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Potential Technology and Research Needs for Rainfed Maize Production in Drought Prone Environments of Southern Africa

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Introduction

In southern Africa, semi-arid areas (here simply defined as areas with less than 700 mm but more than 350 mm of rainfall per annum) can be found from around 100 m to over 1,400 m above sea level. The semi-arid areas most important for maize production are found in the 800-1,250 m range of elevation. Maize is grown under semi-arid conditions in most parts of Zimbabwe outside of the northern central watershed, most of the interior of central southern Mozambique, in the lowveld of Swaziland, parts of eastern and northeastern Botswana, parts of southern Zambia (especially the Zambezi and Luangwa valleys) and parts of southern Malawi. In Zimbabwe, for example, based on data from the AGRITEX extension service, approximately 828,000 ha of maize was planted by smallholder farmers in semi-arid areas in 1986/87. This was approximately 64% of the total smallholder maize area in the country. The semi-arid areas are characterised by wide variation in the amount and distribution of rainfall from year to year. In most years, during parts of the maize growing season heavy storms occur and water is lost because of runoff; at other times in the season dry spells prevail. The development of technologies to cope with both the excess and shortage of water presents a major challenge.

A lot is known about technical requirements for producing sustainable, rather high grain yields (2.5 t/ha or more) of rainfed maize under semi-arid conditions in southern Africa. An optimum production package would include such practices as post-harvest ploughing, deep ploughing, the construction of tied ridges, planting with the onset of the first good rains or perhaps even dry planting, and the control of weeds very early in plant development. Inputs such as a shorter season variety, animal manure, and inorganic fertilisers would be used. The production benefits from most of these maize technologies have long been known (Metelerkamp 1988). However, very few of the technologies have been adopted at biologically optimal levels or even adopted at all by the small-scale farmers predominant in the semi-arid areas, and grain yields remain very low. Grain yields of 400-1,000 kg/ha have been reported in communal areas of Zimbabwe receiving 550-650 mm of rainfall per year at 800-1,000 m above sea level, such as Chivi and Mutoko (Rohrbach, 1987; Shumba, 1984). Yields from 0 kg/ha up to 200-300 kg/ha are common in the driest places where maize is planted.

Most agronomic research for the semi-arid environments of southern Africa has been done by disciplinary or commodity oriented researchers, sometimes working on experiment stations in higher yield potential, sub-humid environments. Such research concentrated on technical options designed to give high 'optimal' yields but neglected socio-economic aspects crucial to possible adoption by the resource-poor, risk-averse farmers characteristic of the semi-arid areas. Technologies have usually been evaluated solely in terms of production per unit area of land, sometimes per unit of water used, and rarely in relation to other resources such as labour or draught power requirements, which are also limiting, and often more limiting, under the extensive farming systems found in drier areas. Many of the current technologies have been found to have technical shortcomings when tested on farms.

On-farm research with a farming systems perspective (OFR/FSP) or farming systems adaptive research (FSAR) is a research approach that was designed to take into account farmers' priorities and circumstances in the development and testing of appropriate production technologies (Simmonds 1986, Merrill-Sands 1986, Collinson 1987). OFR/FSP and FSAR have been practised in some coun-

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1 An earlier version of this review formed part of 'Potential Technology and Research Needed for Rainfed Cereal Production in Drought Prone Environments of Eastern and Southern Africa', written with Joel Ransom, CIMMYT, Nairobi, and presented at the 'Workshop on On-Farm Research in Arid and Semi-Arid Regions of IGADD Countries', 23-26 May, 1988, Djibouti.

tries of southern Africa for almost a decade now. With the notable exception of Botswana, the main target zones for this research have been in the wetter, more productive environments. Relatively little OFR focused on the smallholder farmer has taken place in the important semi-arid environments of southern Africa, and the need for appropriate research for those areas remains.

This paper first reviews production technologies potentially available for maize crops grown by smallholder peasant farmers under rainfed conditions in the semi-arid environments of southern Africa. We look at the results of several types of research in southern Africa. Since water is the main physical constraint to farming in these environments, we examine technologies that improve the use of water. We also describe technologies that address other important constraints, including shortages of labour and draught power. The paper then suggests some research themes and approaches that need attention in the future if new technologies are to be more appropriate to farmers' needs, bearing in mind the resource base and economic conditions under which the farmers operate.

Available Technologies

Germplasm

There has been relatively little effort in southern Africa (excluding the Republic of South Africa) to breed maize for the drier environments. Instead breeders have concentrated on developing materials for wetter, input-intensive zones. This emphasis has changed somewhat in recent years with the realisation that large numbers of poor farm families depend on food produced under rainfed conditions in the semi-arid areas and that for many of those families maize is an important crop. However, most of the extra crop breeding for semi-arid areas focuses on sorghum and pearl millet, which are known to be well adapted physiologically to drier environments but have been found to have serious shortcomings for production and adoption.

Maize is a preferred food for most farmers in the semi-arid zones of Zambia, Zimbabwe, Malawi, Mozambique, Swaziland, and to a lesser extent Botswana. Farmers in those areas attempt to grow the maize materials that are currently available, which have long growing cycles and poor tolerance to drought.

A look at the portfolio of maize materials released for production in Zimbabwe, which has historically the strongest maize breeding programme in the region and large maize plantings in dry areas, shows just two hybrids, R201 and R200 (both three-way cross hybrids), as appropriate for the semi-arid environments (Whingwiri and Harahwa 1985, Metelerkamp 1988). These hybrids take around 120 days to reach physiological maturity at an elevation of 800 m, that is, they mature some 20-25 days earlier than the full season hybrid, SR52. They are also more drought tolerant. In on-farm trials in semi-arid areas of Zimbabwe in 1980/81-1982/83, these two hybrids yielded 32% more than SR52 (Whingwiri and Harahwa 1985).

The Zambian maize programme released three shorter season hybrids (MM501, MM502, and MM504) in 1984 (Ristanovic, Gibson, and Rao 1986). These materials are similar to R201 and R200 in maturity and drought tolerance. The very early maturing (90-100 day) open-pollinated variety, MMV400, is also available to Zambian farmers and is recommended for growing in the semi-arid Zambezi and Luangwa valleys.

Semi-arid areas in southern Africa have a relatively short (90-130 day) and highly variable rainfall season. Several often prolonged dry spells may occur during any part of the growing season. Farmers in these areas are very short of power resources and have to plant some of their crops well after the rains start, thus shortening the growing season further. In addition the soils are usually sandy, which increases the risk of yield loss due to drought. Maize breeding programmes in southern Africa are now placing greater emphasis on developing shorter season maize varieties to escape drought during grain filling and on breeding for characters that confer greater resistance to water deficits experienced during the growing season, as in Zimbabwe (see Olver 1987 and 1988), Zambia (Ristanovic et al. 1986), Malawi (Ngwira and Sibale 1986), and Mozambique (Nunes, Sousa, and Sataric 1986). In Zambia, Malawi, and Mozambique such materials will include open-pollinated varieties so that resource-poor farmers do not have to purchase new seed each year. Breeders in Zimbabwe are developing maize that can produce two ears at low plant population densities and still retain one ear at a high density (Olver 1987). This will reduce the detrimental effect of low plant population densities, which are common and often the result of dry spells during or shortly after crop emergence.

Plant population density

Since the most limiting natural factor in semi-arid regions is moisture, maize crops need to utilize water efficiently if rainfed cropping is to be productive. The best fit of evapotranspiration demand to the crop developmental cycle is vital. The rate of evapotranspiration from a crop is not only a function of atmospheric demand (temperature, humidity, wind speed, and other factors) but also of the number of plants per unit land area, the plant size, the plant leaf area, and the plant pattern on the ground. It is necessary to control plant population density, and to a lesser extent plant spatial arrangement, in order to match moisture input with the atmospheric demand for moisture over the crop cycle.

Little work has been done to determine appropriate plant population densities for maize in the semi-arid areas, presumably because the extremely variable amounts and distributions of rainfall over years in semi-arid areas causes the optimum plant population density to change with years. Such change is especially true with maize, which has a more determinate pattern of development than sorghum or pearl millet, and so is less able to compensate for sub-optimal plant densities by tillering.

Perhaps the most comprehensive attempt at developing recommended plant population densities for maize (and sorghum) in the semi-arid areas of southern Africa was made by the Dryland Farming Research Scheme in Botswana (DLFRS 1985, Jones 1986, 1987a and b). The DLFRS developed a set of optimum plant population densities for the maize hybrid, NPPxK64R, by applying a model of the relationship between grain yields and site rainfall from multilocational trials to long-term rainfall records. Their target populations for small-scale farmers ranged from 10,000 plants/ha in the southwest and extreme east of Botswana, where yields of below 500 kg/ha are normal, to 30,000 plants/ha in the wetter extreme northeast, where yields over 4 t/ha are possible (DLFRS 1985, Jones 1986).

Studies on maize plant population densities in Zimbabwe Natural Region V (which receives 300-500 mm rainfall per year) are few. Researchers at Chiredzi Research Station consider that a low plant population is required for these areas if some grain yield is to be produced in the drier seasons. They recommend 20,000 plants/ha (Jones, Nyamudeza, and Nyati 1988) but caution that their recommendation is based on only two seasons of research, both of which were unusually dry.

In the wetter semi-arid areas of Zimbabwe (Natural Regions III and IV, which receive an average of 700 mm down to 450 mm of rainfall per year), plant densities of up to 48,000 plants/ha have been reported to give the highest yield (Mataruka and Whingwiri 1988), although yields vary greatly from year to year with these densities. Nevertheless, for the popular hybrid, R201, there seemed to be little evidence to support adoption of plant population densities less than 33,000 plants/ha in those areas (Metelerkamp 1988). However, farmers typically use lower fertiliser levels and their weed control is poorer than in most of the trials on which these conclusions were based. This difference in practices suggest that a lower density may be appropriate for farmers.

Row spacing

Most work on row spacing has shown it to be relatively unimportant in determining evapotranspiration rates in maize crops. In the DLFRS work on maize in Botswana, very few row spacing effects were detected, with only small differences in surface evaporation and rooting in favour of a wide spacing. It seems it is the number of plants per unit area of land (and particularly the LAI) that is important in affecting water loss and not so much how those plants are arranged (DLFRS 1985, Jones 1986). This finding means that, within reason, farmers can use the row spacing most appropriate for their planting and weeding operations without reducing yields.

Crop establishment

Farmers working on either the widely distributed sandy soils of southern Africa (or the far less common, heavy, cracking clay soils) find it difficult to consistently establish a target plant population density for their maize crops. Establishment problems resulting in poor stands can decrease maize yield by 40-100% in Zimbabwe (Olver 1987). Three common reasons have been identified for low emergence percentages of cereals on sandy soils in the semi-arid areas:

1) Adequate moisture is not available in the seedbed over sufficient days to complete germination and coleoptile emergence

2) Seeds are unable to imbibe sufficient water even though water is present in the seedbed

3) Soil crusts impede coleoptiles from pushing through the soil surface (this problem is more severe on sandy loams and silty soils)

One way to address the problem of moisture shortage in the seedbed is to speed up the planting operation. In some semi-arid areas of Botswana, mechanical planters or combined plough-planters have been introduced to speed planting. The Evaluation of Farming Systems and Agricultural Implements Project (EFSAIP) in Botswana examined many implements of this type. Plough-planters need to be used with care since in some cases they have led to large reductions in seedling emergence (EFSAIP, no date).

The simplest approach to overcoming a shortage of moisture in the seedbed is to plant only with the onset of very good rains. Many times this solution is not viable because it often means that the farmer has to delay planting parts of the crop, which may result in lower yields. Farmers' problems with finishing ploughing and planting while the seedbed is wet usually result from resource shortages. Ways of speeding up emergence would expose seedlings to a drying seedbed for a shorter time and are another possible way of addressing the problem. Soaking seed for 12-24 hours before planting has been suggested for maize. Studies and farmers' experiences show that, although this procedure results in earlier emergence in some cases, there is a higher risk of failure if the soil dries out rapidly after planting. Seed that has not been soaked remains viable and germinates on the next good rains but soaked seed dies (DLFRS 1985).

Yet another approach to the moisture problem, shallower planting, aims to reduce the time the coleoptile takes to reach the soil surface but is also more risky under a hot sun and dry wind. Neither of these practices has shown sufficient promise. Ways of speeding up planting without sacrificing much accuracy in seed placement and soil covering are still to be developed.

Failure of seed to imbibe sufficient water is often the result of ploughing just before planting, a practice which on sandy soils can produce a 'fluffy' seedbed. A rushed hoe planting will often result in poor contact between the seed and soil for a large seeded cereal like maize. Tapping down each planting station with a foot just after placing the seed is effective, but takes additional time when large areas are being planted. A related problem is that placing fertiliser near the maize seed at planting can remove moisture from the surrounding soil and so reduce germination. This effect has been seen in numerous field trials on sands and is cited by many farmers as a reason for their normal practice of waiting until after seedling emergence before applying the basal dressing of fertiliser.

The problem of soil crusting can be overcome by breaking the crust just before emergence with an implement such as a spike tooth harrow or cultivator, or even a hoe. But the unavailability of implements or shortages of animal traction or labour may prevent farmers from performing this operation. Hill planting has shown promise as another way to facilitate the emergence of maize coleoptiles through a crusted soil surface (DLFRS 1985). Planting 3-5 maize seeds per hill is effective. Unfortunately, hill planting too can have disadvantages. More seed is needed. If most seedlings do emerge, extra labour is required to thin the plants. If plants in dense stands are not thinned then grain yields will be depressed. Even if hills are eventually thinned, the seedlings compete for moisture in the crucial early stages of plant development, leading to reduced plant growth and yield. Rather than thinning or adding more seeds, farmers may often prefer to plant more land, where land is not limiting.

Tillage

In semi-arid areas two major aims of tillage are to facilitate the entry of water into soil and to facilitate the growth of plant roots into the lower reaches of the soil where extra moisture may be held. The most common soil textures in semi-arid areas of Botswana and Zimbabwe are sands, loamy sands, and sandy loams. These soils have little or no crumb structure, are often compact when dry, and some are prone to crusting. Also, the compaction of undisturbed subsoils tends to impede root penetration. For the sandy loam soils of eastern Botswana bulk densities of 1.8 Mg/m^3 are common before tillage. This is well above the critical value for the growth of maize roots (Willcocks 1981). Thus, on the sandy and sandy loam soils some form of tillage is considered essential for crop production. Because draught power is usually in short supply farmers in semi-arid areas practice the minimal amount of tillage necessary to maintain good rooting and water infiltration. Shallow cultivations, such as a standard ox-drawn mouldboard ploughing, and cultivations associated with weedings, are normal.

Deep ploughing--The mouldboard plough has been used by small-scale farmers in southern Africa since the early decades of this century and is the most common implement for land preparation in semi-arid areas where farmers have draught animals. These ox-drawn ploughs are small and plough to a depth of 10-15 cm only. Deeper ploughing to 20-25 cm on hard sandy soils in semi-arid areas has long been advocated as a way of improving maize yields by promoting deeper rooting and thus improving access to water. Long term studies on the deeper ploughing of sands in Zimbabwe have shown yield improvements in maize fields of around 25% (Grant, Meikle, and Mills 1979; Ivy 1987) and similar results are available from Botswana (Willcocks 1981).

Since with deep ploughing reduced bulk densities persist below the soil surface for two to three years, farmers may have to deep plough only once in three years. Such rotational tillage systems, in which ploughing is done once every two to three years and reduced tillage is done in the other years, give only slightly reduced yields compared to conventional tillage but provide big savings in time and energy inputs (Norton 1987). Benefits would accrue for longer periods if extra crop residues could be incorporated, but that is unlikely in low output, extensive farming systems in which livestock are used.

Reduced tillage--To prepare one hectare of land with a mouldboard plough takes about seven times the time and about double the draught power required to prepare the land with a ripper tine. Prompted by the benefits to be had from deep ploughing and aware of draught power shortages, researchers have looked for methods of reducing the dependence of small-scale farmers on mouldboard ploughs. Chisel ploughs offer a way of deep ploughing with a lower power input and little loss of yield. However, the chisel plough requires a toolbar mounting and cannot be used for the combined plough-plant operation practised by many resource-poor farmers in dry areas.

To reduce tillage power requirements even further, various tillage systems restricted to the crop row have been tried. In Botswana, strip tillage has been used with the chisel plough for sorghum and maize (Willcocks 1981, DLFRS 1985). The chisel plough produces a narrow but deep (25 cm or more) disturbance of soil along the line of the intended crop row. The untilled inter-row space can act as a micro-catchment to channel additional water to the tilled strip. Yields are no different than with mouldboard ploughing but the main advantage of this system is the drastically reduced draught power requirement, estimated at just 14% of the requirement for mouldboard ploughing.

Similar work has been done with a shallower ripper-tine on post-harvest ploughed land planted with maize in the Chivi communal area (550 mm annual rainfall) of Zimbabwe (FSRU, no date). With tine tillage, crop residues are left on the surface. The residues not eaten by cattle allow more water to infiltrate into the soil and reduce water losses from evaporation. Over the short term the ripper-tine appears to have little direct effect on grain yield, but it has the advantage of reducing oxen owners' draught power requirement for land preparation and may allow non-owners earlier access to oxen. In turn this should bring forward the mean first planting date (and thus increase grain yields) for farmers who do not own oxen (Shumba 1989). The plough-planters mentioned earlier also reduce draught requirements.

Inter-row ripping during the first half of the rainy season is advocated as an alternative form of reduced tillage useful on soils with a capping problem and low infiltration rate (Norton 1987). Mid-season inter-row ripping can increase the rate of water infiltration into the main rooting zone, giving a quicker response to rain after drought and reducing soil erosion (Norton 1987).

Post-harvest ploughing--Delays in planting maize after the start of the rains are normal, and these plantings give reduced grain yields. A major reason for the delay in planting is that farmers need to wait until the soil is moist before ploughing. Post-harvest ploughing (otherwise known as 'winter' ploughing) in the early part of the dry season is an established technology that will reduce the time and energy needed to prepare the land at the start of the rains (e.g., Norton 1987) and allow planting to occur earlier (if little pre-plant tillage is needed) and into a firmer seedbed. In addition, it has been suggested that winter ploughing may eliminate weeds as a source of water loss by transpiration and that the resulting loose soil surface helps to reduce evaporation during the dry, non-cropping season spanning from about May to November. However, some reports indicate that benefits from the last two sources are only marginal at best. For example, EFSAIP in Botswana observe no difference in moisture at planting between land that was winter ploughed and land that was not.

Often farmers winter plough different small parts of their land each year; only a few winter plough most of their land each year. Farmers do not winter plough more land because:

1) Standing maize crop residues are a vital food for livestock. Farmers are reluctant to plough more crop residues into the soil, and collecting residues so that winter ploughing can be done, is labour intensive.

2) Many soils are hard to plough when dry. This is often the case even just after harvest. Farmers have insufficient draught power and cannot justify the excessive wear on implements.

Mulches

In semi-arid areas, between 20% and 50% of the total evapotranspiration from a crop can be lost in the form of evaporation from the soil surface (e.g., Fischer and Turner 1978, Unger and Stewart 1983). In a widely spaced crop like maize, losses are greatest during early crop growth when transpiration per unit land area is low (there is little crop canopy cover), when the soil surface is wet, and the soil is open to sun and wind. Rapid drying can lead to crop failure early in the season.

The beneficial effects and practicability of crop residue mulches have been well researched in Africa. Such mulches are widely used by farmers in wetter, more productive areas, especially where animals are only a minor component of the system. However, crop residue mulches are largely impracticable for extensive, low input-low output cereal production by small-scale farmers in the semi-arid areas, because only small amounts of plant residue can be produced per hectare per year in those areas and all of it is required for feeding livestock. Residues that are not grazed are consumed by termites before the start of the next rains.

Ridging systems

Ridging systems are designed to reduce the runoff of water from soil and to concentrate water infiltration into specific parts of the soil surface where it can be used by the crop. Numerous changes in soil microtopography have been tried in several projects in southern Africa. These include the construction of ridges and furrows of various widths, and tied ridges and potholes, all combined with plant placement. Rainwater runs down the ridges and concentrates in the furrows or potholes where it infiltrates slowly into the soil.

Trials have been conducted in the Chiredzi area of southern Zimbabwe to conserve and concentrate water using 1- to 2-m wide ridges with plants placed in the furrow (Jones et al. 1988). Over four years of trials the average grain yield improvement for maize was 15% over a flat planting which yielded about 1.5 t/ha (Jones et al. 1988).

In ridge systems, plant placement is important. Planting on top of the ridge can lead to poor emergence and poor crop establishment because of excessively high temperatures and dry soil (DLFRS 1985). In further trials conducted in the Chiredzi area, maize was planted on the ridge slope, to one side of the furrow. Planting on the ridge slope resulted in several beneficial effects compared to planting in the furrow:

1) The chances of poor germination and poor growth are reduced (as a result of periodic waterlogging caused by the concentration of heavy rainfall into the furrow)

2) Exposed hard pans and infertile subsoils at the bottom of the furrow (which are brought closer to the surface and rooting zone by ridging) are avoided

3) Weeding is facilitated

4) Ample space is created on the other side of the furrow for relay cropping should the season's rainfall pattern allow

Although ridging often gives higher yields on vertisols, sandy clay soils, and paragneiss, ridging rarely improves productivity on the sandy soils in dry areas of southern Africa (see Jones et al. 1988, Mataruka and Whingwiri 1988). Farming Systems Research Unit trials in Chivi, Zimbabwe, showed no significant maize yield improvements from ridging or tied ridging on sandy soils. The reason given for the poor performance was that, in years when rain storms are intense, excess water collects in the furrows (FSRU, no date). Ridges on sandy soils may be destroyed by rainfall and by livestock during the dry season. The poor performance of ridges on sandy soils may also be due to the low fertility of these soils (Jones et al. 1988) and their low water holding capacity.

Semi-permanent ridges with ties (which last for three to six seasons) have allowed yields similar to those obtained by conventional ploughing in Zimbabwe and have saved time and energy, except in the season when the ridges are created (Norton 1987).

Two disadvantages of ridging include the high draught requirement needed to construct ridges and the high human labour needs for cross-tying, which are made worse by the lack of appropriate implements for use by small-scale farmers. On the vertisols, the necessary 1- to 2-m wide ridges cannot be made by animal-drawn implements and a tractor is needed. This power constraint effectively prevents the widespread adoption of ridging by small-scale farmers who crop on heavier soils.

Intercropping

Intercropping maize is not a common practice of farmers in the semi-arid areas of southern Africa, and little research has been done on this topic. Reasons commonly cited for intercropping, especially the intercropping of cereals with legumes, include risk insurance, maintenance of soil fertility, provision of fodder for livestock, and the increased total yield or monetary/nutritional value of the intercrop components compared to a monocrop. While these advantages are real in wetter and more productive areas, recent research shows that intercropping has very limited benefits in more marginal semi-arid areas.

For example, in years of average rainfall in Botswana, intercropping cowpeas with sorghum will give the farmer some cowpea yield (up to 400 kg/ha) without reducing the yield of sorghum (approximately 0.5-2 t/ha depending on the rainfall season). This provides an increase of 24% in gross income, no difference in returns to the limited labour resource, and greater returns to the limited draught power (Lightfoot and Tayler 1987), but gives no appreciable increase in yield stability (Lightfoot, Dear, and Mead 1987). However, in drier years the land equivalent ratio can be less than one, and yield stability can decrease during the very years when it can be least tolerated (Rees 1986, DLFRS 1985).

Relay cropping

Metelerkamp (1988) states that relay cropping might be a more effective way of utilising the season to its fullest extent in dry areas. At Chiredzi in Zimbabwe, trials on relay cropping were initiated to see how land use could be maximised under the low cereal plant populations required to ensure some grain yield in drier years. Relay cropping can be useful in seasons where the first crop either fails from early drought or completes its cycle before the rain stops (Jones et al. 1988).

Because maize can be killed by early drought and, unlike sorghum, it does not ratoon, relay cropping is potentially a risk reducing technology for maize. Experiences in the Chiredzi area indicate relay crops such as pigeonpea, pearl millet, or cowpeas give useful additional yield one year in two. There is scope for further research on relay cropping in semi-arid areas of southern Africa, but given the short rainy seasons large gains in production are not to be expected. Indeed, it may be difficult for farmers to accept a chancy relay in many areas where at present cattle are allowed to graze fields soon after the first crop is harvested.

Weed control

Since weeds transpire a lot of water, their control is important in areas where crop yields are limited by lack of water. In many semi-arid, extensive production areas in southern Africa, farmers rely on animal traction to control weeds early in the season. These farmers often fail to remove the within-row weeds early since this can usually be done only with a hand hoe, but it is these very weeds cause the largest losses of maize yield (Metelerkamp 1988).

Soil fertility

The beneficial effects of rotations involving legumes and green manures were demonstrated as early as 1913 in Zimbabwe. Research on rotations, however, waned with the advent of cheap inorganic fertiliser (Metelerkamp 1988). The granitic sands in Zimbabwe are deficient in phosphorus and nitrogen and most studies have shown that the application of animal manure or inorganic fertilisers will improve yields (see Ivy 1987 and Metelerkamp 1988). Because of the relatively high cash cost of inorganic fertilisers, local sources of mineral nutrients, such as cattle manure, are highly prized by farmers. Cattle manure is known to give significant responses if applied in large quantities such as 5-10 t/ha. Under the 'Alvord system' 37 t/ha of cattle manure is recommended to be applied to a hectare of land every four years (Ivy 1987). Such application rates are clearly not sustainable given the relatively large holdings of arable land per family (1.5-4 ha) and low cattle numbers.

As well as improving soil fertility, manure and compost help increase water retention by soils. Extremely large amounts are needed to have much effect. For example, 45 t/ha of organic material are needed to raise the top 30 cm of the soil by 1% in organic matter.

One of the aims of the research work at Chiredzi is to minimise the risk of cropping in Zimbabwe Natural Region V by reducing the amount of purchased fertiliser inputs. 'Response farming' techniques (Stewart and Faught 1984, Stewart and Kashasha 1984), which use early rainfall events to decide on the amount of inputs (such as fertiliser) to apply, are being studied in some of the trials at Chiredzi. If rainfall during the early part of the season is unreliable, then little or no fertiliser is applied. The application of basal fertiliser is withheld until after crop emergence, ensuring that only those plants which germinate receive the fertiliser. More fertiliser is committed as more rain falls and if the crop shows reasonable growth and development. Usually only about one-third of the farmers' level of topdress fertiliser is applied by 30 days post emergence. The rest is committed only if crop development and rainfall are satisfactory.

Future Research Needs

In this final section we first look at some future research needs for specific maize technologies appropriate to the semi-arid areas. We then offer some general thoughts on elements of an effective approach to developing and assessing technologies appropriate for resource-poor smallholder farmers in the semi-arid areas.

Rainfall distribution

The amount of rainfall and its distribution during the season will interact with almost all the possible technologies to be developed. An understanding of the implications of rainfall distribution will often guide the researcher on which types of technology are appropriate and which are not. The analysis of rainfall distribution, using more than 10 years of data where available, should become routine for researchers before they embark on technology development for dry areas. Studies that zone rainfall and moisture availability are useful for breeders seeking to determine priorities within their breeding programmes for semi-arid areas. Simple manual and modelling techniques (e.g., Stern, Dennett, and Dale 1982a and b, Coe and Stern 1987) are available for agronomists to analyse and interpret rainfall data from localised research zones. Without a calculator, a very simple examination of 10-20 years of rainfall over 5-day periods, in relation to development of the maize crop, can be done to determine the percentage of seasons with adequate length and the importance of dry spells. This procedure has for some five years now been a standard part of OFR diagnostic training workshops given by CIMMYT in the Eastern and Southern Africa Region. These techniques are often used but their use needs to become routine. More comprehensive, country-wide analyses of rainfall data in relation to cropping (e.g., Hussein 1988 for Zimbabwe) are necessary once sufficient rainfall data are available from enough sites.

Germplasm

Experience in southern Africa shows that smallholder farmers adopt a relatively cheap input like improved seed very quickly when there are clear benefits from doing so in at least some years. Given the high cost and uncertain returns (i.e., high risk) of most other possible agronomic interventions, improved seed remains the most promising way of raising the productivity of maize in semi-arid parts of southern Africa. This argument assumes that further improvements in maize germplasm are possible. There is little to suggest that the maizes grown in semi-arid areas of southern Africa today are the best that can be achieved. Most researchers agree there is scope for improvement.

Given the high social acceptability of maize in most semi-arid areas more effort is justified in developing open-pollinated varieties and hybrids that offer the farmer a range of options--such as maturities--to choose from, combined with greater tolerance to water deficits.

There is no doubt that breeding for drought tolerance in maize, as in other crops, is difficult. However, progress is possible if a well-planned, well-focused research programme is set up to screen available germplasm in the relevant environments. Breeding techniques and testing sites have to be selected carefully. An example of the progress that can be achieved by such a well-focused breeding effort is described in Fischer, Johnson, and Edmeades (1983). Their work showed that significant improvement in maize grain yield under drought can be achieved through recurrent selection for drought tolerance using an index of several carefully chosen selection criteria. A specific trait that has shown great promise is a reduced anthesis-silking interval under a water deficit (e.g., CIMMYT 1988). As southern African maize breeding programmes progress, there is likely to be a shift towards such forms of selection for performance under marginal moisture conditions.

Other germplasm-related research issues for maize in semi-arid areas worthy of further investigation include:

1) Breeding for specific traits likely to improve seedling emergence and stand establishment, e.g., the ability of seedlings to emerge from depth, tolerance to low seedbed moisture and a weedy seedbed, and the ability to produce more than one ear in a wet year or at low plant population densities and one ear in a dry year. This is a way of buffering against widely varying plant population densities.

2) Improving the efficiency of nitrogen fertiliser use through breeding.

3) Conducting comparative studies on the worth to the farmer of maize vs. sorghum; such studies are overdue for the drier areas. The relative worth of the crops may change as new sorghum and maize varieties become available.

4) Before releasing promising varieties, more testing is needed on farmers' fields under their management and inputs, and with farmers' assessments of the varieties' worth.

OFR can help identify which varietal characteristics are preferred by farmers and may offer guidance to breeders on the types of traits for which they should breed. For example, in Zambia the Eastern Province Adaptive Research Planning Team showed that two maize hybrids, MM502 and MM504, give higher, more stable yields than other currently available materials in the hot and dry Luangwa valley. The team also showed that the open-pollinated variety, MMV400, has a place in the area--not because it yields better than farmers' existing materials (which it does in only the driest, shortest rainy season years)--but that its early maturity provides food during a mid-rainy-season hungry period (ARPT-EP 1987). The same team identified that farmers wanted sorghum with a harder grain because of storage difficulties with soft grain types. This information was relayed to breeders who have now started work to develop the needed hard grain materials.

OFR can show that major improvements in yields are still possible in semi-arid areas of southern Africa through the introduction of more appropriate varieties. For example, OFR/FSP trials with sorghum carried out over three years in the mid 1980s in the Siabuwa Valley area (650 mm rainfall per year) of Zimbabwe indicate that the replacement of long season local materials with improved shorter season varieties would increase yield by up to 62% under farmers' management and inputs (Chiduza 1987). Observations from farmers' fields indicated that shorter season materials could double the yield in the driest years and thus increase the stability of production over years. That work also emphasised the need to introduce materials that conform to farmers' preferences for food taste and grain colour. Semi-arid areas need more work of this type in which technical factors are merged with farmers' preferences and economics, based on their circumstances.

Plant population density

In addition to breeding work to introduce plasticity in the production of ears per plant, long term studies (done over 6-10 years) are still required to determine the best maize densities for 1) maximum stability of yield for subsistence farmers and 2) long-term maximum output for farmers growing maize as a cash crop. Such studies will become more necessary when new varieties are released.

Simple modelling approaches, such as those employed by Jones (1986, 1987b) in Botswana, are valuable now to develop appropriate plant population densities from rainfall data. More complex, computer-based simulation models (see Jones and O'Toole 1987), will be useful after they have been validated for southern Africa.

Crop establishment

Apart from the work on improving the crop establishment abilities of germplasm, an examination of the interactions between seed placement and the timing and amount of rainfall, in relation to planting date for different soil types, needs to be carried out.

Decision making guidelines are necessary for farmers who need to plant on drying seedbeds. These guidelines should be based on research experiences under farmers' conditions. Some good work of this type has been done by EFSAIP in Botswana for sorghum, but more is required for maize.

Soil fertility and water holding capacity

Monitoring how soil fertility is being degraded as well as the rate of degradation under continuous maize production in semi-arid areas (especially those with sandy soils that are tilled regularly) will merit attention. Recently there has been much interest in sustainable cropping systems that are characterised by high internal cycling of mineral nutrients and the conservation of organic matter in the soil (see Dumanski 1984 and Ingram and Swift 1989). While benefits from such effects in semi-arid areas are likely to be considerable, it is not clear how those effects might be achieved. For example, is agroforestry, or widespread intercropping of cereals with legumes, to provide high levels of mineral nutrients and crop residues, practicable in semi-arid areas where short-term benefits from such systems are slight at best? Agronomic (and socio-economic) research is needed on these questions and should examine other possible ways of cycling mineral nutrients and preserving soil organic matter in semi-arid areas.

Long-term studies (6-10 years) are needed on the benefits from returning raw crop residues, manure, and composts to the soil in semi-arid areas. Work should concentrate on the amounts required, efficiency of utilization, and on distribution strategies. For example, do repeated inputs of manure on a small part of a farmer's arable land represent the best strategy to build up water holding capacity and fertility, or would it be better for the farmer to apply small amounts over the whole land area each year?

Better designed fertiliser response trials are needed to look at low levels of nitrogenous and phosphorus fertiliser and manure use under farmers' management, from both the biological and the economic viewpoint and in relation to the use of crop residues. Response farming concepts could be developed further.

Most of the sandy soils under review are acidic (a pH range of 4.2-6.0 with $CaCl_2$ extraction). In Chivi, an area typical of large parts of Zimbabwe that are marginal for growing maize, most of the granitic sands have a pH below pH5 (Shumba 1985) on lands that have received no nitrogenous fertiliser or only some 20-40 kg N/yr for less than 10 years. Experiments are needed to test the yield losses that now occur because of this acidity and the losses likely to occur in the future with the continued use of acidifying nitrogenous fertiliser.

Planting date

More emphasis is required on ways that farmers can bring forward the planting date of their late plantings of maize, coupled with the introduction of earlier maturing, fertiliser efficient cultivars.

Given the resource constraints of farmers in the semi-arid areas, the high risk involved in cropping there, and the areas planted to maize (around 1-3 ha), many farmers will continue to plant some of their maize crops late. Thus, there is also a need to develop agronomic technologies specifically for late planting. This will mean an emphasis on developing shorter season materials and also on developing materials that can establish in wet soils and on weedy seedbeds and that can tolerate lower levels of irradiance. Modified plant population densities and fertiliser levels may also be needed for the later plantings.

In some of the sub-humid areas of southern Africa, such as Natural Region II in Zimbabwe and in southern Zambia, late plantings (6-10 weeks after the rains start) of part of the maize crop are normal. Late-planted maize grows in an environment with a rainfall amount and duration similar to that found in semi-arid areas. Studies are required to examine the degree of similarity between useful technologies for semi-arid areas and for late planting in sub-humid areas.

Ridging

The development of ox-drawn and hand-operated equipment for making ridges and ties should receive greater emphasis. Power requirements--for draught animals, tractors, and human labour--need to be considered before and during an experimental programme, not after. How can the adverse effects of excess rainfall with tied ridges be reduced?

Weeding

A quantification of losses to be expected from weeds is required in semi-arid areas. It is important to look at low cost, low labour requirement methods of controlling weeds within the crop row, e.g., by the banding of granular herbicides.

Soil insects

Termites can devastate maize in preference to sorghum or millet by attacking roots and stem bases from silking onwards, especially in lowland areas of southern Africa. Work to determine the frequency and extent of losses under smallholder agriculture is needed.

Crop-livestock interactions

Crop-livestock interactions are very important in semi-arid farming systems but very little research has been done on them to date. Grain is not the only output from maize that is important to small-scale farmers in semi-arid areas. Since cattle form an essential component of their farming systems, farmers are interested in ways of providing their animals with more fodder, particularly during the dry season. There is a need to do more work on the uses of maize stover as cattle feed. Ways of providing more dry season feed for draught oxen need to be studied, such as undersowing forage legumes in maize or alley cropping. That should bring forward planting dates and increase the land area under soil ridges. However, it is difficult to establish most fodder crops in the dry years when they are most needed.

Economic evaluation

In most cases we do not know what economic benefits farmers would obtain if they adopted the technologies described here. Economic analyses of technologies for semi-arid areas and assessments of risk are required urgently, particularly for technologies involving costly inputs. For example, whereas yield responses to high doses of N fertiliser (over 100 kg N/ha) can be demonstrated with maize in the semi-arid areas of Zimbabwe in wet years, recent economic analyses suggest that only very low levels of fertiliser (approximately 30 kg N/ha) are economic and basal dressings applied in the form of an NPK compound fertiliser are uneconomic (Whingwiri et al. 1988, and Mataruka, Makombe, and Low 1988). Analyses should be updated periodically to make sure recommended practices continue to benefit farmers.

Adoption studies

Studies on the farmers' adoption of technologies for maize are long overdue in the semi-arid areas of southern Africa.

A research approach

Given the relative ease of finding reasons why farmers in semi-arid areas cannot, or will not, adopt technologies, one might despair of most technical innovations ever being used by those farmers. The challenge for maize crop researchers is to develop and adapt appropriate technologies that address the production problems of farmers in semi-arid areas but which are practicable and economical given farmers' circumstances. Such technologies will stand a chance of adoption.

A key point to remember about appropriate technologies is that they will more often than not be non-optimal technologies when evaluated for grain yield or total dry matter produced per unit time. As mentioned earlier, in semi-arid areas land is rarely a major constraint. Shortages of water and draught power or labour (for weeding) are more critical. Farmers are likely to be more concerned with ways of ensuring that crop production does not fall below a minimal level required for subsistence or in getting better returns to draught and labour. The EFSAIP and the ATIP projects in Botswana are among the very few that have evaluated technologies in these terms. More work of this type will be necessary in other parts of southern Africa.

Another important point about a research approach is that small-scale farmers in semi-arid areas are not all alike. Researchers need to pay much more attention to targeting technologies to specific groups of farmers. This is clear from EFSAIP work on planters and plough-planters. A particular model of planter was found to offer major advantages only to a specific grouping of farmers with a certain level of cash, oxen, and land (EFSAIP, no date). The technologies developed will also have to be compatible with longer term issues related to the sustainability of production, which is often perceived by farmers as marginally important, but which is nevertheless critical to farmers' future welfare.

The complexity of the issues to be addressed means they are beyond the scope of commodity, disciplinary, or on-farm researchers working alone. An integrated form of problem-oriented crop (and livestock) research and extension is necessary. Extensionists and on-farm researchers will increasingly have a role in directing the more basic breeding work, pathology, entomology, soils, and agronomy research to the important real technical (and sometimes non-technical) problems that need to be addressed. In turn, on-farm researchers and extensionists will have to be more fully integrated with appropriate, basic experiment station research if they are to test and adapt it to farmers' needs. Only this kind of approach will stand a good chance of ensuring that farmers' maize production problems and their causes help determine appropriate technical research priorities, so that experiment station and on-farm research can better address the difficult constraints found in semi-arid areas.

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