhoeas, Gluacium corniculatum* and *Polygonum aviculare.* Igran at 0.75 and 1 kg a.i $ha^{-1}$, and Karmex at 0.50 kg a.i $ha^{-1}$ reduced weed biomass in both row spacing treatments. Gesatope (simazine) at rates of 0.25 and 0.50 kg a.i $ha^{-1}$ produced significant crop injury and was not selective for lentil. All herbicides tested were applied at the pre-emergence stage of weed

| Table 7. Effect of weed control and row spacing on lentil at Sidi El Aydi, 2000-01. | | | |
|---|---|---|---|
| Weed control (kg a.i. $ha^{-1}$) | Spacing 30 cm | Spacing 60 cm | Average |
| | | Grain yields (kg $ha^{-1}$) | |
| Gesatope 0.25 | 169 | 149 | 159 |
| Gesatope 0.50 | 154 | 162 | 158 |
| Igran 0.75 | 273 | 172 | 222 |
| Igran 1.00 | 232 | 165 | 199 |
| Karmex 0.25 | 190 | 114 | 152 |
| Karmex 0.50 | 215 | 217 | 216 |
| Weedy check | 139 | 110 | 125 |
| Hand weeding | 211 | 151 | 181 |
| Average | 198 | 155 | 176 |
| | | Straw yields (kg $ha^{-1}$) | |
| Gesatope 0.25 | 394 | 322 | 359 |
| Gesatope 0.50 | 460 | 350 | 355 |
| Igran 0.75 | 638 | 372 | 505 |
| Igran 1.00 | 544 | 356 | 450 |
| Karmex 0.25 | 445 | 246 | 346 |
| Karmex 0.50 | 502 | 469 | 486 |
| Weedy check | 326 | 237 | 282 |
| Hand weeding | 494 | 327 | 410 |
| Average | 463 | 335 | 399 |
| | | Weed biomass (g $m^{-2}$) | |
| Gesatope 0.25 | 38.1 | 77.8 | 58.0 |
| Gesatope 0.50 | 57.4 | 81.2 | 69.3 |
| Igran 0.75 | 498 | 966 | 73.2 |
| Igran 1.00 | 51.6 | 54.2 | 52.9 |
| Karmex 0.25 | 549 | 69.5 | 62.2 |
| Karmex 0.50 | 43.2 | 67.4 | 55.3 |
| Weedy check | 54.5 | 88.3 | 71.4 |
| Hand weeding | 38.8 | 83.2 | 61.0 |
| Average | 48.5 | 77.3 | 62.9 |

and lentil, lack of moisture after herbicide application resulted generally in poor to moderate weed control. Basler (1981) reported that efficacy of soil applied herbicides is highly dependent on temperature and moisture conditions.

## Conclusions

Narrower row spacing and an effective pre-emergence herbicide gave significant control over weeds and increase in lentil productivity in a dry environment. This enabled the crop to develop an early crop canopy, and to improve its competitive ability over weeds. Combining the two agronomic options is a meaningful strategy for weed management. Behavior of soil-applied herbicides used in this experiment, and their interaction with weather conditions, need to be considered. There is a need to identify more efficient selective herbicides, and other management strategies for lentil.

## Acknowledgments

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# The Use of Systems Models in Small-Scale Farming in Semi-Arid Areas

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## Introduction

A crop model can be defined as a quantitative scheme for predicting the growth, development and yield of a crop, given a set of genetic coefficients and relevant environmental variables (Monteith 1996). Crop models have current and potential uses for answering questions in research, crop management, and policy (Boote et al. 1996). Researchers can use models as tools to conduct research faster and more cost effectively, while extension officers and producers can use them to determine the risk involved in certain production practices, especially in dry areas with erratic rainfall (Hensley and Snyman 1991). The farmer can use a model to assist in pre-season and in-season management decisions on cultivation practices, fertilization, irrigation, and pesticide use (Bennie et al. 1997, 1998, De Jager and Singels 1990). Models can also assist in synthesis of research understanding about the interactions of genetics, physiology, the environment, integration across disciplines, and organization of data. Crop models can assist policy makers by predicting soil erosion, leaching of agro-chemicals, effects of climatic change, and by making large-area yield forecasts (Schulze 1995). Simulation models are used to estimate potential yield in new areas, to forecast yields before harvest, to estimate sensitivity of crop production to climate change, and to compare management options, technology level, and performance of varieties (Muchow et al. 1990).

While models cannot produce all the answers to crop production problems, when reasonably constructed they can be important heuristic tools in teaching, research and management. They can be used to test hypotheses and the validity of standard practices, thereby allowing users to reason more consistently about factors or conditions that deserve thought by students, additional experimental study by researchers, or more attention from growers. Crop models cannot replace observation, experimentation, and experience, but they can be well supported by them. Because of the large number of situations where the heuristic function of crop models can be a crucial if not an indispensable tool, modeling can have a productive future (Sinclair and Seligman 1996).

Models can also be used to extrapolate results to ecotopes on which field experiments have not been conducted. Crop models can also be used together with long-term climate data to identify the most profitable production techniques under current economic and technology conditions, eg which crop, best planting date, best population, best variety and best rotation.

## The Problem and Proposed Solution

In central South Africa, a large 'resettlement area' of 750,000 ha east of Bloemfontein has been earmarked for developing farmers. There is a large population in the scattered villages, and in the two towns of Thaba Nchu and Botshabelo. This area is marginal for crop production because of low and erratic rainfall, and dominantly clay soils with high runoff, and losses due to evaporation from the soil surface. These losses result in low soil water storage with consequent reduction in crop yields. There is a great need to minimize crop production risk and improve rainfall use efficiency.

Long-term results are necessary for reliable production recommendations and production risk quantification under semi-arid conditions. A valuable property of models is their ability to utilize long-term climate data to provide long-term yield simulations that can quantify risk for various production techniques. Before we had models, land use decisions were based on field experiments at a limited number of sites and generally few seasons. This had limitations that can be overcome by the judicious use of reliable models. In this study the Agricultural Production Systems sIMulator (APSIM) model is used to quantify risk and plan production strategies.

We hypothesise that the APSIM systems model can be used to quantify risk and plan production strategies for small-scale farmers on marginal soils in the semi-arid areas of central Southern Africa. One advantage of APSIM is that it is a three-dimensional model and not a point model. This makes it possible to model more complex production systems. APSIM already simulates yield of crops, pastures, trees, weeds, key soil processes (water, N, P, carbon, pH), surface residue dynamics and erosion, a range of management options, crop rotations + fallowing + mixtures, and short or long term effects. A shortcoming is that it does not yet simulate pests or diseases.

APSIM has been used successfully for cereal-legume rotations, ley farming systems, intercropping systems, alley farming systems, drought policy formulation, erosion impacts, crop-weed associations, genetic trait identification, seasonal climate forecasting, on-farm trial analyses, global change impacts/adaptation, agribusiness value chain, tree windbreak systems, deep drainage assessment, soil acidification, land use change under variable climate, and for risk assessment.

APSIM has also been used to simulate physiological processes, plant organs, crop growth and development, yield of experimental crops, yield of commercial crops, yield of smallholder crops, N response in smallholder crops, seasonal perspectives, yield of crops in rotation, soil water of crops in rotation, evapotranspiration, legume rotation effects, consequence of crop rotations, soil organic matter changes, crop-weed competition, response to manure application, response to N and P fertilizer and manure, on-farm constraints, tree growth and development, agroforestry systems, salt accumulation under trees, acidification in soil profiles under cropping, and change in Australian wheat production under climate change.

An example follows on how the APSIM model was utilized to assist small-scale farmers in Masvingo, Zimbabwe, to improve crop yields. This exercise was conducted during the Linking Logics I workshop in Zimbabwe. If it was possible to make reliable recommendations for smallholder farmers in the remote rural areas of Zimbabwe, then it will be possible to apply APSIM to generate management options elsewhere for other smallholders to improve production strategies. Improved production strategies will lead to the alleviation of malnutrition, the betterment of health, educational endeavours and socio-economic status of the people in poverty stricken Africa.

## Scenarios Modeled

After discussions with farmers to identify the main factors that hinder successful crop production, the following scenarios were proposed for simulation modeling to see if the modeling tool could assist in furthering the interaction with farmers:

- Efficient fertilizer management on maize in different field types - rates, timing, splitting; impact of late planting, low populations; timeliness of weed management
- Rotations and whole-farm resource allocation.

Due to time limitations, simulations were not done for the impact of weed management on crop response, rotations and whole-farm resource allocation. The scenarios modeled focused on the risks associated with use of inorganic N in this environment, the potential benefits of fertilizer use on different field types, and an exploration of the factors that limit responses to inorganic N.

## Simulation Inputs and Assumptions

*Weather data.* Masvingo climate record 1951-1998.

*Soil inputs.* The soil type used was that described for the Makoholi Experimental Site. Soil N was re-initialized each year after harvest to eliminate long-term changes in soil fertility as a result of the scenarios. Soil water was allowed to carry over between seasons.

*Crop management.* Maize cultivar SC501 was sown at 3.5 plants $m^{-2}$ in each season on the first date after 1 November if the following criteria were met: (i) at least 25 mm of rainfall in the previous 10 days, and (ii) soil water content in the 10-30 cm layer had at least 50% of its total plant available water at field capacity. Using this rule maize could be sown every season in the 46-year run. Some simulations were conducted with the sowing window constrained to occur after 1 Dec to explore the impact of late sowing on productivity. Other simulations were conducted with a low population (2 plants $m^{-2}$) to reflect the low densities used in smallholder fields.

*Fertilizer management.* The fertilizer application strategies simulated were: no fertilizer application (as baseline), applications on fixed dates after sowing in each season, and applications conditional upon rainfall. In the conditional strategies, there were three windows of application, 1-10, 20-30 and 40-50 days after sowing during which 15 kg N $ha^{-1}$ could be applied if 20 mm of rainfall occurred in a 20-day period.

*Economic calculations.* Return on fertilizer was calculated as yield multiplied by price per kg of grain minus the fertilizer rate multiplied by the cost of fertilizer per kg. As most maize within the area is produced for home consumption, the price used was based on the cost of buying maize for home consumption.

*Simulation outputs.* APSIM was configured to explore maize response to various amounts and timings of N application and the impact of late planting. Data from past research on maize response to N from on-farm and on-station trials were also collated and analyzed by the researchers and extension officers.

## Simulation outputs, Day 1

Table 1 summarizes the simulation outputs for some scenarios modeled. Without fertilizer, mean grain yield was reduced from 800 kg $ha^{-1}$ with timely planting to <650 kg $ha^{-1}$ with late planting. With fertilizer (15 kg N $ha^{-1}$ applied on 1-3 occasions during the season, depending on rainfall), mean grain yield was reduced by >300 kg $ha^{-1}$ with late planting.

Simulations helped to highlight the variation in yield response across seasons resulting from seasonal variations in amount and distribution of rainfall (Fig. 1).

**Table 1. Example of model outputs - simulated yield (kg $ha^{-1}$) to different N rates and the impact of late planting**

| | Zero N | 3 x 15 kg N* | ZeroN, late plant | 3 x 15 kg N, late plant |
|---|---|---|---|---|
| Mean | 797 | 1799 | 627 | 1449 |
| Maximum | 1355 | 3689 | 1232 | 3310 |
| Minimum | 0 | 0 | 0 | 0 |
| No. of zero values | 1 | 1 | 2 | 4 |
| 25th percentile | 565 | 988 | 419 | 669 |
| Median | 836 | 2146 | 603 | 1657 |
| 75th percentile | 1070 | 2556 | 862 | 2091 |

* Rainfall-directed application, 3 times @ 15 kg N ha-[1]. Average rate = 36 kg N $ha^{-1}$ per year

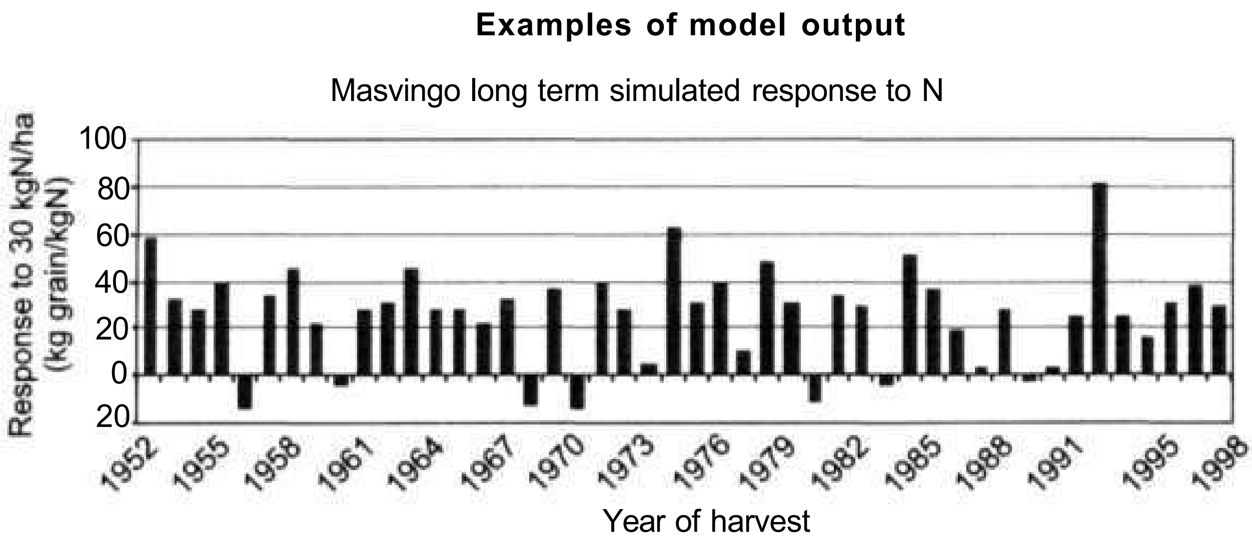


***Figure 1. Seasonal variations in agronomic N use efficiency at Masvingo***

In Figure 2, cumulative probability distribution of gross returns to different fertilizer rates and management strategies indicates the risk associated with inorganic fertilizer use in this low rainfall environment - in 20% of seasons there is no net benefit from using inorganic fertilizers. In addition, mean agronomic N use efficiencies (extra kg grain per kg of N applied) in this environment are about 25 kg maize per kg of N.

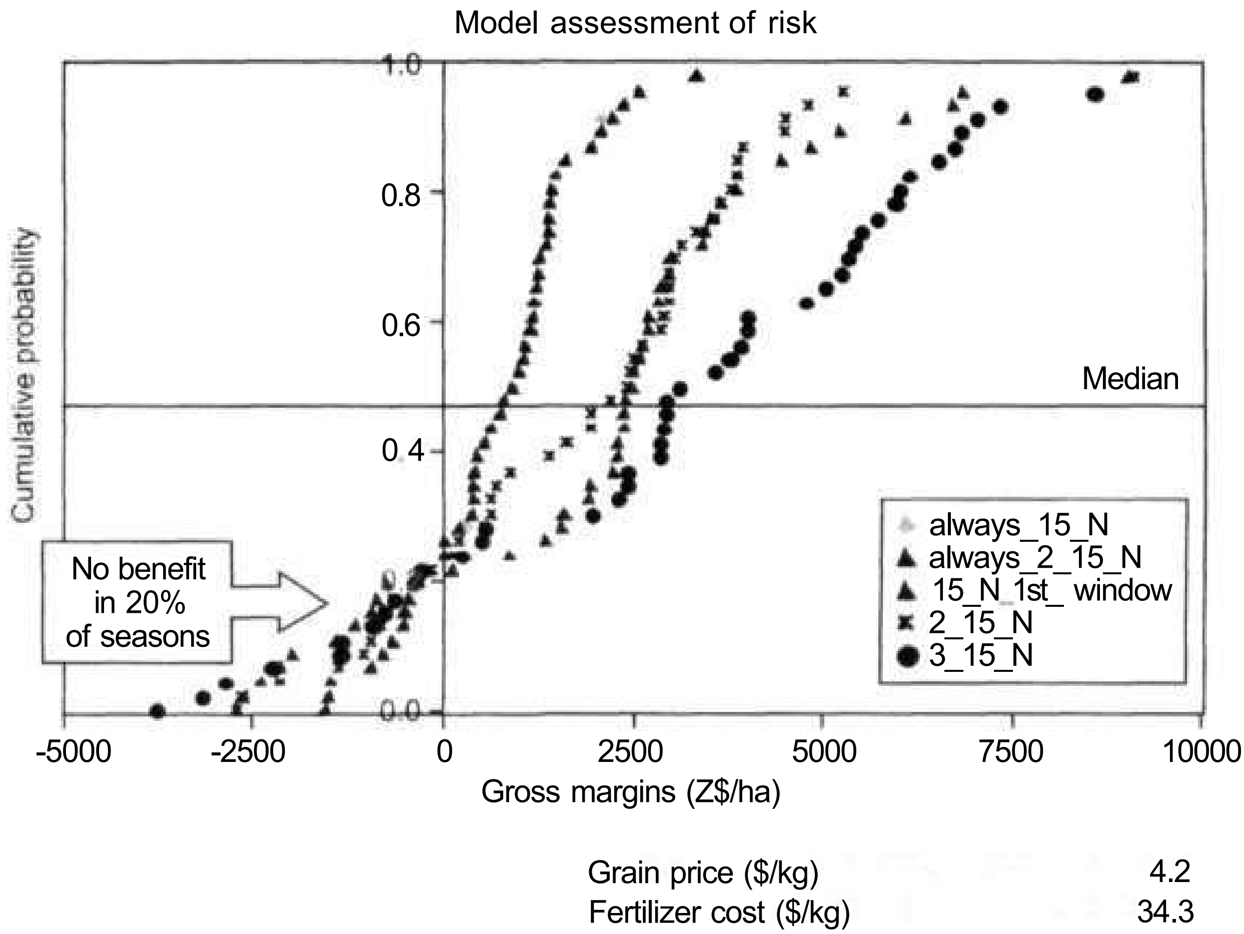


***Figure 2. Assessing the risks associated with using inorganic N fertilizer in Masvingo***

Results from past on-station and on-farm trials of maize response to N show that the agronomic use efficiencies for N on research plots are about twice that on smallholder fields. Simulated efficiencies (Table 2) would represent efficiencies similar to research plots since factors such as weed competition, pests, disease and fertility problems were ignored in the simulation.

*Key insights to take to farmers.* Based on the simulations, past research work, and the farmer discussions on day 1, the researchers and extension officers identified three themes for further discussion with the farmers:

**Table 2. Model estimates of agronomic N use efficiencies for different N management strategies**

| | Grain yield response (kg grain per kg N) | | | | |
|---|---|---|---|---|---|
| | Always 15 N | Always 2 x 15 N | 15 N first | 2 x 15 N | 3 x 15 N |
| Mean | 19 | 25 | 19 | 24 | 26 |
| Maximum | 61 | 80 | 61 | 80 | 65 |
| Minimum | -16 | -13 | -16 | -14 | -14 |
| No. of values < 0 | 8 | 7 | 7 | 8 | 8 |
| 25th percentile | 9 | 16 | 2 | 11 | 10 |
| Median | 22 | 28 | 22 | 28 | 29 |
| 75th percentile | 30 | 35 | 30 | 37 | 39 |

- Potential benefits of inorganic fertilizer use and agronomic N use efficiency
- Factors that limit response to fertilizer
- Risks associated with inorganic N use (no benefit in 20% of seasons)

*Researchers plan how to communicate model insights to farmers.* Having identified the three themes for discussion with farmers, the researchers brainstormed on how best to put across the insights from the models to farmers. For instance, an important question was: How to move from 'researcher' or model units (eg kg $ha^{-1}$ or agronomic N use efficiency, NUE) to units that can be communicated with farmers? The decision was made to convert model units to those in common use by farmers. For example, mean agronomic N use efficiency of 25 kg maize per kg N could be stated as 9 bags of maize per bag of AN. In addition, the notion of NUE could be introduced to through a simple pictorial discussion of extra bags of maize produced by using an additional bag of AN.

## Feedback to farmers. Day 2

Researchers sought to engage farmers ie explore farmer 'models' in the light of research models, for example exploring farmer estimates of returns from fertilizer use for different field types, or exploring reasons for low yield responses to fertilizer.

*Farmer estimates of returns from fertilizer use for different field types.* The discussion began with researchers asking the farmers what sort of yield they would expect on each of their field types if they do not apply fertilizer. Farmers were then asked to give estimates of expected yield from those same field types if they had applied half a bag of AN, or 1 bag of AN. Farmer estimates were then compared with the model estimates. The discussion was expanded to include a simple cost-benefit analysis. From the analysis, it was obvious to the farmers that to at least break-even, they need to get 2-3 bags of extra maize per bag of AN used.

*Reasons for low yield responses to fertilizer use.* Comparison of farmer and model estimates of yield responses to N showed a gap between what the model suggested is achievable, and what farmers are getting in their fields. In an ensuing discussion the farmers gave a thorough account of the causes of the 'efficiency gap', and how these factors reduce their returns to investments in fertilizer.

## Lessons Learnt

### What worked well?

Farmers showed enthusiasm in talking about fertilizer use in terms of 'extra' grain and 'profit'. Farmers' estimates for maize production under different management regimes coincided with model estimates in many instances.

- Risk: no benefit to fertilizer use in 2-3 years out of 10
- Maize yields on the homestead field is approximately 750 kg $ha^{-1}$ when no fertilizer is applied

Farmer estimates of yield responses to N use suggested an efficiency gap - farmer estimates were only 50-75% of model estimates. However, farmers explained the efficiency gap very well. Farmers tended to overestimate yield responses from use of larger amounts of AN (especially on the topland fields), eg when fertilizer was increased from 0.5 bags per acre to 1 bag per acre, farmers estimated the extra grain produced would jump from 2 to 10 bags. This could be partly explained by most farmers in the group having little experience of applying large amounts of fertilizer especially on the topland fields.

### The way forward

We need to do more than just talk about these things. Farmers are looking for practical steps, ie technologies that improve production and returns to investment. They want to work with researchers in on-farm trials, and to be empowered. This in turn will require training-for-transformation.

## Project Goal for South Africa

To develop and evaluate decision support tools for improved soil, water and nutrient management to stabilize and increase crop production in different agro-ecological zones. The project aims to:

- Obtain a working knowledge of the APSIM model
- Test APSIM with local sets of data
- Use APSIM together with long-term climate data and ecotope descriptions to construct for selected crops, long-term cumulative probability functions of yield to quantify risk
- Apply APSIM to generate management options for small-scale farmers to improve production strategies.

## Materials and Methods

Local data sets were obtained from field experiments with maize conducted on two ecotopes (about 300 m apart in well-fenced camps) at the Glen Experimental Research Station (28°57' S, 26°20' E), situated 25 km NE of Bloemfontein, namely the Glen/Bonheim-Onrus ecotope and the Glen/Swartland-Rouxville ecotope. These selected ecotopes on the Glen Research Station are representative of more than half a million hectares of land in the Free State Province, on which a large number of rural households exist. The term ecotope can be defined as an area of land on which the natural resources (climate, topography, soil) that influence yield, are reasonably homogeneous (MacVicar et al. 1974).

*Obtain a working knowledge of APSIM.* Anderson and Botha attended a workshop in Zimbabwe, 14-29 Oct 2001, on 'Exploring linkages between farmer participatory research and computer-based simulation modeling to increase crop productivity at the smallholder level'. This workshop was a joint venture between PGRA, SWNM, ICRISAT and CIMMYT, and provided hands-on experience in the use of APSIM.

*Data collection.* Necessary data from selected ecotopes with marginal rainfall was obtained from field experiments conducted by Hensley et al. (2000) with maize over a period of two years on the Glen/Bonheim and Glen/Swartland ecotopes. Crop growth, climate, and soil water content were monitored throughout the growing seasons. Critical growth stages and visual symptoms of the maize were recorded. Maize biomass was determined at harvest.

Biomass was expressed as oven dry material in kg $ha^{-1}$. Grain yield for maize was determined and expressed as kg $ha^{-1}$ at 13% water content. Climatic variables needed by the model were measured with an automatic weather station. The soil water content of the root zone (2r) was monitored with a neutron water meter (NWM) to a depth of 1.3 m, ie, to a greater depth than that of the root zone. Measurements of 2r were carried out before planting, at planting, and during the growing season at 300 mm depth intervals starting at 150 mm. A Campbell Pacific 503 DR NWM was used. This procedure ensures that the different pedological layers in the soil have been adequately represented.

*Test the model with local sets of data.* APSIM will be tested against local measured data. For testing model performance against measured values the statistical procedure proposed by Willmott (1981) will be used.

*Run the model to present various farming systems scenarios.* APSIM will be run with various farming systems scenarios like different planting dates, fertilizer levels and weeding options.

*Risk assessment.* Risk assessment for various farming scenarios will be done by predicting cumulative yield probability functions (CPFs). These will be obtained by running APSIM with long-term climate data for each ecotope.

## Results and Discussion

The first two days of the workshop focused on experiences in participatory research approaches by Ann Braun, Toon Defoer, Pascal Sanginga, Peter Horne and David Rohrbach, an introduction to APSIM by Peter Carberry, and the experiences of the ICRISAT and CIMMYT teams in linking participation with simulation modeling. The finale for this two day session was a series of group modeling exercises, before fieldwork with host villages. Some simple scenarios were run for a hypothetical farm facing the same weather pattern as real farms in the Tsholotsho and Zimuto communal areas of Zimbabwe, by using much simpler farming strategies than real farms in the region use. Running various scenarios with a hypothetical farm, however, showed the researchers what the APSIM simulation model could do.

Workshop participants were organized into six groups with attention given to the language, disciplinary background and local representation for each group. The groups had little or no experience at interaction with communal farmers using simulation models. The six teams worked with farmers in six villages in Tsholotsho and Zimuto for three days. Each group was then requested to plan their interaction with the farmers based on the background information provided by local researchers. Similarly, the issue of using the model directly with farmers as part of the interaction was left to each group to decide. The aims of the fieldwork were to get a better appreciation of farming systems and where soil fertility fits within the livelihood strategy; and to be able to run simulations of various scenarios for individual farms.

A short review is given on the activities of the team who interacted with 30 farmers in the village of Mkhubazi, Tsholotsho.

On the first of the three days of interaction with farmers in the village, a focus group meeting was held with 21 farmers, half women and half men. The facilitator started the discussion by gaining some valuable information on the taxonomy of the soils in the village. An agricultural activity calendar was then elicited from the farmers, showing the details of dates of planting, weeding, and harvesting for different crops grown on different kind of soils. Different patterns of crop rotations on the same plot or portion of a big plot were also reported. The use of organic (manure) and inorganic fertilizer on the different soil types was also discussed.

These discussions were followed by small group discussions, with the team members interviewing small groups of four to five farmers. Some team members asked individual farmers about their individual farming practices, household food security, and household consumption.

On the second day of fieldwork the work resumed with a short talk by a team member who summarized the main findings of the previous day on one colorful poster (Fig 3). The use of crop growth models to assist farmers in decision making was then introduced in a simple visual way. The group then broke into small groups of four to five farmers to do resource allocation mapping of each household in the group.

On the third day of the fieldwork the overnight runs of each case study for individual farmers were presented as bags per acre for a baseline and a new practice. Model runs were redone after the farmers made suggestions for alternative options. The change in bags per acre was written up on a board and discussed.

The overall feeling from the majority of workshop participants was that they had begun to value the exchanges between different disciplines, and the role each played in helping to resolve production constraints. Unfortunately the six days was only enough to whet most people's appetites.

Back home in South Africa, various plans have already been developed to use APSIM as a decision support tool for improved soil, water and nutrient management to stabilize and increase crop production in the highly populated

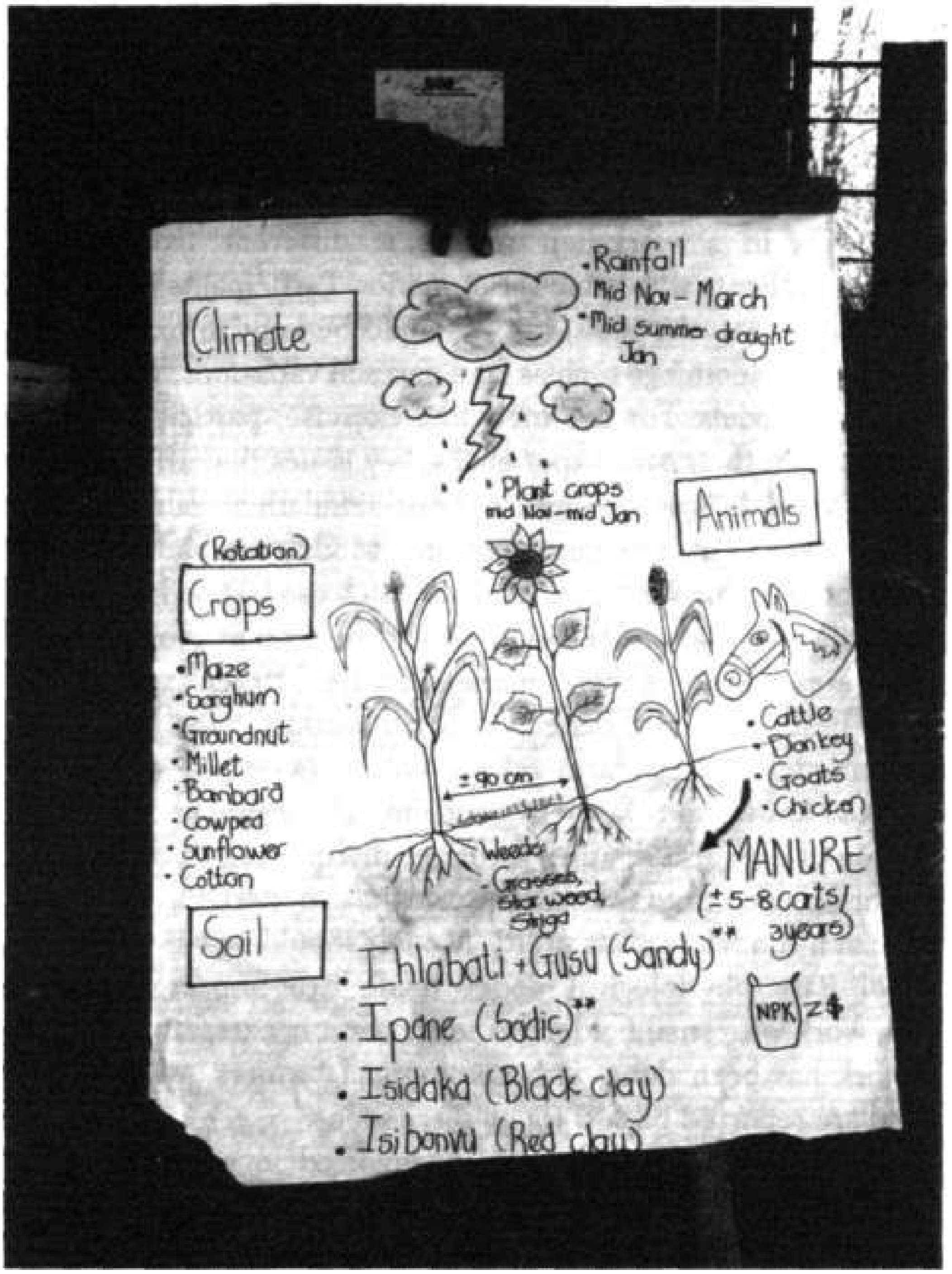


***Figure* 3. *A summary of the farming enterprise in Mkhubazi village, Tsholotso, Zimbabwe***

scattered villages and two towns, Thaba Nchu and Botshabelo east of Bloemfontein. All the necessary weather, soil and crop data have been collected to test model performance under local conditions before it will be widely used to generate management options for small-scale farmers. The project team has requested the APSIM program from APSRU numerous times. The project team is now waiting for software from APSRU to be able to continue with the planned activities.

## Conclusions

Models are complicated, and they have hidden assumptions. For example, there is a need to understand agronomy when considering issues such as nitrogen placement. Models are therefore only rough indicators, which may be good enough in some cases, though overall they are useful tools.

Using models in a workshop setting is different from using them individually with clients who value the scenarios. Participants in the workshop were being exposed to the tools, but it should be kept in mind that models have their own shortcomings such as land and soil variations, which cannot be handled by the models. For the modeling exercise, participants have been asked to pick, from their own experiences, key issues that affect farmers.

The use of models is not so much about simulating reality, as offering a quick way of looking at a range of options. Models enable researchers and farmers to choose options that are best and which can be tried in the field. The models have data limitations and they should be seen as tools for generating researchable areas. There is therefore need to use different agronomy related models. The best choice will depend on what works for the farmer, and how closely the model reflects farmers' current practices. Consequently, it is important to know the farmers' current management practices. The interpretation of data also requires different disciplines.

There is also a need to go through the principles underlying a model in order to convince non-modelers of its utility. Models should be viewed as a learning process/tool. Basic physiological models made little impact. APSIM has not done much work with smallholder farmers except in extracting scenarios. But a lot of work has been done with commercial farmers, where options are elicited and are reported back through discussions.

The ISCW group at Glen is actively involved in modeling. They have already gained valuable knowledge in the use of various other crop models. Knowledge of the APSIM model will help strengthen their expertise. The outcome of this project will also help the ISCW-Glen research team in getting new projects, related to food security, where modeling skills are needed.

## Recommendations

PRA tools can be used to identify options that can be simulated. The results can then be tested with farmers using participatory approaches. Models show part of the picture, but PRA tools and FPR are needed to get an understanding of the farmer's system. However, it should be noted that APSIM deals with major constraints only, such as water and nutrients. Models are seen as reliable and less expensive options than long-term experiments for researchers to look at the temporal implications of a crop management intervention. However, it should be stressed that long-term experimentation still has a role to play in providing hard data on changes in crop management practices and the environmental implications.

The potential benefits of reliable crop models are described in the Introduction. Because of these benefits it is recommended that research in this connection needs to be promoted. A particular need at present is a more integrated multidisciplinary approach. The team at Toowoomba in Australia is a good example of how to achieve this. The overall results of holistic multidisciplinary studies could make a valuable contribution towards integrated resource management.

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# Assessment and Modeling of Water Harvesting Techniques to Optimize Water Use in a Semi-Arid Crop Production Area in South Africa

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## Introduction

In the semi-arid areas of Southern Africa, lack of water and low soil fertility are major factors limiting food production. Developing communities are the most seriously affected by the resultant unsatisfactory levels of food security and sustainability that prevail in these areas. In relation to smallholder agricultural needs in the semi-arid regions of the Southern African Development Community, where some 10 million people live, the need to develop water harvesting and water conservation techniques cannot enough be emphasized (Kronen 1994). In the Free State in South Africa there are also a large number of households living on small-holdings under similar conditions (Department of Agriculture - Free State 1996).

In central South Africa a large area east of Bloemfontein (750,000 ha), sometimes termed the 'resettlement area', has been earmarked for developing farmers. There is a large population in the scattered villages and in the two towns of Thaba Nchu and Botshabelo. The area is marginal for crop production because of relatively low and erratic rainfall and dominantly clay soils which exhibit high runoff losses and losses due to evaporation from the soil surface. These losses result in low soil water storage with consequent reduction in crop yields. There is a great need therefore to minimize crop production risk and improve rainfall use efficiency.

In a jointly-funded (Water Research Commission and ARC) project, an in-field water harvesting micro basin technique (IWHB) developed by the ARC-ISCW research team at Glen Agricultural Research Station (Hensley et al. 2000), combines the advantages of water harvesting, no-till, basin tillage and mulching on high drought risk clay soils (Fig 1). It is hypothesised that a production technique that combines these techniques is the best practice technology for resource poor farmers trying to produce food on these soils compared to the normal conventional way. The specific advantages of each of these techniques are:

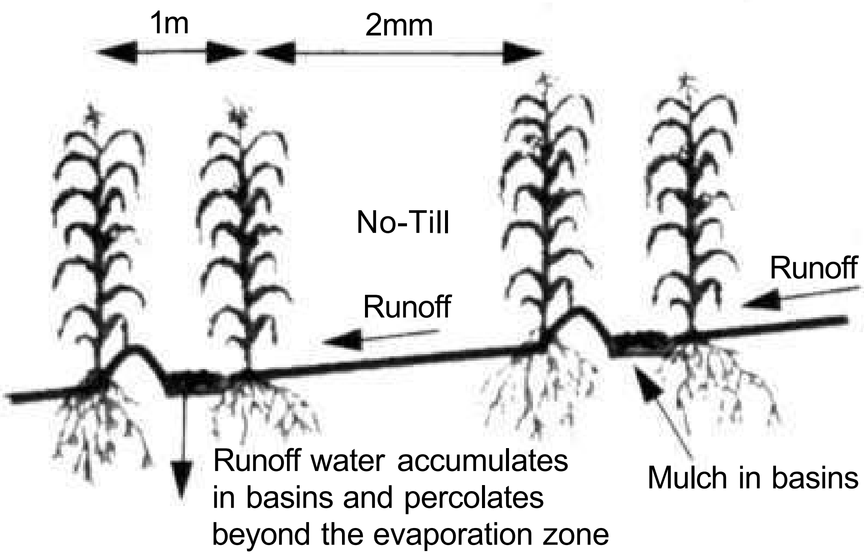


***Figure 1. A diagrammatic representation of the WHB technique***

- Basin tillage will minimize overall runoff from the land
- Water harvesting from the untilled, crusted soil in a 2-m wide row between crop rows, will concentrate runoff water in the basins and thus promote infiltration of water past the evaporation-sensitive surface zone, and so minimize evaporation losses
- Mulch (organic or stone) in the basins will minimize evaporation from the soil surface (Es).

The selection of appropriate production techniques requires long-term information. The lower and more erratic the rainfall, the greater the need for information. Crop models can play a valuable role here. Models can utilize long-term climate data to provide long-term yield simulations which can then be used to quantify crop production risks at regional and farm level. They have many other uses, eg answering research questions, assisting with management decisions on cultivation practices, testing hypotheses, and helping farmers to identify marginal cropping areas.

## Project Goal

Assessment of water harvesting techniques to conserve water, stabilize and increase crop yields, and contribute to sustainable natural resource management and food security. The specific aims are to

- Compare basin tillage with conventional tillage in terms of water use and crop production

- Compare stone and organic mulches in basins in terms of water conservation and yield
- Exchange experience and results on water harvesting techniques and crop modeling with international colleagues.

## Ecotope Characterization: Glen/Bonheim-Onrus Ecotope (Bo)

An ecotope is an area of land on which natural factors (climate, topography and soil) that influence yield, are reasonably homogeneous (MacVicar et al. 1974). The field experiment was conducted on the Glen/Bonheim-Onrus ecotope at the Glen experimental research station (28°57'S, 26°20'E), situated 25 km NE of Bloemfontein. This selected ecotope on the Glen Research Station is representative of more than 500,000 ha in the Free State Province on which exist a large number of rural households.

*Climate.* Rainfall and temperature data for Glen are available for 78 years (1922-2000) and class A pan evaporation data for 42 years (1958-2000). Monthly mean values are presented in Table 1. The high evaporative demand and relatively low rainfall make this a semi-arid climate, with the worst

**Table 1. Long-term monthly and annual climate data from the Glen meteorological station (ARC-ISCW data)**

| | Rainfall (mm) | Evaporation (mm), Class A pan | Mean max temperature (°C) | Mean min temperature (°C) | Mean temperature (°C) | Aridity index* |
|---|---|---|---|---|---|---|
| Jul | 8 | 96 | 17.8 | -1.6 | 8.1 | 0.08 |
| Aug | 12 | 143 | 20.6 | 0.9 | 10.7 | 0.08 |
| Sep | 19 | 219 | 24.5 | 5.2 | 14.9 | 0.09 |
| Oct | 48 | 248 | 26.8 | 9.2 | 18.0 | 0.19 |
| Nov | 67 | 264 | 28.4 | 11.7 | 20.2 | 0.25 |
| Dec | 67 | 301 | 30.3 | 13.9 | 22.1 | 0.22 |
| Jan | 82 | 313 | 30.9 | 15.2 | 23.0 | 0.26 |
| Feb | 79 | 216 | 29.4 | 14.6 | 22.0 | 0.37 |
| Mar | 84 | 186 | 27.2 | 12.3 | 19.7 | 0.45 |
| Apr | 51 | 129 | 23.8 | 7.7 | 15.7 | 0.40 |
| May | 19 | 118 | 20.6 | 2.6 | 11.6 | 0.16 |
| Jun | 9 | 84 | 17.6 | -1.2 | 8.2 | 0.11 |
| Total or mean | 545 | 2317 | 24.8 | 7.5 | 16.2 | 0.24 |

* Aridity index = rain/evaporation

conditions for crop production generally during Dec and Jan. Rainfall during these months is very erratic with much of it as high intensity events. March rainfall is the highest and the most reliable, with the additional advantage of by far the lowest evaporative demand of the summer growing season. Low temperatures are experienced during the winter, and there is little rain. This type of climate is characterised by high radiation intensities and hence increased evaporation from the soil surface.

*Topography.* The experimental plots were on an upper footslope terrain unit with 1 % slope and a westerly aspect.

*Soil.* Important features are summarized in Table 2. The soil is classified, according to the Soil Classification Working Group (1991), as belonging to the Onrus Family of the Bonheim Form, land type Ea39c. It is a dark brown clay soil overlying $CaCO_3$ enriched sandstone saprolite at a depth of 800 mm. The parent material of the solum is a mixture of dolerite and sandstone colluvium, with dolerite dominating. The underlying saprolite is sufficiently weathered to a depth of at least 1200 mm to offer no significant impedance to root development to that depth. The effective root zone is considered to be 0-1200 mm. The soil has a high clay content (45%) and strong structure with a high portion of smectite clay minerals, resulting in a high cation exchange capacity (CEC) of 24-25 $cmol^+ kg^{-1}$ soil. Dry spells cause large cracks that penetrate deep into the soil. Additionally, the surface soil has a high plasticity index of between 21 and 33, and self-mulching properties which promote erosion when high intensity rain falls on the dry soil. In the surface soil the exchangeable Na content is fortunately low (0.7 $cmol^+ kg^{-1}$ soil) and thus cannot be held accountable for the swell-shrink properties. However, the relatively high exchangeable Mg content (11-12 $cmol^+ kg^{-1}$ soil) may promote cracking.

**Table 2. Soil characteristics of the Glen/Bonheim-Onrus ecotope (Soil Classification Working Group 1991)**

| Horizon | Color | Clay (%) | Bulk density (g $cm^{-3}$) | Depth to lower boundary (mm) |
|---|---|---|---|---|
| A | Dark brown | 45 | 1.41 | 400 |
| B1 | Dark brown | 43 | 1.45 | 550 |
| B2 | Dark brown | 40 | 1.45 | 800 |
| C | Many colored geogenic mottles and lime | 38 | 1.45 | 1300 |

## Experimental Plan

*Conventional tillage (CON) vs In-field water harvesting with micro basins (IWHB)*. The aim is to demonstrate the benefits of IWHB tillage with mulch in the basin (MB) in terms of water use and crop production compared to CON tillage. There were two treatments, CON and IWHB-MB tillage, with three replications. The crop was maize, cultivar Phb 33-V08 with a population of 22,000 plants $ha^{-1}$. All fertilizer was applied at a moderate level (target yield of 2.75 t $ha^{-1}$, with 43 kg N $ha^{-1}$, 5 kg P $ha^{-1}$ and 0 kg K $ha^{-1}$) at planting. Planting was done by hand on 19 Dec 2001. Tramline row spacing (1 m x 2 m) was used. Basins were made in two steps, the first one using a one furrow basin-tillage plow. This was followed by laborers using spades to obtain the shape depicted in Figure 2.

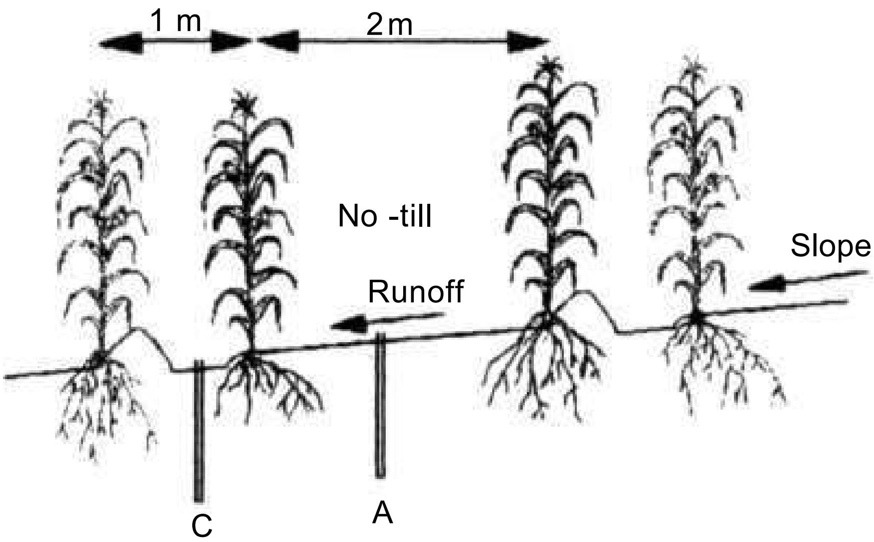


***Figure 2. Positioning of access tubes in the IWHB treatment (same layout in CON treatments)***

The technique consists of promoting rainfall runoff on a 2 m wide strip between crop rows, and storing the runoff water in basins where it penetrates deep into the soil, below the surface layer from which evaporation takes place. The purpose of the mulch treatment in the basins is to suppress evaporation. After the basins had been made, no-till was employed, using chemicals to control weeds. Crops were manually harvested.

*Stone mulch vs organic mulch in micro basins.* The main objective is to compare stone and organic mulch in the basins in terms of water conservation and crop growth and yield. There were two treatments with three replications. The treatments were stone mulch and organic mulch in the micro basins of the IWHB tillage technique. The crop used was maize, cultivar Phb 33-V08 with a population of 22,000 plants $ha^{-1}$. Fertilizer for a target yield of 1500 kg $ha^{-1}$ was applied at planting: 15 kg N $ha^{-1}$, 0 kg P $ha^{-1}$ and 0 kg K $ha^{-1}$. Planting was done by hand on 19 Dec 2001. Tramline row spacing (1 m x 2 m) was used. Basins were made in two steps, the first one using a one furrow basin-tillage plow.

## Measurements Made

### Soil parameters

*Soil water content.* Measured indirectly using the neutron water meter (NWM) and the time and frequency domain reflectometry (TDR and FDR) instruments.

*Neutron water meter.* To monitor the soil water content of the root zone (2r) NWM access tubes were inserted to 1.3 m, ie deeper than the root zone. NWM access tubes (a and c) were located as shown in Figure 3.

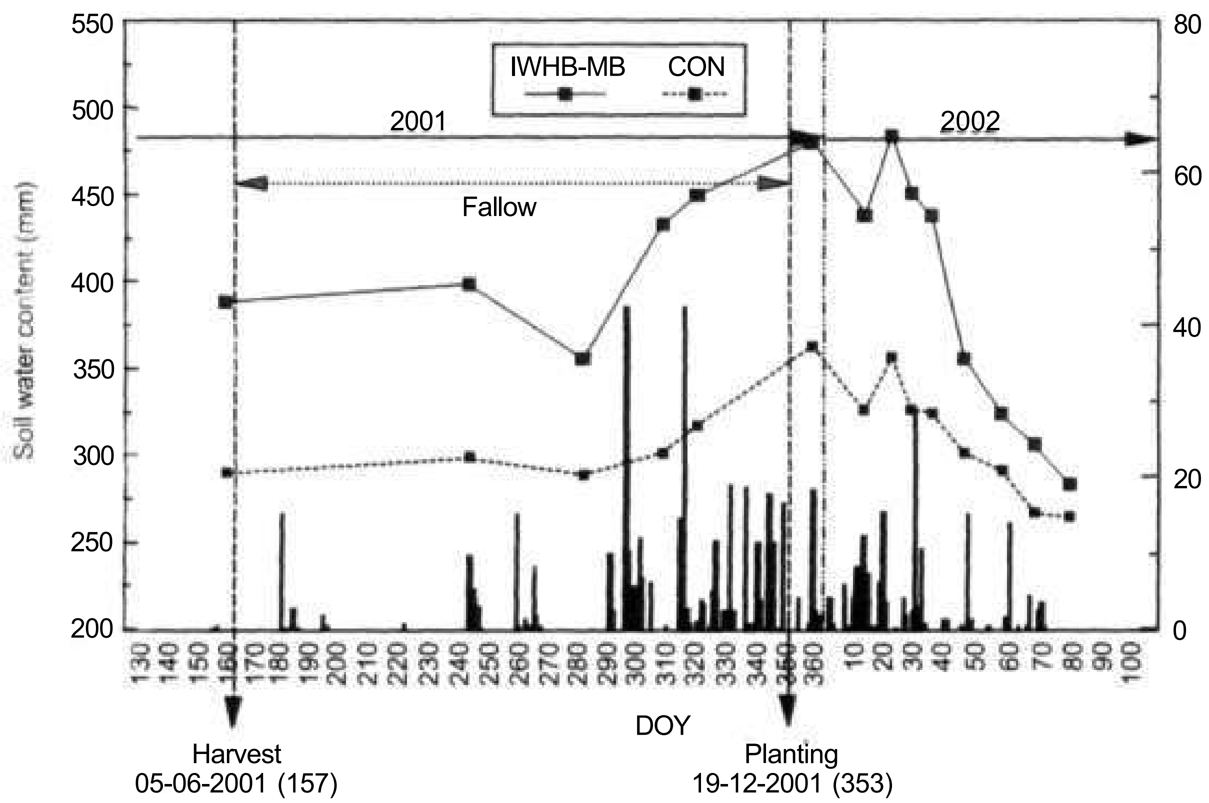


***Figure 3. Changes in soil water content of the root zone as influenced by different tillage treatments, Glen/Bonheim ecotope, 2001/02 season***

Measurements of 2r were carried out before planting, at planting, and during the growing season at 300 mm depth intervals starting at 150 mm. A Campbell Pacific 503 DR NWM was used. This procedure ensures that the different pedological layers in the soil have been adequately represented. The NWM was calibrated for every soil layer by using gravimetric soil water measurements (2m), and bulk densities (BD) of the soil (Robinson and Hubbard 1990). A range of NWM counts for every soil layer, under wet and dry conditions, was made, and at the same time samples for 2m determinations were taken close to the NWM access tubes. The 2m values for every soil layer were multiplied with the appropriate bulk density value to give the volumetric soil water content (2v) of that soil layer. The linear relation between NWM counts and the 2v values provided the calibration equation.

*Time domain rejlectometry.* Three TDR rod probes were installed vertically on one replication of the monitored treatments, at a depth of 0-300 mm. Thus continuous soil water content readings were made for the 0-300 mm soil layer. TDR probes will be calibrated with gravimetric soil water content samples and the corresponding BD values.

*Frequency domain rejlectometry.* FDR probes (CS615) were installed vertically on one replication of the monitored treatments, at two depths, namely 300-600 mm and 600-900 mm. This allowed continuous soil water content readings for the 300-600 and 600-900 mm soil layers. FDR probes will be calibrated with gravimetric soil water content samples and the corresponding BD values.

*Evaporation from soil surface.* Evaporation from the soil surface (Es) is the process by which water in the soil is changed to a vapour or gas (Van der Watt and van Rooyen 1990), and lost to the atmosphere. Use of a transpiration efficiency coefficient (k) provides a simple and effective way of separating Es + Ev (where Ev is evaporation from the vegetation (mm)) into its two components. The value of k is the product of transpiration efficiency (total biomass/T) and the mean saturation deficit over the growing season (D) of the atmosphere during sunlight hours (Tanner and Sinclair 1983, Chapman et al. 1993). The units of k are therefore grams of dry matter per kg water x k Pa. Gregory (1989), following a suggestion by JL Monteith in an earlier paper, 'normalises' the influence of D by multiplying k by $D_o$ (1 k Pa). This eliminates the confusing units of k and they become g dry matter per kg water, which is the same as the more convenient units g $m^{-2}$ $mm^{-1}$. This procedure will be assumed whenever k values are presented in this report.

Using data from 10 different experiments in the USA, and what they considered to be a 'reasonable' ratio for maize (total dry matter / above-ground dry matter = 1.2), Tanner and Sinclair (1983) reported a mean k value of 9.5 g $m^{-2}$ $mm^{-1}$. Working in Canada over a wide range of soil water regimes, and using only above ground biomass, Walker (1986) reported a value of 7.4. Using results from field experiments in South Africa, and also using only above ground biomass Hattingh (1993) reported a value of 8.2.

Using Tanner and Sinclair's factor of 1.2 to estimate total biomass for the last two mentioned estimates yields results of 8.9 and 9.8, and a mean value of 9.4, which is very close to Tanner and Sinclair's value of 9.5. The latter value was considered sufficiently reliable for this study.

## Plant parameters

Rainfall storage efficiency (RSE), which is the ability of the soil to store water in the soil profile during the fallow season, will be calculated using the equation of Mathews and Army (1960):

$$RSE = [2p_{(n)} - 2h_{(n-1)} / P_p] * 100$$

where $2p_{(n)}$ = root zone water content at planting of the current crop (mm), $2h_{(n-1)}$ = root zone water content at harvesting of the previous crop (mm), $P_f$ = rainfall during the fallow season.

*Leaf area index* (*LAI*). The leaf area of all the photosynthetic leaves of four maize plants per replication was measured at the beginning of the crop reproductive stage, using a LICOR leaf area meter. The results will be used to calculate LAI.

*Plant height.* The heights of 12 maize plants per replication were measured at flowering. The results will be used to show any difference between the different treatments.

*Biomass.* The biomass of four maize plants per replication was measured at flowering. The results will be used to show any differences between treatments. Biomass at harvest will measured from 6 rows each 1 m long. Biomass will be expressed as oven dry material in kg $ha^{-1}$. Results will be used to determine Es + Ev.

*Grain yield.* The grain yield for maize will be determined by harvesting 6 rows each 4 m in length. The grain will be weighed oven-dry, adapted to 13% water content and expressed as kg $ha^{-1}$.

*Water use efficiency.* WUE will be determined with the equation used by Hillel (1972), Passioura (1983), and Tanner and Sinclair (1983):

$$WUE = Y / (Ev + Es)$$

where Y = grain yield, Ev + Es = evapotranspiration

WUE therefore measures the efficiency with which a particular crop can convert the water available to it, during a particular growing season, into yield.

### Climatic variables

Weather data, namely wet and dry bulb temperature, radiation, wind speed and direction, and rainfall, were measured with an automatic weather station. Reference crop evaporation (Eo) will be determined with the Penman - Monteith equation (Van den Berg 1997, personal communication).

## Preliminary Results

### Conventional tillage (CON) versus in-field water harvesting with micro-basins (IWHB)

*Rainfall storage efficiency,* RSE gives an indication of the ability of a tillage technique to store soil water in the soil profile during the fallow season. RSE was 26% for the CON tillage and 33% for the IWHB-MB tillage during the 2001 fallow season. During the 2001 growing season IWHB-MB technique's ability to store rainwater in the soil profile was 7% higher than CON. This gave maize plants on the IWHB-MB plot a favorable start with a pre-plant water advantage of 119 mm (Fig 4).

*Soil water content: Neutron water meter.* The change in soil water content of the root zone and individual layers for the maize as influenced by the two treatments during the growing season, are presented in Figures 4 and 5, and will help to explain the yield and water balance data later. Water extraction trends also give an indication of the water conservation effects of the different treatments.

After a favorable start to the 2001/02 season, the IWHB-MB managed to maintain a higher soil water content than the CON tillage. The favorable soil water content on the IWHB-MB plots during the first 30 days after planting contributed to vigorous growth of the maize plants, as indicated in Figure 3 - compare the water extraction curves of the bigger maize plants on the IWHB-MB plot versus the smaller plants on the CON plot. Similarly, increase in soil

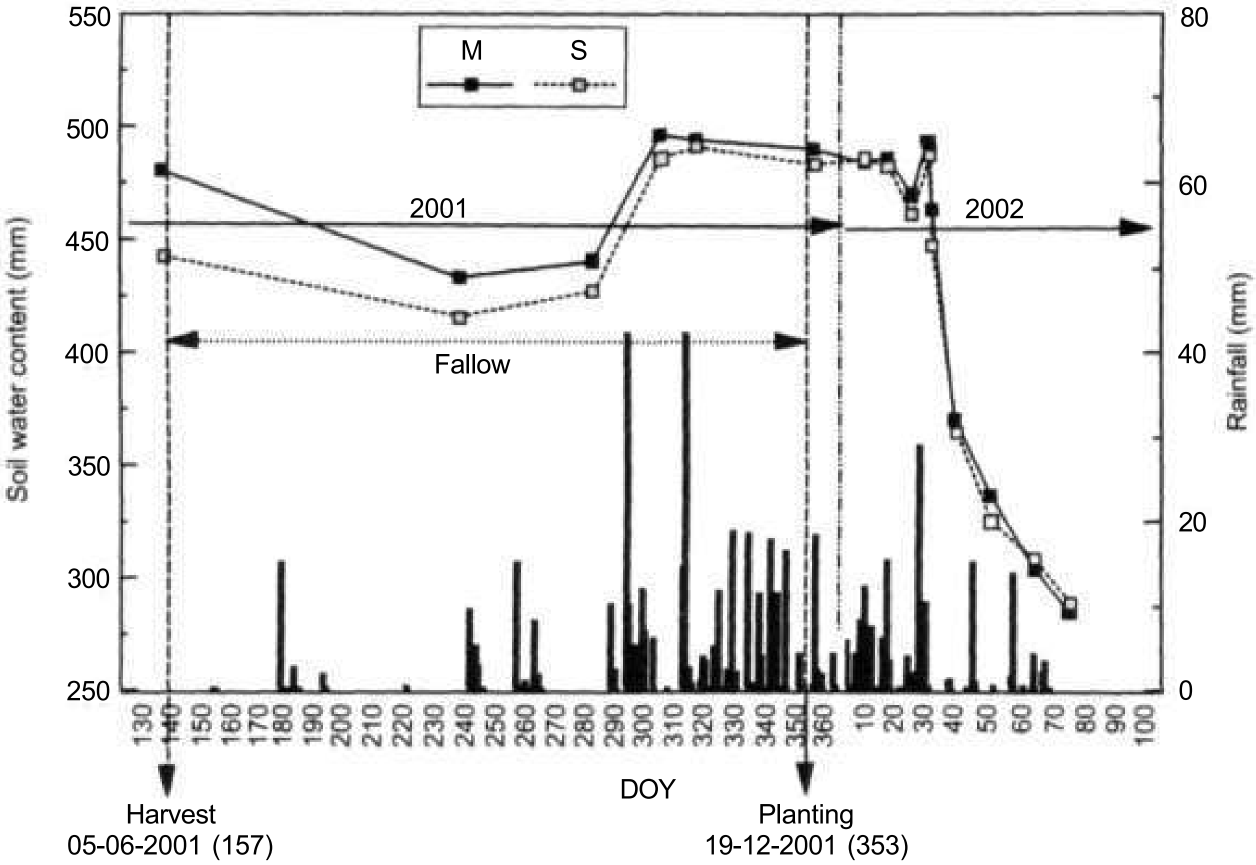


***Figure 4. Changes in soil water content of the root zone as influenced by different mulching strategies, Glen/Bonheim ecotope, 2001/02 season***

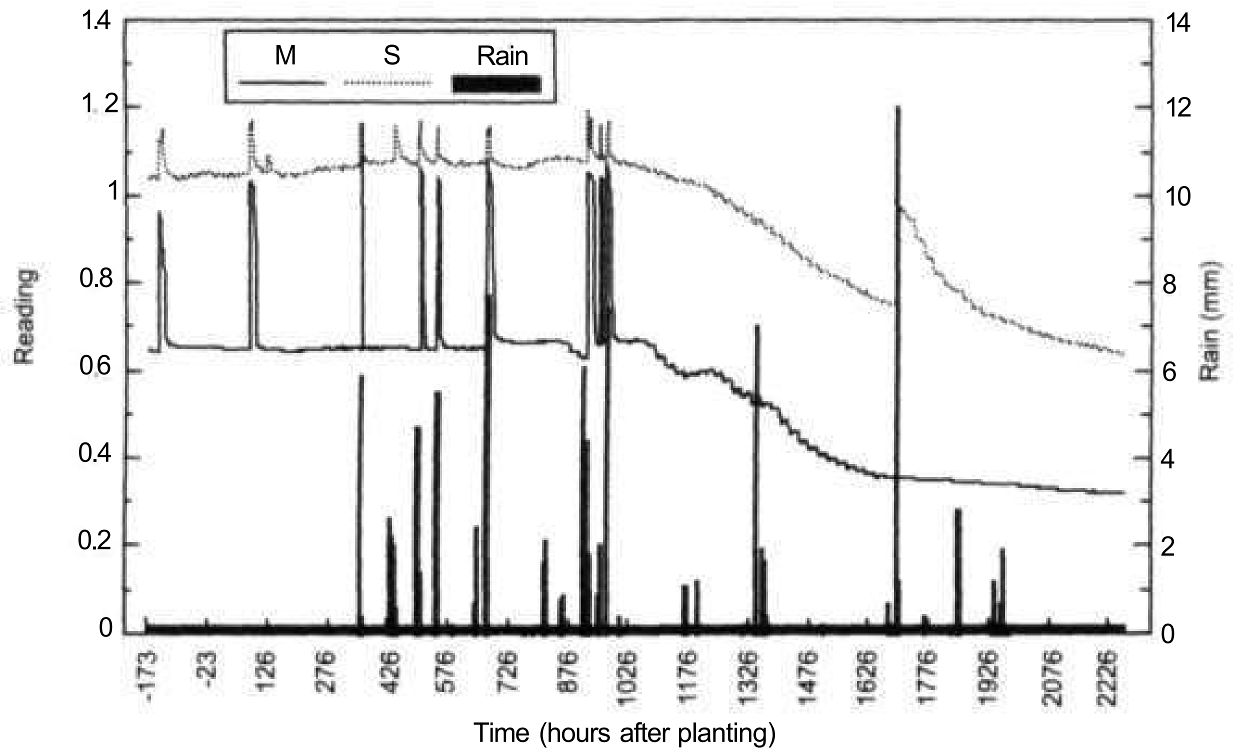


***Figure 5. Changes in soil water in the 300-600 mm layer due to different tillage treatments (measured with FDR), Glen/Bonheim ecotope, 2001/02 season***

water content following rainfall, was clearly better in the IWHB-MB plot compared to CON tillage (data not presented).

*Plant height.* Plant heights for maize are shown in Table 3. Plants on the IWHB-MB plots grew more vigorously than on the CON plots. Maize plants on the IWHB-MB are on average about 40 cm higher than those on the CON plots. This is also an indication of the more favorable vegetative growing season experienced by plants on the IWHB-MB plots due the water conservation effect.

**Table 3. Plant height (cm) of maize under different techniques, Glen/Bonheim ecotope, 2001/02**

| Treatment | Replication 1 | Replication 3 | Replication 3 | Average |
|---|---|---|---|---|
| CON | 190 | 188 | 181 | 186 |
| IWHB-MB | 225 | 226 | 227 | 226 |

## Stone mulch (S) versus organic mulch (M) in micro-basins

*Rainfall storage efficiency.* RSE can be used to compare different tillage techniques in terms of their ability to store rainwater in the soil profile during the fallow season. The RSE of stone mulch in the micro basins (S) during the 2001 fallow period was higher than the RSE of the organic mulch in the micro basins (M), 11.3% vs 2.8%. RSE is not always a very good indicator of the ability of the soil to store rainwater because it can be influenced by the water content of the root zone at harvesting of the previous crop. In this particular case, the soil water content of the S treatment was already high at harvesting the previous crop - 38 mm higher than the M treatment at the same stage. Although the two treatments started the new growing season with almost the same water content, the M treatment afforded a 6 mm higher soil water content than the S treatment at planting. This gave the M treatment a 6 mm pre-plant advantage above the S treatment, while the RSE suggested that the S was higher than the M treatment. In this particular case, the pre-plant water advantage would be a far better parameter than RSE alone.

*Soil water content.* Water extraction trends from the whole root zone (Fig 4) describe the water regime during the growing season and will help to explain the yield and water balance data later. Water extraction trends also give an indication of the water conservation effects of the different treatments. After a favorable start to the 2001/02 growing season, water extraction patterns and soil water contents for maize plants on both treatments are similar. On both treatments, maize plants grew well and extracted much water between 40-90 days after planting. Figure 6 shows the change in soil water content of the individual layers as influenced by different mulching strategies. The soil water content patterns for both treatments in all the layers are almost identical, especially in the 0-300 mm soil layer. This is an indication that there is not a huge difference between the water conservation effects of the two treatments.

Figure 5 shows representative data on changes in soil water content of individual layers as influenced by mulching strategies during the growing season. These were measured with TDR (0-300 mm) and FDR (300-600 and 600-900 mm). These are only preliminary results that still have to be calibrated throughout the 2001/02 season. Non-calibrated data presented in this figure reveal that there is not a big difference between the two mulching strategies.

*Plant height.* Plant heights for maize during the 2001/02 growing season are presented in Table 4. Plants on both treatments are of similar height, with those on the M treatment about 3 cm taller than those on the S treatment.

## Technology Exchange

One member of the project team, JJ Botha, attended the 10th International Conference on Rainwater Catchment Systems in Mannheim, Germany, 10-14 Sep 2001; and made one oral presentation and one poster presentation.

- Converting rainwater into food efficiently (JJ Botha, M Hensley, JJ Anderson, PP van Staden, and LD van Rensburg)
- Water conservation techniques on small plots in semi-arid areas to increase sunflower yields (JJ Botha, JJ Anderson, PP van Staden, and LD van Rensburg)

The conference reflected on the growing realization that rainwater harvesting offers great potential in solving domestic and agricultural water

**Table 4. Plant height (cm) of maize under different mulching techniques, Glen/Bonheim ecotope, 2001/02**

| Treatment | Replication 1 | Replication 3 | Replication 3 | Average |
|---|---|---|---|---|
| S | 230 | 225 | 217 | 224 |
| M | 237 | 224 | 221 | 227 |

problems in humid and semi-arid areas and also many critical urban-related water issues. It also served as a forum to exchange experiences between researchers, manufacturers and industry, professional artisans, and civil servants. Research projects were presented and future research priorities identified.

## Conclusions and Recommendations

Preliminarily results during the 2001/02 season have clearly shown the superiority of IWHB-MB over CON tillage in terms of higher RSE during the 2001 fallow season, a much more favorable soil water content during the 2001/02 growing season, and maize plants with an average height increase of 40 cm. IWHB-MB can definitely be considered as one of the best practices for small-scale farmers.

Preliminarily results during the 2001/02 season have indicated that there is almost no difference between S and M mulching treatments in terms of pre-plant advantage, soil water content during the growing season (measured with a NWM, TDR and FDR) and only a 3 cm difference in plant height between the two treatments.


## Acknowledgments

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- The OSWU consortium for funding the project
- The Management and Administration of the Institute for Soil Climate and Water for their continual support in many ways
- The Water Research RC for agreeing to a collaborative venture with OSWU, thereby sharing data and results of projects
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# Modeling Evaporation from the Soil Surface as Affected by Mulching and Soil Factors

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## Introduction

In the semi-arid areas in the central part of South Africa, the problem of low and erratic rainfall is exacerbated by two major unproductive soil water losses, namely runoff and evaporation from the soil surface (Es). These losses hamper the efficient use of available water for crop production. Runoff can be controlled by basins and in-field water harvesting, leaving Es that needs to be minimized, both during the fallow and crop growing periods. Evaporation models need to be tested and calibrated in order to accurately predict evaporation from the soil surface to identify the best mulching strategy for a specific scenario.

For this purpose field experiments were conducted on two ecotopes, varying in soil texture from sandy loam to clay, and measurements made for the summer and winter periods of 2001. Four treatments with three replications were imposed on 2 m x 2 m plots as follows: (i) bare soil, (ii) stone mulch covering 50% of the surface, (iii) 50% reed mulch, (iv) 100% reed mulch.

The results clearly showed that evaporation could be modified by the type and amount of mulch, climate and soil type. Both summer and winter average evaporation rates of the Glen/Swartland bare soil were 7% higher than the 2.11 and 0.71 mm $day^{-1}$ measured at Bonheim. Mulches reduced evaporation rates by 10-18% at Bonheim depending on the type and amount of mulch and season (climate). These reductions were even more prominent (4-31%) on the Glen/Swartland ecotope.

Plant residue on the soil surface increases resistance to water flow from the soil surface to the atmosphere by (i) increasing the thickness of relative on-turbulent air above the soil, thus decreasing vapor transport away from surface and (ii) lowering daytime soil temperature and thus reducing vapor pressure of the soil water (Army et al. 1961).

In this study three evaporation models will be evaluated in terms of handling a mulch on the soil surface during the evaporation process, namely Choudhury and Monteith (1988), Shuttleworth and Gurney (1990) and Kemper et al. (1994). The first two models take into account the partitioning of energy for soil vegetation systems with more than one effective surface. These models also describe the transport of heat and water vapor from the soil through the canopy to the reference level above the canopy. The theoretical structure of these models allows for the incorporation of a surface mulch in the evaporation flow path (see below).

## Literature Review

### Choudhury and Monteith evaporation model

The Choudhury and Monteith model (C and M model) is based on the principle of the Penman model, which does not take into consideration surface temperature measurement. This model approach is based on the soil and canopy resistance, rather than the surface temperature. The model regards the vegetated surface up to the bottom of the soil layer (Tm) as a system receiving energy. Figure 1 illustrates an analogue to Ohm's law which states that the current flowing through a wire equals the potential difference between its ends divided by the resistance of the wire (Thorn 1975, Oke 1978, Monteith and Unsworth 1990). The system incoming and outgoing energy fluxes, its resistance to flow and the relevant gradients are depicted. The relationship may be written for entities such as heat and water vapor as follows:

Flux = (Concentration difference of property) / (Resistance to flow exerted by system)

where flux is the amount per unit time and area and concentration amount per unit volume.

These specifications, therefore, make possible the mathematical modeling of the physical processes within the soil-plant-atmosphere system as proposed by Choudhury and Monteith (1988) and Shuttleworth and Gurney (1990). The S and C model as applied by Nichols (1992) is dealt with in the following discussion.

This model comprises four surfaces (Fig 1): (i) the reference height in the atmosphere, (ii) the effective sink for momentum within vegetation (canopy), (ii) the soil surface in the absence of vegetation, (iv) the soil horizon above which evaporation from the soil is assumed to be negligible and below which

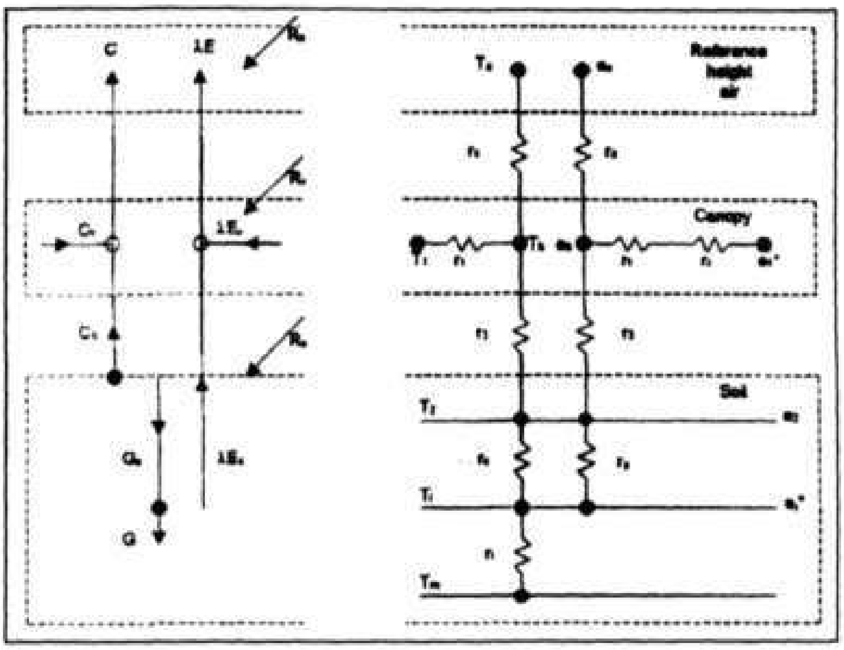


***Figure 1. Choudhury and Monteith model - main component fluxes, resistance network and potentials (after Choudhury and Monteith 1988)***

λE = latent heat flux from vegetated surface
*λE* = latent heat flux from soil surface
$C_v$ = sensible heat from canopy
$e_1$* = saturated vapor pressure at soil surface
$G_o$ = soil heat flux in dry soil layer
$r_1$ = resistance heat flux on canopy
ra = aerodynamic resistance between canopy source height and reference height
rc = stomatal resistance
R = net radiation absorbed by soil surface
$R_v$ = net radiation absorbed by canopy
$T_1$ = temperature at the foliage surface
Tm = temperature at bottom of soil layer

*XV* = latent heat from canopy
c = sensible heat flux from vegetated surface
c = sensible heat from soil surface
$e_2$ = saturated vapor pressure below surface
la = vapor pressure at reference height
$r_2$ = resistance to water vapor flux in dry soil
$r_2$ = aerodynamic resistance between soil surface and canopy height
$r_4$ = resistance of heat flow in dry soil layer
fa = air temperature at reference height
$T_2$ = temperature at soil surface

the soil atmosphere is saturated with water vapor. At the bottom of the fourth layer, soil temperature is kept constant for at least one day.

## Shuttleworth and Gurney evaporation model

This model comprises three surfaces (Fig 2): reference height in the atmosphere, the canopy source height which is a measure of effective sink for momentum within vegetation, and the soil surface. The fundamental difference between these two models is in the approach to surface temperature. Choudhury and Monteith, which is based on the Penman model, avoids the need for surface temperature measurements, whereas

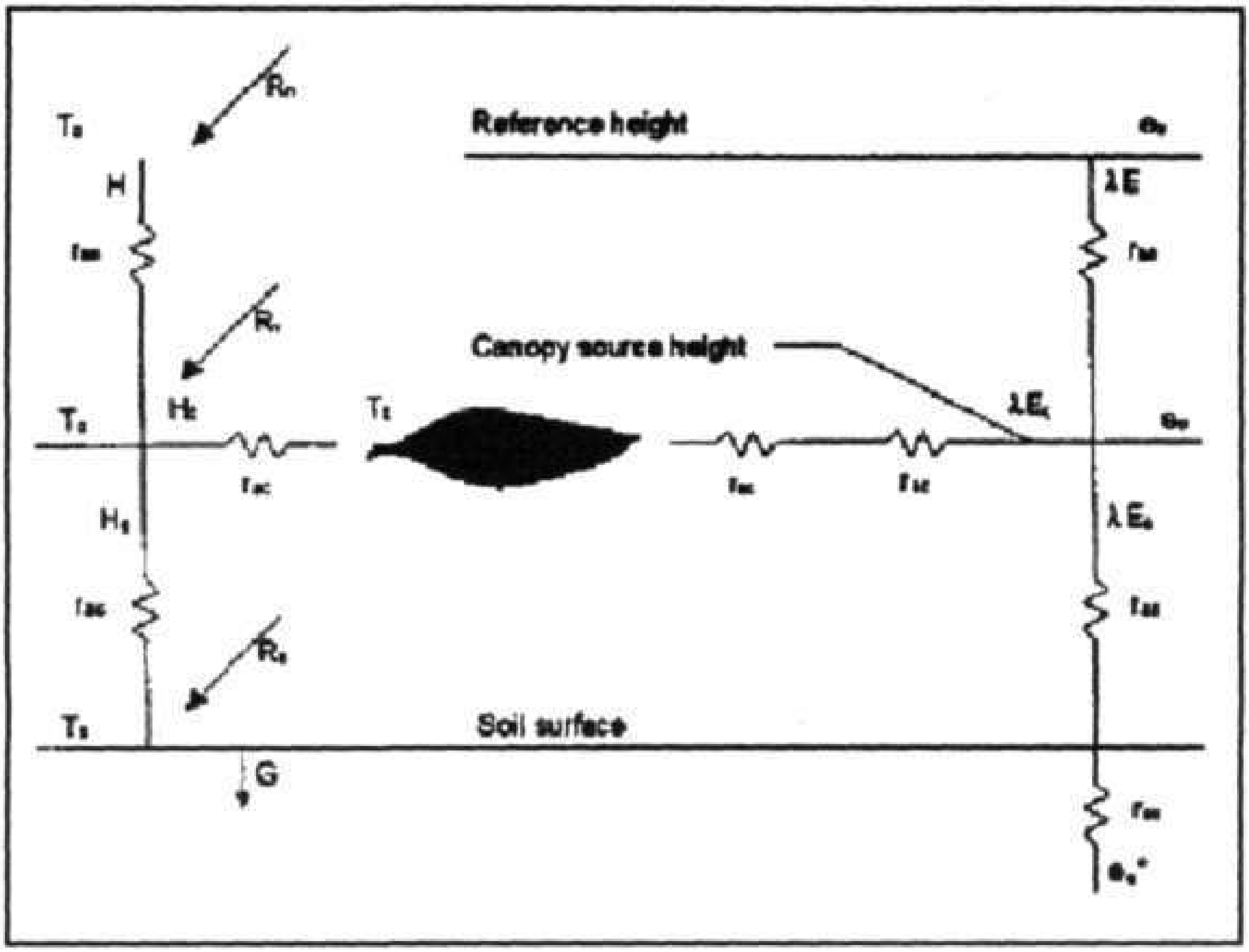


***Figure 2. Shuttleworth and Gurney model - main component fluxes, resistance network and potentials (modified from Shuttleworth and Wallace 1985)***

$\lambda E_s$ = latent heat flux from soil surface
$e_s^*$ = saturated vapor pressure at soil surface
r = leaf boundary layer resistance per unit ground
r = resistance to water vapor flux from soil surface
Tc = temperature at foliage surface
H = crop height
$r_{aa}$ = aerodynamic resistance between canopy source height and reference height
$r_{as}$ = aerodynamic resistance between soil surface and crop source height
To = air temperature at canopy source height
Ts = temperature at soil surface

Shuttleworth and Gurney includes surface temperature in the formulation of its soil and canopy resistances. The benefits of these approaches are found in the application of the models. The database is built on standard meteorological measurements, with no surface temperature recordings.

## Kemper, Nicks and Corey evaporation model

The Kemper, Nicks and Corey model (K, N and C model) is a physical based model used to predict cumulative evaporation (q) over relative long periods.

$$Q = \int_0^{tw} q \, dt + n \, Ab \qquad (1)$$

where $q$ ($g\ m^{-2}\ s^{-1}$) is the flux rate over a specified time ($t$), $n$ is the number of rainfall events and Ab is the water absorption amount of the mulch.

$$q = (D_f + D_s) \qquad \theta(L/Le)^2 \qquad \Delta C/\Delta Z \qquad (2)$$

where $D_f$ ($cm^2\ s^{-1}$) is the diffusion coefficient for water in still air, $D_s$ ($cm^2\ s^{-1}$) is the dispersion coefficient, Q ($m^3\ m^{-3}$) is the pore space, L/Le is the straight line distance through the mulch over the average tortuous path length. AC ($g\ cm^{-3}$) is the water vapor concentration difference across the mulch and AZ (cm) is the thickness of the mulch. Both the diffusion coefficient and concentration of water in air are temperature dependent. Thus, in order to make reasonable predictions of E it is important to predict the temperature near the soil-mulch interface and also near the mulch-air interface.

## Goal and Objectives of the Project

The goal of this project is to improve technologies for more efficient use of water and increased crop production. The objectives are to:

- Determine the input parameters required to run the three evaporation models
- Compare the three evaporation models against measured evaporation data
- Apply a chosen model to predict evaporation for various scenarios of mulching and soil factors to identify the best mulching strategy.

## Scope of This Report

The experiment consists of two phases, the field experiment and modeling. The field experiment can be divided further into two components, summer and winter, to accommodate seasons. The summer season has been completed and the winter measurements will commence in mid April 2002. The modeling phase can be divided into two components, the preparation phase (selection, programming and data preparation), and the execution phase (calibration and testing of models). Models have already been selected and programmed on spreadsheets. Data processing for the summer data set is 80% completed. Calibration and validation of the models for the summer period will be executed soon. Consequently, this report will focus on the results from the field experiment:

- Effect of mulching on temperature profiles
- Effect of mulching on humidity
- Effect of mulching on soil water content.

**Table 1. Model variables that need to be measured to run the various models**

| Equation | Variable | Description of variable to be measured |
|---|---|---|
| Choudhury and Monteith model | | |
| F3 (satVP(Templo)] | E3 = Templo | Temperature lower part of canopy |
| J3[VPDLo] | 13 = VPLo | Vapor pressure low |
| V3[X] | T3 = L | Leaf area index |
| W3[d] | U3 = H | Crop height |
| Y3[K(H)] | P3 = U(0.5) | Wind speed at 0.5 m |
| AJ3 | F3 = SatVA(Templo), E3 = Templo | Saturation vapor pressure Low |
| A03[Rv] | M3 = RnT3 = L | Total solar radiation |
| Av3[$Q_1$] | Tsocl(0.15m),J3 = $VPDL_o$ | Vapor pressure deficit at 0.15 m |
| Az3[$r_{as}$] | X3 = $Z_o$ | Roughness length of the crop |
| Shuttleworth and Gumey model | | |
| Ac3[d] | AB3 = H,AA3 = L | Zeroplane displacement |
| AF3[U*] | S3 = u (1.0 m) | Windspeed |
| AG3[K(H)] | AB3 = H | Eddy coefficient diffusion at Height (H) |
| AC3[rJ | AA3 = L | Leaf boundary layer resistance per unit ground |
| AM3 [Ts] | U3 = Tsoilsun, V3 = Tsoilshade | Temperature at soil surface |
| AN3 [Tc] | W3 = Tleafsun, X3 = Tleafshade | Temperature at foliage surface |
| AP3[AvG] | 03 = G(O),P3 = G(0.25), Q3 = G(0.5) | Soil heat flux in wet soil layer |
| AQ3[$e_b$] | M3 = $R_n$,A03 = $T_b$ | Total incoming solar radiation and air temperature at canopy source height |
| $\int_0$ q dt + n Ab | q, n, Ab | q = flux rate over specified time ($gm^{-2}s^{-1}$)<br>n = number of rainfall events<br>Ab = water absorption amount of the mulch |
| Kemper, Nicks and Corey model | | |
| D, + $D_8$ $\theta(L/Le)^2$ $\Delta C/\Delta Z$ | $D_f D_s$, (L/Le),$\Delta C$,$\Delta Z$ | $D_f$= diffusion coefficient for water in still air ($cm^2$ $s^{-1}$)<br>$D_s$= dispersion coefficient ($cm^2$ $s^{-1}$)<br>6 = pore space ($m^2$ $m^{-3}$)<br>L/Le = straight line distance through mulch over the average tortuous path length<br>AC = water vapor concentration difference across mulch (g $cm^3$)<br>AZ = thickness of mulch |

## Materials and Methods

*Experimental layout.* Four treatments with three replications were employed on the Glen/Bonheim-Onrus ecotope (Fig 3):

- Bare or no mulch on the soil surface, marked as Block IV in Fig 3
- Organic mulch (reed) covering 50% of the soil area (Block III)

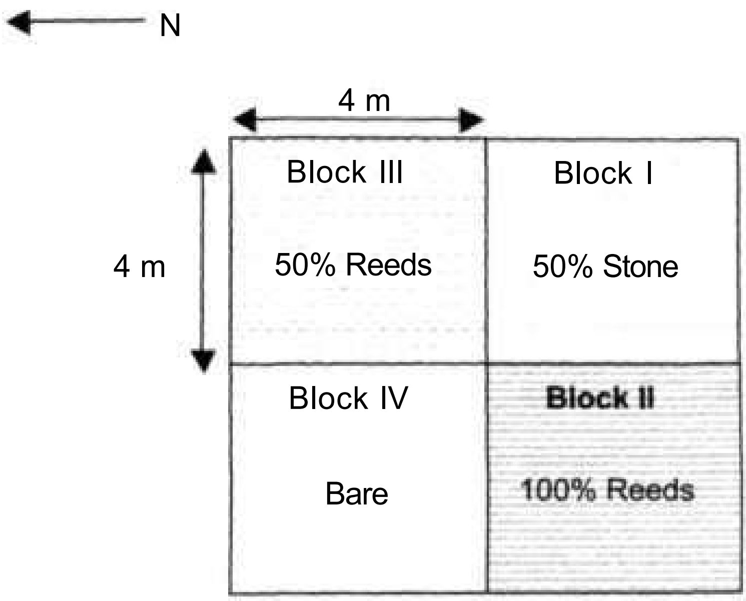


***Figure* 3. *Diagram of the experimental layout***

- Organic mulch (reed) on the soil surface covering ] 00% of the soil area (Block II)
- Inorganic mulch (stones) covering 50% of the soil area (Block I).

Reed was used as the organic mulch due its abundance in the area. The diameter was 11-29 mm (mean 19 mm). Dolerite stones, which are common in this area, were used as the inorganic mulch. The diameter of the stones was 90-160 mm (mean 113 mm).

Instruments were laid out as shown in Figure 4.

*Ecotope description.* An ecotope is an area of land on which the natural resources (climate, topography, soil) that influence yield, are reasonably homogeneous (MacVicar et al. 1974). The field experiment was conducted on the Glen/Bonheim-Onrus ecotope at Glen Experimental Research Station (28°57'S, 26°20'E), 25 km NE of Bloemfontein. The selected ecotope represents a significant area east of Bloemfontein on which a large number of rural households exist.

*Climate.* Rainfall and temperature data for Glen are summarized elsewhere in these proceedings (Assessment and modeling of water harvesting techniques, Botha and Anderson).

*Topography.* The experimental plots were located on an upper footslope terrain unit with a 1% slope and a westerly aspect.

*Soil.* Important features of the soil profile are summarized elsewhere in these proceedings (Assessment and modeling of water harvesting techniques, Botha and Anderson).

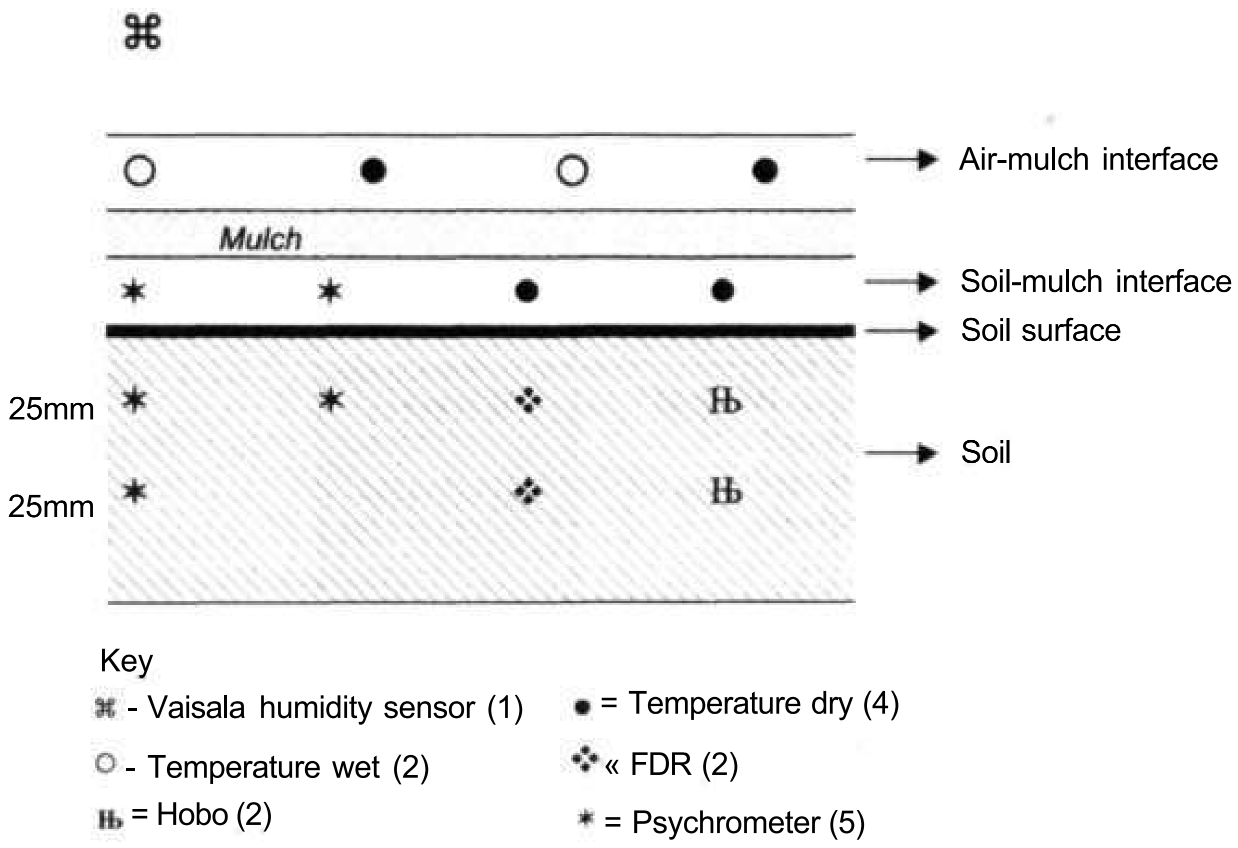


***Figure 4. Diagram illustrating the position of instruments in replicate 1.***

## Input Description of Models

The variables that need to be measured to run the various models are listed in Table 1.

### Measurements of micro climate parameters

*Wind speed.* Wind speed was measured at a height of 2 m with an automatic anemometer, which is part of the equipment of the automatic weather station at the site. Data representing the summer period was recorded on an hourly basis from 25 Jan until 15 Mar 2002.

*Humidity.* Relative humidity was measured hourly at three points above the soil over the summer period. The first was recorded with the Vaisala sensor screen at the automatic weather station at a height of 1500 mm. The second was 160 mm above the soil using a Vaisala sensor screen (see Fig 4 for a layout of instruments on replicate 1). The third was at the air-mulch interface using thermocouples - two dry and two wet sensors coupled to an XR10 logger. The wet bulb was created by covering the sensor with a shoe lace which was linked to a bottle of distilled water immersed in the soil. In the case of the 50% treatments, the sensors were positioned directly above one stick of a reed or stone as well as between adjacent reeds and stones. The average value was used to represent the treatment.

*Air temperature.* Air temperature was measured on an hourly basis over the summer period at various heights above the soil surface (see instrumental layout in Fig 4).

- Standard height of 1500 mm (automatic weather station, Vaisala sensor screen)
- At 160 mm above the surface of the mulch, or 160 mm above the soil surface for the bare treatment, using the Vaisala sensor screen
- At the air-mulch interface (15 mm) with thermocouples, as described for humidity measurements
- At soil surface (-5 mm) using thermocouples coupled to XR10 logger.

*Rainfall.* Rainfall measurements were made by the standard weather station instruments and an extra rain gauge adjacent to replicate 1.

## Measurements of soil parameters

*Soil temperature.* Two temperature sensors coupled to a Hobo XT logger, were inserted in each treatment of replicate 1 to a depth of 25 and 75 mm parallel to the soil surface. After settling for approximately one month, loggers were programmed to take measurements at hourly intervals.

*Soil water content.* Soil water content was measured directly by the gravimetric procedure, and indirectly using the neutron water meter (NWM) and frequency domain reflectometry (FDR) instruments.

*Calibration of neutron water meter.* The Campbell Pacific 503DR neutron water meter was calibrated using gravimetric soil samples at constant depth increments of 150, 450, 750, and 1050 mm. CPN measurements were taken at a setting of 64 seconds. Three soil samples per depth increment were taken and transferred to a glass bottle, sealed, weighed, dried at 104°C and weighed again. A bulk density of 1.6 g $cm^{-3}$ was used to convert gravimetric to volumetric water content. These measurements continued until a range of water content values from very dry to almost saturation were included.

*Volumetric water content (CPN).* Three neutron water meter access tubes were installed near the center of the 4 x 4 m plot for each treatment in all replicates. Two tubes were installed to 1200 mm and the third to 1600 mm to monitor deep drainage. Measurements were taken daily during weekdays at 150, 450, 750, and 1150 mm using a 64 second setting.

*Frequency domain reflectometry.* FDR probes (CS615) were installed on one replication of the monitored treatments at two depths, 25 mm and 75 mm. This allowed continuous soil water content readings to determine D and Es for the 0-100 mm soil layer. FDR probes were calibrated with 2 m determinations, and the corresponding BD values.

*Drainage curve.* The drainage curve was determined during the 2001 season as described by Botha et al. (2001) for the 0-100 mm and 0-300 mm soil layers:

For 0-100 mm, $Y = 49.737 - 1.37 (\ln t)$, and $r^2 = 91$ (1)

For 0-300 mm, $Y = 133.20 - 1.88 (\ln t)$, and $r^2 = 90$ (2)

where: Y = water content of the 0-300 mm soil layer (mm), t = time (hrs) after drainage commenced at the 0-300 mm soil layer.

*Soil water potential.* Soil water potential was measured with psychrometers coupled to the CR7X that were installed under the soil surface (2 sensors), 25 mm depth (2 sensors) and 75 mm depth (1 sensor), as shown in Fig 1. These measurements were recorded hourly during the summer period using an XR10 logger. Calibration was done at the end of winter.

*Evaporation from the soil surface.* This was measured by applying the water balance equation:

Water for yield = water gains - water losses

$Ev = (P+ AS) - (Es+R+D)$ (3)

where Ev = evaporation from the crop (transpiration), P = precipitation, AS = water extracted from the root zone, Es = evaporation from the soil, R = runoff (mm), D = deep drainage. All measured in mm.

## Results and Discussion

The summer measurements were completed in March, and instrument calibration and data analysis was incomplete. This section focuses on preparation to set up the data for running the proposed three models. For this discussion, the data for the warmest day (25 Feb 2002) were selected to demonstrate

- Temperature profile
- Humidity profile
- Water content as affected by mulching over a 24 hour period.

## Temperature profile

The evolution of the hourly temperature is shown in Figure 5 for the bare surface treatment at various levels. The bare treatment was used as a basis to discuss the evolution of temperature during the day of a specific level. Before moving to the next temperature level down the profile, a comparison between mulches was made.

Figure 5 shows that the minimum air temperature (17°C) was at 07h00, and it increased to 33°C (maximum) at 16h00, then decreased to 21°C at 24h00. There was generally no difference during the night between the reference temperature at 1500 mm and those of the mulches at 160 mm. Differentiation started at 07h00 and continued until 19h00, indicating that it

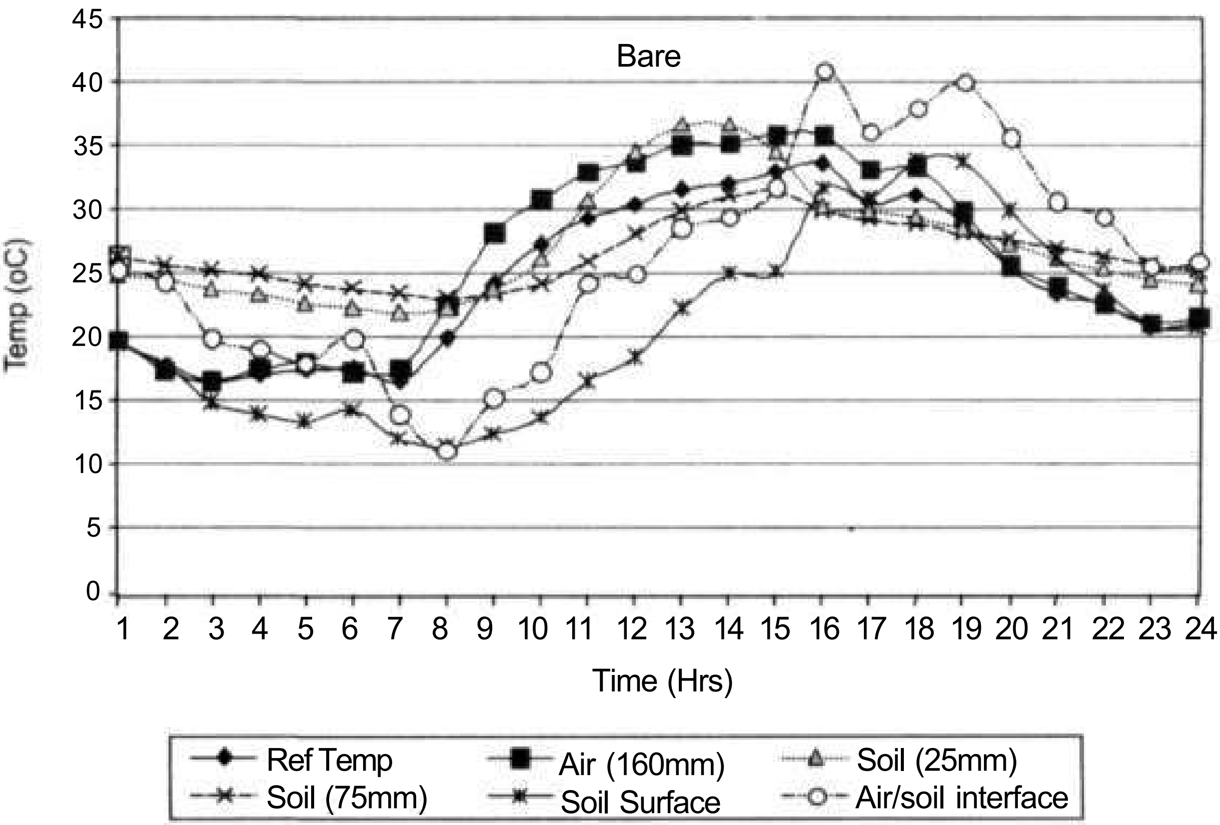


***Figure 5. Evolution of temperatures at various levels for the bare treatment, 25 Feb 2002***

is warmer closer to the soil. Type of mulch did not influence air temperature more than 2°C at any time during the day.

The situation changed drastically close to the mulch, where there was a distinct difference between the air temperature and treatments with mulches throughout the day. During the night, the interface was generally warmer than the reference, whereas during the day (at least to 15h00) the interface was cooler. The patterns showed:

- There was a decrease in temperature of the interface due to mulching in early morning (05h00-08h00). From 15h00 there was an increase (± 7°C) in temperature above the reference.
- Type of mulch could have also modified the minimum and maximum temperatures of the interface by approximately 5°C. At 08h00 the stones induced a higher temperature than the 50% reed, followed by the bare and 100% reed. Around 19h00, the highest temperature was with the 100% reed, and the lowest was for the stone.

Figure 6 shows representative data on the temperature patterns of the various mulching treatments just under the soil surface. Huge differences were visible in comparison to the reference temperature, as well as between different mulches. All treatments induced a higher temperature from 16h00 to 02h00 than the reference temperature. Between 03h00 and 10h00 the situation turns around. Notably the 100% reed exceeded the reference temperature at lOhOO (27°C), followed by the 50% reed at 14h00 (33°C),

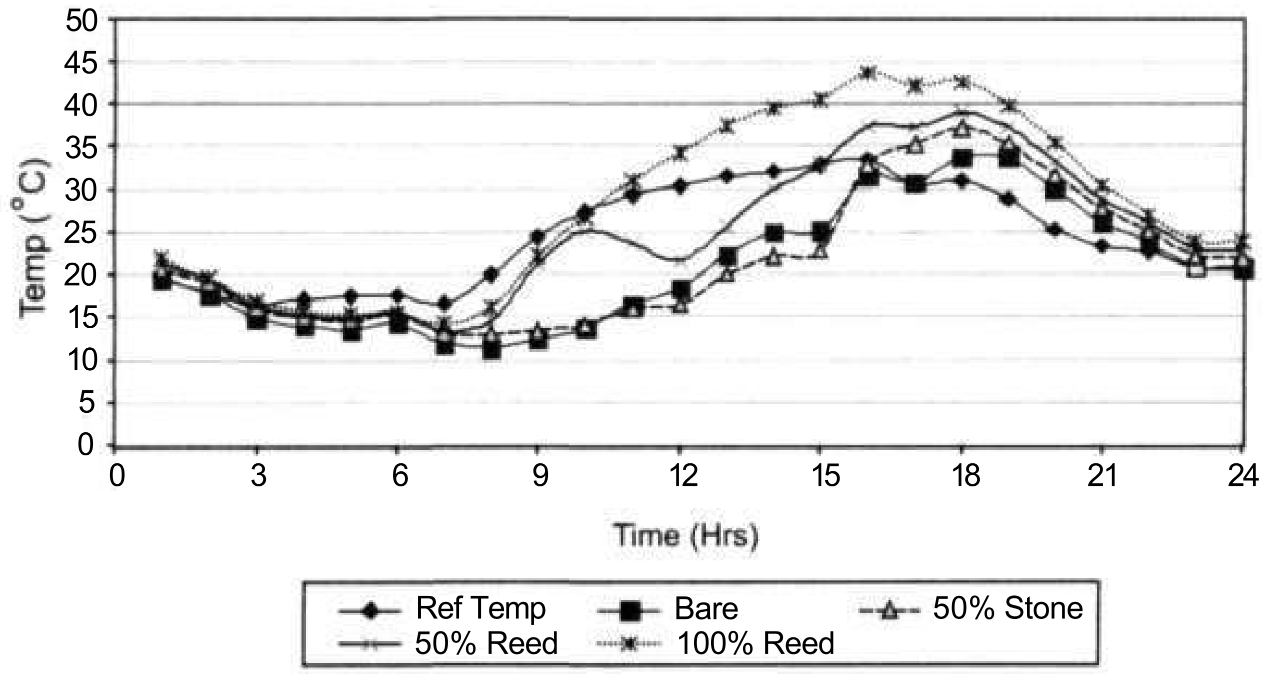


***Figure 6. Effect of mulching on the evolution of temperature just under the soil surface (5 mm soil depth), 25 Feb 2002***

50% stone at 15h00 (34°C), and then bare at 16h00 (31°C). Comparing the mulch treatments, the temperature patterns show that the stones induced a lower temperature throughout the day than both the reed treatments.

Figure 7 shows the effect of mulching on temperatures at 25 mm under the soil surface. Throughout the 24 hours, soil temperature of the 100% reed was lower than the other mulching treatments. The variation between the bare, 50% reed and 50% stone was less than 2°C during the night. Differentiation started at 08h00, peaked at 14h00, and then declined towards the end of the 24 hours. During the peak period, the difference was 15°C, with stones at 43°C and 100% reed at 26°C.

At 75 mm soil depth, temperatures of the 100% reed were lower than the 50% reed, and from 08h00 to 21h00 lower than the bare and 50% stone. The differentiation was again induced at 08h00, with a variation of ± 2°C, and peaked at 16h00, with a variation of 12°C (bare 37°C and 100% reed 25°C).

To establish a holistic view of the temperature profile of a treatment, temperatures were plotted as a function of height for selected times of the day. Two treatments were used, bare (Fig 8) and 100% reed (Fig 9).

At 05h00 the temperature profile of the air was generally lower than the profile of the soil. Hence, there should be a net heat flux towards the air. The surface temperature at 5 mm was lower than both the air above the soil, and the soil at 25 mm. The gradient from the 25 mm layer to the surface was steeper than from the air-soil interface to the surface, and heat should move

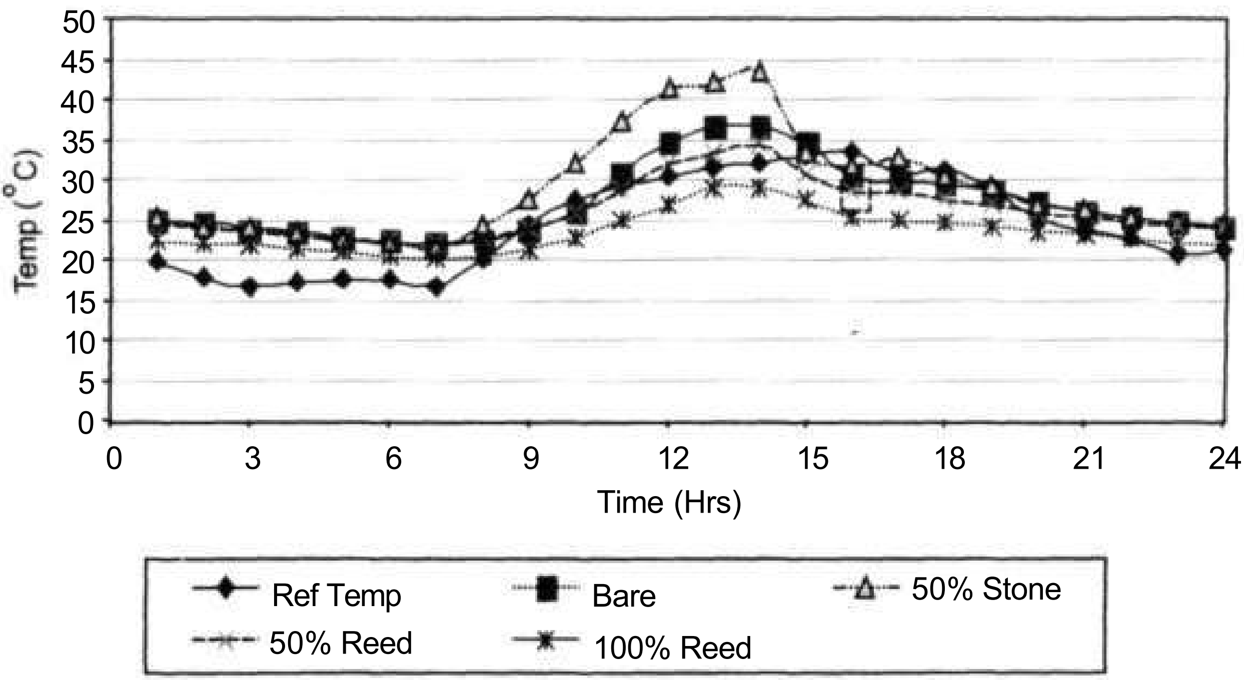


***Figure 7. Effect of mulching on temperature at 25 mm soil depth, 25 Feb 2002***

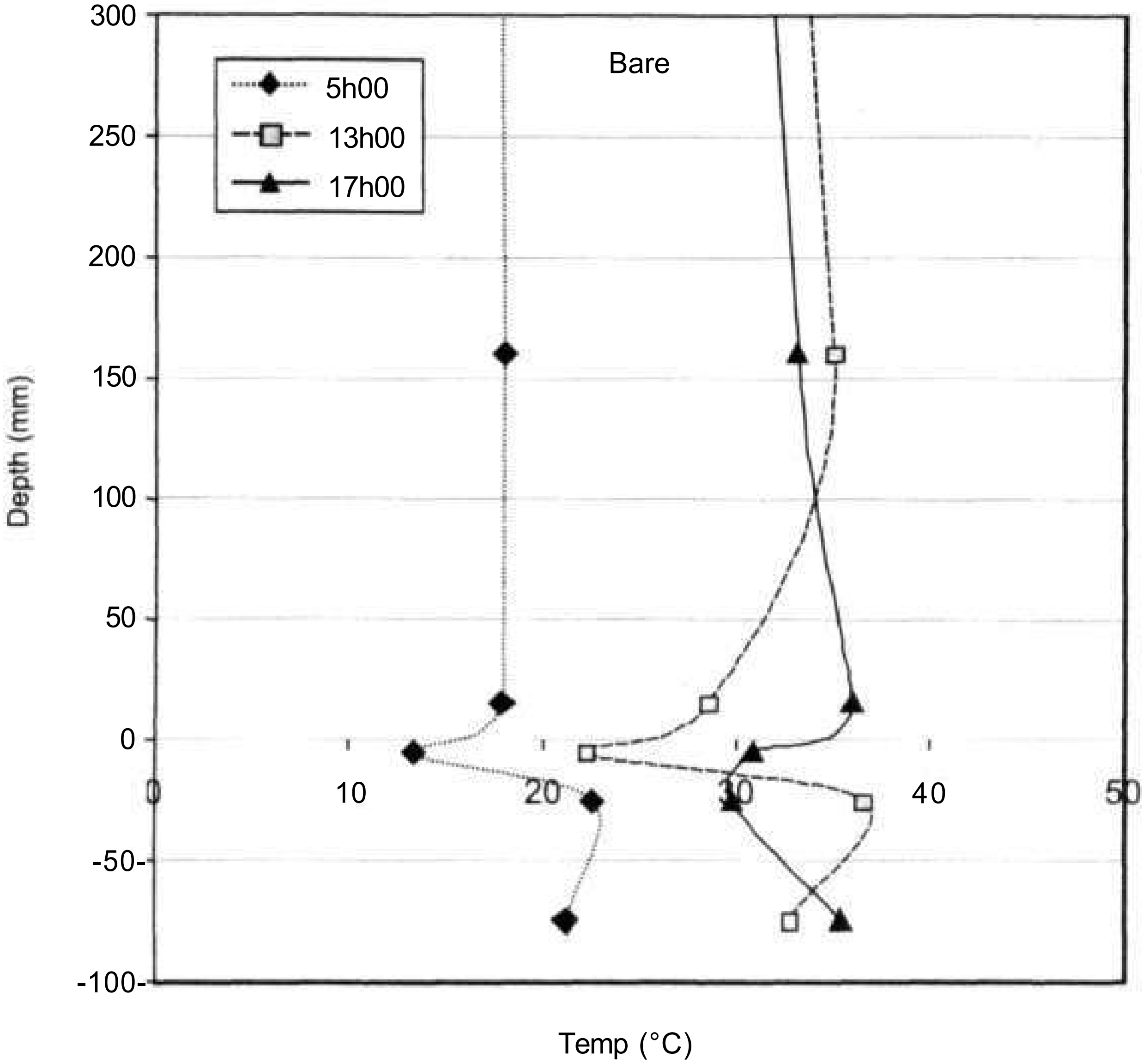


***Figure 8. Temperature profiles of the bare treatment at different times of day, 25 Feb 2002***

through the soil towards the surface. From 05h00 to 01h00, the temperature of the air at 300 mm increased by about 16°C, and a net influx of heat towards the soil was anticipated, as can be seen by the increase in temperature of 14°C at the 25mm depth. Between 13h00 and 17h00, the temperature decreased by 6°C to equilibrate with the lower air temperature.

Temperature profiles at the three selected times for the 100% mulch treatment (Fig 9) showed the insulating properties of the mulch. At 05h00, soil temperatures were generally higher than the air, thus inducing a heat gradient towards the air. The temperature difference between 05h00 and 03h00 was approximately 10°C at 25 mm soil depth, which was 4°C lower

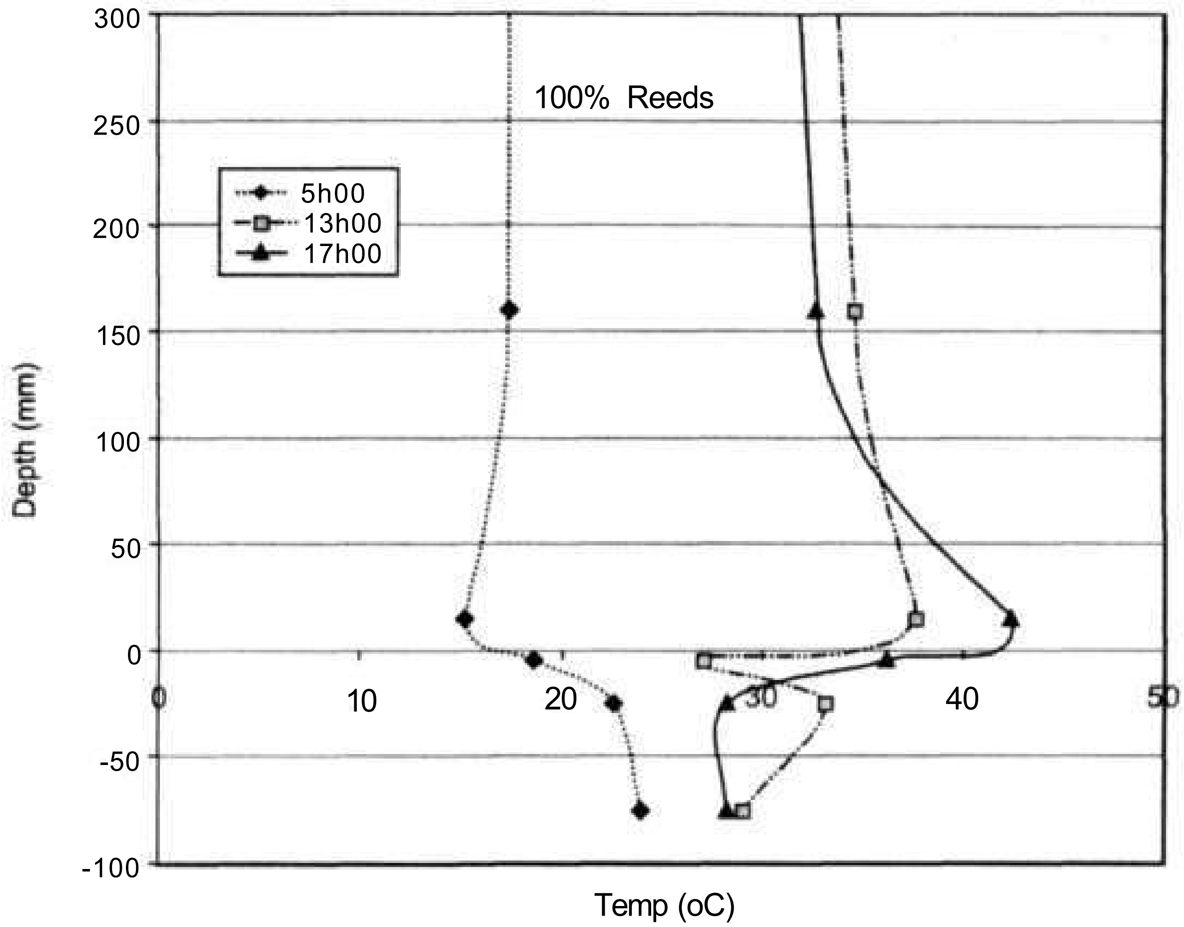


***Figure 9. Temperature profiles of the 100% reed treatment at different times of day, 25 Feb 2002***

than the corresponding bare treatment. The cooling of the soil at 25 mm depth between 13h00 and 17h00 was also less intensive under the mulch than in the bare soil.

## Humidity profile

The humidity profile is not yet developed, due to the wet and dry bulb temperatures and the psychrometers not being calibrated. As with temperature, relative humidities at 160 mm were not affected by mulching. RH varied no more than 3% between treatments during the day. However, it can be expected that the humidity profile could change at the interface, as was the case for temperature. RH values were high (70-80%) from 01h00 to 07h00, then decreased through to 09h00. RH reached a minimum of ± 21% at 16h00 and then increased through to 24h00.

## Soil water content

The soil water content, measured at 25 mm and 75 mm soil depth by FDR, is shown in Figures 10 and 11. The instruments are in the process of calibration. The hourly water content was highest for the 100% reed, followed by the 50% stone, 50% reed and then bare (Fig 10). The bare shows almost a straight line, indicating steady state conditions. All other treatments showed a response at daylight due to evaporation. In these cases, the readings increase and peak at ± 14h00, when $E_o$ is normally at its highest. The 75 mm readings also exhibit the same trends from 08h00 to 19h00, probably due to water flux from deeper soil layers.

CPN readings (counts) of the 0-300 mm soil layer were plotted (data not shown). The frequency of measurements was high to ensure accurate daily evaporation values. These results will form the basis to test the model predictions of evaporation.

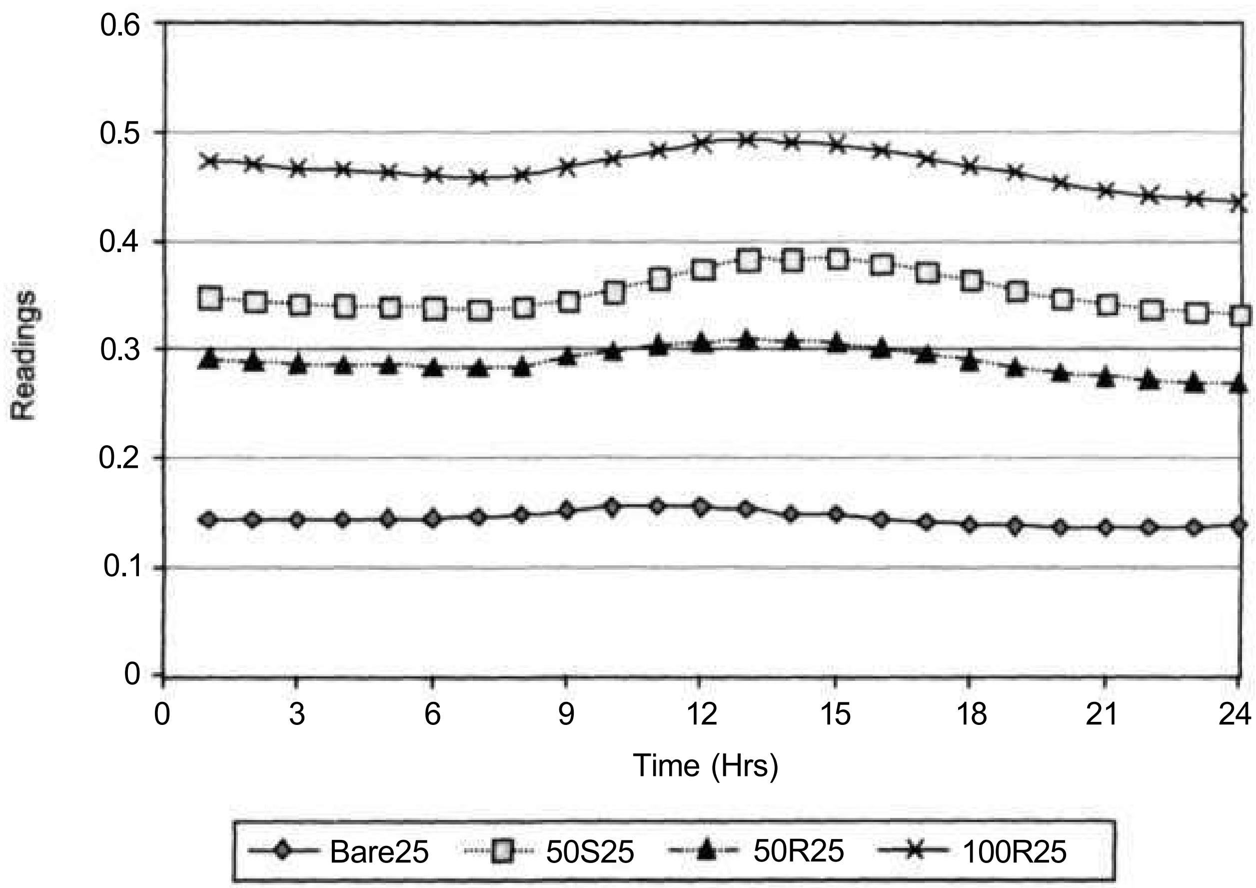


*Figure 10. FDR readings at 25 mm soil depth as affected by mulching, 25 Feb 2002*

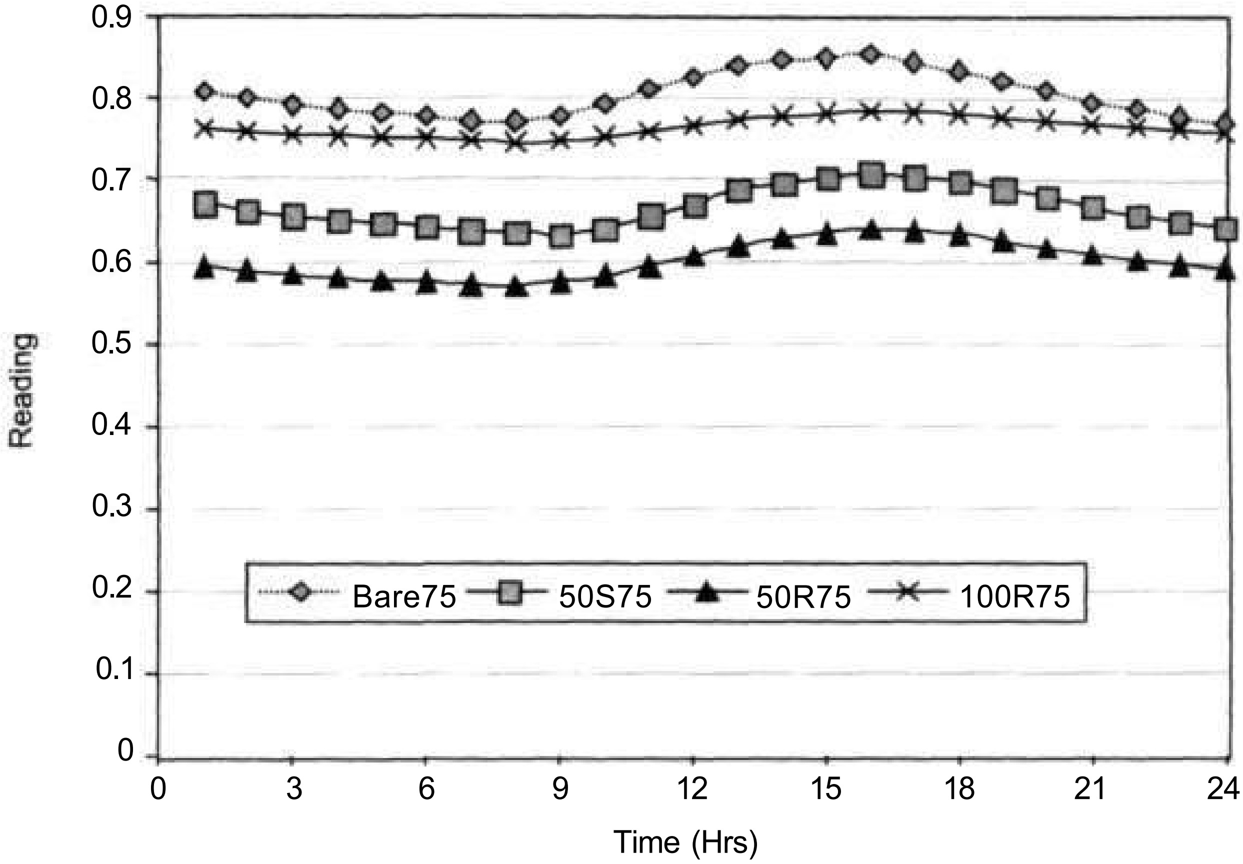


***Figure 11. FDR readings at 75 mm soil depth as affected by mulching, 25 Feb 2002.***

## Conclusions

Due to the incomplete analysis of results, few conclusions are possible. The results do demonstrate the important role of mulches in modifying temperatures at various levels in a micro-scale in and above the soil. The temperature measurements, as well as RH and soil water content, will help us to quantify and ultimately to model the system.

## Acknowledgments

The contributions of the following organizations and people towards the success of this project are gratefully acknowledged: the OSWU consortium for funding the project, the members of the Steering Committee, Dr DJ Beukes as program manager and also for his valuable inputs, Mr R Kuschke for his contribution to establish the field experiment, Dr T Fyfield for providing essential expertise for the field installation of the instruments coupled to the CR7X data logger, Prof JM de Jager, Dr M Hensley, Prof S Walker and Mr Harun Ogrindo from the Department of Agrometeorology, UFS for their technical assistance and fruitful contributions, the Free State Department of Agriculture for providing office accommodation and experimental land, all the non-author members of the ARC-ISCW research team at Glen who worked diligently, loyally and consistently, sometimes under very adverse conditions in the field: Mrs Trix de Bruin, Mr Victor Mandries, and many other laborers who helped establish the treatments.

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# Session 4. Reports on Other OSWU-Related Work

# Agro-Ecosystem Productivity and Food Security for the Semi-Arid Tropics of Southern Africa in the 21st Century

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CGIAR Centers with an interest in resource management have been promoting the idea of an integrated natural resource management (INRM) approach. At a workshop on INRM, initiated by the CGIAR at Penang in Malaysia in August 2000, ICRISAT undertook to set up a 'laboratory' that would use and evaluate an INRM approach in Zimbabwe. In Dec 2000, internal discussions within ICRISAT's former Natural Resource Management Program resulted in broad agreement on procedure. Then in early 2001, there was consultation with a range of IARCs and national stakeholders within Zimbabwe, which was followed by internal revision within ICRISAT in May-July 2001. The result was a national planning workshop held in Bulawayo, Zimbabwe, July 2001. The next move was to set up an INRM steering group in Aug 2001. This progress was reported at the follow-up CGIAR-wide meeting on INRM held in Cali, Colombia, Aug 2001. This report provides an outline of the process towards a ZimSAT partnership to that stage.

## Setting up the Process

In setting up an INRM 'laboratory', it was first necessary to consult potential partners. ICRISAT therefore approached local representatives of CIFOR, ICRAF, CIMMYT, TSBF, Agricultural Research Council, Agritex, Department of Natural Resources, Department of Research and Specialist Services (Matopos Research Station), Forestry Commission, and University of Zimbabwe (Department of Soil Science & Agricultural Engineering, Institute of Environmental Studies).

This was a key part of a process:

- CGIAR Penang Workshop, Aug 2000
- ICRISAT internal discussions, Dec 2000
- Consultation with IARCs and national stakeholders, Jan/March 2001
- ICRISAT internal revisions, May/July 2001

- National planning workshop, July 2001
- Synthesis by steering group, Aug 2001
- CGIAR INRM workshop, Aug 2001
- National forum/conference, 2002

## Identifying the Problems

At the National Planning Workshop, the participants addressed the questions:

- What factors are contributing to underdevelopment in the semi-arid tropics of southern Africa in the 21$^{st}$ century?
- What opportunities are there to enhance development in these systems over the next 10-20 years?

They identified the main factors contributing to underdevelopment as:

- Unreliable rainfall
- Low productivity
- Shortage of livestock feed
- Draft power shortages
- Deforestation
- Land degradation
- Limiting enabling environment
- Unfavorable macro- and micro-policy environments.

It was agreed to address the problem of the long-term decline in annual per capita grain production of SAT crops in Zimbabwe. It was also agreed that livestock production, particularly cattle, plays a central role in the economy of many SAT agro-ecosystems, providing draft power, manure, milk, occasionally meat, and capital investment. However, productivity is low across all sectors. Beef offtake is 18-20% from commercial herds, but only 3-5% per annum in smallholder herds. Milk yields of commercial herds are equivalent to those in other countries, but smallholder milk yields are very low, seldom meeting household needs. Woodlands provide a range of goods and services: timber, firewood, fibre, fruit, animal foods, mushrooms, honey, and medicines. Most harvested trees readily resprout from extensive rootstocks, and regeneration rates of miombo woodland range between 0.8-1.9 $m^3$ $ha^{-1}$ (cf. 0.9-1.6 $m^3$ $ha^{-1}$ for *Eucalyptus camaldulensis* grown in village woodlots).

Other problems identified were:

- Low efficiency of nutrient and water use, particularly in food security crops
- Low nutrient stocks

- Ineffective input/output markets
- Poor seed delivery systems
- Limited access to knowledge
- HIV/AIDS impacts on agricultural production and livelihood security.

## Defining INRM and the Approach

*ZimSAT working definition of INRM.* Maintaining and improving smallholder household food and income security through sustainable utilization and management of resources in semi-arid tropical agro-ecosystems, thereby contributing to rural livelihoods and reducing poverty.

*The ZimSAT INRM approach.* The focal point is that smallholder farming communities in the Zimbabwe SAT:

- lack food security
- lack income earning opportunities
- exist close to or below poverty datum
- are constrained and unable to adopt new technologies
- face a vicious cycle of poverty and resource degradation as soil fertility declines.

## Major issues

The major issues were identified as:

- Lack of social security - need for a safety net
- Poverty - few capital assets (natural resources, financial, physical, human, social), low productivity of assets, vulnerability to shocks and stresses
- Degrading natural resource base - water, land, forests, wildlife
- Community empowerment - farmer participation
- Macro-policies - land tenure, credit facilities, markets
- Micro-policies (institutional arrangements) - gender, culture and tradition
- Information - generation, learning and sharing
- Diversity of livelihood activities - risk spreading, how are new ideas incorporated? what trade-offs are involved?

## Guidelines for implementing an integrated program

- Recognise and encompass the social and biophysical heterogeneity and variability of the SAT
- Capture interdisciplinary and inter-institutional involvement

- Involve and empower communities
- Encourage ownership of project activities by communities
- Mainstreaming gender
- Incorporate HIV/AIDS issues
- Build in continuity and sustainability at both community and institutional levels
- Programmatic approach > 15-year timeframe, in 5-year impact phases
  - Develop and monitor impact indicators as ongoing activity
  - Scales of operation: (i) discrete research areas: benchmarks sites as laboratories, (ii) broader areas: results and experiences made available for possible adoption and adaptation.

*Setting up the ZIMSAT INRM Task Force.* The meeting agreed that the following group would continue with identifying and refining the research focus: Steve Twomlow, ICRISAT, Enos Shumba, Forestry Commission, Isiah Mharapara, ARC, Siboniso Moyo, DRSS, Paul Mapfumo, University of Zimbabwe, and Peter Frost, IES/CIFOR.

*The ZIMSAT INRM goal.* Enhanced adoption of sustainable crop, livestock, woodland and NRM practices in smallholder semi-arid farming systems to improve rural livelihoods and reduce poverty.

*The starting point.* Capitalize and add value to existing collaborative activities/ sites and historical data sets, to better target interventions to increase the adaptive capacity of the agro-ecosystems, enable rural households to cope with uncertainty of risk and change, and help alleviate rural poverty and food insecurity.

## Expected outputs

*Generic outputs.* Three broad groups of outputs are expected:

- Current status of SAT agro-ecosystems and what can be done to maintain sustainability
  - diagnostics
  - improved utilization of available resources
- Sustainable improvements in productivity
  - diversification of crop and livestock enterprises
  - diversification of woodlands and trees
  - development of input/output markets

- Dissemination and technology transfer
  - food supply and security - from Masvingo to Matebeleland
  - selection of benchmark sites from the wet end of the SAT to the marginal SAT
  - characterization of sites at spatial and temporal scales
  - crop, livestock and forestry technology options identified and tested
  - impact monitored, indicators identified and applied.

*Short term.* In the short term (1 to 3 years), the emphasis will be on:

- Diagnostic surveys
  - household coping strategies
  - trade offs between crops/livestock/ trees
  - land use patterns/changes
  - market status
- Environmental audits to provide baseline data
- Identify niches for interventions
- Community empowerment and prioritization

*Medium term.* In the medium term (1 to 10 years) the expected emphasis will be on:

- Technology interventions
  - improve resource use efficiency - crop/livestock
  - diversification, eg more trees, legumes, fodder crops
  - build nutrient stocks/organic matter management
- Trade offs between crops and livestock
- Management issues
  - improved land management - conservation
  - improved livestock management
- Cash generation opportunities
- Market development/linkages
- Land use changes
- Community empowerment/participation
- Develop policy briefs

*Long term.* In the long term (1 to > 10 years) the expected emphasis will be on:

- Change in household investment patterns
- Land use change
- Community empowerment
- Policy changes - advocacy based on short and medium term outputs
  - scale issues
  - public/private sector.

## Research areas

On the basis of these analyses, future research and development areas were identified under several main headings:

- Markets - for crop products, for fertilizer inputs, for seeds, and for natural products, with emphasis on issues of sustainable prices and value addition.
- Sustainable crop production in relation to use of existing resources. Crop diversification (alternatives to maize, legume intensification, cash crops, agroforestry, fodder crops). Improved fertility (small doses of fertilizer, input markets, manure management, application, organic matter management). Residue management (mulching and incorporation), livestock (livestock feed). Household food security (markets for crops with reference to surpluses and income). Seed markets (production, quality, distribution).
- Sustainable livestock production in relation to diversification (improved breeds, wildlife management), grazing management (improved rangeland, stocking density and mix, fodder banks, conservation, agroforestry), residue management (mulching, incorporation, and feed), cropping (food crops, fodder, residues), household food security, and markets for livestock.
- Sustainable woodland management in relation to sustainable crop and livestock production, diversification of uses (mushrooms, mopane worm, beekeeping), policy and institutions, diversification of species (carving, building), household food security, and markets.

Important features of the progress to date include the belief that it is crucial to bring in the potential partners at a very early stage in order to avoid the risk of being seen as a CGIAR top-down approach, and to ensure buying in and ownership of the approach by all partners. The plan was to hold a national forum/conference in 2002.

# Agronomic Management for Improved Water Use Efficiency in the Dry Areas of West Asia and North Africa

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## Introduction

The water resource is of great importance across the West Asia and North Africa (WANA) region, with its scarcity being a major factor limiting agricultural production. Yet high population growth rates in arid and semi-arid regions increase the demand for food, feed, and other agricultural products. Production increases from more favorable lands are also declining, forcing people to use marginal lands. Thus, both marginal and fertile lands are currently suffering from various forms of degradation, including nutrient depletion, soil erosion, and reduction of soil water retention because of mismanagement of the natural resources and improper application of production practices.

Dry areas occupy over 85% of the total of the WANA. In the region, 125 million ha of rainfed agricultural land receive between 200 and 600 mm mean annual rainfall, with high temporal and spatial variability. All winter sown crops, because of their small canopy and low evaporative demands in winter months, are increasingly exposed to drought in the spring or early summer when evaporative demand is high, mostly at flowering and grain filling stages; and are largely dependent on stored soil moisture to complete their growth cycles (Cooper et al. 1987a). In the water scarce areas, a small proportion of the available water is actually transpired by the crop as more water losses such as surface runoff, deep drainage, evaporation from the soil surface and deep cracks, and transpiration by weeds occur. Viable farm-level techniques are needed to reduce those losses and so increase the proportion of available water transpired by the crop.

Increasing demand for food and feed from growing populations makes it essential to increase both crop yields and productivity of water. Improved soil and crop management practices combined with improved crop cultivars are needed to reduce such losses by increasing the transpiration efficiency of cropping systems, and thereby permitting sustainable increases in productivity. In other words, soil quality, fertility, water supplies and crops need to be managed effectively, conserved through husbandry of natural resources, and through land-improving investments. Effective soil, water, and nutrient management requires actions not only at the farm level, but also at community, regional, and national levels.

In addition to improved soil and crop management practices, agricultural productivity in rainfed areas has been increased substantially through irrigation, where water resources are available. More than half the region's crops are produced under irrigation. Such production growth through irrigation cannot be sustained without proper management. But economic pressures force decision makers to reallocate water increasingly away from agriculture to other sectors. Since there is no prospect of any substantial improvement in water supply, if agricultural production and livelihoods are to be sustained even at current levels, much greater priority must be given to enhancing the efficiency of water procurement and utilization. Deficit (supplemental) irrigation can allow more rainfed areas to be supplied with water. Water harvesting, particularly in drier areas, will also help increase water supplies to agricultural production (Oweis et al. 2001).

## Improving Water Use Efficiency In WANA

This paper reviews the present status of research on cropping systems with associated soil and crop management practices, including fertilization, supplemental irrigation and water harvesting in dryland agriculture with respect to increasing water use efficiency and productivity of cropping systems. It discusses a number of soil and crop management practices to optimize rainwater and applied water use efficiency, with specific reference to the WANA region.

In the rainfed farming systems of WANA, seasonal rainfall defines the upper boundaries of crop yield potential. Research has been carried out by ICARDA in collaboration with national agricultural research services (NARS) to overcome the constraints limiting crop and water productivity. Proper and timely tillage, sowing date, stand establishment through optimum seed rate and row spacing, new crop varieties, use of fertilizers, pesticides, and herbicides in suitable crop rotations can increase water supply for increased transpiration and reduce evaporative losses, thus stabilizing crop yields (Harris et al. 1991a). Water harvesting (Oweis et al. 2001) and supplemental irrigation (Oweis 1997) are two other techniques to supply water into rainfed cropping systems.

## Tillage

When the land is not tilled after the previous harvest, in all but the lightest soils it is necessary to wait until the early rains have moistened the soil sufficiently to permit the entry of an implement. A vicious cycle can arise where the crusted surface of hard-setting soil resists infiltration and promotes runoff of much of the heavy early-season rainfall. Research-derived recommendations to cultivate after harvest or before the next rains to assist infiltration are often inapplicable. One problem is the indigenous practice of in situ grazing of residues (barley and sometimes wheat in WANA). Another is that the power available for tillage is inadequate to match the natural strength of the dry soil (Jones et al. 1998). For the driest environments, it may be advantageous to rethink the cropping pattern and its relation to the tillage requirements for water infiltration and weed control.

Currently, most staple cereals (overwhelmingly the predominant crop) continue extracting soil moisture beyond the end of the rainy season, so that after harvest many soils are unworkable until the next season. One solution is to give priority to the basic needs of the tillage operation (rather than those of a particular crop), and to increase the flexibility of the cropping system by introducing new varieties and species of shorter growth cycle, or forage for hay production for early harvest. The underlying logic in all cases should be soil management to optimize the provision of water to crops most able to utilize it productively (Harris et al. 1991a).

In the long term, tillage can be expected to cause breakdown of the surface structure and increased crusting. In soils where the surface structure is inherently weak, cultivation rapidly leads to surface degradation, reduced infiltration, and failure of crops to emerge through the solid crusts (Cooper et al. 1987a). If these same soils are cultivated when dry, the lack of structure renders them susceptible to wind erosion. Again, observations in the region suggest that this is a problem, but its severity is unquantified.

Where arable land in dry areas is cropped every year, inter-season management may significantly affect soil moisture. Post-harvest control of weeds, by tillage or grazing, is important whenever residual moisture is left in the soil by a shallow-rooted, short-cycle, or early harvested crop. In other areas, systems utilizing zero-tillage, reduced-tillage and/or crop residue retention treatments have been credited with reducing evaporation, as well as improving infiltration and reducing erosion (Bolton 1991, Papendick et al. 1991). Pala et al. (2000) report that the general trends in soil water change are the same for all tillage practices. Zero-tillage and minimum tillage treatments leave more water at harvest compared with deep tillage and are more energy efficient, although no yield differences were observed. These results were obtained for crop rotations on lowlands of West Asia. In highland areas, deep tillage during fallow has resulted in higher infiltration rate and moisture storage, giving increased fallow-use and water-use efficiencies as well as associated yields (Durutan et al. 1989, 1991).

## Crop Rotations

There is increasing concern about the deterioration of integrated crop/ livestock systems because of the high pressure put on these systems by increased continuous cereal cropping. Cereal-fallow and continuous cereal cropping are the common crop rotations in the WANA region, but including legumes in the rotation has proved to be beneficial (Harris et al. 1991 b, 1995). Wheat-legumes systems increase soil organic matter content (and hence soil quality) compared to continuous wheat and wheat-fallow (Ryan 1998). The decline in yield under continuous barley is a problem, but the causes of the poor productivity are not clear (Harris 1994).

The major effect of legumes is generally attributed to N fixation and improved soil physical conditions (Masri et al. 1998). Harris (1995) compared seven years' data of a two-course rotation trial with wheat following wheat, medic, chickpea, lentil, vetch, melon and fallow grown in a Mediterranean-type climate. The highest wheat yield (Cham 1, 2.26 t $ha^{-1}$) was obtained from a wheat-fallow rotation, and the lowest yield (1 t $ha^{-1}$) in continuous wheat. Yield increases of wheat following other crops in the rotation compared with that of continuous wheat were 39%, 46, 82, 84, 119 and 126%, respectively. Wheat/fallow systems provide only one crop a year; replacing the fallow with an alternative crop is more economic.

Legumes grown in a crop sequence with cereals improve the system water-use efficiency. Because of their usually shorter growing period, some water may be left in the soil profile to be used by the subsequent cereal crop, increasing the latter's productivity (Karaca et al. 1991, Harris 1995).

## Crop Varieties

Improved varieties well adapted to specific conditions can improve soil water use and increase yield. These varieties should be tolerant to abiotic stresses such as cold, drought and heat, and biotic stresses such as diseases and insects (Dakheel et al. 1993). Varieties with vigorous early growth and a deep root system would use soil water at a rapid rate and would decrease evaporative losses (Gregory 1991)). Selected cultivars adapted to different rainfall zones generally combine high yield potential and stress tolerance and hence high yield stability (Nachit et al. 1992).

Based on on-farm trials in the highlands of Turkey, the highest yielding wheat variety with recommended cultural practices provided 48% more grain yield than a local variety under recommended practices, while the increase was about six times compared with the local variety under local practices (Durutan et al. 1987). Similarly in the lowlands of Syria, the improved bread wheat varieties Cham 4 and 6, gave 30-51% grain yield increase compared to the older variety Mexipak 65, under different water and N regimes (Oweis et al. 1998). These results also show that improved cultivars may not give increased yields unless appropriate cultural practices are applied in a timely manner.

## Crop Stand Establishment

Water use efficiency is the crop yield divided by the water used to produce the crop; or can be indicated as modified from Gregory (1991):

$$WUE = (k / D) / (1 + Es / T)$$

where k is a crop specific constant, Es is seasonal moisture loss due to evaporation from the soil surface under the crop, T is seasonal moisture loss through crop transpiration, and D is saturation deficit of the atmosphere.

This assumes that runoff and drainage are- zero in the parts of the Mediterranean region where soils are deep and precipitation low. Under these conditions, Es + T is almost equal to annual precipitation. On the basis of the equation, WUE would be improved by improved management practices, which reduce the ratio of soil evaporative loss (Es) to transpiration (T) and enhance the rate of crop establishment and canopy expansion for reduced evaporation from the soil surface. This strategy would also increase the energy intercepted by the canopy with increased transpiration (Acevedo et al. 1991). In the same equation, WUE is inversely related to vapor pressure deficit, which is low during the cool winters and early spring, rising rapidly in late spring and summer. Any techniques increasing crop growth and production during periods of low vapor pressure deficit will also improve WUE (Acevedo et al. 1991).

## Early Sowing

Within the concept of improved WUE, water transpired by crops should be increased relative to evaporation from the soil surface. Therefore, directing biomass production into periods of lowest atmospheric demand confers an advantage (Gregory 1991, Gupta 1995). In the winter rainfall environments, despite temperature limitations to growth, early sowing (late fall, early winter) allows as much as possible of the crop's growth cycle to be completed within the cool, rainy winter/early spring period (Cooper and Gregory 1987). Attempts made to persuade WANA farmers to move from spring to winter sowing of chickpea gave 30-70% yield increases (Silim and Saxena 1991, Pala and Mazid 1992a, Erskine and Malhotra 1997). Grain yield increase of 20-25% was obtained by sowing lentil in mid-Nov instead of early Jan (Silim et al. 1991, Pala and Mazid 1992b). Winter sowing produces plants with a larger vegetative frame capable of supporting a bigger reproductive structure, leading to greater WUE and increased productivity (Cooper and Gregory 1987). Keatinge and Cooper (1983) reported that WUE of winter-sown chickpea might be more than 100% higher than in the spring-sown crop.

Early sowing depends on the tillage/crop rotation system employed. In WANAs highland areas, proper fallow tillage practices and sufficient precipitation will improve stand establishment of early sown crops and result in higher yield by extending the period of vegetative growth under cereal-fallow rotation systems (Pala 1991). Delayed sowing will prevent crop germination and seedling establishment because of a rapid drop in air temperature starting in Nov. In the lowlands of the Mediterranean regions, where continuous cropping (pure cereal or cereal-legume rotations) is common, mid-Nov was found to be an optimum sowing date for cereals (Keatinge et al. 1986; Acevedo et al. 1991). Yield declined by 200-250 kg ha$^{1}$ for every week delay from the optimum.

Sometimes tillage applications may create the difference in sowing date. Pala et al. (2000) reported that wheat grain yield increased by 14% (10-year average, range 0-109%) with early sowing in Nov compared to late sowing in Dec. Lentil was even more responsive than wheat. Yield increased by 61%

(10-year average, range 0 to 12-fold) by sowing in mid Oct instead of Dec. Mean WUE increased by about 10% in wheat and 48% in lentil (Pala et al. 2000).

## Sowing Method, Crop Density, and Row Spacing

Poor emergence of crops is common in the region. Early planting combined with proper sowing method will increase crop yield as well as WUE. Drill use usually results in uniform seed depth and stand establishment through a desired row spacing compared with broadcasting, which used by most farmers in the region. Broadcasting is used mainly due to the unavailability of drills and the small landholdings, typically less than 2 ha (Pala 1991). Earlier studies showed that drill sowing can give 10-30% yield increase compared with broadcasting (Saxena 1981).

There is some evidence that row spacing and plant density can play an important role on WUE and yields of some crops under limited moisture conditions (Silim and Saxena 1991). Wider row spacing may reduce the efficiency of light interception by exposing a greater soil surface to the sun, which reduces growth rate, canopy development and yield, and increases water loss. Relative barley grain yield was reduced from 100% at 10 cm row spacing to 85% at 20 cm and 80% at 40 cm row spacing, showing that narrow row spacing was advantageous in dry conditions (Acevedo et al. 1991).

Cereal grain yield is the product of three components: (i) heads per unit area, (ii) kernels per head, and (iii) kernel weight (Bolton 1991). Increasing seeding density can increase heads per unit area, but reduce the other two components (Joseph et al. 1985). There is a compensation, which tends to minimize yield loss when one component is reduced, but such compensation may not be complete. In legume crops, optimum plant density depends upon environmental conditions and genotype. A sowing density of 300-450 lentil seed $nv^{2}$ resulted in the highest yield under Syrian conditions (Silim et al. 1990). Chickpea yield at a density of 50 plants $m^{-2}$ was significantly greater than at 33 plants $m^{-2}$ (Silim and Saxena 1991).

## Soil Fertility Management

Variable and often chronic deficiency of rainfall coupled with widespread N and P deficiencies contribute to uncertainty of crop production (Cooper 1991). Given the inherent low fertility of soils in many dry area, judicious use of fertilizer is particularly important. Fertilizer use increases both productivity and WUE (Cooper et al. 1987b, Cooper 1991). Calcareous soils with high pH are common in the region. High pH reduces availability of micronutrients (copper, iron, manganese and zinc in particular) though responses to micronutrients are less pronounced in rainfed agriculture.

These widespread deficiencies of nutrients (N and P in particular) have prompted research within the region by national and international institutions. This research resulted in recommendations on fertilizer use (Cooper et al. 1987a, Harris et al. 1991a, Jones and Wahbi 1992, Matar et al. 1992, Pala et al. 1996a, Ryan 1997). Research has also demonstrated the benefits of appropriate fertilization on WUE and therefore on production and yield stability of winter-sown crops, especially wheat and barley, in WANA. In deficient soils, P applied together with a small dose of N at planting enhances the rate of leaf expansion, tillering, root growth, and phenological development, ensuring more rapid ground cover and canopy closure, and earlier completion of the growth cycle before the vapor pressure deficit increases as temperatures rise in spring (Gregory et al. 1984, Gregory 1991). The results also confirm the observation that, in the WANA region, responses to N are more important under favorable conditions, while responses to P are higher under dry conditions (Cooper 1991, Jones and Wahbi 1992, Pala et al. 1996a).

## Weed Control

Weeds are integral components of agroecosystems, competing with crops for water, nutrients and light, and decreasing yield. Weeds need to be controlled to supply more water to be transpired by crops (Zimdahl 1980). Competitive interactions are affected by the spatial arrangements of plant components, as well as by the growth form and age of plants (Altieri and Liebman 2000). Thus, crops and weeds compete depending on their aggressiveness in depleting resources. Interactions of crops and weeds are site- and season-specific, and vary according to plant species involved, densities, and management factors such as tillage, sowing date, fertilizer application, and crop rotations to improve WUE (Amor 1991, Durutan et al. 1991, Altieri and Liebman 2000).

Weed problems are dynamic, depending on any changes in the farming system. Weed density and crop yield relationships are not linear but sigmoid (Zimdahl 1980). At low density, weeds do not usually affect crop yields; under some conditions certain weeds even stimulate crop growth (Bhandari and Sen 1979). Thus, competition for water depends on weed types as well as their densities. It is important that an integrated approach to control weeds is adopted. Rather than relying on only one method, several possible alternatives (clean seed, proper and timely cultivation, crop competition, early crop development, crop rotation, grazing, hand weeding, herbicide use, biological control etc.) should be considered, thus increasing the chance of developing economic and sustainable farming systems which are also efficient in water use (Amor 1991).

## Water Harvesting Systems

Optimizing the available water has long been a part of agriculture in WANA. In dry areas, water harvesting is based on the principle of depriving part of the land of its share of rain, and supplementing the water supply in cropped areas. Thus, the water supplied to crop areas could be doubled or more, allowing adequate production even with limited rainfall.

ICARDA's water harvesting work is done in collaboration with NARS scientists: in a low-rainfall area of Jordan, to develop technical hydrologic models and assess the socio-economic potential of the available water harvesting techniques; and, in the Syrian steppe, to understand land-user perceptions of water-harvesting opportunities. The main land users, particularly in Syria, are nomadic herders, illustrating that much of the water-harvesting potential in WANA is in rangeland areas. Identifying the locations where this potential might best be exploited is a major task, and ICARDA has recently established cooperation, with BMZ funding, with German expertise to test and adapt methodologies based on remote sensing. ICARDAs range management research, concerned with steppe rehabilitation and sustainable management, is also relevant here.

Larger-scale alternatives for water harvesting include contour strips and various earthen bunds (a semi-circle, a crescent, or a trapezoid facing directly upslope) and terracing systems (Anonymous 1999a,b, Boutfirass et al. 1999, Oweis et al. 1998, 2001, Somi and Abdul Aal 1999). Terracing is suitable in wet environments where soil erosion by water is severe in sloping areas. The idea of water harvesting is not new in the region. However, ICARDA has been implementing new technologies to identify which areas are suitable for new harvesting schemes. Geographic Information Systems (GIS) and satellite imagery have been used to determine future potential sites and applicable harvesting strategies for an area in Central Syria. By classifying two satellite images from different years it was possible to obtain information on changes in vegetation patterns which can indicate the available water at any point. Added to this was information on slopes, soil types, rainfall and other hydrological data. This information was analyzed using GIS, to develop a map of water harvesting potential in the area, and indicate which of the currently available techniques would best fit each environment (Oweis et al. 2001).

ICARDA's future vision for these areas is of settled, stable land-use systems that, at the scales of farm, catchment and district, integrate the utilization of all locally available, renewable water sources into sustainable and profitable production systems. Rainfall on production areas will be augmented by supplies from wadi flows, from water-harvesting catchments, adapted to local topography and surface conditions, and from shallow groundwater, where available on a sustainable basis. Production units (size and tenure) and their production systems will be matched to those resources, variously combining intensive crop and horticultural production on small areas (supported by extra water) with extensive production of animals on well-managed rangeland (Oweis et al. 2001).

## Supplemental Irrigation

In dry areas, water resources are limited and their share for agricultural use decreases as population and food demand increase. Rainfall is variable in space and time, and is lower than seasonal crop water requirements. Soil moisture in the root zone often does not satisfy crop needs for the whole season. Thus, crop production is variable and yields are usually low. Supplemental irrigation is the addition of small amounts of water to augment and stabilize yields of essentially rainfed crops (Oweis 1997). Such additions, if well managed, increase the utilization efficiency of the rainfall, and also that of the irrigation water compared with most other modes of use. This is particularly true where a winter crop is being supplemented and the alternative use for the water is full irrigation of a summer crop. When rigorously practised, supplementary irrigation follows the principle of 'deficit irrigation'; the soil profile is not irrigated fully to field capacity, and the target is not maximum yield but rather the yield that optimizes WUE.

Research results showed substantial increases in crop yield in response to the application of relatively small amounts of supplemental irrigation in both low and high rainfall areas. The need for supplemental water would vary from 50 mm to 200 mm depending on rainfall.

Average rainwater productivity in the dry areas is about 0.35 kg $m^{-3}$. It may be increased up to 1.0 kg $m^{-3}$ with improved management and favorable rainfall distribution. A cubic meter of water applied at the proper time might produce more than 2 kg of wheat grain more than that from using only rainfall. The high water productivity of supplemental irrigation is mainly attributed to alleviating moisture stress during the most sensitive stages of crop growth. Moisture stress during wheat flowering and grain filling usually causes a collapse in the crop seed filling and reduces yields substantially. When supplementary water is applied before the occurrence of stresses, the plant may produce to its potential (Pala and Oweis 2002).

Optimum levels of irrigation to maximize water productivity need to consider all management factors such as sowing date, fertilization and cultivars used (Oweis et al. 1998). Experience from Syria showed that applying only 50% of the supplementary irrigation needed by rainfed wheat reduces yield by less than 15% while water productivity increases from 10 to 20 kg $ha^{1}$ mm in grain and from 25 to 40 kg $ha^{1}$ mm in total dry matter (Oweis 1997). When water is available, supplemental irrigation can stabilize and sustain crop productivity at adequate levels irrespective of the spatial and temporal variability of the rainfall.

## Conclusions

Much rainwater is lost or not used efficiently in most rainfed areas because of improper soil and crop management practices associated with the use of local varieties, and low adoption of improved technologies. If potential crop/tree yields are to be achieved in the dry areas, improved soil, water and crop management practices need to be adopted at farm level. The choice of crops, improved cultivars, optimum sowing date and plant density, better fertilizer use, and control of pests need to be developed for local environmental conditions through applied and adaptive research using a participatory approach. For yield stability, supplemental irrigation as well as water harvesting techniques must be considered, together with improved soil and crop management practices.

In future, research on optimizing soil-water use in rainfed areas needs to focus at watershed level, rather than field level, because downstream effects of the individual field applications may cause overall degradation of land resources of catchments. Crop simulation models (Pala et al. 1996b) linked to GIS to capture the spatial variability can facilitate the identification of best-bet options for farmers in a given environment. Linkage between biophysical and bio-economic models should be a further step to match identified strategies with the socio-economic conditions of resource-poor farmers in the dry areas of WANA to optimize scarce water resources.

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# Session 5. New Decision Support Tools

# Application of APSIM to Evaluate Crop Improvement Technologies for Enhanced Water Use Efficiency in Zimbabwe's SAT

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Increasing water productivity is an emerging focus for international agricultural research donors and institutions. As noted by the UN Secretary General, "We need a blue revolution in agriculture that focuses on increasing productivity per unit of water - more crop per drop." This agenda would seem paramount across the ecoregions of sub-Saharan Africa where food insecurity, poverty and land degradation continue unabated.

Improved management of water deficits is the priority for cropping systems throughout the semi-arid tropics (SAT). In the last 20 years, there has been considerable research investment through improved germplasm (mainly short season cultivars), water harvesting and water retention techniques as part of improved conservation technologies. However, the ability of these technologies to improve water use efficiency is strongly dependent on soil fertility management.

This paper reports the use of a cropping systems model to compare the payoffs to investment in alternative technology options in dry regions, and how the technology responses translate to improved water use efficiency. The analysis focuses on maize in Zimbabwe, where 80-90% of farmers use improved maize seed, and it is the favored crop for investment by smallholders, even in drier regions.

## Material and Methods

The cropping systems model used in this study is APSIM, the Agricultural Production Systems SIMulator (McCown et al. 1996, Keating et al. 2001). The application of APSIM in simulating productivity in smallholder farming systems in SAT Africa has been tested over several years and in a number of regions. Building on the precursor simulation studies of Keating et al. (1991) in Kenya to simulate maize response to inorganic N, the APSIM model has been tested and used to simulate surface runoff and erosion (Okwach et al. 1999), N fertilizer response (Dimes et al. 1999, Shamudzarira et al. 1999), manure and P responses (Carberry et al. 1999), crop-weed interactions

(Keating et al. 1999, Dimes et al. 2002) and extrapolation of research findings to other sites (Rose and Adiku 1999).

Using APSIM v 1.61, the following analyses explore the response of maize to a range of improved crop management technologies on a shallow sand (plant available water content PAW = 60 mm) of medium fertility (organic carbon OC = 8 g kg$^{-1}$) in Zimbabwe. The weather record used was for Bulawayo (latitude 20.2°S) extending from 1951 to 1999 (48 crop seasons, Nov-Apr average annual rainfall 590 mm). Seasons were simulated independently by re-initialization of water and N (PAW 0, mineral N = 9 kg N ha$^{-1}$, OC 8 g kg$^{-1}$) at sowing on 1 Dec each year. Plant population for all simulations is 2 plants m$^{2}$. Re-setting PAW to zero assumes that pre-sowing rainfall is largely lost via soil evaporation and/or weed growth. Re-setting OC each year ensures simulated yield outputs are not confounded by effects of soil fertility decline. All crop residues were removed at harvest.

The technology options simulated are short season germplasm, water conservation and fertility management. The baseline for comparison is a long season maize cultivar with no N inputs - it is assumed that all other nutrients are non-limiting and there are no pest and disease constraints. The short season maize cultivar is SC401, and the fertility input is 1 bag ha'$^{1}$ ammonium nitrate fertilizer (17.5 kg N ha$^{-1}$) at 35 days after sowing. As APSIM does not simulate surface ponding, improved water availability with tied-ridging technology was simulated by daily re-setting water to drained upper limit in all soil layers following crop flowering. This assumes the extreme position that the technology was able to deliver zero moisture stress post-flowering in every season.

Due to the effect of variable rainfall distribution, no technology performs best in every season. To compare and quantify the long-term advantage of one crop improvement technology over another, the difference between annual simulated grain yield for the two technologies is calculated and depicted as graph.

For this study, water use efficiencies (WUE, kg grain per mm in-crop rain) are calculated using simulated grain yield and the amount of rainfall between sowing and harvest. This approach increases the calculated WUE in relation to the seasonal rainfall since pre-sowing and post-harvest rainfall is ignored. However, it underestimates the physiological WUE (kg grain per mm uptake) since water remaining in the soil layers at harvest is not subtracted from the in-crop rainfall. In any case, it should be noted that since phenology varies between cultivars, and is sensitive to N stress, varying amounts of rainfall are sampled for the various N and germplasm combinations simulated in this study. Hence, the average in-crop rainfall for the short season cultivar is 385 mm and for the long season cultivar, 440 mm.

# Results

## Germplasm comparisons

Simulated maize yield for long and short season cultivars with no N inputs at Bulawayo is shown in Figure 1. The simulated long-term average grain yield for both cultivars is low (long 664 kg, short 680 kg ha$^{-1}$) and year-to-year variability is high, although substantially less for the short season cultivar: stdev 298 kg ha$^{-1}$ compared to 436 kg ha$^{-1}$ for the long season cultivar.

In Figure 2, results in Figure 1 are converted into an annualized difference for the cultivar responses. The effect of applying N fertilizer is also included. With no N applied, the yield advantage of the short season cultivar averages 300 kg ha$^{-1}$ and is achieved in 48% of years. In comparison, the long season type has an average yield advantage of 250 kg ha$^{-1}$ and this is achieved in 52% of years. If a small amount of N is applied then there is a considerable shift in favor of the short season cultivar - average yield advantage is 600 kg ha$^{-1}$, and an advantage is seen in 60% of years. But in 40% of years, the long season cultivar still outperforms the short season cultivar, by an average of 390 kg ha$^{-1}$.

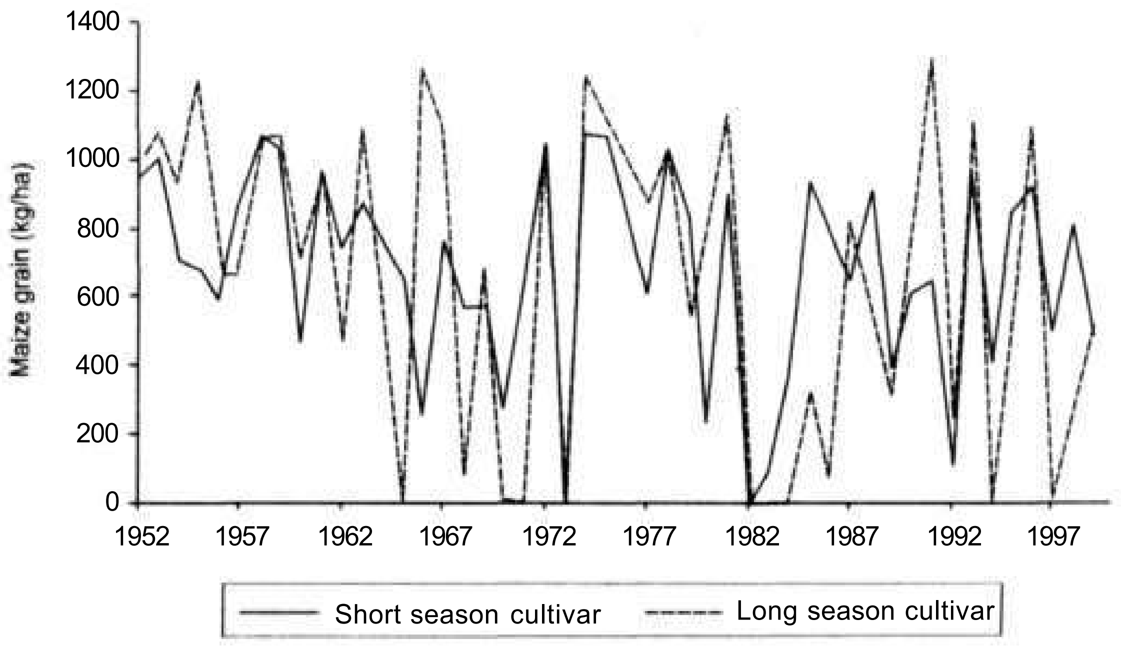


*Figure 1. Simulated maize grain yield for long and short season cultivars with no N inputs at Bulawayo, 1951 to 1998*

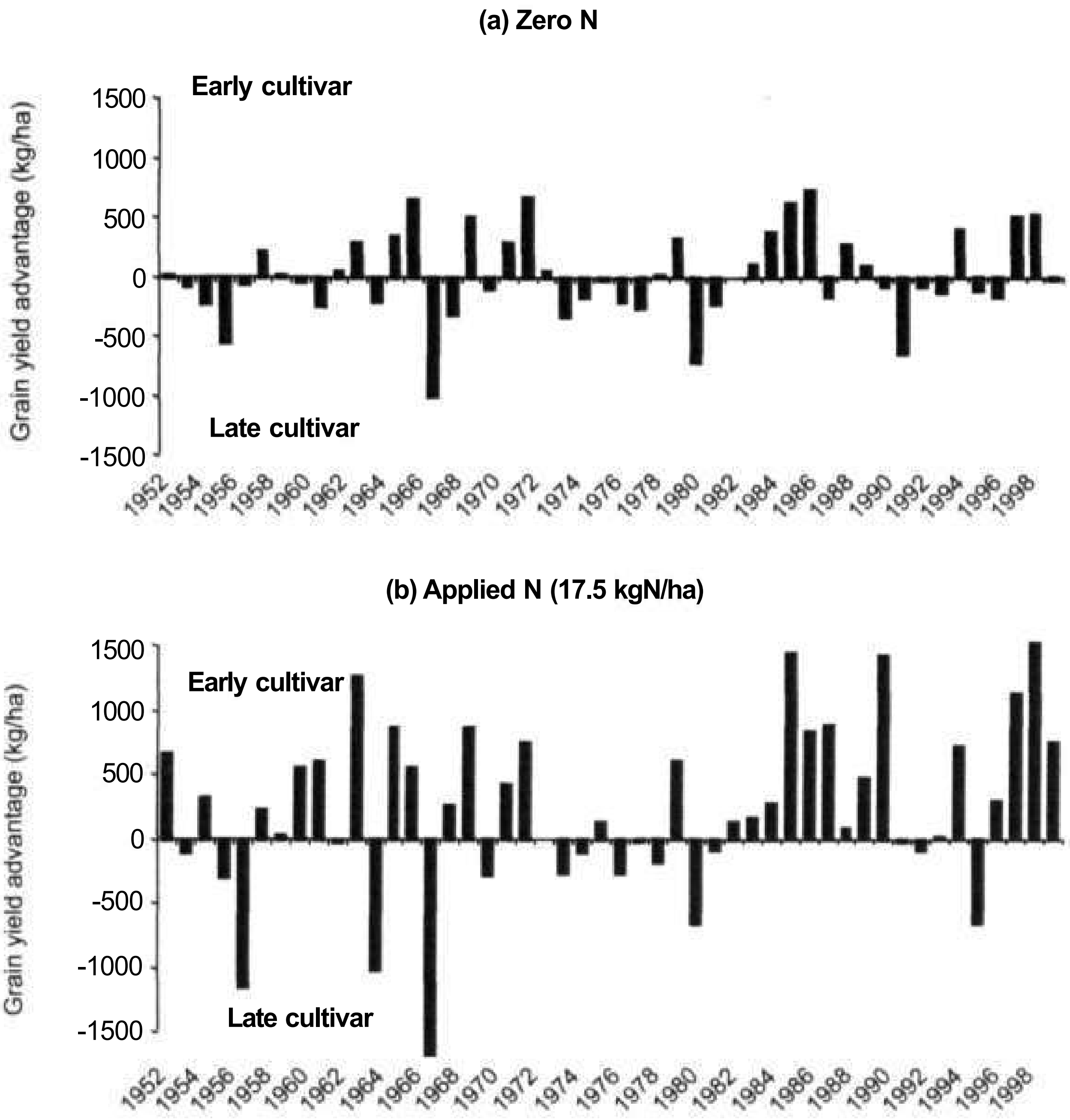


***Figure 2. Annual grain yield difference between short and long duration maize cultivars simulated for Bulawayo, 1952 to 1998, with and without N fertilizer***

*Water conservation.* Figure 3 shows a hypothetical case where post-flowering moisture stress has been eliminated through water conservation techniques. There is a grain yield benefit in 83% of years. While the simulated benefit is as large as 400 kg ha$^{-1}$ in a few seasons, in the absence of any N inputs, the average benefit is quite small, *66* kg grain ha$^{-1}$ . With the application of a small amount of N, the average benefit for the hypothetical system increases dramatically to 350 kg ha$^{-1}$, but more significantly, the reliability of the water benefit approaches 100% of years, reflecting the strong interaction of soil water and N supply on crop yield.

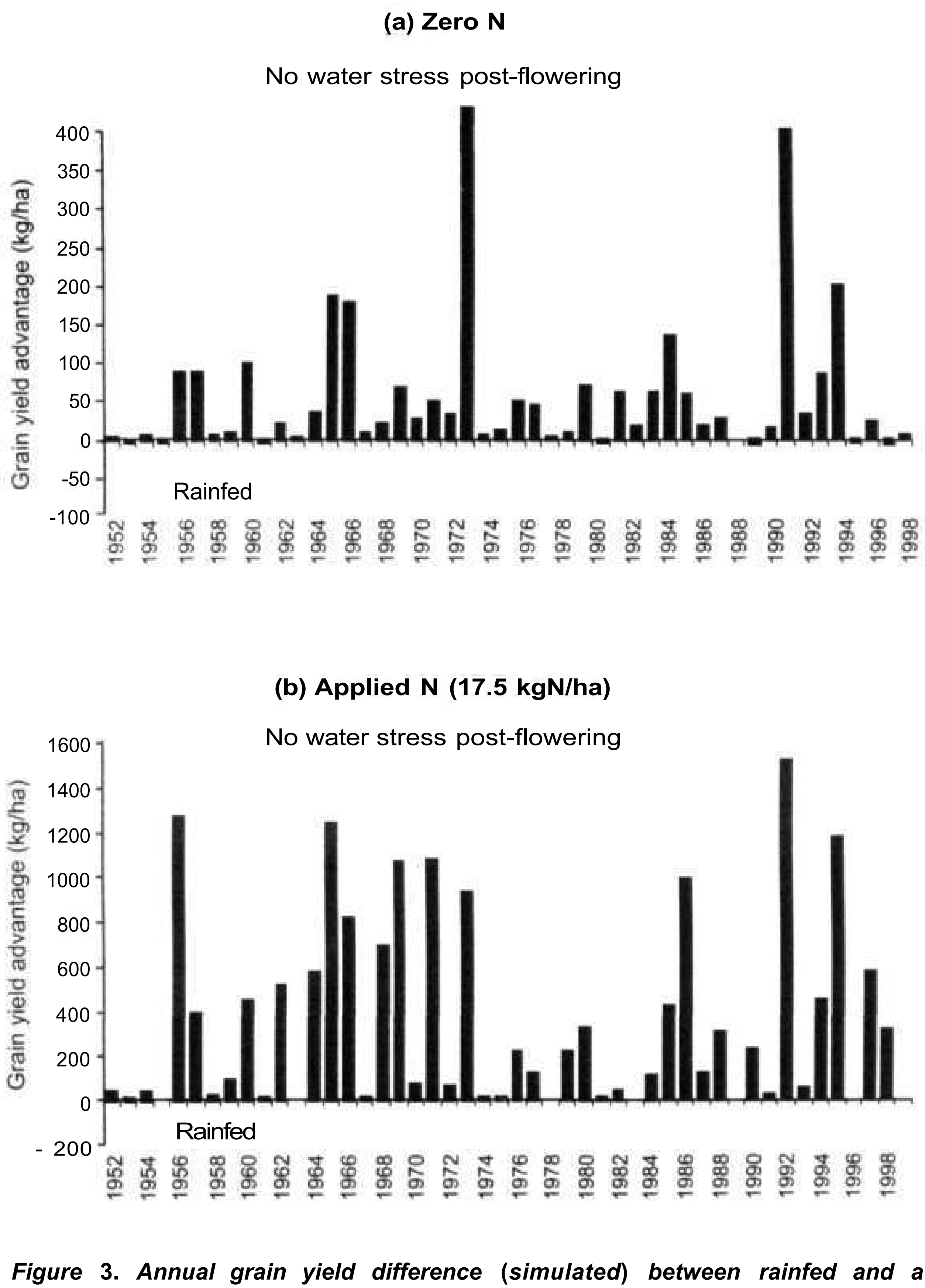


***Figure* 3. *Annual grain yield difference* (*simulated*) *between rainfed and a treatment eliminating post-flowering water stress, in short season maize in Bulawayo, with and without N fertilizer***

## N fertilizer comparisons

The benefit of a small amount of N fertilizer on crop yield in rainfed systems is shown in Figure 4. With N applied, the average grain yield increase compared to zero N is 600 kg ha$^{-1}$, and an increase is achieved in 92% of years. The negative effect of N inputs on crop yield, a common concern of farmers in drier regions, actually occurs in only 8% of years. In these seasons, yield without N fertilizer is higher than yield with N, by an average of 120 kg ha$^{-1}$.

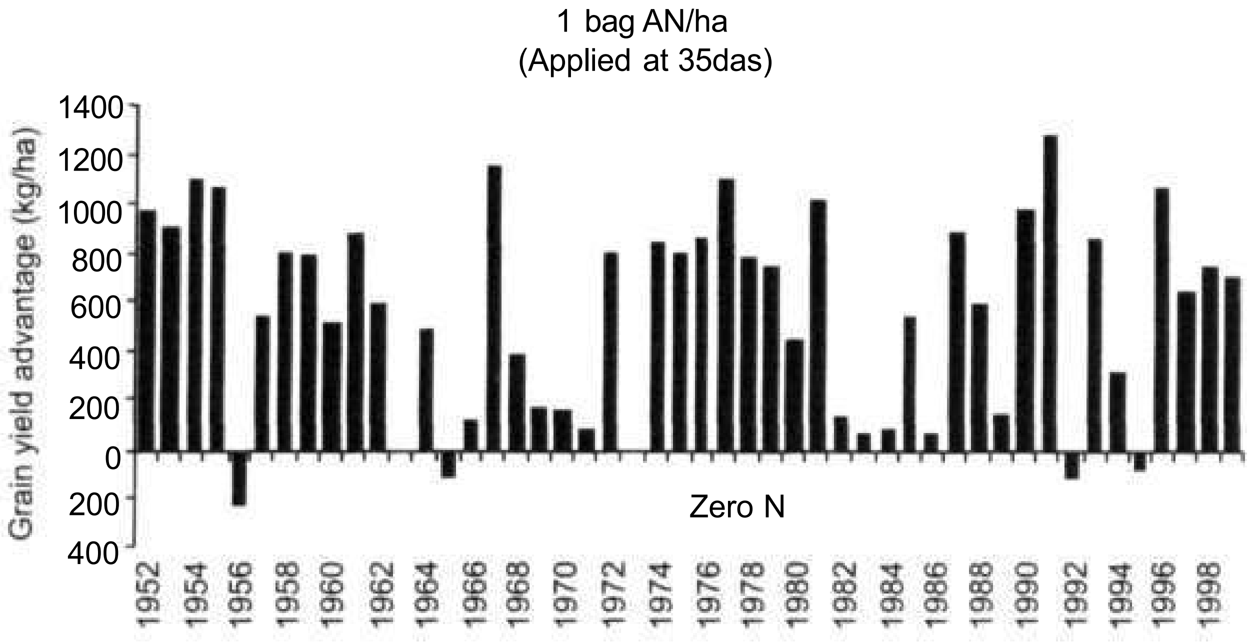


***Figure 4. Annual grain yield difference due to fertilizer application (1 bag AN, ie 17.5 kg N ha$^{-1}$ versus zero N applied) to short season maize, Bulawayo***

## impact of technologies on WUE

The average WUE calculated from 48 simulated maize crops for various combinations of technology options is shown in Table 1. Average WUE is very low (1.5) in a traditional farming system utilizing long season cultivars with no N inputs. There is only a marginal increase (20%) in WUE with a short season cultivar, if no N is applied. But WUE increases by 17% (short season) and 33% (long season) if all moisture stress post-flowering could somehow be eliminated using water conservation techniques. The higher percentage increase for the long season cultivar in this instance is consistent with alleviating the terminal moisture stress typically associated with such cultivars in the SAT. However, the results for both cultivars under the conditions of zero N input still represent very low WUE overall.

**Table 1. WUE calculated from in-crop rainfall and simulated grain yield for a range of technology options**

| | WUE (kg grain per mm rainfall) |
|---|---|
| Long season cultivar, zero N | 1.5 |
| Short season cultivar, zero N | 1.8 |
| Long season, water conservation, zero N | 2.0 |
| Short season, water conservation, zero N | 2.1 |
| Long season, N applied (17 kg $ha^{-1}$) | 2.1 |
| Short season, N applied (17 kg $ha^{-1}$) | 3.2 |
| Long season, water conservation, N applied | 3.7 |
| Short season, water conservation, N applied | 4.5 |

If a small amount of N is applied, there is a 40% increase in WUE for the long season cultivar (from 1.5 to 2.1), and almost 80% increase for the short season (from 1.8 to 3.2). The 40% increase for the long season cultivar is only marginally better than the no moisture stress scenario with zero N (33% increase), while the reverse is true for the short season cultivar (80% versus 17%). These results suggest that a traditional long season cultivar has lower N responsiveness than a short season cultivar.

As expected, WUE increases if N application is combined with moisture conservation, and again the short season cultivar is most favored (4.5). However, this is still considerably below the typical WUE for the environment (10-12 kg grain $mm^{-1}$) achieved with high input systems.

## Conclusions

Despite decades of investment in breeding short season crop cultivars and (more recently) in improving seed availability to smallholder farmers, returns on these investments in drier regions will continue to be severely restricted unless farmers can be encouraged to invest in soil fertility. This is already evident in Zimbabwe, where despite widespread uptake of improved maize varieties, smallholder grain yields in the dry regions remain in the range of 500 to 1000 kg $ha^{-1}$. In other words, with average annual rainfall of 450-600 mm, farmers make poor use of the rainfall that they receive each season with improved maize varieties, and this is mainly because of the low levels of investment in soil fertility management (Ahmed et al. 1997, Mapfumo and Giller 2001).

The WUE analysis presented here provides supporting evidence that crop productivity in smallholder farming systems can be substantially increased by an integrated genetic, nutrient and water management approach. However, it also separates and quantifies the payoffs to incremental uptake of the technology options. This information may be more practical to smallholder farmers facing severe resource constraints by helping to better prioritize their investment choices.

Research rhetoric on cropping system problems in the semi-arid tropics typically advocates developing technologies that overcome drought and improve water management (eg CGIAR's Water and Food Challenge Program for Limpopo Basin). Results of the analysis reported here suggest that a different emphasis may be warranted - that the problem is not so much drought (which occurs perhaps 1 or 2 years in 10) or lack of water, but rather low productivity (and low WUE) of rainfed systems as a consequence of investment uncertainties that stem from drought risk. Hence the more fundamental question is: What constraints need to be overcome, or incentives put in place, to encourage subsistence farmers to invest in crop improvement technologies in drought-prone environments, to improve food security and livelihoods? This analysis suggests low rates of N fertilizer could be a useful starting point.

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# Linking Logics II - Exploring Linkages between Farmer Participatory Research and Simulation Modeling to Increase Crop Productivity at Smallholder Level

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This workshop was held in Bulawayo, Zimbabwe during 15-20 Oct 2001, jointly planned and run by PRGA, SWNM (OSWU), ICRISAT and CIMMYT. The objective was to further explore linkages between farmer-participatory research approaches and simulation modeling to increase crop productivity at the smallholder level. The idea came from a group interested in participatory research and gender analysis methods (PRGA), and a group interested in how simulation tools can be used to help farmers (OSWU). Disparate groups cam together - modelers, participatory researchers, farmers, and scientists. This led to unusual situations such as smallholder farmers and scientists jostling to view the contents of the simulation modeler's computer screen in a small village in southwestern Zimbabwe. The simulation modeler hardly noticed because he was trying to get as many simulations done as possible before his computer battery ran out. It also led to international scientists rubbing shoulders with smallholder farmers on equal terms.

Linking Logics II was a joint venture between the CGIAR programs on Participatory Research and Gender Analysis for Technology Development and Institutional Innovation (PRGA), Soil Water Nutrient Management (SWMN), ICRISAT and CIMMYT. We sought to use complementarities between farmer-participatory research approaches and computer-based simulation modeling, to address the soil fertility management issues of smallholder farmers. The workshop was in response to a request from the SWMN (OSWU) to strengthen its members' capabilities in farmer participatory research approaches and simulation modeling, and brought together two previously disparate groups of researchers: those who specialize in participatory research approaches, and soil scientists who specialize in crop-soil interactions and frequently use simulation modeling for temporal and spatial analysis.

Fifty participants attended, from R&D institutes based in Australia, Burkina Faso, Cote d'Ivoire, Kenya, Laos, New Zealand, Niger, South Africa, Uganda, USA, and Zimbabwe. OSWU was represented by participants from Burkina Faso, Kenya, Niger, South Africa, and Zimbabwe. The workshop was the fourth in a series organized jointly by ICRISAT and CIMMYT in southern Africa. Both institutes, in collaboration with local NARS, have been integrating participatory approaches with on-farm research and systems simulation using the APSIM model.

The first two days of the workshop focused on experiences in participatory research, with reports by Ann Braun, Toon Defoer, Pascal Sanginga, Peter Home and David Rohrbach; an introduction to APSIM by Peter Carberry; and the experiences of ICRISAT and CIMMYT in linking participation with simulation modeling. Bob Myers made a presentation on what SWNM and OSWU were all about. The finale for this 2-day session was a series of group modeling exercises, prior to three days field work with smallholder communities in Tsholotsho and Zimuto Communal Areas. We confess that the social scientists developed the highest yielding scenarios and the agronomists the poorest, emphasizing the old adage that a little knowledge can be dangerous. On completing the plenary sessions, the groups disbursed for field work, three groups traveling to Masvingo, and three remaining in Bulawayo. In three days of field work, participants interacted with over 150 farmers, ranging from established farmer field schools to more traditional farmer research groups.

Each group consisted of resource persons with backgrounds in participatory research, simulation modeling and the local farming systems. Despite the initial diversity of backgrounds and interests, the groups quickly meshed and had an extremely informative interchange with their respective farmer groups. By the end of the third day most groups found it extremely difficult to exit from their host farmer groups, particularly where 'What if scenarios had been developed and simulated on the computer. The model was used to link the experiences of the farmers with the knowledge of the researchers. Peter Carberry's model runs attracted scientists and farmers alike! Peter was only able to extricate himself when his battery finally died.

The overall feeling from the majority of workshop participants was that they had begun to value the exchanges between different disciplines and the role each played in helping resolve smallholders' production constraints. Unfortunately the six days was only enough to whet most peoples appetites, and regrettably not enough hands-on experience with APSIM was provided.

However, plans were made for future hands-on training. The group of researchers from sub-Saharan African countries went home with various plans to develop the tools into further research through their participation in the SWMN.

Since the workshop, ICRISAT staff have made follow up visits to three of the six communities and have begun a program of farmer-led experimentation based on the scenarios developed. ICRISAT is determined that this will be a workshop with long-term benefits.

The six groups agreed that each would prepare a document describing their experiences, and these would be combined into a workshop proceedings to be distributed as a CD-ROM.

# Decision Tree for Land Management Options Based on Efficient Rainwater Use in Burkina Faso

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This report describes the testing in Burkina Faso of the OSWU decision tree for crop water requirements. Developing recommendations for optimizing soil water use is not an easy task. The OSWU decision tree (Table 1, Van Duivenbooden et al. 2000) was developed as a simple decision process for choosing technological options to optimize the use of rainfall (and thus soil water). The choice depends on the degree to which the water requirements of the crops are met by rainfall (first column in Table 1), and on the relative risk of occurrence of climatic and edaphic drought (2$^{nd}$, 3$^{rd}$ and 4$^{th}$ columns). Edaphic drought risk can be based on the actual amount of rainfall infiltrating into the soil and on the relative amount of plant available water (PAW). PAW is calculated on the basis of the maximum amount of water that can be stored within the rooting zone of the soil profile and that is potentially extractable by crops. It therefore reflects both the water retention properties of the soil and the ability of the roots of a given crop to explore a given soil volume and extract water from it. Edaphic drought risk will therefore be high if PAW is low, if the runoff potential is high, or both. In essence, the table argues that if a high risk of climatic or edaphic drought exists, technologies should be implemented to deal with these problems first, to ensure that technologies aimed at optimizing soil water use will be profitable.

## Testing in Six Environments

The testing in Burkina Faso was conducted at six locations, and the process is summarized in Tables 2-7. The locations were in four of Burkina Faso's main agroecological zones, and some rainfall probability information for three of these zones is provided in Table 8. Soil physical properties are summarized for five of the soils in Tables 9-13. Simple water balance information is given in Table 14.

**Table 1. Decision tree for priority actions and technical options for optimizing rainfall water use in sub-Saharan Africa, depending on environmental conditions (Van Duivenbooden et al. 2000)**

| Edaphic drought risk | | | |
|---|---|---|---|
| Climatic drought risk | Plant available water (PAW) | Runoff potential | Required priority actions and technical options |
| **Rainfall sufficient for crop requirement** | | | |
| Low | High | Low | 1. Ensure optimal use of stored water through adequate soil and crop management practices (eg fertilization, tillage and residue management, cropping system, choice of crops) |
| | | High | 2. Improve soil surface characteristics such as roughness, barriers, crusts (eg tillage, residue management, crop management)<br>3. Reduce the effect of low permeability layers in the soil (eg deep plowing, subsoiling) |
| | Low | Low | 4. Correct soil chemical deficiencies preventing full root development (eg fertilization, micro-nutrients, liming, residue management)<br>5. Correct soil physical factors limiting root development (eg tillage, subsoiling)<br>6. Increase soil water holding capacity (theoretically feasible but not practical in most cases) |
| | | High | ■ Correct low PAW and high runoff potential simultaneously: apply no 2,3,4,5, and 6. |
| Hig | High | Low | 7. Use supplemental irrigation from tanks and reservoirs (eg water harvesting from areas with high runoff potential in the landscape). |
| | | High | 8. Take advantage of runoff to increase locally the amount of water infiltrating into the soil during rainy periods, thereby increasing soil water storage in the root zone for use during dry spells (eg water collection, Zai, demi-lunes) |
| | Low | Low | ■ Apply 4 or 5 in addition to 7 |
| | | High | ■ Apply 4 or 5 in addition to 8 |
| **Rainfall insufficient for crop requirement** | | | |
| High | High | Low | ■ Apply 7 |
| | | High | ■ Apply 7 or 8 |
| | Low | Low | ■ Apply 4 or 5 in addition to 7 |
| | | High | ■ Apply 4 or 5 in addition to 7 or 8 |

**Table 2. Decision tree interpretation for Farako-ba**

| Rainfall crop water requirement satisfaction | Climatic drought risk | Edaphic drought risk | |
|---|---|---|---|
| | | PAW | Runoff potential |
| Insufficient<br>Rainfall 950 mm, ET 1700 mm | Low | Low<br>Deep and light soil | Low<br>Good vegetation cover, presence of fallow land |

- Use tillage, tied-ridging, adequate organic (manure, compost, cover crops) and mineral fertilizer to improve biomass production and soil infiltration capacity and decrease deep drainage
- Ridge tillage commonly used to combat not only runoff but also waterlogging
- Use adequate management of crop residues instead of burning (compost pits, 'parcs d'hivemage', mulching)
- Use improved fallow technique, diversify crops in rotation with cash crop (cotton, groundnut, etc)
- Use mulching to route more water towards transpiration

**Table 3. Decision tree interpretation for Saria**

| Rainfall crop water requirement satisfaction | Climatic drought risk | Edaphic drought risk | |
|---|---|---|---|
| | | PAW | Runoff potential |
| Insufficient<br>Rainfall 750 mm, ET 2000 mm | Low | High<br>Shallow and gravely soils | High<br>Soils sensitive to crusting |

- Use tied-ridging, adequate organic (manure, compost) and mineral fertilizer to improve biomass production and soil infiltration capacity and reduce deep drainage
- Use mulching to direct more water toward transpiration
- Use tillage, animal drawn sub-soiling (tine IR12), mulch and organic input to control crusting and to rehabilitate degraded soils

**Table 4. Decision tree interpretation for Kaya**

| Rainfall crop water requirement satisfaction | Climatic drought risk | Edaphic drought risk | |
|---|---|---|---|
| | | PAW | Runoff potential |
| Insufficient<br>Rainfall 600 mm, ET 2500 mm | High | High<br>Shallow and gravely soils | High<br>Soils sensitive to crusting and sloping |

- Use barriers, at watershed or field levels, (vegetation bunds, stone lines) to check runoff. This is a precondition for any improved technology
- Use tillage, animal drawn sub-soiling (tine IR12) to break up the soil crust and other water harvesting methods (zai, demi-lunes) to collect and save water and to rehabilitate degraded soils
- Use adequate organic (manure, compost) and mineral fertilizer to improve biomass production and soil infiltration capacity
- Supplemental irrigation (through water harvesting) is useful
- Use mulch to decrease evaporation and direct more water towards transpiration

**Table 5. Decision tree interpretation for Manga**

| Rainfall crop water requirement satisfaction | Climatic drought risk | Edaphic drought risk | |
|---|---|---|---|
| | | PAW | Runoff potential |
| Insufficient<br>Rainfall 800 mm, ET 2000 mm | Low | Low<br>Vertisols, deep and fine textured | Low<br>Good vegetation cover, gentle slope, good water storage capacity |

- Use tillage, tied-ridging, adequate organic (manure, compost, green manure) and mineral fertilizer to improve biomass production and soil infiltration capacity, and reduce deep drainage due to bypass flow
- Use mulching to direct more water toward transpiration
- Improve drainage system to avoid waterlogging

**Table 6. Decision tree interpretation for Sabouna**

| Rainfall crop water requirement satisfaction | Climatic drought risk | Edaphic drought risk | |
|---|---|---|---|
| | | PAW | Runoff potential |
| Insufficient<br>Rainfall 600 mm, ET 2200 mm | Low | Low<br>Deep clayey soils | High<br>Broad crusted sloping areas near Birrimian hills |

- Use soil and water conservation technologies (stone lines, zai, demi-Lunes) to mitigate runoff and erosion on cropped soils and to retrieve degraded soil
- Use organic fertilizer (compost, animal manure) to improve biomass production
- Use natural parklands regeneration technologies to reduce ET

**Table 7. Decision tree interpretation for Kouare**

| Rainfall crop water requirement satisfaction | Climatic drought risk | Edaphic drought risk | |
|---|---|---|---|
| | | PAW | Runoff potential |
| Insufficient<br>Rainfall 750 mm, ET 2000 mm | Low | Low<br>Deep light soils | Low<br>Good vegetation cover, presence of fallow lands |

- Use tillage, tied-ridging, adequate organic (manure, compost, cover crops) and mineral fertilizer to improve biomass production, soil infiltration capacity, and reduce deep drainage
- Use improved fallow technique (shorten fallow duration) to combat runoff and soil fertility depletion
- Use mulching to route more water towards transpiration

**Table 8. Frequency distribution of annual rainfall (mm) in the three agroecological zones of Burkina Faso, 1970-1990**

| Probability | South Sudanian zone | North Sudanian zone | Sahel |
|---|---|---|---|
| 8 years out of 10 | 940 | 686 | 263 |
| 5 years out of 10 | 1043 | 720 | 340 |
| 2 years out of 10 | 1205 | 792 | 408 |
| Average for the period | 1071 | 743 | 328 |

**Table 9. Soil physical properties, Farako-ba Research Station**

| Depth, cm | Texture: Clay (1/1) % | Loam % | Sand % | Bulk density, g $cm^{-3}$ | Water retention at pF 2.5 (%) | Wilting point pF 4.2(%) | Field capacity mm |
|---|---|---|---|---|---|---|---|
| 0-20 | 6.6 | 11.5 | 84.4 | 1.6 | 8.5 | 2.8 | 18.4 |
| 20-40 | 22.0 | 13.9 | 64.1 | 1.5 | 13.1 | 7.8 | 34.1 |
| 40-60 | 29.0 | 13.1 | 57.9 | 1.5 | 17.7 | 11.9 | 52.1 |
| 60-80 | 28.8 | 12.8 | 58.4 | 1.6 | 19.3 | 13.0 | 72.8 |
| 80-100 | 28.0 | 19.6 | 58.3 | 1.7 | 18.6 | 12.9 | 111.1 |

Location: 4°20'W, 11°06'N

Annual rainfall 950 mm (Apr-Oct), annual evaporation 1700 mm

Annual min temperature 15°C, max temperature 35°C

Main cropping system: maize, yielding 1 to 2.5 t $ha^{-1}$, in rotation with cotton in the cotton-producing areas. Animal-drawn or motorized implements are used

**Table 10. Soil physical properties at Saria Research Station**

| Depth, cm | Texture: Clay (1/1) % | Loam % | Sand % | Bulk density, g $cm^{-3}$ | Water retention at pF 2.5(%) | Wilting point pF 4.2(%) | Field capacity mm |
|---|---|---|---|---|---|---|---|
| 0-20 | 10.7 | 7.1 | 82.2 | 1.7 | 13.5 | 6.5 | 17.9 |
| 2040 | 14.8 | 7.0 | 78.1 | 1.7 | 19.1 | 10.1 | 40.1 |
| 40-60 | 22.2 | 8.4 | 79.4 | 1.9 | 20.7 | 13.9 | 61.5 |
| 60-80 | 24.9 | 11.8 | 63.3 | 1.8 | 20.0 | 14.3 | 79.7 |
| 80-100 | 33.6 | 12.8 | 58.6 | 1.9 | 21.7 | 14.8 | 102.3 |

Location: 2°09'W, 12°16'N

Annual rainfall 700 mm (May-Sep), annual evaporation 2000 mm

Annual min temperature 15°C, max temperature 40°C

Main cropping system: traditional sorghum-based production, yielding 700-800 kg $ha^{-1}$, in rotation or association with millet, cowpea, groundnut, etc

**Table 11. Soil physical properties of Sabouna (farmers' field)**

| Depth, cm | Texture: Clay (2/1) % | Loam % | Sand % | Bulk density, g $cm^{-3}$ | Water retention at pF 2.5 (%) | Wilting point pF 4.2(%) | Field capacity mm |
|---|---|---|---|---|---|---|---|
| 0-20 | 22.3 | 8.5 | 69.1 | 1.4 | 15.7 | 8.2 | 22.2 |
| 20-40 | 31.5 | 9.4 | 59.1 | 1.7 | 21.4 | 12.3 | 53.3 |
| 40-60 | 32.4 | 9.8 | 57.8 | 1.8 | 23.2 | 12.8 | 90.0 |
| 60-80 | 33.2 | 9.9 | 56.8 | 2.4 | 25.3 | 13.3 | 149.8 |
| 80-100 | 34.4 | 10.2 | 55.4 | 1.8 | 25.9 | 14.1 | 236.4 |

Location: 2°30' W, 14° N

Annual rainfall 600 mm (June-Sep), annual evaporation 2200 mm

Annual min temperature 14°C, max temperature 42°C

Main cropping system: traditional millet-based production, yielding 500-600 kg $ha^{-1}$, in rotation or association with groundnut, cowpea, etc

**Table 12. Physical properties of land units in Kaya area (farmers' fields)**

| | Tanga | Rassemp. | Zegedga | Bissiga | Bole | Baongo |
|---|---|---|---|---|---|---|
| Topsoil(0-10 cm) | | | | | | |
| Sand (% 0.05-2 mm) | 45 | 55 | 69 | 91 | 53 | 64 |
| Silt (% 0.002-0.05 mm) | 37 | 18 | 12 | 2 | 22 | 24 |
| Clay (% < 0.002 mm) | 18 | 27 | 19 | 7 | 25 | 13 |
| Gravel (%) | 25 | 10 | 0 | 1 | 0 | 0 |
| pH($H_2O$) | 6.9 | 7.2 | 6.6 | 6.2 | 6.0 | 6.0 |
| Organic matter (%) | 1.19 | 0.74 | 0.97 | 0.42 | 1.0 | 1.05 |
| Physical data | | | | | | |
| Surface storage (mm) | 1 | 1 | 1 | 1 | 1 | 1 |
| Porosity | 0.42 | 0.43 | 0.43 | 0.42 | 0.43 | 0.43 |
| Moisture content at pF 2.0 (v/v) | 0.28 | 0.38 | 0.24 | 0.25 | 0.38 | 0.38 |
| Moisture content at pF 4.2 (v/v) | 0.04 | 0.10 | 0.05 | 0.03 | 0.10 | 0.10 |
| Available water in profile (mm) * | 38 | 126 | 226 | 414 | 290 | 560 |
| Sat. conductivity (cm $day^{-1}$) | 18 | 18 | 10 | 30 | 6 | 2 |

* [m.c. at pF 2.0 - m.c. at pF 4.2] x rooting depth x 1000 x [(100 - %gravel)/100]

Sat. conductivity based on texture

| Table 13. Physical properties of land units in Manga area (farmers' fields) | | | | | | |
|---|---|---|---|---|---|---|
| | Tanga | Rassemp. | Zegedga | Bissiga | Bole | Baongo |
| Topsoil(0-10cm) | | | | | | |
| Sand (% 0.05-2 mm) | 73 | 68 | 64 | 80 | 22 | 11 |
| Silt (% 0.002-0.05 mm) | 22 | 20 | 18 | 15 | 26 | 55 |
| Clay (% < 0.002 mm) | 5 | 12 | 18 | 5 | 52 | 34 |
| Gravel (%) | 2 | 16 | 30 | 15 | 10 | 0 |
| PH($H_2O$) | 6.4 | 6.7 | 7.1 | 6.5 | 6.0 | 6.1 |
| Organic matter (%) | 0.88 | 1.04 | 1.2 | 0.66 | 2.07 | 2.05 |
| Rooting depth (m) | 0.35 | 0.4 | 0.8 | 1.2 | 1.0 | 1.2 |
| Physical data | | | | | | |
| Surface storage (mm) | 1 | 1 | 1 | 2 | 2 | 2 |
| Porosity | 0.45 | 0.45 | 0.43 | 0.40 | 0.60 | 0.42 |
| Moisture content at pF 2.0 (v/v) | 0.33 | 0.33 | 0.24 | 0.30 | 0.55 | 0.37 |
| Moisture content at pF 4.2 (v/v) | 0.07 | 0.07 | 0.05 | 0.06 | 0.32 | 0.14 |
| Available water in profile (mm)* | 86 | 86 | 122 | 253 | 156 | 256 |
| Sat. conductivity (cm day$^{1}$) | 18 | 18 | 10 | 30 | 6 | 2 |

* [m.c. at pF 2.0 - m.c. at pF 4.2] x rooting depth x 1000 x [(100 - %gravel)/100]
Sat. conductivity based on texture

| Table 14. Simple water balance for Kaya and Manga | | | | | | |
|---|---|---|---|---|---|---|
| | Dry | | Normal | | Wet | |
| | No crust | Crust | No crust | Crust | No crust | Crust |
| Kaya | | | | | | |
| Total rain (mm) | 532 | | 690 | | 789 | |
| Rain in growing season (mm) | 392 | | 394 | | 503 | |
| Runoff (20 resp. 60%) | 78 | 245 | 79 | 246 | 101 | 302 |
| Infiltration (rain - runoff) | 314 | 157 | 315 | 158 | 402 | 201 |
| Evaporation (est. 2 mm day$^{-1}$) | 120 | 120 | 120 | 120 | 120 | 120 |
| Available for transpiration (mm) | 194 | 37 | 195 | 38 | 282 | 81 |
| Manga | | | | | | |
| Total rain (mm) | 706 | | 882 | | 1040 | |
| Rain in growing season (mm) | 401 | | 448 | | 606 | |
| Runoff (20 resp. 60%) | 80 | 241 | 90 | 269 | 123 | 364 |
| Infiltration (rain -runoff) | 321 | 160 | 358 | 180 | 483 | 242 |
| Evaporation (est. 2 mm day$^{-1}$) | 150 | 150 | 150 | 150 | 150 | 150 |
| Available for transpiration (mm) | 171 | 10 | 208 | 30 | 333 | 92 |

## Technology Generation and Transfer

The process of technology generation and transfer in Burkina Faso is outlined as follows (Fig 1):

1. Production constraints and opportunities are identified through participatory diagnosis, demonstrations, regular meetings involving researchers, extension agents, farmers, NGOs and religious organizations. These constraints are therefore analyzed in line with the farmers' socio-economic environment.
2. The constraints which are identified by both researchers and extension agents constitute the basis of the research program. Technology generation begins, at controlled sites.

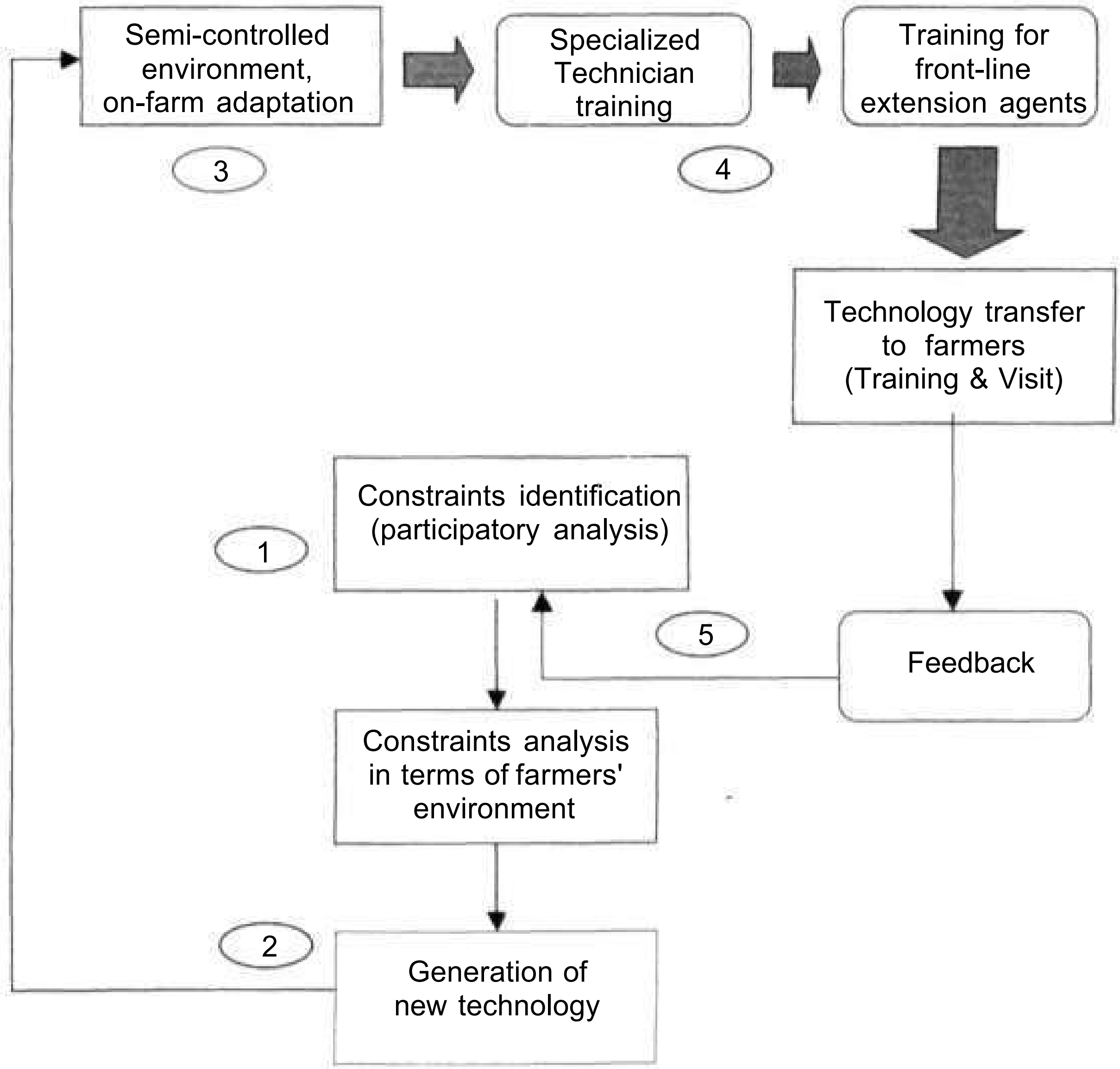


***Figure 1. Simplified process of technology generation and transfer in Burkina Faso***

3. The generated technologies enter an adaptation cycle, in semi-controlled conditions and on farmers fields. This leads to a good understanding of local conditions, essential for subsequent technology transfer.
4. Suitable technologies are transferred to farmers using a series of training activities, involving training for 'Specialized technicians', for front-line extension agents, and for NGO staff. The Training and Visit' approach is the main mechanism of technology transfer.
5. Through the technology transfer process, other constraints are identified. This feedback is valuable for further technology generation.

## Reference

**Van Duivenbooden N, Pala M, Studer C, Bielders CL, and Beukes DJ. 2000.** Cropping systems and crop complementarity in dryland agriculture to increase soil water use efficiency: a review. Netherlands Journal of Agricultural Science 48: 213-236.

# Decision Tree for Land Management Options Based on Efficient Rainwater Use under Different Environmental Conditions

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## Introduction

In the Chaouia region of Morocco, three farming systems, wheat, barley, and rangeland, were identified as the major representatives of the agricultural system. Since these systems are based on the rainfall gradient and soil types, the parameters used to identify different cases adopted in the decision tree for technical options (DTTO) fit within these systems.

*Wheat system.* Wheat (durum and bread) is the major crop. It is grown in the more favorable parts of the semi-arid areas, with annual rainfall of 300-450 mm and deep clay soils. This system offers opportunities for intensification and crop diversification. Crop production risks are low and it is grain production oriented. Moreover, the system offers important crop rotation possibilities. Both biennial (wheat/food legume, wheat/forage crop, and wheat/maize or fallow) and triennial (wheat, forage crop and fallow) rotations are used. Grain production is the main objective, but livestock production (sheep and cattle) is also important.

*Barley system.* This is an extensive crop production system tightly linked to small ruminants, especially sheep. The system prevails under less favourable environments where annual rainfall ranges from 220 to 300 mm, and soils are shallow with low water storage capacity. Production potential in these areas is limited and biomass production is most targeted. The main crop rotation is biennial, barley rotated with weedy fallow.

*Rangeland system.* In Morocco, 60% of sheep and 80% of goats are raised on rangeland, which provides more than 65% of their nutritional needs. In the Chaouia region, most of the rangeland is localized on marginal, highly degraded, and overgrazed areas, with annual rainfall below 250 mm, and shallow rocky soils. In some cases, cereals are sown on this land, giving low yields and causing further degradation. Biomass production on such rangeland ranges from 100 to 240 feed units (FU) $ha^{-1}$ $year^{-1}$.

## Methodology

A pre-validation of the DTTO was done with researchers from the Aridoculture Center to obtain agreement on the technology options. The validation was implemented during three workshops with farmers and extension agents. Three groups of farmers from representative areas of the three agricultural systems of the Chaouia region (as described above) contributed to the workshops. During the workshops, extension agents discussed and evaluated the different alternatives presented.

The workshops were held at three local extension agencies (Centre de Travaux Agricoles, CT) which are representative of different edaphic and climatic conditions of dry areas of the Chaouia region. Berrechid area is a wheat system, Settat is a barley system, while El Brouj is a rangeland system.

The first meeting was in Berrechid CT and was attended by 10 farmers, six extensionists and two researchers. The second meeting was in Settat CT (wheat and barley systems) and attended by 12 farmers, 10 extensionists and two researchers. The third was in El Brouj region at a cooperative (barley and rangeland systems) and attended by 12 farmers, six extensionists and two researchers.

Different conditions and parameters were explained and an open discussion was initiated. Comments and suggestions by farmers were reported.

Since we received the DTTO late in the cropping season, larger diffusion will be ensured next season, and the sheet will be translated into Arabic. A follow up with a sample of farmers will be implemented with the participation of extensionists.

## Results of Validation

The DTTO was examined and validated for seven scenarios, as described below.

### Scenario 1

| Rainfall crop water requirement satisfaction | Climatic drought risk | Edaphic drought risk | |
|---|---|---|---|
| | | PAW | Runoff potential |
| Sufficient | Low | High | Low |

Remove fallow, diversify crops in rotation, apply adequate fertilizers, minimum tillage for energy use efficiency, graze, bale or incorporate residues as needed. (However, clean fallows are destructive of soil organic matter, whereas green fallows increase soil organic matter but may increase drought risk.)

*Validation.* Farmers, particularly those with large farms, maintain clean fallow (weedy plowed not chemical). This facilitates early preparation of seed bed when it is plowed during spring, therefore early planting is adequate. Fertilization is based on soil test calibration for the majority of farmers and this practice has been disseminated for the last 5 years. Split application of fertilizer is also practiced to manage drought occurrence. Farmers practice chemical weed control but chemical disease control is rare. Minimum tillage is common. Farmers are aware about water losses due to multiple passes. They also mentioned the importance of organic residues in maintaining soil structure. However, straw is baled to avoid social problems, fire etc. In small farms and during very dry years they graze whatever is left in the field after baling. This was related to the high prices of barley grain. Deep plowing to remove rocks (depierrage) is practiced in order to increase soil water storage capacity.

As wheat is the pivotal crop in the system, the best rotation is wheat/row crops (lentil, chickpea, pigeonpea, corn, some oilcrops, onion). However, farmers prefer wheat/fallow because row crops are highly demanding in terms of labor.

## Scenario 2

| Rainfall crop water requirement satisfaction | Climatic drought risk | Edaphic drought risk | |
|---|---|---|---|
| | | PAW | Runoff potential |
| Sufficient | Low | Low | Low |

Use crops with low water requirement, apply adequate macro and micronutrients to stimulate crop growth, use deep rooted crops for more water extraction (safflower or pigeonpea, depending on climate). Leave residue on the surface for increasing soil water storage. Correct soil physical factors limiting root development (tillage, sub-soiling, etc). Increase soil water holding capacity by adding manure if available (theoretically feasible but not practical in most cases).

*Validation.* Crops with low water requirement are used, especially early maturing varieties. Safflower was used for few seasons but disappeared because of market problems. Sub-soiling is used to break the hard pan and extract rocks from the field.,In light soils, the roller is used to compact the soil surface to ensure better seed germination. Minimum tillage is the most practiced. Otherwise, everything else is done the same way as in Scenario 1.

## Scenario 3

| Rainfall crop water requirement satisfaction | Climatic drought risk | Edaphic drought risk | |
|---|---|---|---|
| | | PAW | Runoff potential |
| Sufficient | Low | High | High |

Correct surface sealing problems - proper tillage with chisel, cultivator; leave crop residue on the surface, optimum sowing date, plant perpendicular to slope, plant with narrow row spacing, apply adequate fertilizer, apply weed control in time, etc. Use deep plowing or sub-soiling to reduce the effect of low permeability layers in the soil.

*Validation.* Farmers admit the importance of leaving crop residues on the surface. However, the residues are baled or grazed to avoid social problems. Narrow spacing is already imposed by commercial drills because most of them are set to 11-12 cm row space. Perpendicular planting to the slope is well known and largely used in the region when sowing is done with drills.

## Scenario 4

| Rainfall crop water requirement satisfaction | Climatic drought risk | Edaphic drought risk | |
|---|---|---|---|
| | | PAW | Runoff potential |
| Sufficient | High | High or Low | Low |

Timely tillage with proper implements and adequate fertilize to ensure optimal soil physical and chemical conditions favoring root development and plant access to stored water. Apply supplemental irrigation from tanks or reservoirs as available (water harvesting from areas with high runoff potential).

*Validation.* In deep soils, the cropping system is different from that in shallow soils. Fallow is mostly practiced in deep soils whereas in shallow soils, food legumes are planted after wheat. Durum wheat (high water requirement) is never planted in shallow soils - farmers plant generally bread wheat or barley. Supplemental irrigation is used when water is available, from wells or reservoirs.

**Scenario 5**

| Rainfall crop water requirement satisfaction | Climatic drought risk | Edaphic drought risk | |
|---|---|---|---|
| | | PAW | Runoff potential |
| Sufficient | High | High or low | High |

Timely tillage with proper implements and adequate fertilizer to ensure optimal soil physical and chemical conditions favoring root development and plant access to stored water. Apply supplemental irrigation from tanks or reservoirs as available (water harvesting from areas with high runoff potential). Take advantage of runoff to increase locally the amount of water infiltrating into the root zone during rainy periods (water collection, zai, demi-lunes, strip farming etc).

*Validation.* Most water harvesting techniques are known to farmers, but are not well mastered and practiced. Farmers showed interest in using demi-lunes combined with olive trees or shrubs, and strip farming. However, demonstration trials should be undertaken. The chisel implement is now used instead of the offset disc, to improve water infiltration in the soil profile.

**Scenario 6**

| Rainfall crop water requirement satisfaction | Climatic drought risk | Edaphic drought risk | |
|---|---|---|---|
| | | PAW | Runoff potential |
| Insufficient | High | High or Low | Low |

Timely tillage with proper implement and adequate fertilize to ensure optimal soil physical and chemical conditions favoring root development and plant access to stored water; apply supplemental irrigation from tanks or reservoirs as available (water harvesting from areas with high runoff potential).

*Validation.* Under these conditions, we have the barley and rangeland agricultural systems, where crops receive minimum inputs at planting, because climatic drought risk is very high. Planting time is determined by the first significant rain. The most used implement is the offset disc, but the chisel is sometimes used in deep soil as a primary tillage. Little or no fertilizers, and no chemicals are used. Barley is the most common crop.

Farmers increase seeding rate because they do not focus on tillers that might be lost. In Settat area, which is representative of the intermediate system, triticale was mentioned as an interesting crop under dry conditions. However, it is not planted on a large scale because of marketing problems. Most water harvesting techniques are known to farmers, but are not well mastered and practiced. Farmers showed interest in using demi-lunes combined with olive trees or shrubs, and strip farming. However, demonstration trials should be undertaken in the region. Livestock is tightly integrated to cereals and rangeland has to be improved in terms of biomass production and management.

## Scenario 7

| Rainfall crop water requirement satisfaction | Climatic drought risk | Edaphic drought risk | |
|---|---|---|---|
| | | PAW | Runoff potential |
| Insufficient | High | High or low | High |

Timely tillage with proper implements and adequate fertilizer to ensure optimal soil physical and chemical conditions favoring root development and plant access to stored water. Apply supplemental irrigation from tanks or reservoirs as available (water harvesting from areas with high runoff potential). Take advantage of runoff to increase locally the amount of water infiltrating into the root zone during rainy periods (water collection, zai, demi-lunes, strip farming, etc).

*Validation.* Under these conditions, we have the barley and rangeland agricultural systems, where crops receive minimum inputs at planting because climatic drought risk is very high. Planting time is determined by the first significant rain. The most used implement is the offset disc, but the chisel is sometimes used in deep soil as a primary tillage. Little or no fertilizers, and no chemicals are used. Whenever chemical weeding is practiced it is first applied on bread wheat. Barley is the most common crop. Dual purpose varieties are grown, grazed at tillering and then left to grow for grain. In very dry years it is all grazed. Farmers know about forage mixtures (cereals/vetch) but cannot find legume seeds locally.

Most water harvesting techniques are known to farmers, but are not well mastered and practiced. Farmers showed interest in using the demi-lunes combined with olive trees or shrubs, and strip farming. However, demonstration trials should undertaken. Livestock is tightly integrated to cereals and rangeland has to be improved in terms of biomass production and management.

## Conclusions

The workshops held to validate the proposed technological options for such dry areas showed that farmers:

- have a clear perception of their environment and farming systems
- know they need to improve what they do
- adopt practices and techniques that optimize production
- are open to technological changes.

The workshops highlighted also the complexity of the farming systems and the strong integration of crop and livestock in these areas. It was also stressed that institutional and organizational deficiencies are the major constraints to technology use and adoption. Farmers do know about the work done by research and extension in their region. They know about crops with low water requirement (triticale), water harvesting techniques, zero or minimum tillage, forage mixtures, etc. They also know that crop residues improve soils and water storage in soils. However, inputs such as seeds, and materials such as drills are not available locally, and high feed prices force farmers to collect all crop residues.

Continuing to train farmers on new technologies, through demonstration trials and field days, is necessary. However, this will be more efficient and productive if it is done within an organizational and community perspective. Most of the suggested technologies (no-till drills, improved varieties, seeds, etc) could never be adopted by single farmers, but they could be used by groups or communities - for example, on-farm community-based informal seed production, or community-wide adoption of zero tillage.

# Session 6. New Proposals for OSWU Short-Term Funding

# Evaluation of Agroecological and Socioeconomic Constraints to Crop Production across Transects in East and West Africa: Contributing Towards Utilization of Resources Effectively in Sub-Saharan Africa - a Concept Note

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## The Problem

Productivity gains in many parts of sub-Saharan Africa still fall short of those required to feed the burgeoning population, despite a long history of agricultural research in the region (Crosson and Anderson 1994). The reasons are complex but include the fact that there has been little transfer and adoption of technology by smallholder farmers. Our limited understanding of what farmers do, why they do it, and what fits their aspirations remains a significant barrier to the development of adoptable technology. Inaccessibility of inputs (seeds, fertilizers, manure), availability of output markets, and credit to smallholder farmers remain major problems. Increased competition caused by globalization of agriculture and the need to adopt more sustainable farming systems is making agricultural decision-making more complex.

Simultaneously, resources for research continue to dwindle, meaning that research must be more efficient and effective, and therefore must utilize new research tools. This has greatly increased the need to manage the way research is conducted and the information combined and used for decision-making. Both CNDC and OSWU face similar problems - getting more production per unit of nutrient and water applied. This task becomes more challenging given the low nutrient- and water-holding capacity of most African soils and the lack of a readily accessible information base.

## A Solution

We propose to use a systems-based transect approach that encompasses agroecological and socioeconomic conditions to identify and quantify constraints to crop production as caused by water, nutrients, and/or *management constraints. The* project aims to help develop improved recommendations for resource management and more profitable cropping systems through closer matching of management options to agroecological and *socioeconomic constraints.*

A transect would include a minimum of three sites or villages along a rainfall gradient that will encompass more- and less-favored parts of the semi-arid zone. Overlaid on the rainfall gradient will be different soil types, cropping systems, human resources and socioeconomic data. The transect approach considers the peculiarities of the region and develops a partnership between one or more international centers, national research and extension, and NGOs to develop and implement methodologies based on the use of systems and participatory approaches that result in sustainable and profitable practices.

We propose to generate sustained interest in the use and application of decision support tools in agricultural planning and decision-making, by targeting a researchable issue of utmost national and regional importance - soil fertility improvement. Breeding advances are unlikely to make significant impact partly due to the low quality and quantity of natural resources - "there is no breeding-based Green Revolution waiting to happen in sub-Saharan Africa" (Rohrbach 1994). However, the synergistic effects of increased nutrient recovery on increased economic feasibility will trigger competitive production and rural development, an essential requirement for sustainable development in sub-Saharan Africa (SSA).

In order to remain within the modest limits of funding available within OSWU, it is logical to implement this concept as a small pilot project. Therefore this proposal is for ICRISAT to initiate activities in Zimbabwe.

## The Approach

The proposed transect study ensures that water, nutrients, their interactions, and other management options are evaluated within the context of agroecological and socioeconomic characteristics of the farms. A by-product of the study is to achieve greater understanding and impact from present OSWU research, and if necessary then initiate new research. The yield-gap analyses will be conducted at various levels to identify and quantify:

- Yield-gap between potential production (non-limiting) and rainfed potential production (for water as constraint)
- Possible management options to reduce water stress, eg planting date, varieties, irrigation, etc

- Yield-gap between rainfed potential and nutrient-limited production would help identify the type and intensity of nutrient management intervention options
- Comparison of any of the above yields with the actual yields at research stations and farmers' fields may indicate the nature of constraints, effectiveness/ineffectiveness of technology transfer and/or adoption, and the need for socioeconomic input.

The utility of this approach is not limited to interpretation and interpolation within the transect but also extrapolation to other potential sites. The crucial question is that when we conduct trials, whether on research stations or farmers' fields, do we know the yield potential of the crop (genotype)? If not, then how are we recommending appropriate management practices? What are the key constraints - water, nutrients, pests and diseases, economics, socio-cultural? The proposed transect study aims to take up the above issues and provide farmers with alternative management options. The project hopes to capture a wide range of agroecological and socioeconomic peculiarities of cropping systems.

The proposed project will also take advantage of available expertise and on-going projects. The chosen transect sites are benchmark or pilot sites of ICRISAT Thus the proposed work will benefit from some agroecological and socioeconomic data that have been already generated. The proposed activity to its utmost extent will utilize the existing soil, climate, and crop databases, crop simulation models, and decision support systems, and will accumulate new data that will add value to existing information.

## Goals and Objectives

The goal of the project is to contribute towards effective resource utilization, and achieve more profitable and sustainable cropping systems in transects of agroecological and socioeconomic conditions in SSA.

The objective is to fulfil the productivity and livelihood goals set under the SWNM Program, address the issues on cooperation and integration of soil water and nutrient programs raised in the Rosswall Report (SWNM 2000), and develop methodologies that expedite research and result in effective transfer of technologies to farmers. Specifically, the objectives are to identify the key causes of yield-gaps in the principal crops/cropping systems, and technology options to overcome them. Yield-gaps will be identified using (i) actual yield information, (ii) simulated yields under potential production system, (iii) simulated yields under rainfed production system, (iv) simulated yields under water and nutrient limitations.

## SWNM and Partner Country Priority

ICRISAT, as a co-convenor of OSWU, is committed to the goals set by the SWNM Program to increase productivity, reduce poverty, and conserve and enhance land and water resources. The SWNM Program is working with farmers and researchers to reverse the degradation of tropical soils through sustainable practices for managing soil, water, and nutrients. The SWNM, a systemwide program of the Consultative Group on International Agricultural Research (CG1AR), helps farmers and scientists rise to this challenge through four complementary research consortia, one of which is OSWU, which devises technologies and strategies to maximize water use efficiency in SSA and West Asia-North Africa.

ICRISAT has a long association in the region, and has implemented integrated soil fertility and water management programs. It has also played a lead role in promotion and use of systems tools and decision support systems (DSS) in the region. ICRISAT has developed skills in using and adapting the APSIM model (Agricultural Production Systems Simulator) for applications in agricultural decision-making in SSA.

All countries in SSA, and in particular potential collaborating countries in the transect study, have identified soil fertility, inclusive of water and nutrient management, as a matter of highest priority. ICRISAT participates in task forces set up to tackle the serious problem of declining soil fertility.

## Methodology

### Transects

The transect system consisting of environmental conditions (soil, climate) overlaid with appropriate technologies, will be used to assess the profitability and sustainability of cropping systems. Assessment of biophysical risks and human resources database including information on size of landholding, land tenure, on-farm labor availability/requirement, gender, off-farm employment, income level, ethnic/cultural group, education, role of livestock, and accessibility to markets and inputs will be used to identify and minimize the constraints to adoption of prescribed management options. The socioeconomic 'filters' would therefore screen out options that are not feasible under current socioeconomic conditions.

The sites chosen for the transect study should be well characterized with respect to soils, climate, crop, and socioeconomic data. They would represent different agroecological zones - a range of soil types (texture, depth, presence/absence of hard hoe or plow pan), fertility gradient, moisture gradient, cropping systems - and socioeconomic conditions.

## Yield-gap analyses

Simulations for potential production, rainfed-potential production, and water and nutrient-limited production will be done as an ex-ante analysis to identify possible yield constraints. The current status of production and technology-gap would be gauged from actual yield information. First, the information on the magnitude of the yield difference between non-limiting (non-stressed production) versus rainfed potential will be identified. Next, management options to narrow this 'gap' could be identified (eg planting dates, genotypes, soil constraints). By simulating crop production with both limiting water and nutrients the constraints due to nutrients could be estimated. Management options to improve water and nutrient use will be derived. Large yield-gaps between simulated and actual results could imply the effect of other constraints that were not taken into account by the model or the field researchers. This in turn will force researchers and extensionists to identify the constraints and seek alternative management options that may be acceptable to farmers.

No new field trials will be conducted to validate the cropping systems models. However, results from ongoing and past work by ICRISAT and its partners will be used to validate crop simulation models. The choice of APSIM is based on its capacity to deal with semi-arid cropping systems, nature of constraints, the accessibility of the model to NARES, and its ease of use.

## Integrated water and nutrient management trials

A series of integrated water and nutrient management trials at selected sites across the transect will help improve our understanding of the role of organic residue/manure additions in combination with inorganic fertilizers on nutrient supply and availability, moisture holding capacity of soil, infiltration of rain water, and on root distribution. These trials will also provide additional good quality data for model validation. The trials will capture the transect effects due to environmental and socioeconomic conditions). Ideally the trials will include treatments of water and nutrients at each site. Detailed soil and plant data collection would be limited to 2-3 selected treatments. However, OSWU partners will be free to add 1-2 site-specific treatments from which detailed data will also be collected.

### Developing capacity

The project will expose the participating NARES to modern tools and innovative methodologies for addressing production constraints associated with agroclimatic factors, and identifying suitable technology options for smallholder farmers. NARES partners will also develop skills in applying simulation modeling, on-farm participatory methods, and minimum data sets for more appropriate on-farm experimentation and monitoring. It is envisaged that the systematic data collection, thorough observations, and the interdisciplinary approach used in the project will also be adopted by the NARES when dealing with production constraints on farmers' fields.

## Outputs and Activities

The key outputs of the project will be more profitable and sustainable cropping systems for smallholder farmers in semi-arid regions of southern Africa, and technologies and management options that will be more acceptable to farmers. The outputs and anticipated activities from this 3-year project are:

- An established transect that quantifies water and nutrient deficiencies and also captures the effects of agroecological (soil, climate, crop) and socioeconomic factors on crop performance
- Quantification of the synergistic effects of integrated water and nutrient management with respect to integrated use of organic and inorganic nutrient sources, and hence a set of management recommendations for improved use efficiencies of water, inorganic fertilizers, and organic amendments
- Management recommendations and methodologies for inter-consortia and ecoregional applications.

These outputs imply that NARES will have the capacity to utilize systems tools to identify and quantify production constraints associated with water and nutrient limitations and/or other management constraints that may be either biophysical or socioeconomic. Thus soil water and fertility recommendations will be tailored to match farmers' resources. In addition NARES will be able to analyze the consequences of soil fertility improvement technologies on agricultural production, economic development, and environmental stability.

## Economic, Environmental, and Social Impacts

By utilizing simulation modeling, agroecological and socioeconomic databases, and farmer participatory research within the proposed transects, the project will have the following impacts:

- Increased production and improved farmer livelihoods
- Improved water and nutrient use efficiency
- Greater adoption of technologies by farmers, hence more efficient use of research and extension services
- Soil rejuvenation and fertility improvement combined with synchrony between nutrient supply and crop demand would reverse land degradation, runoff and leaching losses of nutrients

Successful implementation of the project, leading to improved farmer livelihoods, would also open avenues for agribusiness development, commercial farming systems, and improved crop and land husbandry.

### Impact on ecoregional and system-wide programs

The project will impact ecoregional programs and the system-wide SWNM programs in general by:

- Providing developed methodologies and processes by which agricultural production constraints are identified and quantified as influenced by agroecological and/or socioeconomic conditions
- Providing management options that are agroecologically sound, economically feasible, and socioculturally acceptable to farmers - thus standing a greater chance of adoption
- Providing validated systems tools for the transfer of appropriate soil fertility recommendations and other technology to farmers
- Assisting in establishing priorities for research and development through improved understanding of, for example, the locality, incidence, pace, and consequences of soil degradation
- Integrating a farmer participatory research approach with a systems approach in the adaptation of improved nutrient management practices so that they better fit the circumstances of defined farming systems
- Accelerating farmer adoption of suitable nutrient management practices through appropriate kinds of policy and institutional change
- Pinpointing information needs and generating some of the information required for development of private initiatives in the agriculture sector, such as marketing and distribution of inputs and outputs

- Building institutional capacity through training in conjunction with the international research community, NARES, and NGOs.

We believe that the transect combined with a systems approach will contribute towards effective utilization of resources in other ecoregions.

## Budget

The work will be implemented by use of resources already available to ICRISAT and its partners, supplemented by modest funding of $5000 from OSWU.

## Supporting Literature


**Crosson P, and Anderson JK. 1994.** Achieving a sustainable agricultural system in sub-Saharan Africa: 1990-2025. World Bank Technical Paper. Washington DC, USA: The World Bank.

**IITA. 1997.** Ecoregional Program for the Humid and Sub-Humid Tropics of Sub-Saharan Africa (EPHTA): mechanism for sustainability and partnership in agriculture. Ibadan, Nigeria: International Institute for Tropical Agriculture.

**Rohrbach D. 1994.** Maize research in stressed environments in perspective: the broader challenge of improving farmer well-being in semiarid areas. Proceedings of the Fourth Eastern and Southern Africa Regional Maize Conference on Maize Research for Stress Environments, Harare, Zimbabwe, 28 Mar - 1 Apr 1994.

**SWNM. 1996.** Soil, Water and Nutrient Management Program: A proposal for consid.-eration by TAC, March 25-29, 1996. Rome, Italy SWNM.

# Application of Modeling Tools to Evaluate Improved Nutrient and Water Conservation Techniques for Increased Crop Productivity in the Semi-Arid Areas of Zimbabwe

## Project leader and principal investigator

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## Collaborators and consultants

- T Sithole, Soil Productivity Research Laboratory, collaborator on soil fertility aspects.
- PP Chivenge, consultant on APSIM support. TSBF-CIAT-Zimbabwe, PO Box MP228, Mt Pleasant, Harare.
- J Gotosa, consultant on soil water aspects. Chemistry and Soil Research Institute, PO Box CY550, Causeway, Harare.
- JP Dimes, collaborator on APSIM applications and OSWU. ICRISAT, PO Box 776, Bulawayo, Zimbabwe.

SPRL will collaborate with the Agronomy Institute, TSBF-CIAT, CSRI and ICRISAT. Collaborators are selected for relevant expertise, namely nutrient management, soil water relations, and crop simulation modeling.

## Total cost of the project

US$ 5000

## Project duration

One year

## Location of project

The project will be based on data generated from trials conducted in Zimbabwe.

## Rationale and background

In the semi-arid areas of Zimbabwe, rainfall is low and seasonal distribution is erratic. Farmers and researchers working in such environments are faced with uncertainties about suitability and sustainability of farming practice options. Water conservation technologies can increase productivity, but if implemented alone, without consideration of improved crop husbandry and soil fertility, will result only in minor yield increases. The integrated use of effective soil water and nutrient conservation techniques is key to sustainable crop production. Tied ridging has emerged as a promising and practical means of increasing water availability to crops. Combining organic and inorganic nutrient sources, eg combinations of cattle manure and mineral fertilizers, is an efficient way to improve crop nutrient supply, particularly in high potential areas, but there is a lack of knowledge available on practical options for farmers in the SAT. Options that combine low amounts of inorganic fertilizer with manure may be attractive to resource-poor farmers. Assessing the potential use of integrated soil moisture and nutrient technologies to improve yields is therefore an important next step because of the need to evaluate the climatic risk associated with resource input options, and the sustainability and long-term effects of continued inputs. Simulation models could assist greatly in these evaluations, and permit extrapolation to agro-ecological zones beyond those where the options have been tested. A range of potential options is necessary in order to help overcome poverty and improve household livelihoods in the SAT.

The development of computer simulation models for agricultural systems has advanced to a stage where it can be applied to add value to field research. Models such as APSIM can be used to handle the variable climatic conditions between regions and predict yields over longer periods of time. They can also be used to evaluate different management and input scenarios and thereby offer farmers new information to assist decisions on utilization of limited resources.

## Project goal

The goal of the project is to reduce risk of crop failure through the optimal use of available soil moisture and nutrients and thus improve the livelihoods of resource-poor smallholder farmers in the semi-arid areas of Zimbabwe.

## Project purpose

The project will use modeling tools to test effective integrated soil moisture and nutrient conservation technologies that reduce incidence of crop failure, increase crop production and reduce risk. The project will address the following practical problems:

- Low water holding capacities of most soils in smallholder farming areas
- Low nutrient buffering and holding capacities of sandy soils
- Poor synchrony between supply and demand of crop nutrients
- The effect of midseason drought on crop performance.

The objective is to use APSIM to assess the potential of using integrated nutrient and water management practices, ie organic and inorganic fertilizer combinations together with water conservation techniques. Simulation will be used to predict crop performance as well as long-term effects under different climatic conditions.

## Methodology

The proposed work will be done over a period of one year. The study will compare how the combined nutrient sources perform when used together with different tillage and water conservation techniques. Manure has been chosen as the organic nutrient source because of its wide use and availability. The combinations will be applied to two tillage methods, conventional and tied ridging.

In recent years, field experiments on nutrient and water management have been conducted in the Zimbabwe SAT. Some of the results will be used to test the performance of APSIM in predicting the short- and long-term effects of the treatment combinations on crop production and soil resources.

Data sets will be collected from existing reports prior to the modeling exercise. To fulfill the minimum data requirements for the modeling process, it is expected that some further measurements will be required from the experimental sites. The following data will be needed:

- Soil and site characterizations (profile descriptions including soil water, organic C)
- Grain and stover yields, and N concentration at harvest and at any intermediate stages that were sampled
- Available soil measurements taken at the end of the season
- Weather data, including rainfall, maximum and minimum temperature and radiation
- Crop cultivar characteristics.

Following the collection of these data, the two major activities will then be to:

- Validate the model by simulating the treatments in experiments and comparing model outputs with actual results
- Conduct further model runs to evaluate a series of management options for short and long terms at several locations.

## Expected outcomes

Some of the options tested are expected to be of interest to farmers. These will be recommended for inclusion in further on-station and on-farm testing. The main outputs will therefore be:

- Improved understanding of the effect of manure and inorganic N combinations on maize yields and N uptake under moisture limiting conditions
- Information on the interactions of water/nutrient stresses as influenced by the rainfall pattern
- Model validation results for use by model developers, identification of gaps in modeling capacity
- Assessment of other options/scenarios outside the study treatments, using the model
- Extension messages on adoptable nutrient and water management techniques.

## Beneficiaries

Smallholder farmers of Zimbabwe, the majority of whom are women and children, are the targeted beneficiaries. They are practicing agriculture under climatically risky conditions where management of nutrients and soil water are critical for successful crop production. Farmers visit SPRL at the beginning of each season to get soil samples analyzed and seek advice on how best to manage soil fertility for a range of crops.

Research and extension personnel from project partners (CIMMYT, ICRISAT, TSBF) and other institutions - especially NGOs - will also benefit from information generated. APSRU, the APSIM model developers will benefit from having APSIM validated in a new and different environment.

## Relevance of the project

The proposal has high relevance in that it addresses the recommendation of the Rosswall review of SWNM to link together the water and nutrient constraints to cropping system productivity, and also the idea of using modeling to add value to existing experimentation, rather than continuing to do more experiments. Most of all it addresses soil fertility, which has been repeatedly identified as a major problem for food production in sub-Saharan Africa.

## Staff and responsibilities

- N Nhamo. Leader of project, who will assemble all the necessary data. Has experience with APSIM and will do the modeling component of the project. Will allocate 25% of his time to the project.
- T Sithole. Soil scientist with expertise in N dynamics in farming systems and past experience of nutrient and water conservation research in semi-arid areas. Will work with Nhamo on assembling the data sets. Will allocate 5% of his time to the project.
- P Chivenge. Soil scientist/model user, will be consulted by Nhamo when modeling support is needed.
- J Gotosa. Soil water specialist. Will be consulted on soil water dynamics issues.
- JP Dimes. OSWU co-convener/modeler, with expertise in N dynamics, model application and natural resource management. Will provide guidance and support on model simulations, generation of options, and validation of the model. Will allocate 5% of his time to this project.

## Financial summary

The host institute will provide fixed assets such as vehicles, laboratory facilities and other infrastructural support. The' institutions will pay salaries for the staff. The requested money will add on to the Institute's ZW$ 15 million annual budget for research.

## Budget

| Activity | Cost(US$) |
|---|---|
| 1. Computer and printer | 2000 |
| 2. Travel for modeling support | 1000 |
| 3. Travel for additional soil sampling and collection of weather data sets | 500 |
| 4. Analyses of samples | 700 |
| 5. Casual labor | 200 |
| 6. Communication | 250 |
| 7. Incidentals | 350 |
| Total | 5000 |

*Explanatory notes to budget*

1. Computer and the APSIM software together with other software, which support the handling and processing of data generated during the course of the project. This will enable simulation of the different crop responses to the experimental treatments used
2. Travel for meetings with Dimes at ICRISAT in Bulawayo
3. Travel costs to collect soil samples for analysis to complete data sets
4. Soil analysis to complete data sets, including purchase of chemicals
5. Casual labor for assistance in soil sampling and profile description, ie digging of pits
6. Communication with collaborators, consultants and other institutions supplying data
7. Other expenses related to the project

## Project Logical Framework

| Narrative summary | Verifiable indicators | Means of verification | Important assumptions |
|---|---|---|---|
| *Goal:* | | | |
| To reduce risk of crop failure through optimal use of available soil moisture and nutrients, and to improve livelihoods of poor small-holder farmers in semi-arid areas of Zimbabwe | Improved under-standing on technical options; adoption of technologies on soil water conser-vation | SPRL/CSRI and AREX annual reports | Availability of funds, data and collaboration with identified institutions |
| *Purpose:* | | | |
| To use modeling tools to test and develop integrated soil-water-nutrient technologies that reduce incidence of crop failure | Methods validated by end of the year | Extension, farmer organizations, Project reports, SPRL reports, OSWU evaluation reports | |
| *Outputs:* | | | |
| 1. Improved understanding of effect of manure and inorganic N combinations on maize yields and N uptake under moisture limiting conditions<br>2. Information on interactions of water/nutrient stresses as influenced by rainfall pattern<br>3. Model validation results for use by model developers, identify gaps in modeling capacity<br>4. Assess other options/ scenarios outside the study treatments, using the model<br>5. Extension messages on adoptable nutrient and water management techniques | New understanding shared with other stakeholders<br>New information discussed with other stakeholders<br>Modeling problems reported to model developer<br>Options and scenario analysis results documented<br>Extension messages documented | Project annual reports, project evaluation reports, scientific papers and reports | Thorough testing of the technologies generated |

**GANT Table**

| Activities | June | July | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Data collection and preparation into APSIM format (climatic, soil description data, cultural practices, cultivar characteristics) | xxx | xxx | xxx | | | | | | | |
| 2. APSIM license request | x | x | | | | | | | | |
| 3. Simulation of experiments to evaluate APSIM using existing data | | X | xxx | X | X | xxx | X | X | xxx | |
| 4. Generation of scenarios, extrapolation of results and identification of missing data | | | | xxx | X | x | xxx | x | | |
| 5. Report writing | | | | | | xxx | | X | X | XXX |
| 6. Publication of results | | | | | | | | xxx | X | XXX |
| 7. Preparation of extension material | | | | | | | | | X | XXX |

# Calibration of CROPSYST Simulation Model in Cereal Production for Generalizing Outputs to Wider Areas in Semi-Arid Regions of Morocco

## Project manager

M Boutfirass, Agronomist, CRRA-INRA, BP 589, Settat, Morocco

## Principal investigators


- H Benaouda, ICARDA, Aleppo, Syria
- M Boutfirass, DPA, Settat, Morocco


## Collaborators

CO Stockle, WS University

## Duration

1 year, Jan-Dec 2002

## Cost of the project

US$5000

## Location of the project

CRRA-INRA, Settat, Morocco

## Background

Simulation models allow integrated evaluation of research and other policy instruments. Well-validated and calibrated models can substitute for costly, long-term experiments (El Mourid 1988). Crop models are potential tools to answer research and crop management questions, help in policy decision-making (Boote et al. 1996) and risk analysis (Moussaoui 1994). Building these models, however, requires substantial investment in data collection and in understanding the mechanisms underlying the and production system.

Crop growth simulation models can assist in predicting crop yield response to the biotic and abiotic environment. Under semi-arid conditions, many growth simulation models have been tested, validated and used for cereal production (Simtag, CERES) (El Mourid 1988, Hanchane 1998). However, these models present some weaknesses in estimating some production parameters. Moreover, they assume optimum crop management features during model runs.

The CropSyst model has been recently developed and tested in many areas where climatic and production conditions are similar to the semi-arid conditions in Morocco (Pala 1997). Moreover, this model has more features and sub-routines than the ones already tested and used.

## Project goal

Better targeting of technology development and technology transfer under erratic climatic conditions in order to improve and stabilize cereal crop yields.

*Specific purpose:* To calibrate and evaluate the CropSyst model for a cereal crop under the erratic conditions of semi-arid regions in Morocco, and later extend the work to other crops and different agroecological conditions.

## Project outputs

- CropSyst simulation model calibrated and further validated for cereal crop under semi arid conditions of Morocco
- Outputs of the model evaluated for major crop attributes including yield and components, crop growth and dry matter accumulation, soil water balance and crop phenology
- Outputs evaluated to generate management options to overcome climatic risks.

## Project activities

- Collect the necessary climatic, crop and soil data for the Chaouia region
- Calibrate and test the model with local sets of data
- Simulate different management scenarios and evaluate the outputs.

## Beneficiaries

Research, farmers, extension, decision makers.

## Relevance to the SWNM Program

The project is linked to Output 1, Activity 1.4: *Improve, evaluate and compare crop models.* This project was approved by the steering committee in 2000. It is based on the Logframe of activities that was finalized after the SWNM meeting in Wageningen in Feb 2000, where all consortia under the SWMN Program met to identify synergies and collaboration domains.

## Financial summary

| Activity | Cost(US$) |
|---|---|
| Labor cost | 1000 |
| Travel and consumables | 1500 |
| Equipment | 2000 |
| Reporting | 500 |
| Total | 5000 |

## References

**Boote KJ, Jones JW, and Pickering NB. 1996.** Potential uses and limitations of crop models. Agronomy Journal 88: 704-716.

**El Mourid M. 1988.** Performance of wheat and barley cultivars under different soil moisture regimes in semi-arid region. PhD thesis, Iowa State University, USA.

**Hanchane M. 1998.** Calage, validation et application du modele Ceres-Orge pour l'analyse des risques climatiques en fonction des choix de la variete et de la date de semis en conditions climatiques Marocaines.

**Moussaoui M. 1994.** An ex ante evaluation of the interaction between risk behavior and technology adoption in Morocco's dryland agriculture: The case of supplementary irrigation. PhD thesis, University of Nebraska, USA.

**Pala M. 1997.** Use of models to enhance nitrogen use by wheat. Pages 135-144 *in* Accomplishments and future challenges in dryland soil fertility research in the Mediterranean area. Proceedings of the Soil Fertility Workshop, 19-23 Nov 1995 (Ryan J, ed). Aleppo, Syria: ICARDA.

# Impact Assessment of Technology Transfer In Relation to Soil Water Use in the Chaouia Region, Central Morocco

## Project manager

Mohamed Boutfirass, INRA-CRRA, Settat, Morocco

## Principal investigators

- Mohamed Boutfirass (Agronomy), CRRA, Settat
- Abderrahmane Ait Lhaj (Research-Extension), CRRA, Settat
- Mohamed Boughlal (Agroeconomy), Extension services, DPA, Settat

## Total cost of the project

US$5000

## Project duration

June 2002 to Jan 2003 (8 months)

## Location of project

Chaouia region, Central Morocco

## Background

The National Institute of Agronomic Research in Morocco (INRA) established a dryland agricultural research center (Centre Aridoculture, Settat) in 1982 to address problems in arid and semi-arid areas of Morocco. The most important thrusts are: (i) conservation of soil, water, and genetic resources, improvement of their management and optimization of their use; (ii) development of agronomic, biophysical, and socioeconomic databases, use of modeling and decision-support systems.

The research strategy aims to (i) characterize the environment and its variability in order to target research and orient farm management towards better use of the available water; (ii) develop water and soil conservation techniques that decrease runoff, evaporation and erosion, and increase soil water availability to plants; (iii) implement techniques that allow the use of plant-available water more efficiently.

During its 20 years, this Center has developed methods and technologies to alleviate the constraints of fragile dryland farming systems and natural resources of Morocco. Studies were conducted on new varieties, crop rotations, tillage, water harvesting, sowing date and plant population, supplemental irrigation and weed control (Boutfirass et al. 1999). Most of the research findings have been taken to farmers' fields either as single technologies or as a 'package'. Different methods of technology transfer have been used depending on the degree of farmer' involvement in the verification trials. All the technologies tried with the farmers showed a positive effect in all regions (El Mejahed 1998, Anonymous 1997, 1998). However, no comprehensive studies have been done on adoption or economic impact.

## Project goal

Better understand key factors that hinder the transfer and adoption of dryland technologies, and find suitable solutions.

*Specific purpose:* To quantify the economic impact and adoption levels of technologies that have been transferred to farmers in the Chaouia region.

## Research outputs

- Degrees of adoption by different categories of farmers
- Problems associated with non-adoption or low adoption rates
- Economic impact of adopted technologies

## Activities

- Select technologies or packages
- Select impact indicators, prepare questionnaires
- Select farmers and implement surveys
- Data analysis and reporting.

## Beneficiaries

Research, extension, and farmers.

## Relevance of the project to SWNM program

This proposal relates to the logframe Output 3, *Impacts of improved practices on production, the environment and socioeconomic conditions assessed.*

## Financial summary

| Activity | Cost (USD) |
|---|---|
| Materials | 1000 |
| Operations, equipment and maintenance | 1600 |
| Publications | 400 |
| Travel expenses | 2000 |
| Total | 5000 |

## References


**Anonymous. 1997.** Rapport des essais d'adaptation chez les agriculteurs, Zone de Ouled Amrane. Convention INRA/ORMVAD. Settat, Maroc: INRA, CRRA, 41 pp.

**Anonymous. 1998.** Introduction du semis direct chez les agriculteurs. Marche n 26/ 96/AGR/DAF/DRCTA. Settat, Maroc: INRA, CRRA, 29 pp.

**Boutfirass M, El Gharous M, El Mourid M, and Karrou M.1999.** Optimizing soil water use research in deficient water environment of Morocco. Pages 125-142 *in* Efficient soil water use: the key to sustainable crop production in the dry areas of West Asia, and North and Sub-Saharan Africa. Proceedings of the 1998 (Niger) and 1999 (Jordan) workshops of the OSWU Consortium (van Duivenbooden N, Pala M, Studer C, and Bielders CL, eds). Aleppo, Syria: ICARDA, and Patancheru, India: ICRISAT.

**El Mejahed, K. 1998.** Amelioration de la production des cereales et la gestion de l'elevage dans la zone Bour du Tadla, cas de Beni Oukil, Juin 98. Settat, Maroc: INRA, CRRA, 30 pp.

# Simulation of Crop Yields in Various Dryland Crop Rotations in Central Anatolia


## Project manager and institute

Muzaffer Avci, Central Research Institute For Field Crops (CRIFC), PO Box 226, Ankara, Turkey

## Principal investigators

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## Collaborators

- Mustafa Pala, ICARDA, Syria
- Stileyman Kodal, Agricultural Faculty of Ankara
- Boachan Benli, Agricultural Faculty of Ankara
- Relevant departments of Middle East Technical University, Ankara
- Cemal Cekic, Anatolia Agricultural Research Institute, Esksiehir


## Total cost of project

US$5000

## Duration of project

1 year

## Location of project

Ankara, Turkey

## Background

Central Anatolia covers about 40,000 $km^2$, roughly one-fifth of Turkey. Annual rainfall varies between 250-450 mm; much lower in the Konya salt lake region and increasing closer to the coast (Transitional areas). Average temperature is near or below zero in winter, which retards growth of winter crops such as wheat and barley. Towards the east of the area, elevation increases, so the climate gets very cold. It is milder in transitional areas near the coast. The inland of the plateau is continental and very cold in winter, hot and dry in summer. As expected, crop yields are very much influenced by this climatic variation within the plateau. The temporal variation in rainfall is higher than the spatial. For instance, Ankara receives 400 mm average annual rainfall, within the limits 230-550 mm.

In contrast to climate, the plateau has almost uniform soil characteristics. The soil group is Great Brown. Severe soil erosion takes place. The soil profile is shallow and the slope is steep. The pH is near neutral; soil texture is mostly loam or clayey loam.

In this region, a long term rotational trial has been conducted for 20 years in order to identify alternative crops that can replace fallow, and to determine the sustainability of these rotation systems.

The concern is how the results of the rotation experiments can be generalized throughout Central Anatolia. Models will be useful in this process, and can help develop recommendations for varying climate and soils of the plateau. The earlier experiments may also become a base for further study to validate the model for variety recommendations and other technologies.

The models proposed are sophisticated tools that can be used to assist the decision-making process. They include Cropsyst (Stockle et al. 1994, Stockle and Nelson 1994), which is a management-oriented cropping system model that is able to simulate various rotations and weather/management scenarios.

## Project goal

To use new methodologies such as modeling to extrapolate site-specific technologies to broader target areas, thereby helping decision makers.

*Specific purpose:* to evaluate CropSyst in terms of wheat yield and yield components, using data on for dryland crop rotations conducted for 20 years in Central Anatolia.

## Research outputs and activities

*Output 1.* Simulated crop yields and yield parameters (Jan to April)

Activities:
1. Learning the underlying assumptions and principles of the model
2. Compiling the previous data for use
3. Preparing parameter files (crop, weather, location) for CropSyst
4. Running the model to simulate yield and yield parameters

*Output 2.* Results of validation with existing data (April to June)

Activities:
1. Run the model with 20 years weather files
2. Plot existing and simulated data, carry out validation analysis
3. Run model for various soil and climatic data of locations to extrapolate findings

*Output 3.* Prepare final report (Oct to Nov)

Activities:
1. Review validation data to identify weak and strong points of the model
2. Rearrange parameter files accordingly, and rerun the model to obtain simulated values with better agreement to measured values
3. Prepare reports

## Beneficiaries

*Research and extension services.* If the model performs well, research efficiency can be by reducing the number of adaptation trials and demonstrations for the transfer of technology. Besides this, recommendations can be made more precise in terms of soil and climatic variations. This study will pave the way for further study, using the model, on other technologies suitable for the region.

*Farmers.* The ultimate beneficiaries are the farmers of Central Anatolia. Appropriate technologies can be transferred to farmers quickly and efficiently.

## Relevance of the project to SWNM

The project conforms to SWNP logframe Output 1 and Activity 1.4: *Improve, evaluate and compare crop/system models; Evaluation of CROPSYST using OSWU-funded field activities and other available data sets.* The project will deal with are dryland rotations, whose main purpose is to use restricted soil water efficiently and produce economic crops. The project is thus highly relevant to the SWNM Program and contributes to the knowledge generated by the program. Making use of tools that will guide policy makers in transferring technologies also matches the program objectives.

## Activities and financial summary

| Activity | Time frame | Cost(US$) |
|---|---|---|
| Understanding the model assumptions | Jan-Feb 2003 | 1500 |
| Obtain local data sets, test model | Jan-Mar 2003 | 1500 |
| Run model to obtain various scenarios | Apr-Jun 2003 | 1500 |
| Compile final report and presentations | Sep-Nov 2003 | 500 |
| Total | | 5000 |

Responsibility for all activities -Agronomy Department of CRIFC

# Economic Impact of Transferred SWNM Technologies in Central Anatolia

## Project manager

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## Principal investigators and addresses


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- Kader Meyveci, Agronomy Deparment CRIFC, kmeyveci@yahoo.com
- Celal Cevher, Economy Department, CRIFC


## Collaborators

- OSWU consortium
- Institute of Economic Research, Ankara

## Total cost of project

US$5000

## Project duration

1 year, Jan 2002 to Jan 2003

## Location of project

Central Plateau of Anatolia, Turkey

## Background

In Turkey, research on soil preparation in fallow systems, crop husbandry and crop rotations has a long history, starting in 1928 and still continuing. Rapid transfer of technology coincided with expansion of mechanization after the mid sixties, during the period of the Marshall Plan, which allowed peasants to cultivate larger areas.

With the initiation of the National Wheat Research Project in 1960, the primary emphasis was on developing a package of practices suitable for the region, and effective extension and farmer education. Between 1973 and 1977, a high-yielding package was identified, and adaptive trials conducted to compare it with yields on adjacent farmers' fields. This was done for 5 years in five provinces of the Central Plateau. The recommended system always gave higher yield than farmer practice. Interestingly, farmer yields gradually increased over time, once the trials began. After 5 years of testing, results of research on tillage implements was verified on farmers' fields, and adoption escalated.

After 1980 the available technologies were transferred to farmers through research and extension projects (NAD and TYUAP). New cropping systems which eliminate fallow, were introduced. The NAD project (Utilization of fallow areas) substantially reduced the fallow areas in Turkey, from 8.5 million ha in 1980 to 3.9 million ha, according to 1994 statistics. Although overall production increased, farmers neglected their fallow practices because they were obtaining reasonable wheat yields from annual cropping.

Between 1980 and 1996, substantial research was conducted on the problems that arose from annual cropping, such as seedbed preparation and soil fertility. Solutions were developed, but were not adequately transferred to farmers.

There has been no comprehensive study on adoption of the technologies, and the impacts of farmers' incomes and well-being. One such study carried out in only one province, indicated that 59% of Central Anatolian farmers had adopted the recommended wheat technologies for wheat-fallow system. But adoption of the whole package was only 9.4%. The reasons for non-adoption were complexity of the technologies, lack of information, and cost/ unavailability of inputs (Uzunlu 1992). This may reflect a small part of the reality but not show the complete situation, and it did not cover the OSWU concept. Survey work is needed, covering more provinces in the region, and interviewing more farmers using well-designed questionnaires and skillful questioners.

## Project goal

To understand the general characteristics of problems and solutions for transfer and adoption of dryland technologies.

*Specific purpose:* To quantify the economic and social impacts, and adoption levels of the technologies that were transferred by research and extension agents in previous years in the Central Anatolian Plateau.

## Research outputs

The following outputs are expected:

- Adoption levels of SWNM technologies by different socioeconomic groups of farmers documented
- Problems associated with non-adoption or low adoption rates identified
- Socio-economic impact of adopted technologies assessed.

## Activities

- *Feb-Mar 2002.* Careful selection of regions and villages to be surveyed, using information from previous surveys, statistical data, and directly from extension agents. Finalize questionnaires on SWNM impact, changes in farmers', lives, and current problems of agriculture
- *Mar-Apr 2002.* Develop implementation plan for the project, conduct survey
- *May-June 2002.* Transform data into electronic form, perform data analysis
- *Oct-Nov 2002.* Report the results

CRIFC has a good agronomy team, with experience in executing survey work, substantial information and experience about the region, and qualified agricultural economists with experience in surveys and evaluation of survey data. The Sivas-Kayseri Project (Bayaner and Uzunlu 1993) is a good example of collaborative research between CRIFC and ICARDA. The SWNM Program can provide technical support to CRIFC scientists when needed.

## Beneficiaries

The immediate beneficiaries are research and extension agents. The ultimate beneficiaries are the Central Anatolian farmers.

## Relevance of the project to the SWNM Program

The project will quantify the impacts of dryland technologies on farmers, and the possible reasons for non-adoption. The proposal conforms to Logframe-Budget, Output 3: *Impact of improved practices on production, environmental* *and socioeconomic conditions assesed.* All this information on dryland agriculture is relevant to the SWNM Program goals, and will contribute to the program.

## Financial summary including matching funds

| Activities | Cost(US$) |
|---|---|
| Material cost | 1500 |
| Operations, equipment and maintenance | 1250 |
| Publications | 250 |
| Travel expenses | 2000 |
| Total | 5000 |

## References


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# Evaluation of Soil and Water Conservation Technologies on the Efficiency of Nutrient Management, using APSIM Model

## Project team


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## Total cost of project

US$ 8500

## Project duration

1 year, to be completed in Aug 2003.

## Location of project

The project will be based on data generated from the IFAD/IFS/INERA trial 'Impact of water and nutrient management' conducted at Saria Agricultural Station, Burkina Faso.

## Rationale

Extreme climatic conditions and rainfall fluctuations, frequent periods of water shortage, and the presence of large areas of inherently low-fertility, crust-prone soils, have resulted in severe human-induced land degradation in the Sahel. Nutrient depletion and surface sealing or crusting (which increases water loss through runoff) are the main causes of degradation. Several techniques including stone lines, mulching, hedgerow, earth bunds etc, improve water availability for plant growth. However, these soil and water conservation techniques have limited effect on soil fertility. Cultivated lands in this area have nutrient depleted soils, especially N and P. Nutrient mining is the fundamental biophysical cause for declining per capita food production in sub-Saharan Africa. Thus, water conservation alone will not sustain crop yield, certainly not in the long run. Nutrient replenishment has to be ensured as well because soil fertility, water holding capacity and soil surface conditions are intimately linked to water issues, in determining the potential for biomass production. Integrated soil management, including nutrient, water and biomass management, should be promoted to increase water infiltration and reduce runoff and soil erosion for better crop production.

Simulation models can help our understanding of biophysical processes and permit extrapolation to alternative agro-ecological zones and management systems. The Agricultural Production Systems Simulator (APSIM) is a cropping systems model well adapted to low input smallholder farming systems, and has capability for simulating runoff and soil loss in response to ground cover (crop and residue) and soil properties. It can also be used to evaluate management and input scenarios and thereby offer farmers information to assist decisions on utilization of limited resources.

## Project goal and purpose

The study which this project complements, aims to maintain and enhance biomass production in dry tropical zones, with technically appropriate, environmentally sound and socio-economically acceptable water and nutrient technologies in a landscape where soil physical properties and soil fertility deterioration seriously limit crop yields.

The purpose of this project is to evaluate APSIM as a tool for capturing the interaction of soil conservation and nutrient technologies in improving and sustaining crop productivity under adverse soil and climatic conditions, and to allow more efficient evaluation of these technologies for smallholder farming systems in the central plateau of Burkina Faso, and elsewhere.

## Project objectives

The main objective is to evaluate APSIM performance for capturing the interactive effects of soil and water conservation barriers in combination with plant nutrient supply on crop productivity, runoff and soil loss; and in conjunction with long-term climate data, use simulation to examine the longer term impacts on crop productivity, profitability and maintenance of the soil resource. Specific objectives are to:

- Obtain a working knowledge of APSIM with the aid of a specialist modeler
- Collate the inputs necessary to run the APSIM model
- Simulate experimental treatments and compare outputs with measured data (evaluation/calibration)
- Collate long-term climate data and use calibrated model to predict long term impacts of SWC and nutrient management on productivity and profitability of management options
- Develop an institutional capacity for application of simulation modeling for systems analysis.

## Methodology and approach

Experimental results from an established runoff trial at Saria Agricultural Research Station, situated at 80 km SW of Ouagadougou (12°16' N, 2° 9' W; 300 m above sea level) will be used to evaluate APSIM for simulating runoff, soil loss and crop response to soil and water conservation and nutrient management treatments. The trial has been running since 2000 and its design and initial results have been prepared for publication (Zougmore, Mando, and Stroosnijder, draft conference paper). Background on-farm research leading to current on-station study has also been published (3 papers by Zougmore).

The climate is of the north-Sudanian type. Average annual rainfall is 800 mm (30-year average), mono-modal and lasts for 6 months from May to October. The distribution is irregular in time and space. The soil type is Ferric Lixisol with hardpan at variable depth (30-80 cm). Contents of organic matter, N, exchangeable K and available P are very low. The field experiment consists of nine instrumented runoff plots, as follows:

| | |
|---|---|
| Control | Stone lines (3 lines, 33m apart) |
| Urea | Grass strips (*Andropogon gayanus*) (3 lines, 33m apart) |
| Compost manure | Stone + Urea |
| Stone + Compost manure | Grass + Urea |
| Grass + Compost manure | |

The design was changed to the above in 2001, hence results for the 2002 season are needed to provide additional replications. All plots are treated with 20 kg P $ha^{-1}$. Sorghum is the test crop. Plot size is 100 m x 25 m.

Current measurements include soil moisture, runoff, soil loss, crop biomass, and grain yield. Background soil physical and chemical properties were determined but key parameters (bulk density, organic carbon, total N, mineral N, extractable P, total P to rooting depth) are to be re-sampled at the end of the 2002 season. Manure compost samples and soil sediment samples have been collected but await analysis for total N, C and P. There is also a backlog of plant samples for chemical analysis to determine N uptake. Completing the chemical analysis is the first priority.

Completing field sampling (Oct 2002) is the next priority, followed by collation and analysis of data for all seasons (Jan 2003). Collation of climate data for the experimental site and long-term climate data for selected sites on Burkina plateau (Met Bureau) also has to be completed before modeling can begin.

APSIM licensing and training of lead scientist is planned for Feb 2003 in Zimbabwe and will include simulation and evaluation of APSIM performance using the experimental results. It is envisaged that this activity will produce a calibrated model for application to sorghum-based cropping systems in the Burkina Central Plateau.

Long term climate data will be checked using TAMMET (APSRU utility). In conjunction with the calibrated model, the trained scientist will evaluate productivity and risk of cropping options as part of training for INERA colleagues in Burkina Faso.

## Expected outputs

- Comprehensive data set for evaluating simulation of sorghum response to SWC and nutrient management in hard-setting soils in low rainfall environments of Burkina Faso
- Calibrated APSIM model for simulating runoff and soil loss for hard-setting soils in the semi-arid tropics
- Regional evaluation of SWC and nutrient management options for improved livelihoods and reduced environmental degradation of smallholder farming systems in Central Plateau
- INERA staff trained in use of APSIM and systems simulation applications.

## Beneficiaries

In the Central Plateau of Burkina Faso (research zone), many development projects, NGOs and government agencies are promoting the use of stone lines and contour hedgerows in fields to reduce runoff and soil loss. *Andropogon gayanus* grass strips could be a sustainable alternative because of scarcity of stones in certain regions. Moreover, its biomass is valuable for many purposes (roofs, doors, huts, barns, etc). Using these techniques in conjunction with fertilizers (compost, animal manure, mineral fertilizers) can improve crop nutrient use efficiency, particularly for N and P, the most deficient elements in cultivated soils of this area.

## Team responsibilities

The group conducting this study has adequate knowledge of agricultural production constraints in the Sahel, and of the major research areas proposed, ie soil erosion, soil and water conservation measures, plant nutrition, agricultural farming systems in Burkina, and agricultural policies. There is also experience of the simulation model QWERT.

In collaboration with the INERA regional research team at Saria station (scientists, field assistants), supervision and field monitoring will be readily done.

## Budget

| Activity | Cost(US$) |
|---|---|
| New computer (Pentium 4 laptop) | 2500 |
| Model training and support<br>(2 weeks in Zimbabwe, 1 week in Burkina Faso) | 3500 |
| Additional sample analyses and collation<br>(eg TN of sediment, 2001 and 2002 compost, N and P uptake) | 200 |
| Communications and incidentals | 500 |
| Total | 8500 |

# Session 7. Strategic Planning on Future of OSWU and Related Issues

# Strategic Planning Session on the Future of OSWU - Planning in Turbulent Times

**TS Newby**

*ARC-ISCW, P Bag X79, Pretoria, South Africa*

The strategic planning session, *Planning in turbulent times,* was facilitated by TS Newby from ARC-ISCW; South Africa. The facilitator first asked the group to look more generally at issues and not get bogged down by detail, particularly in view of the time constraint. He suggested that participants make use of the first impression, turn challenges into opportunities, mix and match opportunities with strengths, integrate and cooperate, and be creative in thinking. Participants were asked to decide who are the stakeholders of OSWU, what are their needs and expectations, and also what makes OSWU unique. The format used was:

- Stakeholder analysis
- External analysis
  - Trends
  - Opportunities and threats
- Internal analysis
  - Strengths and weaknesses
- Key success factors
- Headlines in 2005 newspapers
- Vision
- Goals and objectives.

After fruitful discussion, a Draft Strategic Plan 2002-2005, which includes an Action Plan 2002-05, was drawn up.

## Trends

- Global climate change - higher drought frequency in some areas, more favorable production conditions in other areas
- Greater international trade in agricultural commodities and exports from developing countries; but reduced trade in some countries
- Increase in food imports
- General decline in health in some countries due to AIDS, TB, malaria
- Decrease in agricultural labor due to migration and AIDS; higher labor costs
- Gradual increase in demand for mechanization

- Increase in levels of education
- Increase in conditional R&D funding (restrictions on use), decrease in non-conditional funding without such restrictions
- Increase in pollution and land degradation
- Increase in the incorporation of indigenous knowledge into technologies
- Increase in international environmental conventions that NARES must adhere to
- Greater awareness of the need for sustainable use of resources
- Decline in per capita food production in Africa
- Increasing demand for more nutritious food.

## Opportunities

- Soil water and nutrient use (SWN) technology for sustainability, degradation, and climate change
- SWN technologies for increasing nutritional content of food
- Technologies for servicing international conventions
- SWN technologies for addressing production constraints such as drought
- Demand for improved SWN technologies because of globalization, trade policies, commercialization and export possibilities
- Demand for improved SWN technologies to improve household food security
- Demand for enhanced capacity in use of new tools leads to capacity building opportunities including the use of participatory methods such as. farmer field schools
- Demand for labor-saving technologies creates opportunity for innovative SWN technologies that are labor efficient
- International trend towards integrated approaches (INRM) creates opportunities for partnership formation and scientific exchange
- Demand for technologies that promote sustainability and reduce degradation offer the opportunity for innovative SWN technology.

## Anticipated 2005 headlines

- Farmers in Africa and West Asia increasingly using OSWU technologies
- Famine in Africa - dramatic decrease
- Population in SADC stabilizes - AIDS beaten, family planning recognized
- Natural resource degradation rate reduced
- WANA rapidly becoming world bread basket

Donors see results - more development funds available
Food surplus in Niger - thanks to *zai* technology
Lots of new technologies for rehabilitating degraded land
Large area of unproductive land returned to production

## Key success factors

Collective ownership of the OSWU vision by its members
Realistic analysis of production and development constraints before starting research
Comparable research conducted in various agro-ecological regions
Clearly defined areas targeted for optimizing impact of developed technologies
Technology exchange component incorporated into all activities
INRM principles incorporated into all activities
Ex ante and ex post impact assessment conducted for all activities, using acceptable methodologies
Applied and adaptive research adopted as fundamental principle
Regular communication through workshops and publication of results
Accessibility to natural resource databases of participating countries established
Actively talk with farmers and land users to scale out technology
Active investment by agribusiness in OSWU activities especially relating to food quality
Active strategy to promote OSWU technologies to farmers
Formation of national and international partnerships
Use of modern techniques and technologies in research activities (GIS, remote sensing)

## Strengths and weaknesses

*Strengths*

Diversity (both scientific and geographic) of members - large body of knowledge and resources available
Shared concern for sustainability and the environment
Shared concern for optimal water and nutrient use in rainfed arid and semi-arid areas
Common focus on farmer-field and catchment scales
Experience from varied agro-ecological zones shared

- Culture of integrated and systems approach (soil water and nutrient system)
- Regular contact through meetings, workshops and e-mail
- Culture of working in partnerships
- Culture of efficiency through symbiotic use of funding (NARS and OSWU) - strengthen/broaden NARS projects with OSWU funding

*Weaknesses*

- Lack of ability to attract additional donor funds
- Unknown as a group outside of CGIAR - poor image outside of CGIAR

## Vision

We will contribute significantly to sustainable agricultural production in arid and semi-arid areas by developing, promoting and fostering environmentally friendly, affordable, and socially acceptable optimal water and nutrient use technologies.

*This will be achieved through:*

- Facilitated application of collective OSWU knowledge
- An integrated systems approach to agricultural production including INRM principles
- Employing applied and adaptive research methodologies
- Forming research, extension and land user partnerships
- Facilitating technology exchange through new and innovative participatory methodologies as well as regular scientific communications
- Research at both field and catchment scale
- Mainstreaming OSWU activities within NARES-driven activities to ensure optimal use of resources and to maximize impact.

*This will lead to:*

- Technology awareness and adoption by land users, decision makers and other stakeholders
- Capacity building of NARES, land users and other stakeholders
- Empowerment of poor smallholder farmers
- Sounder risk management.

## Mission

Innovative, yet practical, optimal water and nutrient management for all.

# OSWU Draft Strategic Plan 2002-2005

| Stakeholder | Expectation |
|---|---|
| CGIAR | Accountability for funds given and quality of science<br>Show real return on investment<br>Show efficiency in use of resources<br>Demonstrate (auditable) positive impact of activities<br>Produce publications to enhance scientific status of CGIAR<br>Show evidence of partnership formation and linkages with other consortia<br>Show evidence of active capacity enhancement |
| NARES | Supplement financial and scientific resources<br>Promote capacity development<br>Demonstrate (auditable) positive impact of activities<br>Use a participatory approach in all activities<br>Promote networking within and between countries |
| Researchers | Provide or facilitate access to research funding<br>Promote suitable research methodologies and technologies<br>Establish clear policies and guidelines for participation in OSWU activities including clear and realistic objectives<br>Provide backstopping, technical support, capacity enhancement and access to collective knowledge<br>Provide opportunity for scientific publication<br>Facilitate opportunities for enhancing scientific status |
| Donors, Investors | Accountability for funds given and quality of science<br>Show real return on investment<br>Demonstrate (auditable) positive impact of activities<br>Show evidence of active capacity enhancement<br>Show efficiency in use of resources |
| Farmers, Land users | Economic empowerment<br>Experience real positive impact of promoted technology<br>Affordable, environment friendly, socially and culturally acceptable technologies<br>Training and capacity development in the use of soil, water and nutrient use technologies<br>Incorporation of indigenous knowledge into new SWN technologies<br>Demonstrated incentives for adopting technologies<br>Access to collective scientific and technical knowledge |
| Agribusiness | Access to collective scientific knowledge<br>Access to developed technologies<br>Access to intellectual property for commercial gain<br>Access to research capacity |

## Draft OSWU Action Plan 2002-05

| Objective | | Responsibility | Due date | Budget |
|---|---|---|---|---|
| **1. Efficient consortium management, communication, monitoring, and evaluation systems established** | | | | |
| 1.1 | Establish an updateable directory of OSWU members that can be used for communicating (containing name, organization, e-mails, fax, telephone numbers). The directory should also include a note on scientific capacity of member | Steering Committee | April 2003 | |
| 1.2 | OSWU members commit themselves to an organizational culture in which receipt is acknowledged on ALL communications. sending/receiving communications | All members | May 2002 | |
| 1.3 | An annual membership check will be carried out to confirm member contact details, membership status and interest in OSWU. Non-response to membership checks will be followed up with the head of the member organization | ICARDA, ICRISAT | Annually | |
| 1.4 | In proposals, progress reports and final reports, all partnerships need to be reported so that a register of partnerships can be kept up to date to confirm OSWU's commitment to partnership formation | Steering Committee | Annually | |
| 1.5 | OSWU will establish a peer review based evaluation system for evaluating reports and proposals. The system will allow for documentation of evaluation results so that accountability can be audited | Steering Committee (DJ Beukes to send out draft for comment) | Apr 2003 | |
| **2. OSWU will maintain itself financially by seeking alternative and varied funding sources** | | | | |
| 2.1 | OSWU will compile and submit a number of project proposals to donors for external funding. Projects will be country specific, regional or OSWU wide. (An existing draft will be resent to members for expansion, adaptation and comment) | ICARDA, ICRISAT | Continuously | |
| **3. Decision support tools for improved SWNM will be developed and evaluated in various agro-ecological zones** | | | | |
| 3.1 | Application of modeling tools for evaluation of technologies | Zimbabwe | Oct 2003 | 5000 |

*Continued*

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| Objective | | Responsibility | Due date | Budget |
|---|---|---|---|---|
| 3.2 | Calibration of CropSyst simulation model in cereal production | Morocco | Oct 2003 | 5000 |
| 3.3 | Simulation of crop yields in central Anatolia | Turkey | Oct 2003 | 5000 |
| 3.4 | Evaluation of CropSyst simulation model | Jordan | Oct 2003 | 5000 |
| 3.5 | Use of systems modeling (existing project) | South Africa | Dec 2002 | 1750 |
| 3.6 | Modeling of water and nutrient aspects | Burkina Faso | Oct 2003 | 5000 |
| 3.7 | Modeling of water and nutrient aspects | Kenya | Oct 2003 | 5000 |
| **4. Improved technologies for increased agricultural production based on efficient use of water and nutrients will be adopted and applied by land users** | | | | |
| 4.1 | Development and testing of pedotransfer functions | South Africa | Oct 2003 | 7800 |
| 4.2 | Existing projects: (i) Modeling evaporation from the soil surface, (ii) Assessment and modeling of water harvesting techniques | South Africa | Dec 2002 | (i) 5000<br>(ii) 5800 |
| 4.3 | Extension of field study on management practices for final reporting | Morocco | Dec 2002 | 1000 |
| 4.4 | Extension of no-till study for final reporting | Turkey | Dec 2002 | 1000 |
| **5. Impacts of improved practices on production, the environment and socio-economic conditions will be assessed** | | | | |
| 5.1 | Impact analysis of transferred SWNM technologies | Turkey | Oct 2003 | 5000 |
| 5.2 | Adoption and impact analysis of research and SWC technologies | Burkina Faso | Oct 2003 | 5000 |
| 5.3 | Impact analysis of OSWU technologies | Morocco | Oct 2003 | 5000 |
| 5.4 | Impact analysis of improved SWNM practices | Other countries (Kenya, South Africa, Zimbabwe, Jordan) | Oct 2003 | 20000 |
| **6. Improved information and communication exchange framework will be established; materials will be produced for stakeholders** | | | | |
| 6.1 | All project proposals will include a technology exchange component to ensure that developed technologies reach target stakeholders, specifically farmers. This component will be specifically evaluated during project evaluations | All members submitting proposals | Apr 2003 | |
| 6.2 | Workshop proceedings (April 2002) will be published | Steering Committee | Dec 2002 | 15,000 |
| 6.3 | Communication between OSWU members | NARS | | 1500 |

*Continued*

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| Objective | | Responsibility | Due date | Budget |
|---|---|---|---|---|
| **7. Stakeholder capacity for better SWNM will be enhanced.** | | | | |
| 7.1 | Workshop and symposium on water conservation technologies (IWMI, ICARDA, ICRISAT) | Steering Committee | Apr 2003 | |
| 7.2 | Other training ad hoc | | | 15,000 |
| **8. Adopt an integrated approach to research and technology development** | | | | |
| 8.1 | Explore partnership formation with:<br>- PRGA to help achieve OSWU objectives<br>- IWMI and ICARDA for on-farm water harvesting<br>-CNDC<br>-DMP | Steering Committee | Apr 2003 | |

# About OSWU

The Optimizing Soil Water Use (OSWU) Consortium is part of the CGIAR System-wide Soil, Water, and Nutrient Management Program. The overall goal of the consortium is sustainable and profitable agricultural production in dry areas, based upon the optimal use of available water. The consortium is convened by ICARDA, ICRISAT, and ARC-ISCW of South Africa. Member countries include Burkina Faso, Egypt, Iran, Jordan, Kenya, Mali, Morocco, Niger, South Africa, Syria, Turkey, and Zimbabwe.

Populations in arid and semi-arid regions are growing rapidly, while the possibilities of increasing cultivated area are limited. Therefore, the priority for all dry-area farming systems in sub-Saharan Africa and West Asia and North Africa (WANA) is to increase the biological and economic yield per unit of water. Water-use efficiency in these regions is generally low. The consortium aims to develop and disseminate effective and practical solutions for resource-poor farmers, adapted to local biophysical and socioeconomic conditions, being aware of the uncertainties of applying classical principles of soil-crop-water relations in rainfed and marginal environments. A holistic approach considering the entire production system and socioeconomic environment will help increase production in a sustainable way, and minimize the risk of crop failure.

The consortium's approach is based on partnerships between national agricultural research systems, international research centers, NGOs, and advanced research organizations. Local farming communities work together with research and extension teams to develop and test potential improvements. Their perceptions of the problems, their indigenous knowledge, and their production objectives and priorities, are fully incorporated into the R&D process. By bringing together researchers and farmers from different environments, the OSWU consortium promotes the exchange of ideas, experiences and, most importantly practical techniques to combat the effects of water scarcity, and to sustainably improve production, security, and livelihoods of farmers in the dry areas of WANA and sub-Saharan Africa.

OSWU is funded by the governments of Germany, the Netherlands, Norway, Switzerland, and the UK.

## About ICARDA

Established in 1977, the International Center for Agricultural Research in the Dry Areas (ICARDA) is one of 15 centers supported by the CGIAR. ICARDA's mission is to improve the welfare of poor people through research and training in dry areas of the developing world, by increasing the production, productivity and nutritional quality of food, while preserving and enhancing the natural resource base.

ICARDA serves the entire developing world for the improvement of lentil, barley and faba bean; all dry-area developing countries for the improvement of on-farm water-use efficiency, rangeland and small-ruminant production; and the West and Central Asia and North Africa (CWANA) region for the improvement of bread and durum wheats, chickpea, pasture and forage legumes, and farming systems. ICARDA's research provides global benefits of poverty alleviation through productivity improvements integrated with sustainable natural-resource management practices. ICARDA meets this challenge through research, training, and dissemination of information in partnership with national, regional and international agricultural research and development systems.

## About ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a non-profit, non-political, international organization for science-based agricultural development. ICRISAT conducts research on sorghum, pearl millet, chickpea, pigeonpea and groundnut – crops that support the livelihoods of the poorest of the poor in the semi-arid tropics encompassing 48 countries. ICRISAT also shares information and knowledge through capacity building, publications and information and communication technologies (ICTs). Established in 1972, it is one of 15 Centers supported by the Consultative Group on International Agricultural Research (CGIAR).

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