DEPARTMENT FOR INTERNATIONAL DEVELOPMENT

STRATEGY FOR RESEARCH AND KNOWLEDGE ON RENEWABLE NATURAL RESOURCES

NATURAL RESOURCES SYSTEMS PROGRAMME

FINAL TECHNICAL REPORT

DFID Project Number:

R4840

Project Title:

Conservation Tillage Management for Marginal Small Farm Systems in Zimbabwe

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NRSP Production System

Semi Arid

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Executive Summary

This project has undertaken participatory on-farm research of farmer selected conservation tillage, crop establishment and weed management systems. The work was originated under RAFS, initially funded by NRSP for one year (1995/96) and then extended for a further two and a half years being completed in September 1998. It has been undertaken in close collaboration with **R6655**[1] (a Crop Protection Programme Project) investigating weed management alternatives. The project provided researcher and farmer evaluation of technologies that has facilitated the development of a series of Best Practice Guidelines undertaken in conjunction with other funding agencies, extension organizations and farmers **(R7085).**

Project Achievements:

The project has delivered the following Outputs:

1. *Assessment of the technical and socio-economic potential for improved conservation tillage,* through: • A workshop for research and extension staff to review the present status of soil and water conservation in semi-and Zimbabwe at project initiation.

• Research station visits by farmers to view researcher managed conservation and weeding trials.
• An initial PRA of on-farm areas targeted for participatory research.

2. Participatory evaluation and development of tillage, planting and weeding options in cotton and make cropping systems.

These included on-station and on-farm assessment of winter, spring and no tillage land preparation options; planting using open plough furrow plant, third furrow plough and ripper systems; weeding by hand, plough and ox-cultivator combined with creation of tied ridges (post crop establishment) either by plough or cultivator with hilling blades, combining moisture retention and weeding operations. This has involved:

- Quantification of agronomic responses to the alternative tillage, crop establishment and weeding options.
- An evaluation of the condition and use of draught animal implements
- Identification of farmers' decision making criteria and farmer appraisal of the systems options
- An assessment of adoption patterns
- An economic analysis of the alternatives, which will be finalised under R6655 following a further season of evaluation by farmer.

Through working closely with farmers the following criteria were identified as key to adoption: •

- The need to match technologies to farmers' resources;
- The availability of draught animal power;
- The poor performance of farmers' draught animal implements due to poor Maintenance and use.
- Lack of skills amongst local artisans to provide Maintenance and repair facilities, or fabrication of simple tie-makers or ripper tines.
- Lack of access by farmers to reference material on existing or improved technologies, relying totally on local extension workers and other farmers for dissemination.
- Manufacturers being unwilling/unable to supply new implements without guaranteed sales.
- Farmers being unwilling/unable to adopt new systems due to lack of innovative implements and back up technical support.

3. Description of soil water regimes and development of a soil-water model

Key Findings have been

• Irrespective of soil type the quantity of water present in a soil profile at the beginning of the following season depends on the combined effect of the amount and distribution of rain in the previous season, the crop grown,

[1]R6655 was extended to September 1999 to allow a further seasons evaluation by farmers of the alternative systems.

[2] The soil and water modeling work was funded by Central Science Grant Project 0409 (Soil and water modeling under semi-arid conditions) and an SRI Studentship (Modelling tropical soil water regimes in semi-arid environments)

level of weed control and tillage practised.

- Generally tillage treatments that capture the most water are the wettest, however, the incomplete wetting up of pre-plant tied ridges early in a growing season frequently results in either poor crop establishment or a delay in planting-
- Conventionally tilled soils are more uniformly wet in the top 200 mm of the soil profile and significantly wetter than ridged structures early in the season.
- Furrows created by open plough furrow planting or with the ripper tine conserved more moisture early in the season than traditional third furrow planting and improved crop establishment.
- Mid season ridging with a plough, with the body attached, achieved efficient weed control and the ridges created increased water retention.
- Soil water regimes that develop under any tillage system are strongly influenced by the timing and frequency of weeding.
- In terms of crop water use, efficiency weeding at 2 and then b weeks after crop emergence performed, better than single weeding at four weeks.
- A weed management and water competition routine has been developed, to simulate the effect of weed management on crop performance. This routine has been incorporated in the PARCHED-THIRST crop growth model and calibrated with results from a 2-year weeding trial. The effects of weed competition on crop performance were assessed over a 30-year simulation period, for four levels of access to DAP and Iabour. The results demonstrate how sub-optimal crop management affects weed competition and crop production.

4. Project outputs have been promoted through:

- Annual reviews and evaluation field days with farmers, government and NGO extension staff.
- Options for tillage and demonstration have been provided by farmers leading to extension material being drafted and finalised in project R7085.
- Selected technologies have been promoted by the Cotton Training Centre
- 30 peer reviewed/edited papers, 13 unpublished reports/presentations and 7 project reports have been produced.

Contribution of Outputs to Project Goal:

The outputs of this project have contributed substantially towards the achievements of the Programme Purpose by ensuring that the Department for Research and Specialist Services, Agritex and NGOs have access to a range of efficient technologies that will permit more viable use of time or land which, depending on the livelihood strategy of particular farmers, might result in a reduced need for ploughing, a freeing-up of draught power, reduction of number of hours that women in particular spend weeding and a general improvement in the productivity of the system. In addition the project has increased the capacity of DR&SS and Agritex to carry out participatory research projects and led to the establishment of permanent Farmer Groups in Sanyati and Nembudziya, which have continued to experiment, evaluate and adopt dead level contours, runoff orchards and conservation tillage practices post project, and have provided a focus for inter farmer visits and networking arrangements between NGOs and farmers from other areas.

To date the technological options developed with the farmers in this project have been incorporated into: the Cotton Training Centre Syllabus and 1998 Training Manual; the CIMMYT Maize breeding programme; DR&SS Weed Research Team and Institute of Agricultural Engineering research and dissemination programmes, Agritex staff in Sanyati and Nembudziya Districts are promoting the technologies; Presentations have been made to numerous local, national and international workshops; The technologies have been included with others under NRSP SAPS Project R7085 which developed dissemination materials on soil and water management appropriate to the needs of the farmer.

Background

Semi-arid rainfed crop production in southern Africa is mainly conducted by farmers who are very conservation conscious but havc: limited resources. Previous conservation tillage research has tended to focus on tractor-based systems, whereas traditional systems use hand hoes or animal drawn mouldboard ploughs (preferably before the rains in October/November) and planting on the flat (Smith, 1988; Willcocks and Twomlow, 1993). Apart from nutrient deficiencies (Grant, 1981), the sandy soils cultivated by small holders in Zimbabwe have a poor structure, some are prone to surface crusting and compact under natural rainfall to develop layers that are resistant to root penetration. Water conservation is essential if crop reliability and yield is to be improved. Adoptable conservation measures are needed urgently as a rapidly increasing population is demanding more reliable cropping from marginal areas previously considered unsuitable for arable farming (World Bank, 1989).

Promotion of 'improved' conservation tillage practices in sub-Saharan Africa over the past twenty years has tended to be based on large scale dryland farming systems developed in the USA (e.g. Unger, 1984). Such systems do not take account of the technical, social and economic constraints faced by resource poor farmers (Willcocks and Twomlow, 1993; Twomlow et al., 1995). Projects have tried to address such issues (Willcocks, 1988) and further work needs to include agronomic, socioeconomic, meteorological, farm power and soil issues that *relate to* actual production systems (Willcocks et al., 1993). Improved technolo[g]ies should not require costly inputs, unavailable skills nor compete for labour when crops or land demand attention (Barrow, 1988), Farmer uptake must be the goal and this will entail the innovative: use of existing implements and resources (Ellis-Jones and Mudhara, 1995).

Recent studies have examined the effects of tillage practices and land forms (e.g. potholes and furrows) on water conservation and cotton and maize yields in the semi-arid communal farming areas (Tagwira, 1992). Recommendations have been that crops should be planted on ridges along the contour to help reduce erosion and water logging and to improve rooting volume in shallow soils (e.g. Elwell and Norton, 1988; Gollifer, 1993). Sheet erosion is negligible under no-till tied ridging but the system may generate adverse *e*daphic micro-environments for crops (e.g. Vogel, 1993). The major disadvantages with ridges (Gollifer, 1993), are higher soil temperatures and rapid drying in the ridges, which can result in poor crop establishment and growth. Other problems with ridge systems, compared to flat cultivation practices, include a high labour requirement for construction, difficulties in planting and weeding, and ridge maintenance. Consequently, work is required to identify low input improved land and crop husbandry options that are appropriate to the wide range of environmental, social and economic constraints faced by the farmer, increasing available crop water and reducing the level of inputs (EIlis-Jones and Mudhara, 1995).

Evidence of demand for the research was accumulated from previous projects funded by DFID, GTL and the Government of Zimbabwe. The aim of these projects was to develop through on-station and on-farm researchers managed trials soil and weed control management systems that conserve water, soil and energy for rainfed crop production in semi-arid regions (Shumba *et al.,* 1992; Willcocks et al,.1993; Hagmann, 1998). Results from these researcher-led initiatives showed that innovative cultivation and weeding practices that exploited existing hand hoes and mouldboard ploughs and enhanced the retention of scarce rain water could be developed. Results showed that potholing (Mashavira et al., 1995), ripping (Shumba *et al.,* 1992), open plough furrow planting (Twomlow et al.. 1994) and ridging up with the plough or ridger at first weeding (Ellis-Jones *et* al,1993) could both enhance mid-season water conservation by as much as 20%, significantly reduced labour for weeding and make crop yields more reliable through better crop establishment. However, the generic applicability of these results to different wealth categories of farmers and their different biophysical resources was and the appropriate dissemination strategies were unknown.

Project Purpose

The Project addressed NRSP Semi-arid Purpose 1:

Commodity production increased through improved conservation and use of water resources

and Purpose 2:

Risk reduction strategies enhanced through optimisation of land use and cropping patterns. The

specific Project purpose was:

Improved techniques for water conservation tillage and weed control developed and promoted.

The project undertook participatory on-farm evaluation of conservation tillage, crop establishment and complementary weed management systems that had been previously investigated through a series of researchers managed trials.

Research Activities

Planned inputs were all achieved either directly by this project or indirectly by feeding project outputs into other DFID-funded projects or Silsoe Research Institute-funded activities e.g.

- NRSP-funded project R7085 (Promotion of practical approaches to soil and water conservation for smallholder farmers in sub-Saharan Africa);
- Crop Protection Programme Project R6655 (Moisture Conservation through improved weed management in savannah cropping systems)
- Central Science Grant Project 0409 (Soil and water modelling under semi-arid conditions)
- SRI Studentship (Modelling tropical soil water regimes in semi-arid environments)

Output 1. Assessment of the technical and socio-economic potential far improved conservation tillage

1. L A workshop for research and extension staff to review the present status of soil and water conservation in semi-arid Zimbabwe at project initiation.

AGRITEX/GTZ Conservation Tillage Project, GTZ CARD Programme, Silsoe Research Institute, and their collaborating institutions within AGRITEX and DR&SS agreed the need for a joint workshop to be held in April 1995 Msavingo (Twomlow et al., 1995). More than 70 delegates from participating organisations and other key contributors attended the workshop and used the opportunity for brain storming, presenting papers and work programmes, sharing experiences and agreeing on necessary revisions of extension messages and current transfer strategies and on setting of priorities for future research activities. The main aim of the workshop was to present the state of affairs in the field of soil and water conservation and to formulate recommendations for research and extension.

The main outputs were of the April 1995 workshop:

Extension messages

1. Should contain options, not blanket recommendations.
2. Must be situation specific with regard to locations and to the prevailing production conditions.
3. Be specific for different management levels, especially taking care of the limited management capabilities of the disadvantaged groups of the rural population due to resource constraints.
4. They must integrate different aspects (soil fertility, conservation of soil and water, sustainability) in the framework of a holistic approach towards agricultural development.
5. They are to specifically address ecological issues

For more details see Annex A: **(Accompanying Document)**

1.2 An initial PRA of on farm areas targeted for participatory research and research station visits.

An initial PRA (Mazhangara et al., 1995) (Annex AO) was undertaken by a 16 person team comprised of research and extension staff from DRSS and AGRITEX. Field work was over a four day period used standard participatory techniques (group discussion, transect walks and mapping, matrix ranking of major problems and identification of farmers criteria for wealth ranking). Team members compiled notes from farmer discussion groups and individual interviews and these were used in the compilation of a report by a smaller (five person) working group which consolidated existing biophysical and socio-economic data with information provided by farmers. Information provided by farmers that was particularly relevant to the study included:

- Tillage practices (land preparation, planting and weeding).
- Implement ownership.
- Livestock ownership.
- Division of labour for the main household activities.
- Identification and ranking of the main problems.
- Characterisation of farmers according to resource availability.

For more details see Appendix AC (Accompanying report)

Although the PRA provided an important initial insight to how local farming systems in Zimuto relate to soil and water conservation technologies, it also provided opportunity for research and extension staff to interrelate with farmers forming a first step in the further identification, planning and implementation of on-farm research activities, which included:

- On farm trials over three seasons
- An assessment of the use and condition of farmers' implements (Chatizwa and Ellis-Jones, 1997; Chatizwa and Kosa, 1998).

Participatory monitoring and evaluation of research activities during and at the end of each season.
The latter is reported in detail in Chatizwa *et al.,* 1998 as well as in other publications. This included regular sometimes informal meetings of stakeholders to ensure their continued involvement in the project and that researchers fully understood how the alternative tillage and weeding systems fit with existing farming systems. Particularly important in this regard was a Workshop at Makoholi followed by discussion days with farmers involving visits to farms and field inspections across typical soil catenas and transects to review farmer practices and weed problems on various soil types. This helped to identify farmers' perceptions of the advantages and disadvantages of the alternative

crop establishment and weeding methods and from this to rank the criteria that farmers themselves use in assessing the alternatives.

For more details see Appendix AK (Accompanying report)

Output 2 Participatory evaluation and development of tillage, planting and weeding options in cotton and maize cropping systems.

2.1 Quantification of agronomic responses to the alternative tillage, crop establishment and weeding options.

A range of tillage and weeding experiments were carried out during the life of the project and are summarised in Table 1. The trial designs at each site varied with the objectives of the experiment and included criss cross plot designs; with tillage/crop establishment strips as main plot factors and weeding treatments as cross plot factors; and conventional randomized block designs for pure weeding trials. Plot sizes varied from 10 m long by 6 m wide for on-station researcher managed trials to 20 m by 10 m plots for on-farm farmer managed trials, with a minimum replication of three plots per treatment combination and a maximum of eight (see Table 1). The tillage systems investigated included:

Primary land preparation with an ox-drawn mouldboard plough:

- winter ploughing (WP)
- spring ploughing (SP)
- winter and spring ploughing (WPSP) or
- no primary tillage (NT)

Crop establishment techniques:

- open plough furrow planting (OPFP), seed planted into furrows opened with a single pass of a plough at the desired inter-row spacing, and subsequently covered with a hand hoe.
- ripper planting (RIP)Planting into a 0.2 to 0.3 m deep rip line created by a commercially available ripper tine mounted on a standard plough beam.
- traditional farmer practice of third furrow planting (TFP), dropping seed into the plough furrow to be subsequently covered by the next pass of the plough.
- pre-plant ridges: Tied Ridge and D) Tied Furrow; constructed in September of each season at 0.9 m intervals with an initial amplitude of 0.13 m and cross ties every 2.0 m.

Weeding practices:

- the common farmer practice of overall hand hoe weeding (HH),
- ox-cultivator weeding with crop rows subsequently weeded by hand-hoe if necessary (OCHH)
- ox-plough weeding with mouldboard left in place, with crop rows subsequently weeded by hand-hoe if necessary (OPHH). The ridges formed at weeding with the mouldboard plough were crossed tied at two to three m intervals (using hand hoes) to prevent water movement.

Trials planted with Maize seed (80 mm deep) were thinned to a 0.9 m by 0.3 m spacing after emergence. Fertilizer, 12 kg N, 21 kg P, and l4kg K per ha, was applied at planting and crops were top dressed with 52 kg/ha of N at four, six and eight weeks after planting, unless the farmers specified other wise. Cotton seed was sown 30 mm deep in 1.0 m rows and thinned to 0.3 m between plants at the five leaf stage. Fertilizer, 12.5 kg N, kg P, and 25 kg K per ha, was applied at planting and crops were top dressed with 34.5 kg/ha of N at first flowering, unless the farmers specified otherwise. Plots were uniformly hand weeded as the need arose unless the experimental protocol stated otherwise.

Total maize grain yield and biomass was determined and adjusted to 12.5% moisture content. Total weed biomass was recorded at harvest from quadrats 0.5 by 0.5 m at five random positions in each plot unless experimental stated otherwise. Weed and crop data was subjected to an analysis of variance and treatment comparisons were made using paired t-tests *($P<0.05$).*

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[3] Ripper tines were initially provided by the project as they were unavailable in Mshagashe or Zimuto. Local artisans were subsequently trained to fabricate the tine attachments.

Where the trials were established on farmers fields, the farmers were invited to review researcher managed trials As a result farmers made an input into the selection of technologies to be evaluated, the selection of host farmers, the design of field experimentation and primary land preparation. Host farmers were selected by the community in each area as representative of the three main wealth categories identified during the PRA exercises. The trials were consultative, managed by researchers and extensionists, but implemented by the farmers, and replicated across the main sail types of the area. The basic principles of the trials were discussed with the farmers and appropriate management practices agreed so that data from individual farms within an area could be compared and used in combined statistical analyses.

Statistical advice was provided by the resident biometricans at Silsoe and DRSS, with additional support from the Statistical Services Centre, reading.

Table 1: Summary of experiments conducted

Type of experiment	Design	Reference and location with respect to this report
soil physical characteristics (n=replication)	randomised blocks	Bruneau & Twomlow 1999 (n=5) (Appendix V,p 157) Twomlow & Bruneau (1999 in press)) (n=5) (Appendix W, p164) van der Meer *et al.,* (1998) (Appendix X, p178)
Tillage Experiments (n=replication)	randomised blocks Criss cross	Dhliwayo, 1996 (4) (Appendix AH, accompanying report) Mashavira *et al., 1995* (n=3) (Appendix C, accompanying report) Mashavira et *al.,* 1997 (n=3) (Appendix K, p71) Twomlow *et al.,* 1997 (n=3) (Appendix E, p32) Twomlow & Bruneau (1999 in press) (n=5) (Appendix W, p 164)
Weeding Experiments (n=replication)	randomised blocks	Dhliwayo, 1996 (n=4) (Appendix AH, accompanying document) Riches *et al.,* 1997 (n=4) (Appendix J, p56) Twomlow *et al.,* 1997 (n=4) (Appendix M, 85)
Tilla[g]e/crop establishment by weeding	randomised blocks Criss cross	Muza *et al.,* 1996 (n=3) (Appendix I, p51) Mashavira *et al.,* 1997 n=(3)(Appendix K, p71) Chatizwa *et al.,* 1998 (n=3) (Appendix AK, accompanying report) Riches *et al.,* 1998 (n=3) (Appendix Q, p115) Twomlow *et al,* 1998 (n=3) (Appendix N, p 91) Twomlow and Dhliwayo 1999 (n=8) (Appendix AR, p 276)

2.2. An evaluation of the condition and use of draught animal implements

This was achieved through farmer discussion groups, field days, individual interviews and formal surveys.

For more details see Appendices L (p81), Al (p224), AK (Accompanying report),

2.3 *Identification of farmers' decision making criteria and farmer appraisal of the systems options* This was achieved through farmer discussion groups, field days, individual interviews and formal surveys.

For more details see Appendices P (p107), Q (p115), AJ (p240), AK (Accompanying report)

2.4 An assessment of adoption patterns.

This was achieved through farmer discussion groups, field days, individual interviews and formal surveys.

For more details see Appendix A and B (Accompanying report), Appendices Q (p 115)

A final survey of farmers adoption patterns is being carried out within R6655

2.5 An economic analysis of the alternatives, which will be finalised under R6655following a further season of evaluation by farmers.

This was achieved through farmer discussion groups, field days, individual interviews and formal surveys and partial budgets calculated, based on yield and labour data collected from the agronomic trials.

For more details see Appendices E (p32), L (81), P (p107), AF (Accompanying report), AK (Accompanying report)

A final economic analysis of technologies is being carried out within R6655

Output 3 Description of soil water regimes for use in a soil-water model.

3.1 Soil water regimes described

Soil water content profiles were determined with a "Wallingford Neutron Probe Moisture Meter", at weekly intervals from planting of the first test crop at each site (Mashavira *et al.,* 1995; Twomlow *et al.,* 1997), or at set periods after an application of water using the sprinkler irrigation system to simulate homogenous rainfall events on a 10 x 10 m square (Twomlow, 1994; Bruneau and Twomlow, 1999). Measurements were made in up to three positions on the ridge system (top ridge, side ridge and furrow bottom) and in the planting line of the flat cultivation at 100 nun depth intervals to a maximum depth of 900 mm. These were supplemented by volumetric sampling of the top 150 mm of the profile. Each sampling position was replicated three times.

3.2 Soil and water data analysis.

Volumetric water content was subjected to an analysis of variance by date and by treatment and comparisons were made using paired t-tests *($P<0.05$).* Total seasonal water use for each water regime was calculated from rainfall and the soil-water balance between the date of sowing and the harvest of the crop. No attempt was made to distinguish between soil evaporation or crop transpiration and drainage was assumed to be negligible. The ratio of total above-ground dry matter production (crop biomass) to total seasonal water use provided an estimate of water use efficiency (WUE) at harvest. WUE was expressed as:

WUE (kg/ha/mm) = crop biomass (kg(ha) / water use (mm).

For more details see Appendix C (Accompanying report), Appendices M (p85), V(p157) and W (p164)

3.3 Soil and water modeling

Using the data base of soil water records collected during this project a SRI PhD Student has been developing routines that simulate the effects of different tillage practices (land forms) and weed management regimes on soil water regimes and crop performance. Once the routines had been developed they were incorporated into the PARCH-THIRST crop growth model and a 30 year simulation carried out on crop performance for different farmer resource categories.

For more details see Appendices T (p142), U (p151), Y (p178) and AS (p282)

Output 4 Promotion of Project Outputs

Options for tillage and demonstration have been provided by farmers leading to extension material being drafted and finalised in project R7085.

Field days, annual reviews and evaluations were held in each area with farmer research groups, extension staff and NGOs in 1995, 1996, 1997 and I998, and subsequently in 1999 throu[g]h the Crop Protection Project R6655.

For more details see Appendix B (Accompanying report), Appendices Q (p115), AJ (p240), AK (Accompanying report)

Selected technologies have been promoted by the Cotton Training Centre. **For more details see Appendix Z (p189):**

Project results and innovative concepts have been presented to numerous workshops and conferences, supported by local, regional and international publications.

Outputs

The project has delivered the following Outputs:

Output I Assessment of the technical and socio-economic potential for improved conservation tillage, **through:**

- A workshop for research and extension staff to review the present status of soil and water conservation in semi-arid Zimbabwe at project initiation.
- Research station visits by farmers to view researcher managed conservation and weeding trials. • An initial PRA of on-farm areas targeted for participatory research.

In Zimbabwe a host of Government, Non-Government Organisations, aid funding and development agencies are working towards developing soil and water conservation packages that can be adopted by smallholder farmers. In the past many of these programmes have concentrated on the technological package, with only limited consideration given to the constraints experienced by farmers and extensions services. For optimum tillage, planting and crop management systems to be developed, promoted and subsequently adopted, socioeconomic studies have shown that it is essential for researchers/extension/development agencies to understand the constraints within which individual farmers operate. Other experiences are that conventional transfer strategies, i.e. Master Farmer Training, T&V with interest groups, has not resulted in the expected rate of adoption of promoted conservation tillage technologies.

Promotion of improved' conservation practices in Sub-Saharan Africa have rarely taken account of the practical, social and economic constraints faced by resource poor farmers. Problems faced by communal smallholder farmers in these areas cannot be solved by simply adaption and introduction of already existing technologies. Apart from technologies for maize and cotton successfully developed for high potential areas, technology does not exist or is inappropriate as it is perceived as too risky by farmers. To make research more effective more attention needs to be given to project identification, design and appraisal with active involvement and consultation with intended beneficiaries and stakeholders using more participatory methods that consider socioeconomic acceptability and identify dissemination pathways.

New technologies need to improve the supply and utilization of limited resources in these environments to satisfy the specific demands of the growing crop. At the same time they must not require costly inputs, unavailable skills nor increase the demand on labour. Farmer uptake is therefore dependent upon the innovative use of existing implements, and thereby making the best use of what is generally available.

Results of farmer managed trials so far indicate that effective, low cost, conservation tillage practices can be achieved using existing implements to enhance water conservation, which will allow: i) earlier and more even crop establishment; ii) reduce effect of mid-season droughts and iii) extend the growing season where there is an early cut off to the rains. In order to identify which systems are appropriate and acceptable to dryland conditions, smallholder farmers must be fully involved in the selection and development of those technologies under investigation.

The PRA exercises undertaken in July 1995 (Mazhangara *et al.,* 1995) and 1997 (Chatizwa *et al.,* 1998) described the existing crop production practices in the area (see Table 2), and involved farmers in the identification of issues and constraints related to crop production (Table 3), and thirdly the identification of future research activities. Transect walks, group discussions with farmers, extension staff and other key informants in the community, matrix ranking of constraints, wealth ranking of households (Table 2) and a review of on-station crop establishment and weed control research at Makoholi (Muza *et al.,* 1996; Mashavira *et al.,* 1997) were used (Table 4 and 5).

Table 2: Existing Farm Systems in Mshagashe Small Scale Commercial Farming Area and Zimuto Communal Area for Three Farmer Categories

FARMER WEALTH CATEGORY	1 **Full DAP** Full implements **Few labour constraints** **Little outside income** **Regular farm sales**			2 **Partial DAP** **Plough only** **Some labour constraints** **Variable outside incomes** **Farm sales in good years**			3 **Little or no DAP** **No DAP implements** **Severe labour constraints** Remittances/relief **Subsistence production**		
Soil ca[ena	T	VM	V	T	VM	V	T	VNI	V
Land preparation									
Winter plough	*	*	*		*	*			*
Use of manures	*	*	*	*	*	*			
Crops	**M;Mi; Cp;Bn**	**M;Gn; Bn;V Wheat**	**M/Ri;Gn V;Wheat**	**M;Mi; CP;Bn**	**M;GN; Bn**	**M/Ri;Gn**	**M;CP; Bn**	**M;Gn**	**M/Ri**
Crop establishment									
Priorities Dates	3 Nov/Dec	2 Oct-Dec	1 Aug/Sept-Dec	3 Nov/Dec	2 Nov/Dec	1 Aug-Oct	3 Dec/Jan	2 Dec	1 Aug-Nov
Hoe	(*)		(*)		(*)		(*)		(*)
Third furrow									
OPFP	(*)	(*)	(*)						
Cultivations									
1st	H C	H C	H C (P)	H	H	H	H	H	H
2nd	H C	H C	H C	H P	H P	H			
Use of inputs									
Seed	*	:	*	*	*	*	*	*	*
Fertiliser	*	*		*	*	(*)	(*)		(*)
Chemicals	*	*	*	*	*	*			
Hired labour	*	*	*						
Hired DAP or borrowed							*	*	*
Works for others at key periods							*	*	*

M - Maize; Mi - finger millet; Cp - Cowpea; Bn - Bambara; M/Ri - Maize-rice intercrop; V - vegetables.
( ) - used by a few farmers, but not the dominant practice.
H - hoe; P - plough; C - cultivator

Output 2: Participatory evaluation and development of tillage, planting and weeding options in cotton and maize cropping systems.
This work has included both on-station and on-farm assessment of winter, spring and no tillage land preparation options; planting using open plough furrow plant, third furrow plough and ripper systems; weeding by hand, plough and ox-Cultivator combined with creation of tied ridges (post crop establishment) either by plough or cultivator with hitting blades, combining moisture retention and weeding operations. This has involved

- Quantification of agronomic responses to the alternative tillage, crop establishment and weeding options.
- An evaluation of the condition and use of draught animal implements .
- Identification of farmers' decision making criteria and farmer appraisal of the systems options
- An assessment of adoption patterns
- An economic analysis of the alternatives, which will be finalised under R6655 following a further season of evaluation by farmers.

Table 3. Ranking of criteria used to assess technology according to Mshagashe and Zimuto farmers

1. Moisture conservation -making best use of moisture for planting;

2. Crop emergence - looking for technology to provide a good stand;

3. Soil loosening - to allow good root development;

4. Depth of planting - to optimise emergence over range of conditions;

5a. Timeliness - ease of implementation over a large area as fast as possible to make use of moisture;
5b. Reduced gap filling for minimising seed cost;
5c. Successful emergence with dry planting - especially in vleis;

6. Reducing seed toss by predators;

7. Flexibility - technology needed for range of soil types, ease of use, speed, labour

need; 8. Weeding - farmers will accept weeds at crop emergence if advantages 1-7

result;

9a. Labour - need for technology which reduces labour demand, but will accept increased tabour input if other advantages result;
9b . DAP - Although not all farmers have cattle they will hire to obtain advantages listed above (Note: It is rare for Mshagashe farmers to have a draught constraint).

Through working closely with farmers the following criteria were identified as key to adoption: • The need to match technologies to farmers' resources;

- The availability of draught animal power;
- The poor performance of farmers' draught animal implements due to poor 'Maintenance and use.
- Lack of skills amongst local artisans to provide Maintenance and repair facilities, or fabrication of simple tie-makers or ripper tines.
- Lack of access by farmers to reference material on existing or improved technologies, relying totally on local • extension workers and other farmers for dissemination.
- Manufacturers being unwilling/unable to supply new implements without guaranteed sales.
- Farmers being unwilling/unable to adopt new systems due to lack of innovative implements and back up technical support.

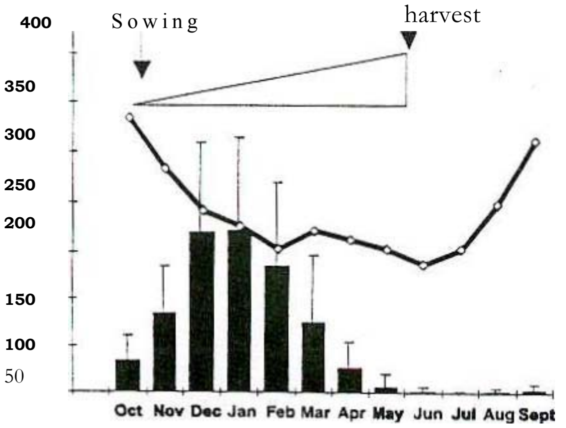

Figure 1 Schematic crop production calender for semi-arid Zimbabwe (▌ monthly rainfall: ◊ open pan evaporation; ┬ rainfall standard deviation)

With the cropping period in most semi-arid regions being relatively short (Figure 1), the timing of field operations is critical is considered critical. In our work we have examined the effects of tillage practices (primary land preparation) and land forms (e.g. potholes, furrows and ridge structures) on soil and water conservation and its subsequent impacts on crop establishment and weed control

From our work it is clear that farmers in southern Africa already employ tillage practices with the aim of accomplishing several short-term goals including seedbed preparation, weed control and rainwater retention. In Zimbabwe farmers recognise that timely inter-row cultivation is important for both weed control and for maintaining a rough soil surface which can

Table 4. Zimuto farmers' perceptions of advantages and disadvantages of technologies.

A. Establishment methods

RIP		`FFP		OPFP	
Advantage	Disadvantage	Advantage	Disadvantage	Advantage	**Disadvantage**
1. Good emergence; 2. Cost saving, timeliness; 3. Labour saving; 4. Breaks soil cap, 5. Better yields than farmer practice.	1. Weed growth between crop rows but farmer prepared to accept trade-off; 2. Poor emergence in low rainfall.	1. Good when moisture is 2. Easy to do; 3. Good weed control especially in vlei,	1. Soil caps if rain follows planting; 2. Poor emergence, need for replanting; 3. Uses more seed.	As for ripper.	As for ripper.

B Weeding Methods.

H11		OCIIH		OPHH	
Advantage	Disadvantage	Advantage	Disadvantage	Advantage	**Disadvantage**
1. Allows clean weeding; 2. Affordable.	1. Back breaking, labour intensive.	1. Timeliness; 2 wick on inter-raw weeds	1. Only efficient when weeds are small.	1. Smothers small weeds; 2. Conserves moisture if ridges are tied; 3. Allows drainage; 4. Good on topland.	None.

Table 5. Mshagashe farmers' perceptions of advantages and disadvantages of technologies. A.

Establishment methods

RIP		TFP		OPFP	
Advantage	Disadvantage	Advantage	Disadvantage	Advantage	Disadvantage
1 Good crop emergence; 2. Loosens plough pan; 3. Opens a small furrow; 4. Saves time; 5. Low draught (requirement.	1. Weed growth between rows after emergence; 2. Poor for dry planting; 3. Covering seed with hoe is labour intensive,	1. Less work involved; I Seed is planted on moisture; 3. Less seed loss to predators; 4. Good weed control,	1. Poor emergence in vlei at dry planting due to clods; 2. High labour requirement; 3. Poor row spacing 4 Poor emergence generally; 5. Requires gap tilling; 6. Inconsistent cultivation; 7. Inconsistent planting depth; b. Seed near plough pan, poor crop root growth.	1. Saves time; I Enables farmer to catch moisture; 3. Good emergence (100%).	1. Poor weed control; 2. Can be difficult to control depth - leads to poor emergence.

B Weeding Methods.

HH		OCHH		OPH	
Advantage	Disadvantage	Advantage	Disadvantage	Advantage	Disadvantage
. Kills all weeds.	1. Back breaking, labour intensive; 2. Slow.	I. Loosens soil, moisture conservation; 2. Quick; 3. Effective in inter-row; 4. Aerates soil; 5. Can produce ridges.	1. Reduces maize stand if crop is poorly spaced; 2 Only efficient when weeds are small•	None.	I . Large furrows encourage erosion; 2. Covers in-row weeds which are difficult to remove by hand; 3 Covers maize when plants are small.

retain subsequent rainfall (EIlis-Jones et al., 1993). The widespread adoption of minimum-till and no-till systems in the capital-intensive agricultural systems of North America, Australia and other countries has been facilitated by innovations in equipment and herbicide technology (Halvorson *et al,* 1997). Modified tillage regimes, including no-till tied ridging, proposed as a sustainable conservation tillage system in both Zambia (Meijer, 1992) and Zimbabwe (Elwell and Norton, 1988), to reduce soil and water losses and improve the utilization of available draught power resources, have not been adopted on any scale. This is attributed to the resource needs of the system being beyond those available to many households. There are also other problems perceived by farmers,, compared to flat cultivation practices, that include a high labour requirement for construction (Twomlow *et* al., 1997a), difficulties in planting and weeding (Meijer, 1992), and ridge maintenance, with no overall economic benefit (Table 6) compared to traditional systems they are intended to replace. Low resource-endowed farmers tend to choose cheaper and less labour demanding techniques for

Table 6 _ Economic analysis of method of ridging trial at Makoholi Experimental Station

Tillage system	Flat control	Ridged by hand	Ridged by plough	Ridged by ridger
Grain yield, kg ha^{-1}	2772	2976	2682	2662
Stover yield, kg ha^{-1}	1424	1582	1539	1500
1. Gross income$^{\partial}$ Z$	2953	3172	2862	2840
2. Purchased inputs Z$	1985	2028	1966	1962
3. DAP cost Z$	301	301	410	447
4. Labour cost Z$	252	340	252	252
5. Total Costs Z$ (2+3+4)	2538	2669	2628	2661
6. Gross Mar^g^in Z$ (1-5)	415	503	234	179
7. Total labour, hours	275	362	282	284
8. Returns to labour Z$ h^{-1} ((6+4)17)	2.43	2.33	1.72	1.52
Return to cash expenditure Z$ Z$$^{-1}$ (1/2)	1.49	1.56	1.46	1.45

Maize grain - 1050 Z$ t^{-1} Maize stover - 30 Z$ t^{-1} (Twomlow *et al.,* 1997a)

sustainable crop production. Recent studies in east Africa (Tengberg et *al.,* 1998) have shown, that in general, farmers have a good understanding of their circumstances (biophysical and economic) and rationalise their farming practices to address these issues. Similar observations have been made in southern Africa, where our studies have confirmed that farmers have a good understanding of the strong relationship between crop growth, soil fertility, and water and labor availability (Table 7).

Table 7 Socio-economic and bio-physical factors considered by households

Socio-economic factors	**Biophysical factors**
Land availability (and land tenure)	Rainfall
Labour availability	Soil type and soil fertility
Draught power availability	Soil moisture
Implement availability and condition	Crop establishment methods
Timeliness and risk considerations	Weeding methods Profitability of farming systems

However, in contrast to the majority of farmers in the rest of sub-Saharan Africa, smallholder farmers in semi-arid Zimbabwe rely heavily an draught animal power (DAP) and ox-drawn mouldboard ploughs for primary tillage and crop establishment. Seed is planted by hand into a furrow made by the plough and covered during the next pass, ensuring the maize germinates in a relatively weed-free seedbed. Farmers face the problem that the peak demand for DAP coincides with the time that animals are in weakest condition after a long dry sea (Shumba *et* al., 1992). Achieving timely planting and good germination is particularly important, which can be difficult for.

those without access to adequate DAP. Farmers recognise the need for weed control to remove weeds and allow enhanced capture of rainfall. Weed management is a key component of conservation tillage (Norton, 1987; Riches *et al.,* 1997) and with weeding [with either hand tools or DAP implements] accounting for up to 60% of pre-harvest labour input for maize production (Akobundu, 1987; MLARR, 1992; Rogan and O'Neill, 1993), considerable strain is placed on household supplied labour. This can be reduced through the use of the ox-cultivator or plough.

Despite this investment in labour, our experimental evidence suggests that with the farmers existing weeding practice (a single weeding at 4 weeks) more than 30% of the potential yield of cereal crops is commonly lost to weed infestation. This may be due to late and inadequate weeding, with high labour demands for hoe weeding and a shortage of DAP and suitable implements for ox-cultivation contributing to weed problems (Chatizwa *et al.,* 1998). In our studies, the optimum timing for weeding, based upon identification of the "critical period of competition" typically indicate the need to maintain maize free of weeds from 2 to 6 weeks from planting to achieve maximum water use efficiency and crop productivity (Table 8, Twomlow *et al.,* 1997b), irrespective of the conservation tillage practices (Table 9, Twomlow and Dhliwayo, 1999).

Table 8. Total crop biomass (kg/ ha), total crop water use (mm/ha) and water use efficiency (WUE, kg/mm) in response to time and frequency of weeding at Makoholi Experimental Station

Weeding Treatment	1991/92			1992/93		
	biomass	crop water use	WUE	biomass	crop water use	WUE
weed at 2 wks	760	218.9	3.47	3143	3964	7.89
weed at 2+4+6 wks	1350	210.3	6.42	4147	367.9	11.17
weed at 4 wks	1485	214.9	6.91	3235	411.2	8.13
kept weed free	1805	163.8	11.01	3178	393.1	8.09
unweeded control	489	210	2.33	1014	465.4	2.17
s.e.d.#	132.1***	6.63***	1.75***	496.5**	11.12***	1.467**

Significant treatment effect * *P > 0.05; *** P>0.001* source: Twomlow *et al.,* 1997b

Table 9. Maize grain yield (kg/ha), total crop water use (mm/ha) and water use efficiency (WUE, kg/mm) in response to conservation tillage and time of weeding at Makoholi.

Tillage	1994/95			1995/96			1996/97		
	Grain	Crop water use	WUE	Grain	Crop water use	WUE	Grain	Crop water use	WUE
OPFP	1,282	294	4.4	707	331	2.1	2,435	307	7.9
OPFP+MR	1,471	297	5.0	1,073	335	3.2	1,981	290	6.8
Tied ridge	1,280	290	4.4	495	332	1.5	3,429	312	11.0
Tied Furrow	1,234	304	4.1	302	335	0.9	2,577	300	8.6
s.e.d#	158.6	4.4*	0.947	82.9***	5.5	0.44***	259.7***	15.0	1.29*
Weeding Regime - weeks									
4	1,165	299	3.9	466	328	I.4	2,604	303	8.6
2+6	1,468	293	5.0	823	338	2.4	2,608	302	8.6
s.e.d	112.1 **	3.1	0.669	58.6***	3.92*	0.32***	183.6	10.6	0.91

Significant treatment effects * *P<0.05; ** P<0.01; *** P<0.001*

Weed management is therefore a key element in the design of any sustainable and adoptable tillage system aimed at raising smallholders' production and has a major impact on both yield and available soil water (Twomlow and Bruneau, 1999).

Our on-farm work has focussed on developing weed control strategies that complement primary tillage techniques for the majority of communal area farmers who cannot afford purchased inputs, including herbicides. Because of poor returns to cropping and an acute shortage of labour in many households, tillage/weed control systems should be based on low cost, labour saving technologies (Ellis-Jones and Mudhara, 1995). We have shown that the use of the mouldboard plough with body attached during weeding allows the creation of a ridge and furrow land form that can enhance soil water retention (Table 10, Riches *et at,* 1997). The soil thrown towards the crop row smothers weeds and reduces the need for subsequent labour-intensive inter-plant weeding. Labour productivity, in terms of grain/cotton harvested, can be considerably higher with this technique than following the use of existing hand hoe or cultivator followed by hoe systems. While 76% of households own a plough in southern Zimbabwe, only 23% own a cultivator, so "plough weeding" provides an opportunity for increasing the timeliness of weed control, for farmers who currently weed by hand, without the need for additional capital investment, if they have access to DAP.

Table 10 Maize yields, labour requirements and returns to labour for four weeding systems at Makoholi Experimental Station.

	Yield kg ha"	labour hours spent weeding			returns to weeding
		manual	mechanical	total	kg h"
			1992/93		
Hand-weed	5195	I32.5	0	132.5	39.3
Cultivator	4552	52.2	16.2	68.3	66.7
Plough with body	4345	26.8	28.3	55.2	78.7
Plough less body	2766	45.4	40.4	85.8	32.5
expt. s.e.	310	-	-	-	4.41
			1993/94		
Hand-weed	2251	126	0	126	17.9
Cultivator	2092	45.3	15.1	60	35
Plough with body'	3047	20.3	36.8	57	53.5
Plough less body	1636	45.3	36.3	82	20
expt. s.c.	204	-	-	-	-
			1994/95		
Hand-weed	3670	155.6	0	155.6	23.6
Cultivator	3990	42.6	13.5	56.1	71.1
Plough with body'	3896	0	34.6	34.6	112.6
Plough less body	2590	41.4	34.7	76.1	34
exot. s.e.	344	-	-	-	8.3

Source: Riches *et al.,* 1997

* ridges were tied after weeding in 1993/94 and 1994/95
'labour for hand-hoeing estimated from on-farm records.

Prior work has shown the advantages of establishing a crop within either a rip line (Shumba, *et al,* 1992) or a planting furrow opened with a plough on winter or previously spring ploughed land (Mashavira *et al,* 1995; *1997;* Muza *et al.,* 1996; Twomlow *et al,* 1995). Although these techniques of crop establishment can reduce DAP inputs for seedbed preparation and allow timely planting, a heavier and earlier weed burden results than that for overall ploughing and planting together, the prevailing practice (Shumba *et al.,* 1992). If combined with weeding with a plough (or a cultivator with ridging blades), timely planting, better soil water conservation, weed control and labour reduction can be achieved (Table 11).

Table 11 Maize Yield Response to Methods of Crop Establishment and Weeding on Spring Ploughed Land, Winter and Spring Ploughed Land and Unploughed Fallow Land in 1995196

	Spring Ploughed Land			Winter and Spring Ploughed Land			Unploughed Weedy Fallowed Land		
Crop Establishment	Grain Yield kg ha	Total Labo h/ha	Return to Labour kg/h	Grain Yield kg/ha	Total Labour h/ha	Return to Labour kg/h	Grain Yield kg/ha	Total Labour h/ha	Return Labour kg/h
Hand Plant	620.9	193.1	3.2	596.2	144.8	4.1	395.0	215.1	1.8
Open Plough Furrow Plant	596.8	98.1	6.1	796.3	95.4	8.3	961.3	124.9	7.7
Rip to 0.3m depth	961.3	105.9	9.1	1276.5	85.9	14.9	973.9	135.4	7.2
Method of Weeding									
Hand-hoe	587.4	194.1	3.0	856.4	166.4	5.2	779.4	175.8	4.4
Ox-Cultivator	953.5	106.2	9.0	680.0	65.9	10.3	7·18.8	165.0	4.5
Ox-plough	638.0	111.5	5.7	t0t8.6	88.0	11.6	802.0	134.6	6.0
Tillage s.e.	187.2	6.05***	2.3*	286.3	7.36**	3.42**	132.9***	14.56***	1.29***
Weeding s.e.	187.2	6.05*	2.3***	247.9	7.24***	2.96*	132.9	14.56**	1.3

Significant treatment effect * P > 0.05, ** P > 0.01, ***P > 0.001 Mashavira et *al.,* 1997

The law-draught, minimum tillage planting techniques for establishing the maize crop have been favourably received by farmers who have participated in or monitored the on-Farm trials in Zimuto and Mshagashe. The crop establishment methods selected by farmers for testing included: the traditional farmer practice of third furrow plough planting (TFP), planting in rip lines (RIP) and the innovative farmer practice of ploughing and planting every third row (OPFP). Weeding methods included: the use of hand weeding only (HH), ox-plough combined with the hand hoe (OPHH) and ox-cultivator combined with the hand hoe (OCHH). Planting into the rip line, made by a rip tine bolted onto the mouldboard plough beam, resulted in good crop stands at topland and vlei margin sites. This provided improved returns, when used iii combination with hand weeding or the cultivator for weeding, on the Copland compared to the common farmer practice of planting behind the plough.

Maize grain yields were highest *Vlei* margin soils in the wet 1995/96 season, Toplands in the wet 1996197 and *Vleis* in the dry 1997/98 season. In 1995/96 and 1996/97 seasons the best planting and weeding combinations on Topland and Vlet-margin soils was planting in *a* rip line followed by overall hand weeding. The best combination in the *Vleis* was traditional third furrow planting, dropping seed behind the ox-plough, followed by either ox-cultivating, or post plant tie-ridging with an ox-plough and in-row hand weeding. In the drier 1997!98 open plough furrow planting followed by weeding by hand or the ox-plough yielded the best on all soil types (Table 12).

For each season a partial budget analysis was undertaken for each combination, based on maize yields for each soil type ((Ellis-Jones *et al.,* 1998)). Maize prices varied from Z$900 per tonne, paid by traders at the farm gate, up to ZS4000 per tonne when sold in small quantities. Labour is usually paid for undertaking a given task, which currently equates to Z$28 per day. DAP is rarely hired as share and borrowing arrangements are more common, but when it does occur ploughing costs range from Z$400 (winter ploughing) to Z$550 per ha (spring ploughing). Hiring DAP for weeding is not common but farmers indicate it would cost about Z$300 per ha. The best and worst technology options for crop establishment and weeding in terms of lowest and highest productivity are shown in Table 13, along with average maize yields and rainfall experienced in each season. Even with the contrasting rainy seasons experienced RIP and OPFP crop establishment methods proved the best options for toplands and vlei margins. HH proved the best weeding method for most soil types in most seasons though the ox plough shows its advantages for vlei sites where ridging is important for increasing rooting depth and improving drainage in a wet year, and conserving moisture in a dry year.

Table 12: Summary of Best and Worst Maize Yield Responses to Different Crop Establishment and Weed Control Combinations

Soil Types	1995/96	1996/97	1997/98
Best Options (kg/ha)			
Topland	RIPHH (1242)	RIPHH (4076)	OPFPHH (1789)
Vlei margin	RIPHH (2685)	RIPOPHH (3094)	OPFPHH (1605)
	RIPOPHH (2555)	OPFPOPHH (2718)	
Vlei	TFPOCHH (1753)	TFPOPHH (3763)	OPFPOCHH (2717)
			RIPOCHH (2607)
			OPFPHH (2416)
			OPFPOPHH (2416)
Worst Options (kg/ha)			
Topland	OPFPOCHH (580)	OPFPOPHH (2605)	RIPOPHH (775)
Vlei margin	OPFPHH (912)	TFPHH (2085)	RIPOCHH (550)
Vlei	RIPOCHH (855)	RIPOPHH (628)	RIPHH (1889)

Table 13: Summary of results for three seasons showing average yields, best and worst productivity options, based on partial budgets

Soil Types	1995/96	1996/97	1997/98
Mean yields (kg per ha)	1208	3670	1227
Topland	1687	1587	755
Vlei-margin	886	771	1597
Best productivity options			
Topland	RIP/HH	RIP/HH	OPFP/HH
Vlei-margin	RIP/HH	OPFP /HH	OPFP/HH
Vlei	RIP/HH	TFP/OPHH	OPFP/OCHH
Worst productivity options			
Topland	TFP/OPHH*	TFP/OPHH *	TFP/OPHH
Vlei-margin	TFP/OCHH*	TFP/OPHH *	TFP/OPHH*
Vlei	TFP/HH	TFP/OCHH *	TFP/OCHH*

* Partial budget analysis indicates that these options are worse than TFP/HH, the most widely used farmer practice (Ellis-Jones et *al.,* 1998)

The low draught minimum tillage planting techniques of OPFP and RIP, were associated with greater weed infestations than observed on plots established by farmer practice of TFP (Table I4). High numbers of *H. meeusei, C. benghalensis, C. subulata, A. hispidum* and E. *indica* were found following OPFP and RIP. TFP tended to stimulate the emergence of *R. scabra and F. exilis.* Low numbers of some common species emerged following the use of OPHH, particularly *E. indica* and A. *hispidum,* compared to HH and OCHH. The weeding methods evaluated generally gave a similar level of weed control (Table 15) (Mabasa *et al.,* 1998).

Table 14. Effect of crop establishment techniques on weed biomass (g/m) at 4 weeks after crop emergence across soil types.

	Crop establishment technique			
Soil type	**TFP**	**RIP**	**OPFP**	**SED**
		***1996/97* season**		
Topland	47	78	69	7.6*#
***Vlei* margin**	56	64	52	11.9 ns
Vlei	188	216	214	23.1 ns
		1997/98 season		
Topland	20	54	38	13.0*
***Vlei* margin**	107	143	152	28.1 ns
Vlei	34	46	69	11.9*

* = P<0.05 ns = not significant at P<0.05.

Table 15. Effect of weeding methods on weed biomass (g/m^2) 4 weeks after crop emergence on three soil types.

	Weeding method			
Soil type	**HH**	**OPHH**	**OCHH**	**SED**
		1996/97 season		
Topland	72	52	71	3.8*#
***Vlei* margin**	52	56	64	24.6 ns
Vlei	214	192	216	33.3 ns
		1997/98 season		
Topland	40	36	*37*	13
Vlei **margin**	107	100	152	28.1 ns
Vlei	34	46	69	11.9* #

* = P<0.05 ns = not significant at P<0.05.

However, the poor performance of the draught animal weeding methods is largely due to the poor condition of the implements and their use. Implement assessment revealed that although some implements were less than five years old, most were substantially older with a number of ploughs and cultivators more than 30 years old being in regular use. Often parts were missing and farmers had little knowledge of maintenance or use. Only major parts were available in local stores, with running repairs being carried out only when absolutely necessary to ensure work could be continued. These practices have been confirmed to be fairly widespread throughout Zimbabwe (Chatizwa et al., 1997). Ripper attachments for ploughs and hilling blades for cultivators for ridging were not available. The lack of knowledge and non-availability of spare parts or innovative implements was seen as a major constraint in ensuring farmers are able to test and adopt the promising techniques.

Farmers have a deep understanding of the factors which need to be considered in achieving acceptable maize yields (Table 16). A number of tradeoffs have to be considered in achieving timely planting, good crop stands and acceptable levels of weeding with decision making largely dependant on access to resources. Timely planting in relation to periods of good seed-bed moisture are the key farmer criteria for selection of planting method. Category l uses the ox-cultivator supplemented by hand weeding. Category 2 rely largely on the hand hoe, but occasionally use the plough while category 3 farmers are restricted to the hand hoe. Availabilities of DAP, labour and appropriate implements are the key resources which guide farmers in selecting the crop establishment and weeding options available to them. Cat 1 households with the greatest access to DAP and labour seem prepared to accept that earlier weeding will be needed following planting into rip lines or OPFP, if this consistently allows more timely planting and results in a good crop stand. Those households with low DAP and low labour are less willing to accept the tradeoff and see TFP as less risky and more appropriate method of saving both DAP and labour. Such households are unlikely to benefit from these technologies, unless a reduction in DAP requirements associated with widespread adoption of rip or OPFP techniques allow more timely borrowing or hiring. Reduced or no-tillage techniques without increasing weed burdens remains a priority concern for category 3 households.

Table 16. Farmers' Perceptions of Crop Establishment and Weeding Method

Practice	Strengths	Weaknesses
Crop establishment		
Third furrow planting behind plough	Combines ploughing and planting, giving an overall saving in DAP and labour Ensures early weed control	Poor germination Higher labour and DAP than rip and OPFP
Rip or Open Plough Furrow Planting	Good crop emergence DAP and labour reducing Improves soil moisture retention Loosens plough pan Increases yields	Land has to be ploughed before planting operation Early weed growth between crop rows Seed may not be well covered
Weeding		
Hand hoe	Ensures clean weeding	Labour intensive and back breaking
Ox-drawn five tine Cultivator	Labour saving and fast for interrow weeding	Weeds must be small Crop damage
Ox-Drawn Plough with mouldboard	Labour saving, smothers weeds conserves moisture when ridges tied, promotes drainage in vleis	Crop damage May cause erosion if ridges are not tied

source: Riches *et al.,* 1998

Output 3. Soil water regimes and development of a soil water

This work has made use of both on-station and on-farm data collected under this project and associated projects funded from SRls Central Science Grant. To improve the effectiveness of crop production in these marginal rainfall regions, cultural practices which extend the period of water availability to the crop are essential. Unfortunately, little is known about the *in situ* hydrological properties of cultivated semi-arid soils in southern Africa. To help resolve the is situation during the course of this present project, detailed soil-water measurements have been made under a variety of conservation tillage/weed management systems to help explain the impact of the practices on crop yields and labour requirements (Table 1). We specifically investigated the hydrological and physical responses of three fersiallitic soils to conventional (flat) and improved (tied ridge) tillage practices (Twomlow and Bruneau, 1999) and gave special attention to the dynamic nature of soil surface characteristics early in the growing seasons. Previous work in sub-Saharan Africa having shown the importance of the first rain on soil-water recharge and subsequent crop growth (Vogel, *1993;* Harris *et at.,* 1994; Hoogmoed, 1999). *Key Findings have been*

- Irrespective of soil type the quantity of water present in a soil profile at the beginning of the following season depends on the combined effect of the amount and distribution of rain in the previous season, the crop grown, level of weed control and tillage practised.
- Generally tillage treatments that capture the most water are the wettest, however, the incomplete wetting up of pre-plant tied ridges early in a growing season frequently results in either poor crop establishment or a delay in planting.
- Conventionally tilled soils are more uniformly wet in the top 240 mm of the soil profile and significantly wetter than ridged structures early in the season.
- Furrows created by open plough furrow planting or with the ripper tine conserved more moisture early in the season than traditional third furrow planting and improved crop establishment.
- Mid season ridging with a plough, with the body attached, achieved efficient weed control and the ridges.

created increased water retention.

- Soil water regimes that develop under any tillage system are strongly influenced by the timing and frequency of weeding.
- In terms of crop water use, efficiency weeding at 2 and then 6 weeks after crop emergence performed, better than single weeding at four weeks.
- A weed management and water competition routine has been developed, to simulate the effect of weed management on crop performance. This routine has been incorporated in the PARCHED-THIRST crop growth model and calibrated with results from a 2-year weeding trial. The effects of weed competition on crop performance were assessed over a 30-year simulation period, for four levels of access to DAP and labour. The results demonstrate how sub-optimal crop management affects weed competition and crop production.

Long term monitoring has shown that at the end of the dry season, the quantity of water stored in the top 0.3m of the profile is negligible, typically below permanent wilting point (Twomlow and Bruneau , 1999). Yet, in the whole 0.9m of the profile the amount of water stored at the end of the dry season is more variable and depends on the combined effect of the amount and distribution of rain in the previous wet season, the type of crop grown and the tillage management.

At the beginning of the wet season, the recharge of the whole soil profile is of fundamental importance to subsequent crop establishment and can benefit from improved soil water storage in the previous season and tillage practices that help to catch the first rains of the wet season. In general terms the tillage treatment that impounds the most water (tied ridges) was the wettest, whatever the soil type, as long as the ridges were tied (Figure 2). However, the incomplete wetting up of the tied ridges early in the wet season, irrespective of soil type, frequently resulted in poor crop establishment or a delay in planting until the ridge structure was fully wetted (Bruneau and Twomlow, 1999; Twomlow and Bruneau, 1999). This was in contrast to the conventionally tilled soils, which were more uniformly wet in the top 200 mm of the soil profile and significantly wetter than the ridged soils early in the wet season (Figure 3). Although it is possible to establish crops in the furrow bottom of the tied ridge system on most soil types, the crop is prone to water logging in wet seasons, and a crop in the furrow bottom prevents the use of animal drawn weeders used by many smallholder farmers. Irrespective of tillage technique, good weed management is critical to maximize the availability of water for crop growth (Table 7 and 8).

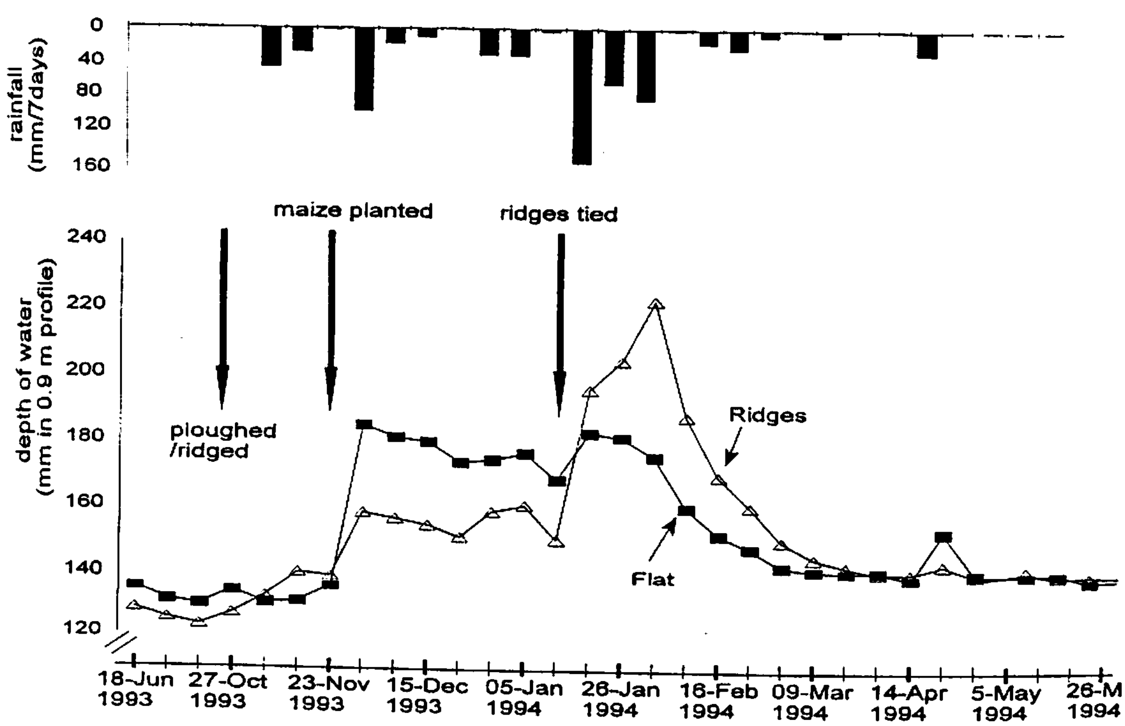

Figure 2 Seasonal fluctuations in soil water content (mm) of the Ntini Sandy Loam for a 0.9 m deep profile in response to flat (■) and tied ridge (△) cultivation for the 1993/94 season when ridges were tied late.

Unfortunately, computer simulation studies to date have often failed to relate crop responses to management restrictions and weed competition. To redress this situation, complementary PhD studies funded from SRI's Central Science Grant have used the soil water data base collected and developed weed management and water competition routine, to simulate the effect of weed management on crop performance. The routines have been incorporated in the PARCHED-THIRST crop growth model and calibrated with results from a 2-year weeding trial (Van der Meer *et al.*,. 1998ab, 1999ab)

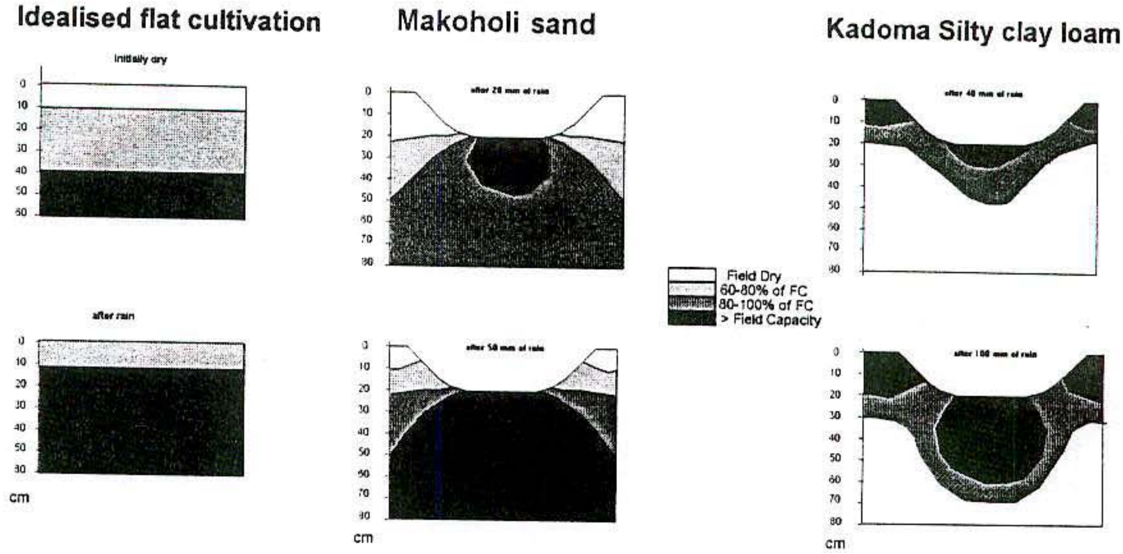

Figure 3 Progression of wetting fronts for a coventional flat system compared to ridges constructed on Makoholi sand and Kadoma silty loam from an initially dry state to a wet state

Table 17. Typical crop management scenarios available to farmers with different resources at their disposal. Winter ploughing takes place 21 days after the simulation indicates crop maturity. The four scenarios represent decreasing levels of weed control.

Farmer Category	**Winter Ploughing**	Planting	Weeding (weeks after emergence)	Reference in Text
Well-Resourced	Yes	Timely	2+6	WP 2+6
Medium Resourced	No	Timely	2+6	nWP 2+6
Poorly Resourced I	No	Timely	44	nWP 4
Poorly Resourced II	No	Late (21 days)		nWP 4 LP

The effects of weed competition on crop performance were assessed over a 30-year simulation period, for four levels of access to DAP and labour (Table 17) (van der Meer *et al.*, 1999b). The results demonstrate how sub-optimal crop management affects weed competition and crop production. The timely access to sufficient DAP and labour is particularly crucial during planting operations, as a delay in planting can severely reduce crop performance.

Yield effects of the four scenarios are presented in Figure 4. The difference in yields between the treatments *nWP 2+6* and *nWP 4* show the effects of the application of two weedings rather than one weeding operation. This effect appeared to be strongest during seasons with above average rainfall, and thus higher yields. Although the reductions in crop transpiration between these two treatments were limited (van der Meer, 1999), the predicted yields at the upper quartile showed a marked decrease from 1.85 to 1.44 ton.ha^{-1}. It was argued that because a well developed crop has a higher potential transpiration rate, it will be more susceptible to within-season drought spells. The increased rate of depletion of the soil profile, due to weed competition for soil moisture, is likely to increase the detrimental effects of intra-seasonal drought spells on crop production. While winter ploughing and weeding frequency did affect crop performance, the most pronounced reductions in crop yields were found to be the result of the delay in planting (treatment nWP 4 LP). The effect of the planting

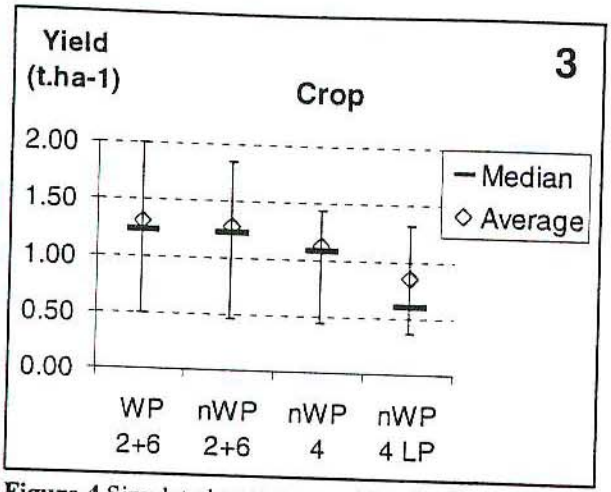

Figure 4 Simulated mean crop yields for four farming scenarios with different levels of weed control and land preparation practices. Error bars indicate the lower and upper quartiles

delay on annual weed transpiration was limited, but as crop establishment took place under sub-optimal conditions, crop development was badly affected. Furthermore, maturity was reached later in the season, and this increased the risk of experiencing an intra-seasonal drought. Weed control was limited as a result of the single weeding, and the additional water extraction by weeds further decreased the soil water availability to crops during such dry spells, leading to the simulated yield reductions.

Output 4. ***Project outputs have been promoted*** **through:**

- Annual reviews and evaluation field days with farmers, government and NGO extension staff.
- Options for tillage and demonstration have been provided by farmers leading to extension material being drafted and finalised in project R7085.
- Selected technologies have been promoted by the Cotton Training Centre
- 30 peer reviewed/edited papers, 13 unpublished reports/presentations and 7 project reports have been produced.

Contribution of Outputs:

The outputs of this project have contributed substantially towards the achievements of the Programme Purpose by ensuring that the Department for Research and Specialist Services, Agritex and NGOs have access to a range of efficient technologies that will permit more viable use of time or land which, depending on the livelihood strategy of particular farmers, might result in a reduced need for ploughing, a freeing-up of draught power, reduction of number of hours that women in particular spend weeding and a general improvement in the productivity of the system.

The direct contribution of the project outputs to meet the development need includes:

- ♦ introduction and adaptation of conservation tillage techniques for smallholder farmers;
- ♦ improved capacity of DR&SS and Agritex to carry out participatory research projects - also analytical and evaluation skills;
- ♦ training/workshops for farmers in the technologies;
- ♦ exposure of CARE field staff working with similar farmer groups to PTDA process and technologies;
- ♦ establishment permanent of farmer research groups in Sanyati and Nembudziya following completion of the project in those areas;
- ♦ the training of local artisans, notably blacksmiths, to support the technologies that have been developed.

To date the technological options developed with the farmers in this project have been incorporated into:

- ♦ the Cotton Training Centre Syllabus and 1998 Training Manual;
- ♦ the CIMMYT Maize breeding programme;
- ♦ DR&SS Weed Research Team and Institute of Agricultural Engineering research and dissemination programmes;

- Agritex staff in Sanyati and Nembudziya Districts are promoting the technologies;
- Presentations have been made to numerous local, national and international workshops;
- The technologies have been included with others under NRSP SAPS Project R7085 which developed dissemination materials on soil and water management appropriate to the needs of the farmer.

What is clear from this project is that there is no single method of soil and water management that will fit all circumstances to achieve sustainable agricultural production at the small holder level in sub-Saharan Africa. Each technology/option has advantages and limitations depending on the biophysical (soil and rainfall) resources, crops grown, availability of crop residues and manures, farmer resources and Farmers' diverse and complex criteria for decision making. However, significant increases in crop yields will only occur when improved conservation practices, for example conservation tillage, are combined with improved soil fertility management (both organic and inorganic) and effective weed management. Our research results also indicate that the performance of soil and water management technologies is highly dependant, not only on an extreme variability of the soils natural potential, but even more on the management capacity of farmers themselves. Unless smallholder farmers themselves help develop the understanding and skills required to manage their land in a way which combines production and conservation, the potential impact of all this knowledge and research will remain unfulfilled.

It is being increasingly recognised that farmers in sub-Saharan Africa often have a clear understanding of the interrelationships between the range of issues, including available household resources, which need to be integrated to achieve a good crop stand, and to grow a weed-free crop in synchronisation with available soil moisture . Rather than being prescriptive, researchers and extensionists need to work closely with farmers to explain more fully how and why a particular practice works, so that they are in a better position to determine for themselves what they can and can not afford to do. The risks and benefits of technology options can then be evaluated by farmers according to their criteria and their resources (Table 15). In southern Zimbabwe, for example, many farmers seem prepared to accept that earlier weeding, with greater draught and labour inputs, will be needed after planting into a rip line, so long as this consistently allows timely planting and results in a good crop stand. Although farmers are looking for technologies which ease labour and DAP constraints, they are prepared to accept certain tradeoffs to achieve the all-important crop stand with a minimum of risk. The success with which tradeoffs in the system and flexibility in management decision-making can be maintained as the season unfolds and weather patterns change, depend largely on a household's access to resources. Some *35%* of the communal farms in southern Zimbabwe, with only limited labour. and who either hire or borrow DAP from other families, are probably unable to respond to the changing soil moisture situation by weeding with a plough, for example, to conserve moisture on the dry sandy upland fields or to encourage drainage in the seasonally inundated valley bottom *vlei* fields. It is difficult to foresee how these resource-constrained households can benefit from the introduction of sustainable production methods, even those which involve limited modification of existing systems, without considerable financial support.

In addition to the above our work has identified the urgent need for further training of farmers on implement use, setting and maintenance as well the introduction of innovative implements such as rippers and sweep-tine weeders, which will require support from manufacturers and rural artisans.

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