Methodological Development in Linking Farmer Participatory Research with Simulation Modelling for Improved Resource Management and Productivity in Southern Zimbabwe

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Abstract: This report outlines a methodology whereby whole farm fertiliser and crop management strategies for maize based systems, are jointly developed and evaluated by communal farmer and researchers with the assistance of a simulation model. The decision making process by the farmers is documented and the management scenarios pre-tested using the APSIM (Agricultural Production Systems Simulator) farming systems model over a range of seasons to provide information on possible outcomes. With this information and increased farmer participation in developing plausible simulations, farmers and researchers are able to explore targeted options for the maximum use of scarce resources for optimal yields. This methodology is only in it's infancy, but provides a means to review and develop, alternative soil fertility technologies and the constraints to agricultural production in the low fertility, climatically variable environments of southern Zimbabwe.

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1. Introduction

Climatic risk is a major constraint to the development and adoption of improved technologies for smallholders in southern Zimbabwe. Farmers also face the challenge of cropping some of the poorest soils in the region in an economic environment where both fertilizers and labour are costly necessities. The CIMMYT/APSRU Risk Management project (RMP) in Zimbabwe has been exploring the use of crop simulation models to evaluate a range of options which offer farmers much needed flexibility in terms of both planting and agronomic management whilst maximizing yield. One of the project's principal aims is to use the indigenous knowledge of farmers to develop new soil fertility technologies, which reduce the adverse impact of climatic variation. A key part of this process has been the evaluation of these technologies with crop simulation models. This unique methodology of linking crop models to farmer circumstances and decision making, allows the rapid evaluation of different resource allocation scenarios for a wide range of climatic scenarios It also enables farmers to review and refine their own "rules of thumb" in decision making and the tradeoffs for different resource allocation strategies

The aim of this particular study was to pilot test a methodology whereby farmers developed plausible management strategies through group participation, these strategies were then evaluated in terms of yield potential using a crop simulation model. With these pre-tests of management options for different climate scenarios, farmers could be in a better position to make crucial decisions in the allocation of scarce resources for optimal crop production.

Firstly, farm level factors affecting farmer decision making for weeding, nitrogen fertiliser and manure management were identified. Secondly, the farmers idealised best fertiliser management practices were elicited through discussion. Consideration was given as to how farmers use their scarce resources on the whole farm faced with varying levels of resource constraints. Finally, these scenarios were evaluated in terms of production capacity by a crop simulation model and management strategies are re-evaluated in light of productivity estimates across the whole farm. A range of crop management and soil fertility options, responding to different climatic and soil fertility considerations can be rapidly evaluated by simulation models. The combined use of the two approaches (farmer participation and simulation) ensures farmers, extension and researchers develop a better understanding of the resource allocation tradeoffs around the farm system and start to promote the more efficient allocation and timing of scarce external resources.

2. Materials and Method

The RMP researchers worked within the smallholder farming community in Maraire Maraire (Latitude –19.83 degrees, Longitude 30.78 degrees, elevation 1204 masl) in Natural Region IV in southern Zimbabwe during the 1999/2000 season. Maraire is located in the centre of Zimuto district, north of Masvingo town. The area is characterised by inherently infertile sandy soils with low water holding capacities. Farming activities in the area are risky because of climatic variability and unreliable yields. These factors are further compounded by socio-economic factors, such as a lack of credit facilities, lack of draught animal power, the fluctuating cost of overheads and inadequate household labour.

A focus groups of 12 male and female farmers, members of a local NGO, Agritex, DRSS and CIMMYT worked together to explore, design and evaluate a variety of scenarios for allocation of scarce N fertiliser. This group represented farmers from a wide variety of wealth and resource categories.

2.1. Farmer land holdings and management

The average land area cultivated by the farmer focus group was 6.3 acres (2.5 ha) ranging from 9.4 acres (3.8 ha) for resource group 1 (RG1) to 3.5 acres (1.4 ha) for RG4's (Figure 1). The lower resource categories characteristically cultivated smaller areas of each land type with RG4s having a greater proportion of homestead fields and toplands than other groups. Most land preparation takes place from August through to December (Figure 2) with topland areas planted mainly in November.

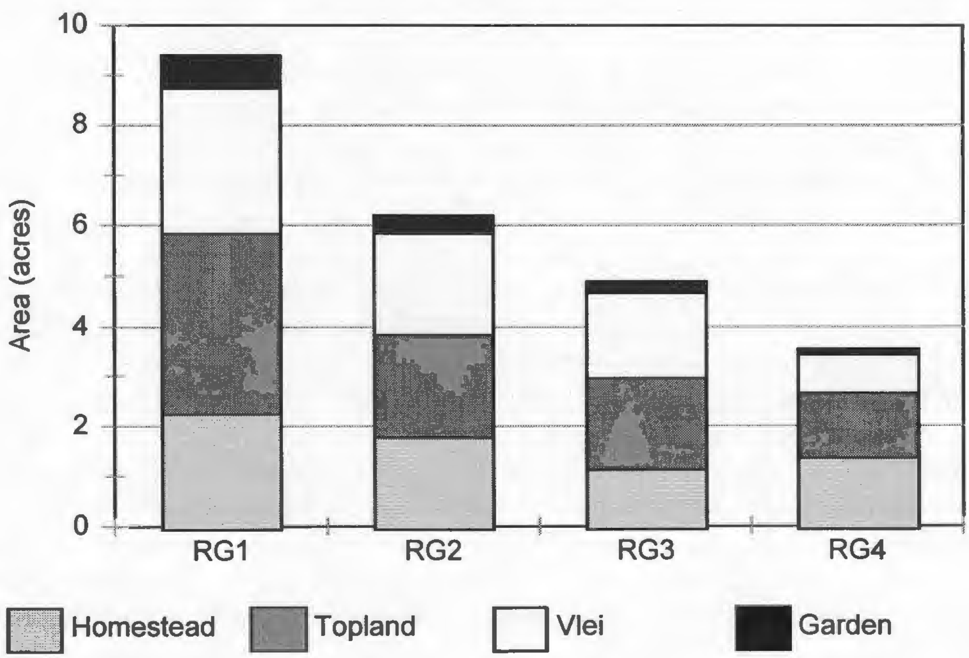

Figure 1. Land areas for resource category (median) in Maraire farmer group

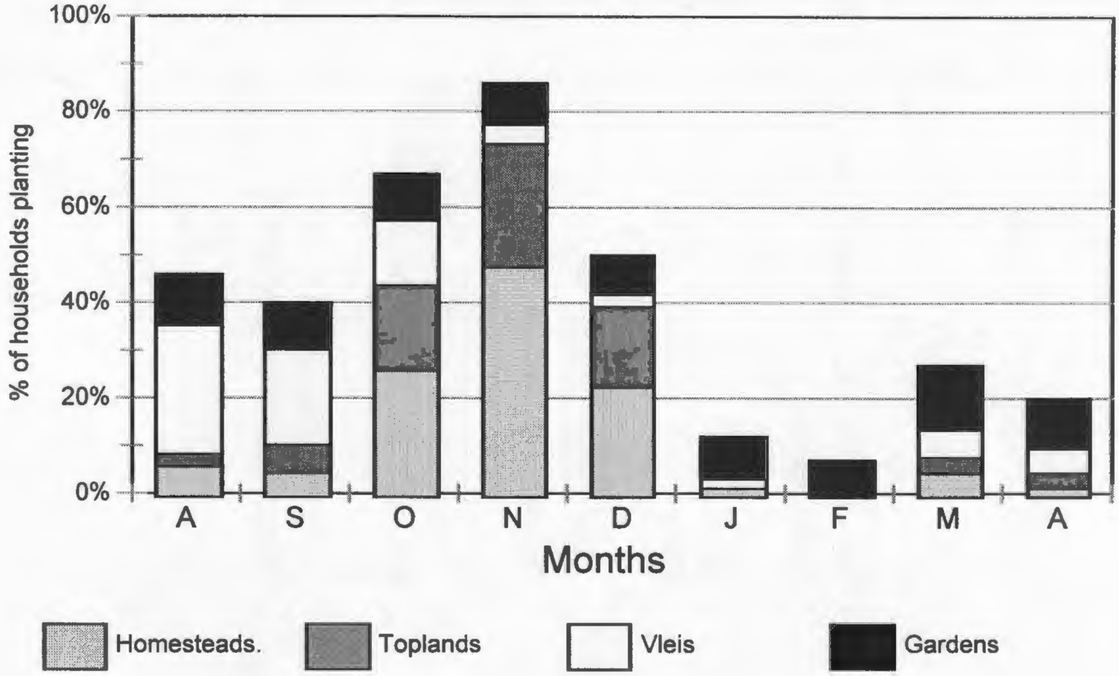

Figure 2. Land preparation on different land types

2.2. Farmer soil fertility practices

Households used a variety of soil fertility management practices (Table 1). Over 75% used a crop rotation on their homestead and topland fields, and some 50 % on their vlei lands. The main reason given for the use of rotations was enhancing soil fertility (95%). Other important considerations were crop diseases (28%), pests (23%) and weeds (14%). Application of soil fertility treatments was almost entirely confined to maize with other crops receiving no fertility treatment other than the residual effects of treatments supplied to maize. Lower RGs were less likely to use fertility management practices (Figure 3).

Table 1. Households using different soil fertility practices (%)

Fertility practice	Homestead fields	Toplands	Vleis	Gardens (summer)	Gardens (winter)
Rotations	77	75	52		
Manure	60	29	33	60	91
Anthill soil	18	7	7	69	81
Compound D at planting	32	20	18	51	83
Compound D at topdressing	10	6	4		
AN as a topdressing	73	39	38	72	78
Compost	43	7	3	55	90
Leaf litter	16	2	2	72	72
Lime	1	2	1	0	0

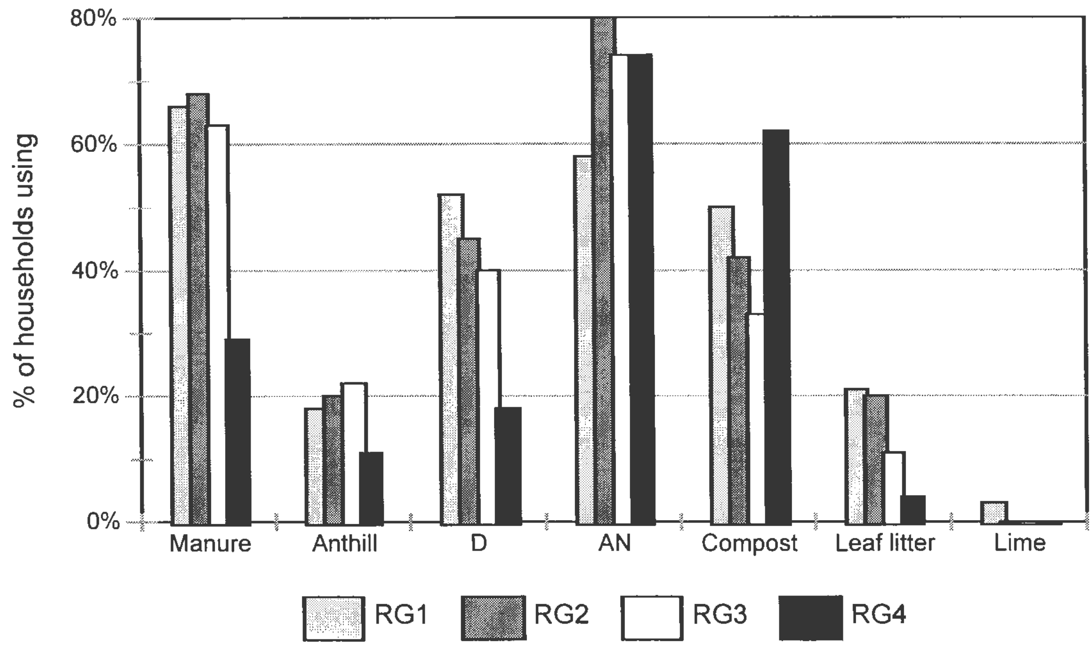

Figure 3. Fertility practices used by different resource categories

2.3. The participatory process

Throughout the season, researchers and farmers worked together in developing participatory resource allocation flow maps for a number of farms in the area (Figure 4), defining key field types, soil fertility and crop management practices. These maps were used to monitor where and when farmers allocate their scarce resources (inorganic and organic fertilisers, labour etc) around the farm system. Rates of fertiliser used and application methods as well as the field and crop type where monitored as where planting and weeding dates and recorded by farmers and enumerators on their own resource allocation maps.

The group then developed a contextual and idealised farm system based on their own maps and experiences, having been given resource availability specifications for a typical farming situation in the area (i.e. finite resources- labour, fertilisers, manure etc.) and asked to develop through discussion, alternative resource allocation strategies.

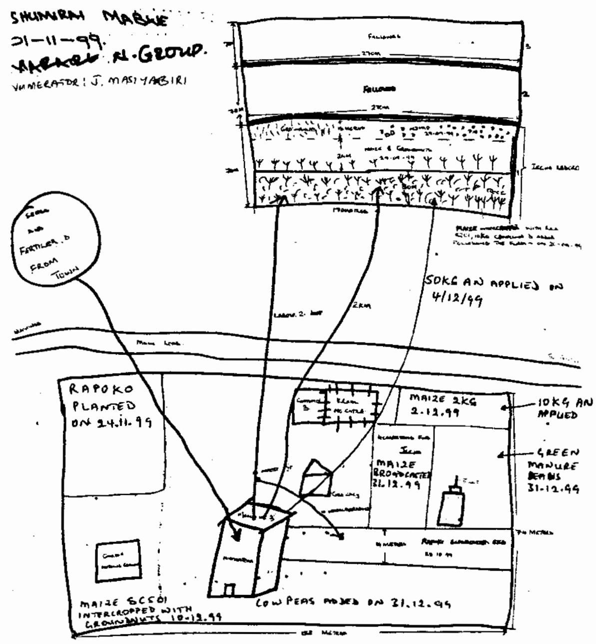

Figure 4. An example of a resource flow map developed by one of the participating farmers

2.3.1. The simplified farm system

The farm was specified as having four equal sized fields each measuring one-hectare. Labour and oxen for land preparation were limited such that only one field could be prepared every 20 days (approximately). A total of 7-10 scotch-carts (about 2 t) of low quality manure were available annually on the farm from the cattle kraal. The farm had a "base" fertiliser supply of one 50 kg bag of fertiliser, supplying in total 17.5 kg N. The farm only had sufficient in-house labour resources to weed two of the four fields.

Initially, the RMP team had specified all four fields as being topland fields with shallow sand of low carbon content. Through discussions with farmers on how realistic the farm specifications were it soon became apparent that farmers in this area have three main field types: vlei, topland and homestead fields. Vlei's constitute an important component of the farming system as their more favourable moisture status (due to their lower position on the catena) make them less vulnerable to erratic rains. It was therefore suggested that to make the farm settings more realistic, one of the four fields be called a vlei field and the rest topland or homestead fields.

The farm settings were then re-configured to take into account the different field types. After farmers had described and discussed in detail the simplified hypothetical farm system, they were then asked to discuss amongst themselves, how realistic the farm was to their local environment and where and why they would allocate the manure and a 50-kg bag of AN fertiliser around the farm system. They were first asked to list and discuss the variables they consider when allocating fertiliser and secondly, describe the variety of allocation scenarios they would consider and finally what was considered the best option. Two farmers (one male and one female) were separately asked to suggest the way they would best use the resources available at the farm.

2.4. Farming system simulations

After the farmers had outlined their different strategies, the APSIM (Agricultural Production Systems Simulator) model was then configured to simulate the productivity of the different strategies across a number of seasons. The model had been validated for production estimates in this environment in response to N fertiliser and weed competition. The climatic record used was that of nearby Makoholi for the seasons 1991/92 to 1997/98 (Figure 5).

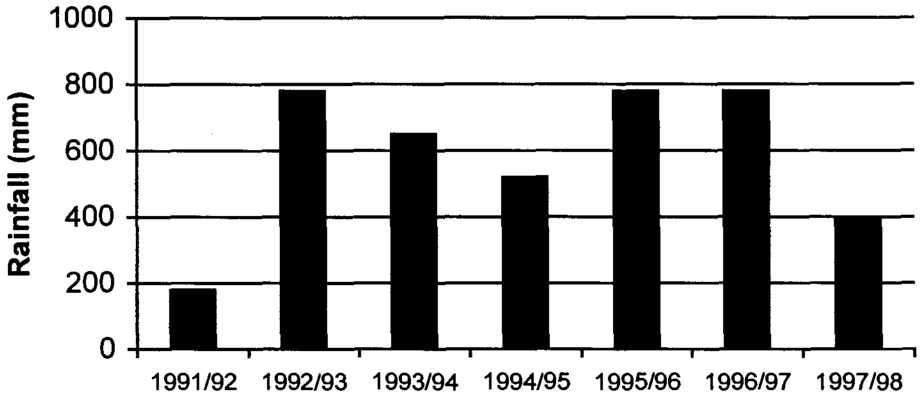

Figure 5. Seasonal variation in annual rainfall for Masvingo, Zimbabwe for the period 1991/92 to 1997/98.

3. Results

3.1. Farmer identified factors affecting on-farm management

Many of the variables effecting decision making by farmers are inter-related. Understanding the complex interactions between these factors make successful farm management all the more difficult. The key factors are outlined in the following sections.

3.1.1. Field type

Within Zimuto district there is a great deal of variation of soils across the catena. This together with crop management practices and soil types has resulted in a number of different field types, all of which receive different levels of resources and crop production practices. The distinction between and classification of field types is well recognised and used by farmers to classify different fields, and management operations revolve around the prioritisation of activities to different field types and plots. In Zimuto farmers identified three main field types namely vleis, topland and homestead fields. Table 2 summarises the main characteristics of these three field types:

Table 2. Field types and characteristics

Characteristic	Homestead Fields	Vlei Fields	Topland fields
Description	Mainly found on the upland areas. Soils comprising well drained, moderately shallow coarse to medium grained dark yellow/brown sands to sandy loams.	Shallow to moderately shallow poorly drained dark grey brown coarse grained to loamy sands. Dense soil layer observed on all vlei sites between 20 and 30 cm depth that may impede drainage and root growth.	Soils on the upper and mid slopes and crests with rock outcrops comprising well drained moderately shallow coarse to medium grained dark yellow/brown sands to sandy loams.
Location on Catena	Flat ground, close to homestead,	Wetter valleys, flat.	Top of catena, sloping to flat.
Soil fertility status	Medium, close to kraal and manure, compost, wood ash and homestead labour sources.	Highest, good soil structure but more weeds.	Lowest, often very depleted, poor soil structure.
Farmers resource priority	2	1	3
Water relationship	Better soil structure and water holding capacity. In poor rainfall seasons these soils are drought prone and may suffer severe leaching in wetter seasons.	Wet all year able to early plant- prone to waterlogging.	Low water holding capacity, high runoff. In poor rainfall seasons these soils are drought prone and can suffer severe leaching problems in wetter seasons.
Crop pattern and fallowing	Maize, groundnuts, bambara, rapoko and root vegetables. Often in rotations. Planted second. Rarely left to fallow as close to home and higher fertility status.	Primarily continuous maize but sometimes inter-cropped with rice. Rotations are rare. Planted first in season. Rarely fallowed as primary production unit higher, soil fertility status and wetter earlier in the season.	Maize, groundnuts, bambara and rapoko. Rarely rotated. Planted last if at all. Often fallowed anything from 1-15 years.

This variation in field types and soil fertility status results in farmers having different management practices, especially the timing and priority allocation of different soil fertility inputs, for different fields. Moreover, within a single field, farmers often have smaller management units or plots. Thus in one field type there could be numerous plots planted on different dates, to different crops or crop cultivars and receiving different levels of weeding and fertilisers. The fallowing of predominantly topland and homestead fields plays a key role in the farm system and is related to available household resources, soil fertility status, location, and distance. Rotations are practised but vary again by field type and farmer resource category.

3.1.2. Fertiliser management

The high price of fertiliser and lack of access to credit, coupled with a risky production environment, mean that fertiliser is a scarce commodity that few farmers can afford. Provision of information regarding the timely use and application of fertiliser could increase farmers' returns from this scarce resource. The RMP aims to develop simple rules of thumb, integrating farmers and researchers best practice, to provide farmers a sufficient knowledge base to be able to make the best use of their scarce N resources.

Farmers' rules of thumb for fertiliser management are variable by resource and wealth group. In addition, the farmer's level of knowledge and experience also have a major influence. It is thus difficult to come up with one composite guide relating to farmers' rules of thumb. However, there are some major differences between recommended Agritex practice and those commonly employed by farmers as outlined in Table 3.

Farmers are often constrained by the availability of fertiliser, either there is nothing in the shops or they do not have sufficient resources to purchase at the time when the crop needs it the most. Farmers are constrained by inadequate household finances or lack of access to credit that would enable them to procure and apply fertiliser on time. Often they have spent their household resources on other crop establishment factors such as land preparation and seed purchases. However, farmers have a hope value, in that they intend to purchase fertilisers during the crop season if sufficient finances become available.

Farmers will rarely have fertiliser sitting and ready to be applied when the crop requires it. A large proportion of the smallholder farmers apply fertiliser rates that are far below the recommended rates and they judge the amounts to apply by availability and plant health and needs. Farmers rarely use units of measurement and instead use their hands for application, and adjust rates depending on the amount in the bag and the field size, thus adjusting the rate up if they are within a field and finishing or down if they want to finish the field. In addition to this, farmers will target fertiliser to different plants within a plot e.g. those plants showing yellowing or looking sickly. Farmers will then purchase fertiliser for sick looking plants, or if its late in the season target the best plants that look as if they would provide the additional yield benefits derived from an increased fertiliser dose. This means there is often a great deal of in-plot variability in the rates of fertiliser

Table 3. Farmer fertilizer practices versus AGRITEX recommendations

Farmer practices	Agritex recommendations
Compound D Rates vary from 0 to 150 kg depending on farmer resources and field soil fertility levels, particularly if manure has been applied	**Compound D** Rates 150 – 200kg/ha
Application method • Make a hole, put fertilizer and maize seed and then cover with soil. • Banded in the furrow. • Most resource poor farmers apply fertilizer after crop emergence to avoid loss due to the risk of poor seed germination.	**Application method** • Make a hole or furrow, put compound D, cover with soil, put maize seed on top of the soil and then completely cover with soil.
Ammonium Nitrate: Rates vary from 0 to 150 kg depending on farmer resources and field soil fertility levels.	**Ammonium Nitrate** Rate is 250-300kgha
Application method • Weeding is undertaken when labour available not directly related to fertiliser application. • Application is based on crop color and appearance. Farmers tend to spot apply fertilizer to crops with a yellowish and purplish color rather than the whole field and apply post emergence for first application • Application in relation to other inputs, where manure, compost or churu has been previously applied, neither AN nor compound D is used on that field, probably for the first two years. Farmers will then use AN but not D for another few years. • Farmers apply by eye and hand across field area unmeasured, but estimated.	**Application method.** • No recommendations relating to weeding • Application- beside each maize seed or broadcasted. • Application in relation to other inputs, no Agritex recommendations exist for fertilizer application where other SF inputs have been used. • Recommended to use fertilizer cup size number 6
Timing of application • Farmers will apply in relation to rainfall and the quantity of fertilizer available and plant growth first at knee height and then at tasselling if AN available.	**Timing of application** • No recommendations currently available.
Farmer resource levels and rates • The application of fertilizers in terms of amounts differs between farmers and AGRITEX and even among the farmers themselves depending on fertilizer availability/cash, labour, knowledge, soil type, crop appearance, rainfall etc.	**Farmer resource levels and rates** • Currently one recommendation fits all, rates do not take into account the difference in farmer resource levels, nor the efficient use of fertiliser.

application. As for targeting of fertiliser, they will tend to concentrate on their earlier planted plots, of a higher soil fertility that are likely to result in the best yields. Farmers employ a number of different methods for application ranging from, broadcasting, banding in the furrow to splatter to spot application. All of these methods will affect the availability of the fertiliser for plant root uptake.

Farmers identified rainfall as a key factor for the allocation of fertiliser. Some farmers split their timing of fertiliser application especially if they have sufficient amounts and the rains are heavy. Most farmers are aware that fertiliser is less effective in very wet seasons due to leaching. The allocation of N depends, among other things, on field types and their inherent fertility. Thus, a farmer is unlikely to use his scarce fertiliser on a degraded top land field, when it could be applied to a vlei field, where its more likely to gain a higher return, or on those fields that have recently received kraal manure. The use of manure significantly affects crop growth; it has the effect of adding N and ameliorating soil acidity problems. Farmers will often not apply any Compound D fertiliser where they have previously applied manure in the last two years. Some farmers will come in with a mix of D and AN if they have missed the first application, in the hope that the mix of fertiliser will supply the needed plant nutrients.

3.1.3. Field preparation and planting dates

Farmers' biggest constraint to production within season has been identified as a lack of access to adequate draft animal power to be able to plough and plant early all fields and thereby take advantage of the first rainfall opportunities. This is key to success in areas characterised by low and erratic rainfall. If farmers can get a crop established with the first rains, the crop is better able to withstand mid season droughts and take full advantage of the first N flush. At the beginning of the rainy season cattle are in poor health and weaker thus it takes longer to plough and plant the whole farm until their strength is restored. Farmers will endeavour to plough and plant on the same day, following behind the oxen with the seed and then covering with the returning plough. In discussion farmers stated that the number of oxen they actually used in the preparation and sowing had an impact on timeliness of operations. Some resource rich farmers undertake winter ploughing. Farmers will plant the vlei field first as these are of a higher moisture status and they can plough and plant early. In addition most of the vlei fields are prone to waterlogging making them inaccessible for ploughing, planting and weeding if these operations are not done early in the season. Those farmer who lack access to cattle, yet have sufficient labour will dry plant by hand in the hope of early rains and thus making a good start in the season.

3.1.4. Manure

Manure is a valuable source of nutrients and a key soil fertility ameliorant that affects the allocation of inorganic N by farmers because of its well known residual effects on soil fertility. The amount and targeting depends primarily on livestock ownership (mainly cattle and goats) and access to labour and scotch carts to move the animal manure. Manure is often applied to the homestead field for ease of transporting and to the vleis as a primary production unit.

Under the simplified farm system manure was applied to a homestead field. Farmers said they would not apply Compound D to a field that received manure as the two act in a similar way. Farmers will also target their manure on one area and rotate every two to three years. They will also consider field soil types and fertility status as well as previous seasons yields.

3.1.5. Weed management

Timely weeding is a major factor affecting crop growth and yield. The following factors were identified by farmers as being key determinants as to timing and frequency of weeding:

1. Availability of labour.
2. Crop growth- state of competition and crops vigour.
3. Crop type. Some crops more difficult to weed than others.
4. Soil and field type- how weedy the field is and its priority as a production unit. The fields planted first tend to get weeded first. Vleis normally have the highest weed pressure.
5. Weather conditions. If it is too wet, farmers cannot get into their fields to weed and if too dry they may leave the weeds.
6. Access to draught animal power. Farmers from high resource groups will endeavour to use cultivators and draught animal power to assist in weeding operations if available.
7. Fertiliser applications. Farmers will try to weed before applying.
8. Weed type. Farmers are aware that different weed species may have profoundly different impacts on crop growth and they would tend to try and remove the problem weeds first.

3.1.6. Farm inputs

Farmers access to inputs such as seed and fertiliser is constrained by market and policy factors, e.g. sourcing seed of the right variety and at the right time is often a major constraint and some farmers resort to using saved hybrid seed. Farmers will aim to access resources throughout the season and will rarely have sufficient seed or fertiliser for the season already in store before the beginning of the season.

3.1.7. Rainfall and weather taxonomies

The amount and timing of rainfall affects the crop management practices such as ploughing, planting, weeding and fertiliser application.

Different weather conditions are experienced in the area. The most common are:

1. Rains start early and evenly distributed.
2. Rains start early with dry spells.
3. Rainfall starts late but evenly distributed, end early.
4. Excessive rainfall throughout the season.

5. Rainfall starts early, evenly distributed and then it becomes excessive.
6. Low rainfall throughout season.

Farmers characterise their cropping season into seven key stages of maize crop management and growth: planting, crop emergence, weeding (first, second, third, etc), fertiliser application (first, second, third, etc), tasselling, silking, harvesting. Based on farmer experiences, the amount of fertiliser applied at the earlier various stages will vary according to the prevailing weather conditions and crop performance (Table 3).

3.1.8. Farmer resource categories

This variable can be cross-referenced to the majority of the preceding factors. Farmer resource category is directly related to household size, access to draught animal power, labour and resource availability. The household size will affect resource allocation, as the farm will need to produce a certain amount of food to meet household needs. Thus, the area under maize is directly proportional to the household food needs and labour availability. There are a number of gender-disaggregated and age related crop management activities and farmers often face seasonal labour shortages as well as buy and sell labour depending on their resource needs and resource level status. Although broadcasting is much less labour intensive than spot applicatio, few farmers will broadcast due to the high cost and scarcity of fertiliser. They want to target it directly to individual plants adjusting rates up and down within a field to meet per plant nutrient demands. In addition, access to labour also affects land preparation and planting, weeding and harvesting.

Within Zimuto, there is a great deal of variation between the different types of farmers, especially their resource levels. During the 1999/00 cropping season participatory wealth ranking technique were used to identify the key wealth resource groups. The key variables that farmers and researchers used were number of implements and access to draught animal power (Figures 6 and 7). Access to draught animal power was seen as the key constraint as it affects the farmer's ability to undertake timely operations. Farmers that lack cattle are often unable to undertake their land preparation in time and often miss the optimum time of planting, especially if they are spreading resources around the farm system rather than concentrating in a given area or field.

Table 3. Maize growth & management stages and their relationship to rainfall distribution fertiliser applications and crop performance.

Stages	Rainfall starts early and evenly distributed	Rainfall starts early with dry spells	Rainfall starts late, evenly distribute ends early	Excessive rainfall through the season	Rainfall starts early, evenly distribute, becomes excessive	Low rainfall throughout the season
Planting	Planting is on time in October	Planting is on time in October	Some farmers dry plant, others wait for rains	Planting on time in October	Planting on time in October	Planting dependent on soil moisture
Crop emergence	Almost 90% maize crop emergence	Emergence is affected, especially if planted with compound D	Emergence on dry planted fields is below 70%	Maize germination is poor due to lack of aeration	Almost 100% crop emergence is achieved	Poor germination. Farmers gap fill once or more
Weeding	Weeding more than once and yields are likely to be higher	Weeding is at the first stage, there after its difficult due to wilting	Weeding may be done once	Weeding is difficult affecting maize growth rate and yields	Early weeding, with late weedings affected by the rains	Weeding dependent on appearance
Fertilizer application	Applied on time	Less AN is applied because of insufficient and variable rainfall	AN is not well timed because of the short period of rainfall	Resourced farmers apply AN more than once, with poor farmers avoiding possible leaching loses	Fertilizer application becomes difficult as rainfall becomes excessive	AN applied depending on moisture. Fertilizer applied when maize crop knee high, but may be late
Tasseling and silking	Crop tassels better	Yields are affected if dry spell coincides with either tasseling or silking	Tasselling and silking affected if farmers planted on toplands after rainfall	Silking is affected and cob size among most farmers is reduced	Maize planted early tassels well	Tasselling and silking are affected, leading to low maize yields
Harvesting	Harvesting is on time	Little is harvested	Less is harvested	Harvesting is low due to failure by farmers to carry out farm activities	Harvesting tends to be difficult	Harvesting is properly done if there are yields

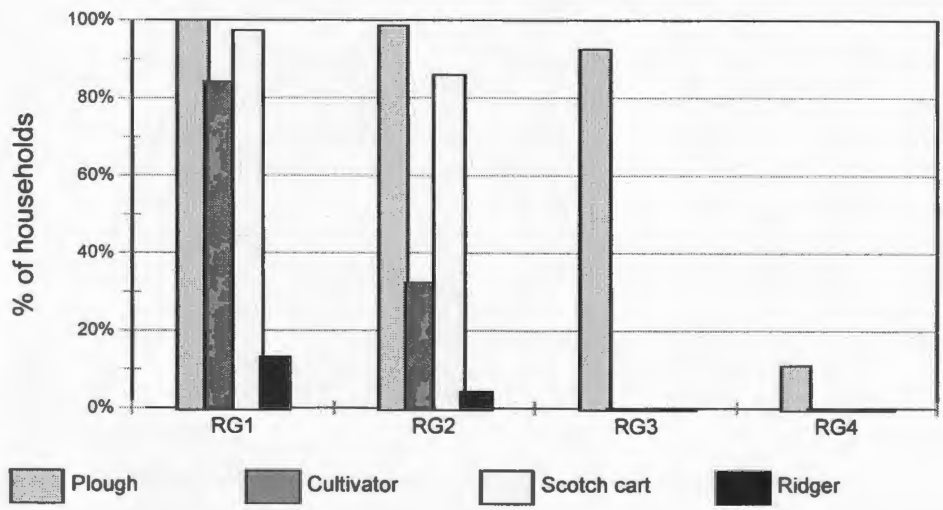

Figure 6. Implements owned by different resource categories

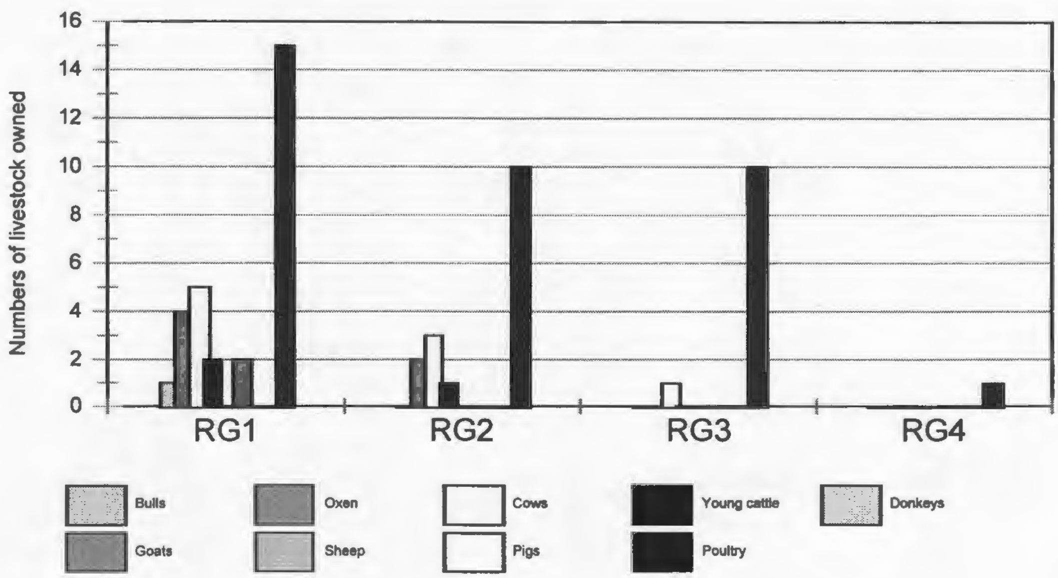

Figure 7. Head of livestock owned by different resource categories

3.2. Ability of the simulation model to duplicate on-farm management

3.2.1. Field type

The APSIM model simulates crop growth and development as point estimates in space and gives the output on a per unit square meter or per hectare. For the modelling of real on-farm situations it should be possible to extract the actual field sizes from the resource flow maps and thereby adjust the simulated outputs to the plot size. Of particular concern for modelling is how to deal with the water dynamics for vlei soils. Vleis constitute an important component of the farming system as their more favourable moisture status (due to their position on the catena) make them less vulnerable to erratic rains. In Zimuto, heavy rain leading to waterlogging of vleis is relatively uncommon. The model in its present form cannot handle the lateral inflow of water into these areas thereby making it impossible for us to simulate this critical component of the whole farm.

3.2.2. Fertiliser management

The ability of the APSIM model to simulate the impact of N fertiliser applications on crop performance and yield has been validated in the semi-arid region of Zimbabwe (Shamudzarira and Robertson, 2000). In the model, the assumption is that fertiliser is evenly distributed over a uniform unit area of cropped land. This is rarely the case in reality- at the worst farmers target specific plants within a plot and apply fertiliser to selected plants. An approach to simulating maize yield from a field that had fertiliser applied to some selected plants would be to run parallel simulations with variable rates of fertiliser application. The simulated yields can then be weighed by the relative proportion of the total field receiving the different amounts of fertiliser. The situation is further complicated however, by the fact that localised differences in soil fertility often occur in these fields (either due to presence of anthills, manure application to some parts of the field etc.) resulting in farmers targeting their resources to specific section of the plot. The model cannot directly handle these variations in application method but the initial soil conditions can be specified for individual areas and a similar weighting exercise as specified above could be performed. A balance has to be struck between the level of detail to be considered and the utility of the outputs.

Also, the model at present only considers the N content of the applied fertiliser such that an application of one 100 kg bag of Compound D per hectare yields the same results as an application of 8 kg/ha of urea. The impact of P, K and other nutrients in the applied material is ignored whereas these materials may have a very significant impact on crop responses, especially on the degraded granitic sandy soils typical of most smallholder areas in Zimbabwe.

3.2.3. Field preparation and planting dates

The model requires an indication of planting windows and tillage opportunities. This information is best gathered from the use of seasonal calendar timelines and problem causal diagrams. The model runs will then be constructed with realistic constraints on such agronomic issues.

3.2.4. Manure

The APSIM model has a rudimentary manure decomposition routine which adds inorganic N and P into the soil. Testing of this module has been ongoing in Zimbabwe through the ICRISAT CARMASAT project.

3.2.5. Weed management

The model handles weed pressure by using a generic short statured (maximum height 20 cm), non-N fixing weed species that is assumed to have multiple germinations throughout the season depending on rainfall. Different weeding dates can be handled by a more complex intercropping routine available with the model and water and nutrient constraints are then imposed on the crop as the weed utilises these resources (Keating et al. 1999). Weeding events can be specified with a resultant increase in resource availability. These events could best be specified through the use of seasonal calendars and revisiting the resource flow maps to come up with some generic rules of thumb or planting rules that are realistic for those farmer resource groups and region.

3.2.6. Farm inputs

This does not directly affect the model application but does affect the development of realistic scenarios and the interaction of management activities with farmer wealth groups. The empirical model used in this study is unable to capture the complex level of socio-economic resource input dynamics. However, the access to fertiliser and seed as a result of the household financial constraints and market changes can be indirectly factored into the simulation through the planting and fertiliser strategies specified for the model runs.

3.2.7. Rainfall and weather taxonomies

The model has been developed with climatic constraints on plant growth and development in mind. The soil water balance is probably the most well developed and tested routine of the APSIM model and its performance in response to variations in rainfall has been validated within the RMP (Shamudzarira et al. 1999; Robertson et al. 2000).

3.3. Farmer designed scenario options

For the simplified farm analysis and scenario development, the four fields were considered to different field types. Also farmers have within-field plot management practices in plots of different sizes. It is extremely difficult to get good estimates of the farmer's area under different crops and practices. The two farmers came up with slightly different strategies (Table 4). The female farmer opted to work three fields only and leave one of the topland fields fallow whereas the male farmer planted all four fields. By working three fields only, the female farmer was able to weed all three fields well (using labour saved from not preparing and planting the fourth field) whereas with the male farmer, only two fields were well weeded.

In the scenario developed by the woman farmer in this exercise, who is herself from a single headed household, the main consideration in leaving the fourth field fallow was a labour constraint. Through the labour savings she made in not working the fourth field, she was able to weed all remaining three fields. This is in contrast to the male farmer who opted to plant all four fields but was only able to weed two fields.

Table 4. Summary of the two scenarios suggested by the male and female farmers.

Field type	Male farmer	Female farmer
Vlei	• Plough early-August/September • Two weedings- late September and mid-December • No fertiliser, no manure	• Plough in September and plant maize • Two weedings- early November and late December • No fertiliser, no manure
Homestead	• Apply 2t manure on 1 acre in August • Plough in December and plant maize • Weeding- end of December • Apply 50 kg AN (all at once at the end of December) on the 1 acre that received manure	• Apply 2t manure on 1 acre in August • Plough in October and plant maize • Two weedings- November and December • Apply 50 kg AN (all at once at the end of December) on the 1 acre that received manure
Topland 1	• Plough in January and plant maize • No weeding, no fertiliser	• Fallow- land preparation and planting effort saved and used to weed the homestead maize field and the topland groundnut field
Topland 2	• Plough in December and plant groundnuts • No weeding	• Plough in November and plant groundnuts • Weeding- early January

3.4. Simulation of farmer scenarios

APSIM was the configured to simulate maize yields for an infertile sandy soil of low water holding capacity (Appendix 1 and 2). Maize cultivar SC501 was sown, conditional on rainfall, during different planting windows for individual fields at a plant population of 37 000 plants per hectare Amounts and timing of soil fertility input use on each field was dictated by the strategies devised by each farmer. In simulating production from the vlei fields, the soil water content in the bottom three layers of the soil were re-set to the drained upper limit when 50mm of rainfall was received within 20 days.

Grain yields for maize as simulated by APSIM on the topland field which had not received any manure or fertiliser are outlined in Figure 8. The 1991/92 season was a drought year with crop failure on both male and female farms. On the female farm, the yields ranged from 188 to 418 kg/ha over 6 seasons where rains were sufficient. On the male farm, yields ranged from 139 to 345 kg/ha. On average, the yield over 7 seasons from the female managed topland field was 42% higher than the topland field managed by the male farmer. In all years the female managed field outyielded the male managed field in this scenario.

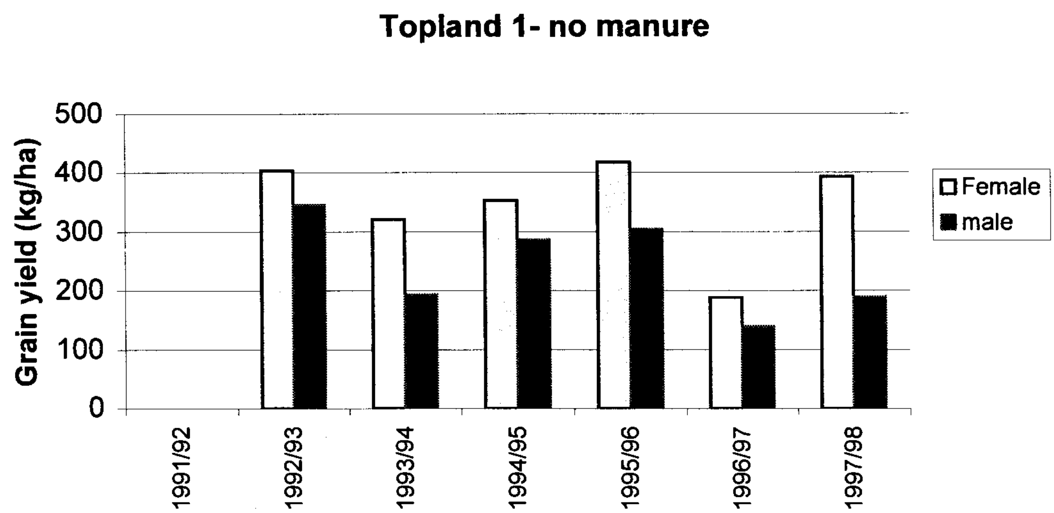

Figure 8. Seasonal variation of maize yields for the male and female-managed topland field receiving neither fertiliser nor manure.

Grain yields for maize as simulated by APSIM on the topland field which had received both 2 t manure and 17.5 kg N fertiliser are outlined in Figure 9. The 1991/92 season was a drought year with crop failure on both male and female farms. On the female farm, the yields ranged from 23 to 1273 kg/ha over 6 seasons where rains were sufficient On the male farm, yields ranged from 174 to 1171 kg/ha. On average, the yield over 7 seasons from the female managed topland field was 19% higher than the topland field managed by the male farmer. The male managed field was actually more consistent in yield performance, eventhough the overall average was lower. The lowest yield in the female field was 23 kg/ha, which was simulated in the 1996/97 season. The lowest yield in the male farmers field was 174 kg/ha, which was simulated in 1997/98. The female managed crop was established in early November and experienced severe N stress from flag leaf stage (in January) onwards whereas the male managed crop established in December did not suffer much from N stress during these periods.

Grain yields for maize as simulated by APSIM on the vlei field which had received neither fertiliser or manure are outlined in Figure 10. There was no significant difference in yield between the female and male managed vlei fields over the 7 seasons used in the simulation exercise (average 590 kg/ha). However, the simulated yields in the vlei fields in 1995/96 were much lower than expected based on data of Twomlow et. al. (personal communication) who conducted on-farm trials in the area at 16 sites during 1995/96 and 1996/97 and at 6 sites in 1997/98. Observed grain yields were 886 kg/ha at the wetland vlei sites and 1030 kg/ha on topland fields in the wet year of 1995/96 when half of the season's rain occurred over a week in mid-January 1996.

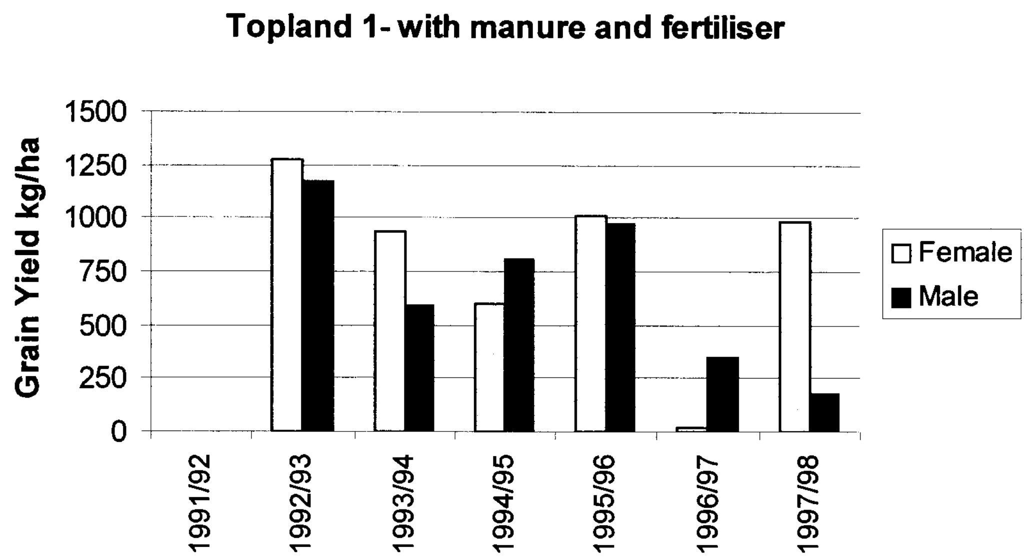

Figure 9. Seasonal variation of maize yields for the male and female-managed topland field receiving 50 kg of AN fertiliser and 2 tonnes of manure.

These low yields were attributed to waterlogging in the vleis. The model did simulate lower than the average yields in the vleis during that year (413 kg/ha), but was unable to reproduce the observed value. In 1996/97, an above-average season with rainfall well distributed within the season, the same workers noted that the topland fields yielded more grain (2998 kg/ha) than the waterlogged vleis (1270 kg/ha). In the drought season of 1997/98 however, they found that the wetland vleis yielded more (2481 kg/ha) than either the topland (1226 kg/ha) or the vlei-margins (875 kg/ha). The observed topland yields are consistent with the simulated well-managed female field in 1997/98, whilst the simulated vlei yields were the highest of the 7 seasons used in the analysis. It is apparent that the APSIM model can accurately simulate topland yields, as well as relative differences in yield in the vlei environment, but because of the complex water balance in the vlei area (i.e. lateral flow), the model requires further calibration in these situations.

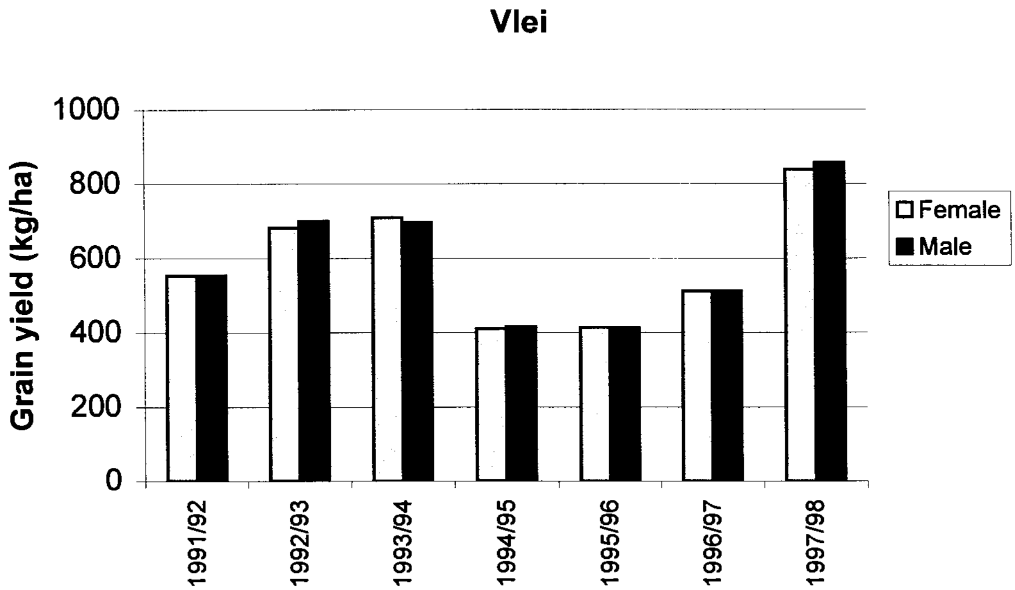

Figure 10. Seasonal variation of maize yields for the male and female-managed vlei field.

Total maize production from all fields for each of the 7 seasons managed by the male and female farmers as simulated by APSIM is presented in Figure 11. The male farmer's strategy produced on average 1408 kg grain per season, whilst the female farmer's management produced 1576 kg of grain, an increase of 12%.

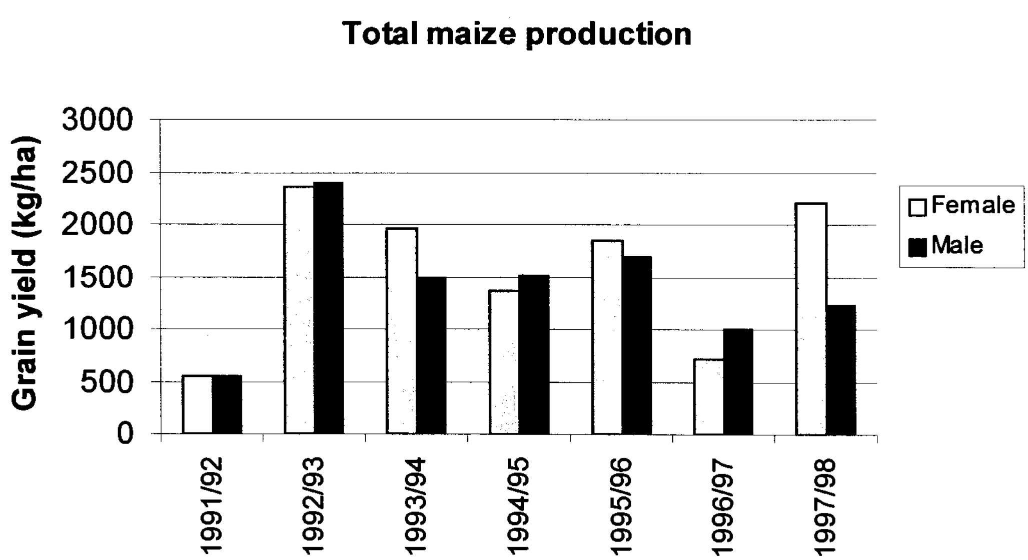

Figure 11. Seasonal variation of total maize production from all the male and female-managed maize fields.

Groundnut yields for the 7 seasons, for both male and female managed farms, are depicted in Figure 12. The average yield for the female managed farm were 449 kg/ha, 28% higher than the average value from the male farm (351 kg/ha). The simulated groundnut yields are much lower than expected based on the climatic resources they receive. There may also be other constraints in the system such as soil acidity, which APSIM does not currently simulate. Modification of the APSIM groundnut model to operate at a lower growth efficiency may overcome this problem in the future.

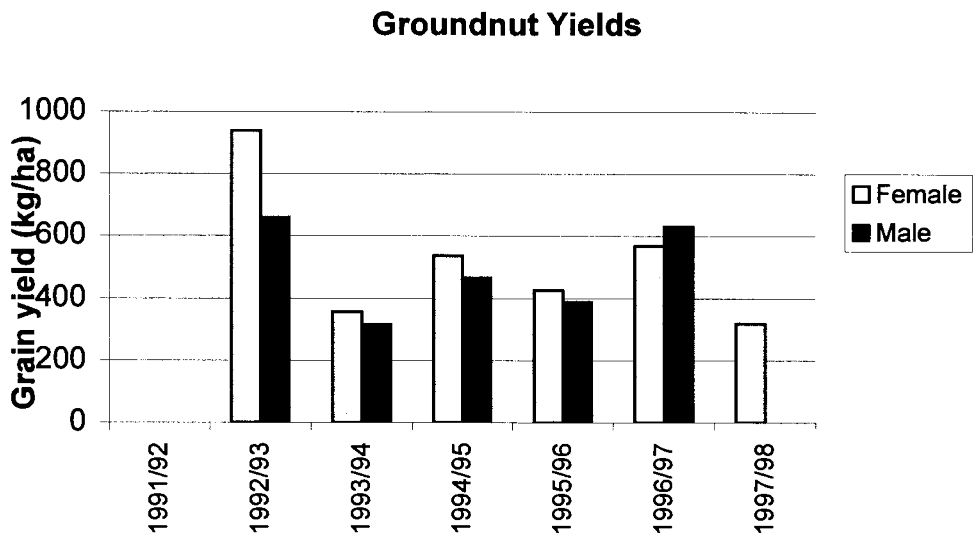

Figure 12. Seasonal variation of groundnut yields for the male and female-managed groundnut field.

3.5. Simulated outputs versus farmers perceptions

All the farmers in discussion (except for the male farmer who designed strategy one) said they preferred the second strategy (the female-derived one). Their reason for choice of strategy two was more efficient resource constraints, primarily the number of cattle and size of household labour. Undoubtedly given the different number of potential variables e.g. planting dates, fertiliser amounts and timing of availability, labour availability, field types and farmer types etc., a number of different scenarios could have been developed. Also the approach used in eliciting the scenarios will have affected and determined the final choices and outcomes.

4. Conclusions

This was the first attempt by researchers to explore the method for linking crop simulation model with farmers' logic. The involvement of farmers in the design and evaluation of scenarios is highly original. It is rare that model outputs are ever discussed at a field level and that farmers have input to design and validate their own, and alternate management scenarios. Whilst models are unable to account and predict all of the variables within a farm system they are able to demonstrate trends and predict a number of possible outcomes and options based on significant biophysical constraints being alleviated. Clearly, the APSIM simulation model used in the RMP is able to successfully predict the impact of interventions in N management (fertiliser, legumes and manure) on maize production. The degree to which we have been able to engage successfully with the farmers on evaluating management options is also dependent on our ability to isolate management issues that can be dealt with clearly and simply by the models. Continued development of the methodology described herein will greatly increase the utility of simulation and its impact on productivity in this region.

To improve this process a number of methodological findings need to be addressed:

1. Improved interpretation of model outputs or options to farmers through the use of resource allocation maps or the use of black or felt boards which enable flexibility in design as the season develops.
2. The full participation of women farmers enabled the discussion to be lively (e.g. the strategy as suggested by the woman farmer of a single headed household was more thought out and logical, clearly relating available resources to land area and production).
3. Research on gender desegregated activities for resource allocation would be useful to indicate common trends and themes in resource allocation by gender.
4. Due to the large differences in farmer resource levels and their allocation strategies, a means will be required in the future to ensure all the group members develop their own scenarios to ensure the needs of the entire community are met. This would best be done by clustering by resource group and field type and developing a number of generic and specific strategies for the coming season.
5. Focus group sessions with farmer groups based on their wealth/resource ranking in order to fine tune scenarios and alternatives and identify generic scenarios that are of relevance and are realistic of a broader target group.
6. To ensure readiness for the coming season, there is a need to pre-plan farmers' planting and crop management activities (and alternatives) with the resource maps and use the models to derive different N management strategies for application, location, splitting, and timing over a range of possible weather scenarios. Strategies can be constructed for individual farms or resource groups with similar field and soil types. Another option is that the simulations can be re-run and management adjusted as the season unfolds.
7. Fine-tuning the "width" of the planting, weeding and fertilising windows and their interactions by determining the relative sensitivity of each across a variety of field and soil types will also aid in the develop of the "rules of thumb" This can be explored with the use of seasonal crop activity timelines by farmer type and field type.
8. Testing of the simulated options for farmer validation and strategy reinforcement could be undertaken with split plots of model versus farmer practice.
9. There is a need to develop a system of evaluating the tradeoffs for different resource allocation scenarios. This could be further explore through the use of participatory budgeting techniques whereby farmers and researchers place values on the tradeoffs and complete partial budgets to consider the profitability and viability of each option.

References

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Appendix 1. Soil water holding capacity characteristics of the soil used in the simulations.

Depth	Unavailable (LL) mm	Available (SW-LL) mm	Max Avail. (DUL-LL) mm	Drainable (SAT-DUL) mm
0.- 150.	6.00	0.00	15.00	45.00
150.- 300.	10.50	0.00	12.00	45.00
300.- 450.	19.50	0.00	10.50	37.50
450.- 600.	19.50	0.00	10.50	30.00
600.- 750.	27.00	0.00	6.00	27.00
750.- 1000.	55.00	0.00	5.00	35.00
Totals	137.50	0.00	59.00	219.50

Appendix 2. Soil profile properties of the soil used in the simulations.

Layer	pH	OC (%)	NO3 (kg/ha)	NH4 (kg/ha)	Urea (kg/ha)
1	6.50	0.76	2.15	1.29	0.00
2	6.20	0.71	2.13	0.21	0.00
3	6.30	0.57	1.06	0.21	0.00
4	6.40	0.57	0.70	0.23	0.00
5	6.50	0.66	0.47	0.23	0.00
6	6.60	0.55	0.40	0.40	0.00
Totals			6.90	2.58	0.00