Management of extensive farming systems for drought-prone environments in North America and Australia

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Abstract
The dryland cropping areas of North America and Australia share many common features, including crops, soil properties, farm size, and most importantly high variability in rainfall. Farmers in both regions have achieved extraordinary levels in productivity by adopting technologies and farming practices that maximize water and nutrient (nitrogen) availability for crop production and that minimize the cost and risk associated with cropping. When soil fertility is non-limiting, crop yield and water supply follow a linear model. Similarly, nitrogen and other macronutrients are proportional to crop growth and, hence, the crop water supply. This paper discusses the role of water supply on crop yield and describes how farmers, managing extensive dryland properties in North America and Australia, utilize improved tillage, residue management, plant arrangement (row spacing and plant population) to optimize the crop water supply and fertility to minimize production risk.

Media summary
Managing crops in drought-prone environments of USA and Australia requires farmers to pay careful attention to the crop water supply. Their first option is irrigation. If sufficient water is available at reasonable cost and appropriate quality attention is focused on maximizing conveyance and application efficiencies and optimizing application timing and amount. Rainfed, those without irrigation, must focus their efforts on using practices that conserve precipitation and maximize the soil water supply for the crop. Over the last 20 years new: tillage practices have been developed that maximize the use of to improve water infiltration and reduce runoff; new row spacing and plant arrangement schemes have been developed to reduce soil temperatures and soil evaporation losses; and crop modeling and weather prediction capabilities have been developed to advise the farmers on the opportune time of sowing that ensures adequate supply of stored soil water in combination with sufficiently high growing season rainfall probability required to satisfy the crop growth requirements and the farmers yield goal.

Keywords
Tillage, crop water-use, plant arrangement, soil water infiltration, soil water evaporation.

Introduction

Agriculture in Australia and USA has evolved into large-scale enterprises that rely on ever-increasing yield and production efficiency to remain profitable. New varieties, machinery, pesticides, and management technologies developed through research have enabled farmers to produce ever-higher yields at lower cost and on more acres. Yet, drought remains a re-occurring feature in large areas of both countries and the losses incurred remains a prime challenge of researchers and farmers as they seek to devise economically viable farming systems to mitigate losses incurred. While progress in drought forecasting has occurred, difficulties remain in accurately predicting it's timing, and its intensity and duration. Farmers in drought-prone areas remain vulnerable to the unexpected losses. They either use practices that maximize the water supply available to their crops or they suffer the consequences. While US farmers receive added protection for weather-related losses through federal guaranteed crop insurance programs (see USDA-Risk Management Agency, http://www.rma.usda.gov/), there are strong incentives to employ cropping practices that effectively use water and other natural resources. This paper explores the relationship of water supply on crop production and the opportunities for farmers of extensive holding in USA and Australia use to minimize the impact of drought.

Crop Water Supply and Yield

While references to the disastrous effects of drought on crop production can be found in man's earliest writings, it was modern scientists like C.T. de Wit (de Wit, 1958), John Hanks (Hanks et al., 1969), Howard Taylor (Taylor, 1983), Joe Ritchie (Ritchie, 1983), C. B. Tanner and T.R. Sinclair (Tanner and

Sinclair, 1983) and many others, who in the latter half of the twentieth century, ushered in a quantitative understanding of water supply on crop yield. Their work formed a foundation upon which present day crop simulation models were built and enable us today to examine the complex interactions of crop management on water-use and fate and productivity.

Using the EPIC farming systems model (Williams, 1985) we simulated grain sorghum (*Sorghum bicolor* L. Moench) production for 40-years (1960 to 2000) in south-central Texas. Regression of the crop water use [i.e., growing season evapotranspiration (ET)] on grain yield revealed that sorghum produced 15.5 kg grain ha^{-1} mm^{-1} (Figure 1) and the growing season ET explained 72 percent of the variability in grain yield. Yet, the numerical average of the 40-years was slightly lower at 12.6 kg grain ha^{-1} mm^{-1}. Similar analyses and regressions of other major crops revealed water use efficiencies of 12.3 kg grain ha^{-1} mm^{-1} for winter wheat (*Triticum aestivum* L.), 19.3 kg grain ha^{-1} mm^{-1} for corn (*Zea mays* L.), and 4.6 kg lint ha^{-1} mm^{-1} for cotton (*Gossypium hirsutum* L). For these crops growing season ET explained 73, 75 and 66 percent of the variability in grain and lint yield. Again, the numerical averages for the 40-years were lower for each crop at 8.2, 16.1 and 3.3 kg ha^{-1} mm^{-1} for wheat, corn and cotton, respectively. While discrepancies exist between the water-use efficiencies derived from regression and those calculated from yearly averages, these numbers clearly illustrate that small changes in the crop water supply can lead to significant changes in yield.

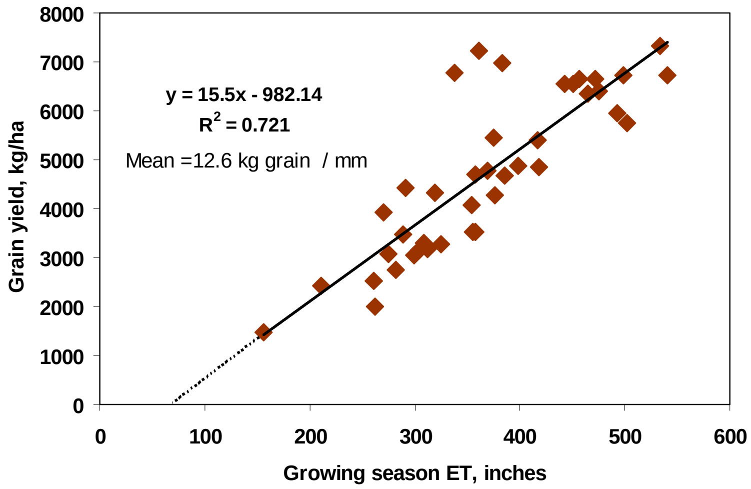


Figure 1. The relationship between grain yield of rainfed sorghum (*Sorghum bicolor L. Moench*) and crop water use (i.e., cumulative crop evapotranspiration) during the growing season derived using the EPIC farming system model over 40 years (1961 to 2000) in south-central Texas.

Managing the Crop Water Balance

Given the close relationship between crop water use and yield, farmers in drought-prone regions must be skilled water managers. Finding ways to increase water supplies available to the crop or minimizing losses of water that bypass the crop must receive top priority. Improvements in supply may be achieved by installing irrigation or by improving irrigation efficiency where supplemental water is available, or by increasing the stored soil water available to the crop. Minimizing water losses can be achieved by reducing runoff or by reducing soil evaporation or both.

Rainfed farmers have less opportunity to increase the crop’s water supply than those who irrigate. Components of the crop water balance and typical values for central Texas illustrate limitations they encounter (Table 1). Of the six components, rainfed farmers can influence the outcome of only two—soil evaporation and runoff. The other components, precipitation, soil water storage capacity, drainage and crop transpiration, are fixed. While loss of water from soil evaporation and runoff has less influence on the crop water supply than the other components, even small reductions in these components can result in significant gain in yield. But influencing soil evaporation and runoff requires major changes in the way farmers manage their land and crops.

Water Source	mm
Precipitation (annual)	876 ± 230
Plant available soil water	150 - 300
Crop transpiration	200 to 500
Evaporation (soil) (annual)	185
Runoff (annual)	130
Drainage	Negligible

Table 1. Components of the crop water balance. Typical annual values for rainfed grain sorghum grown on Houston Black clay in central Texas.

Tillage

Tillage has been and continues to be important in managing crops. But widespread use of glyphosate-resistant crops in the USA and Australia has lessened the need in the use of tillage for weed control and intensified the scrutiny in the role of soil management on crop productivity. Clearly tillage influences the crop water supply and the ability of farmers to reliably produce crops. But the question remains, "How can farmers manage their soil to maximize the crop water supply and yield?" Tension infiltration studies by Potter et al. (1995) illustrate the importance of tillage on increasing the macroporosity of soil and the ability of soil to rapidly absorb water when rain begins when compared to no-tillage systems (Figure 2). While tillage promotes water infiltration in dry soils, crop surface residues play a crucial role in reducing the surface sealing properties of wet soils, allowing them to absorb more water before runoff begins (Table 2). Because tillage equipment mixes soil to different depth and extent (Table 3) and buries surface residues and increases soil evaporation (Figure 3), it might seem no-tillage systems are the system of choice—especially when crop yields appear higher in dry years (Figure 4). Yet, the choice between no-till and tillage is not straightforward. Bulk density of no-tilled soils is substantially than higher than tilled soils when dry (Figure 5). This hinders seeding and crop establishment when dry soils occur at sowing, triggering U.S. farmers and scientists to examine alternative systems, like strip-till or zone-till, that confines tillage to zone 10 to 15 cm wide area and 10-15 cm deep coinciding with the seeding area (Figure 6).

Soil condition	**Till-LR**	**Till-HR**	**NT-LR**	**NT-HR**
		Before runoff (mm)		
Dry	32.4	129	54	75
Wet	1.1	31	1.4	12
		30- minute cumulative infiltration (mm)		
Dry	50	62	61	66
Wet	21	58	28	42

Table 2. The influence of tillage and crop surface residue levels on cumulative infiltration from a rainfall simulator on dry and wet Houston clay soils following harvest of wheat in a long-term wheat-corn-grain sorghum rotation. (Till = chisel tillage, NT= no-tillage, LR = 25-40% crop residue cover, HR= 95-100% crop residue cover) (Potter et al. 1995).

Implement	**Mixing Efficiency**	**Random Roughness**	**Depth**	**Ridge Height**	**Ridge Interval**
	%	*mm*	*mm*	*mm*	*m*
Plow, moldboard	95	30	150	0	0
Disk, tandem	55	50	100	0	0
Cultivator, rolling	50	15	25	100	1
Cultivator, field	30	20	100	25	0.3
Plow, chisel	30	20	150	50	0.3
Cultivator, row	25	15	25	100	1
Subsoiler, deep ripper	25	15	350	0	0
Subsoiler, paraplow	15	15	350	0	0
Rotary hoe	10	13	25	0	0

Table 3. Default parameters for soil mixing efficiency, random surface roughness, soil depth, ridge height and ridge interval for some of the common tillage implements used in the EPIC model to simulate the effects tillage on physical and chemical soil processes.

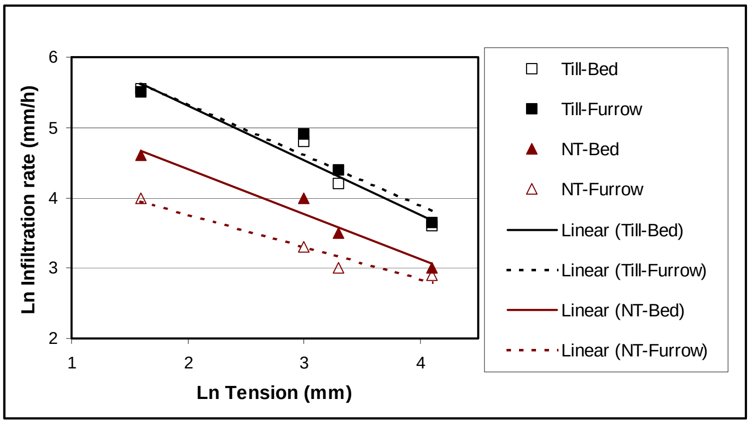
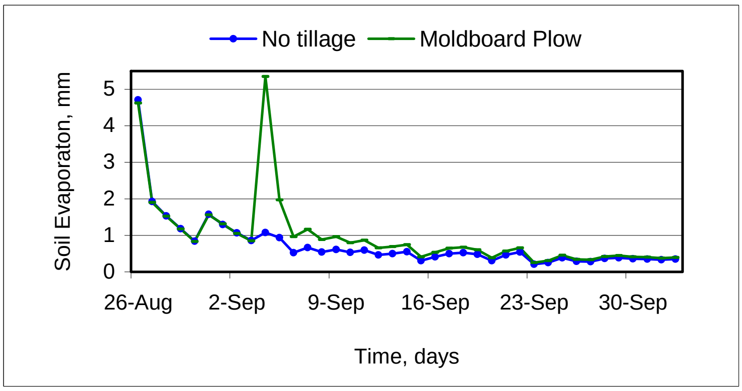


Figure 2. The natural log of the unconfined infiltration rate versus the natural log of tension obtained from the raised beds (bed) and furrow of chisel-tilled (Till) and no-tilled (NT) Houston clay soil following harvest of wheat from a long-term wheat-corn-grain sorghum rotation (Potter et al. 1995).



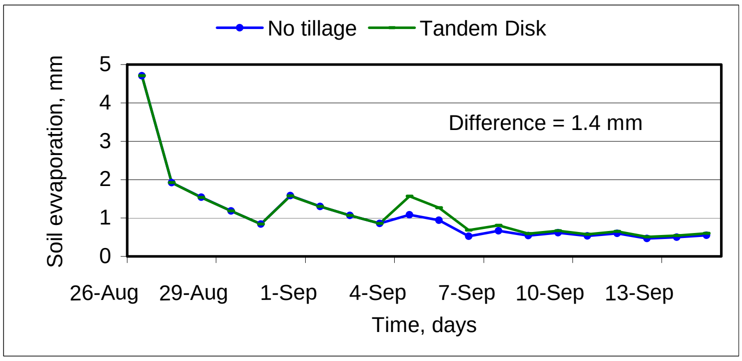


Figure 3. The influence of tillage on soil evaporation. Comparison of simulated soil evaporation for no-tillage with moldboard plow and tandem disk on 5-September following central Texas wheat harvest on soil evaporation from a Houston clay soil following a 75 mm rain on 27 August using the EPIC farming system simulation model.

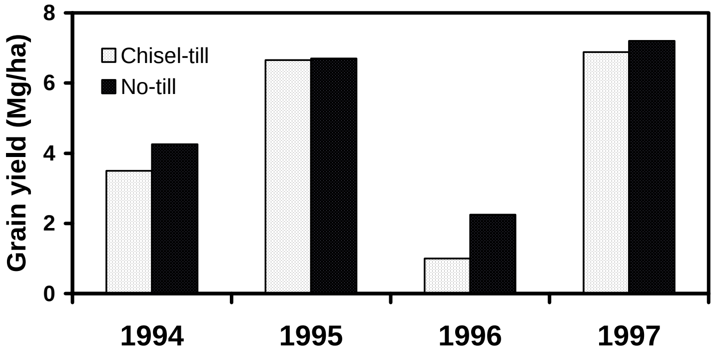
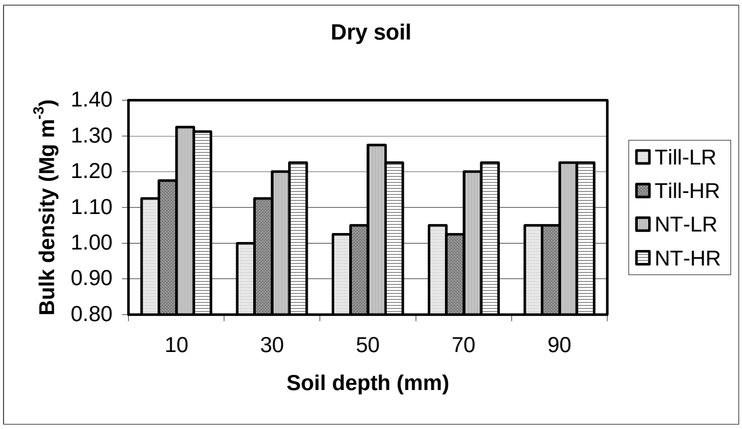


Figure 4. Influence of tillage on grain yield of dryland corn grown on a Houston Clay soil, Temple, TX. Crop growing seasons in 1994 and 1996 were abnormally dry, while 1995 and 1997 were abnormally wet (Torbert et al., 2001).



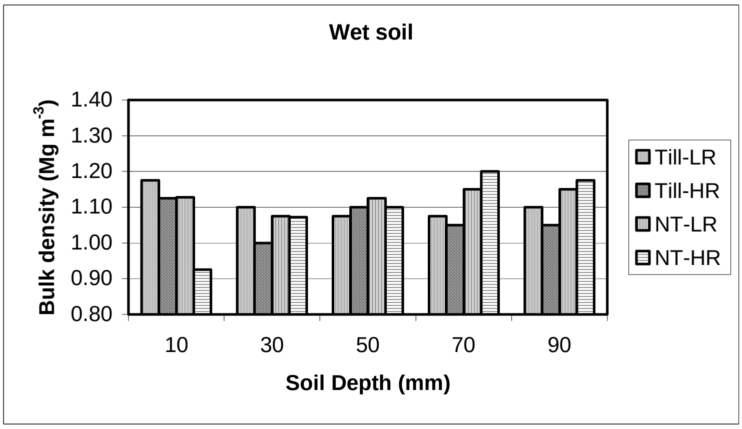


Figure 5. The influence of tillage, surface residue level, and soil moisture condition on the bulk density of a Houston clay soil following harvest of wheat in a long-term wheat-corn-grain sorghum rotation. (Till = chisel tillage, NT= no-tillage, LR = 25-40% crop residue cover, HR= 95-100% crop residue cover) (Potter et al. 1995).

Figure 6. Installation of strip-tillage zones following cotton harvest in central Texas.

Plant configuration.
Another means to alter the crop water supply is to change the plant configuration of a crop. While most attention has been directed toward optimizing plant population, the preponderance of evidence points to a broad range of densities that maximizes yield for each of the major field crops. Recent attention, however, has shifted to examining row spacing of the major summer crops. For years, USA and Australian farmers cultivated summer crops (i.e., corn, grain sorghum, cotton, and sunflowers, soybeans) in 0.75 or 1.0 m rows to manage weeds and other pests. But scientists have known that summer crops grown in ultra-narrow row configurations (i.e., 20 to 50 cm) more effectively intercept solar radiation, thereby lowering soil temperature and soil evaporation. Adams et al. (1976) demonstrated this point by demonstrating 50% or more reductions in Stage I evaporation when row spacing was reduced from 100 to 50 cm (Figure 7). Because most summer cropping regions in the USA and Australia receive much their rain during the growing season, reductions in soil evaporation could increase the crop's supply and increase yield. If one assumes that 25% of precipitation that falls is lost to soil evaporation, theoretically a shift to ultra-narrow row systems could increase the crop water supply from 4 to 6.5 mm per year. This could enable cotton yields to increase from 70 to170 kg ha^{-1} and corn and grain sorghum to increase from 70 to 175 kg ha^{-1} and corn yield from 750 to 1900 kg ha^{-1} over traditional crops grown in traditionally spaced rows. Dryland field studies on cotton, grain sorghum and corn over a six-year period in central Texas Blacklands confirm these assumptions (Gerik et al. 2001). Crop yields increased linearly as row spacing declined from 100 to 20 cm. For cotton, lint yield increased 4 kg ha^{-1} per centimeter row spacing was reduced. Grain yield of grain sorghum and corn increased 27 and 32 kg ha^{-1} per centimeter row spacing was reduced. With most farmers in the Texas Blacklands using 1-m rows and with yields averaging 400, 4000, and 4500 kg ha^{-1} for cotton, grain sorghum, and corn, reducing row spacing can significantly boost productivity.

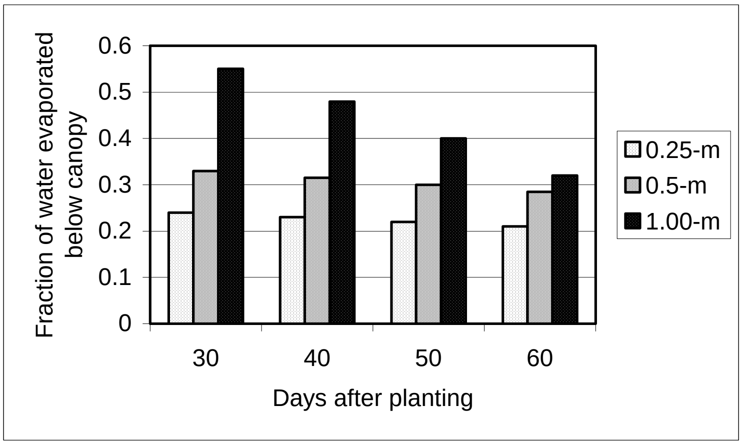
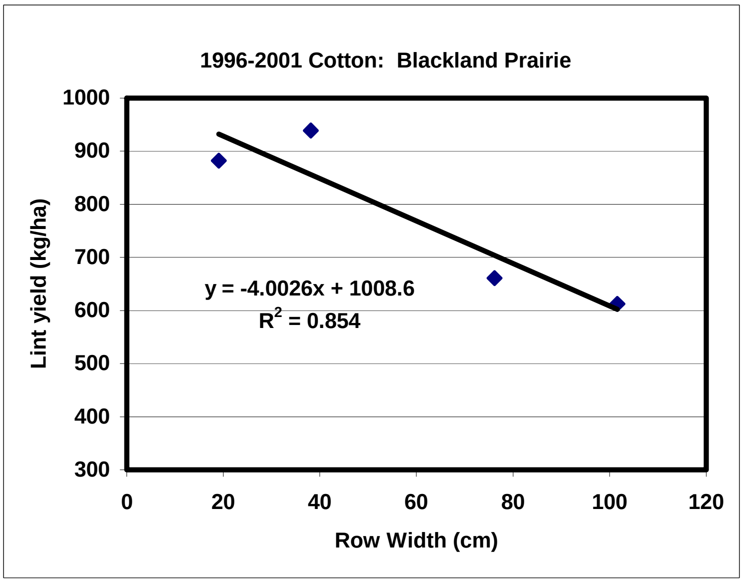


Figure 7. The influence of row spacing on the fraction of water evaporated below the crop canopy (Adams et al. 1976).



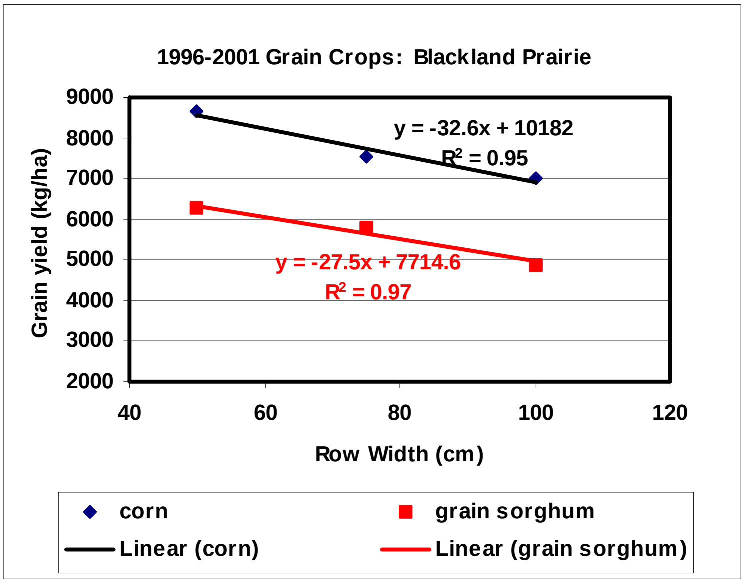


Figure 8. The influence of row spacing on rainfed cotton, corn, and grain sorghum yields in central Texas, 1996-2001.

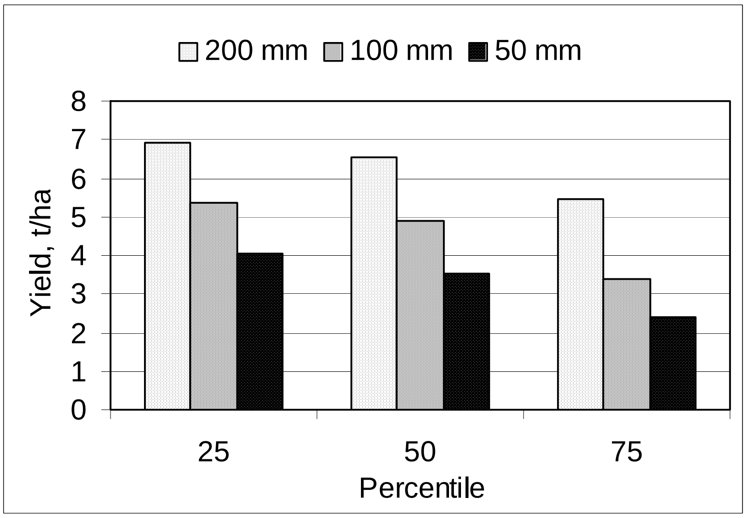


Figure 9. The influence of plant-available soil water at sowing on simulated grain yield of sorghum. Simulations were performed with the EPIC farming system model, where continuous grain sorghum was grown on a deep clay soil in south central Texas containing 50, 100, and 200 mm plant available soil water in a 2-m rooting zone over the 40-year period from 1960 to 2000 with conventional cropping practices. Yields are depicted for the 25, 50 and 75 percentiles. The 25th, 50th, and 75th percentiles represents yields for precipitation levels that were 25% above normal, normal, and 25% below normal, respectively.

Alternative or Opportunity Cropping

Alternative or opportunity cropping is perhaps one of the more exciting and innovative approaches being developed to minimize cropping risk in Australia, where crop insurance and government support programs are not available. The concept centers on obtaining two pieces of information: 1) how much water is in the soil at sowing, and 2) what is the probability of rainfall during the growing season. The concept is illustrated in Figure 9 for rainfed grain sorghum grown on a deep clay soil in central Texas. It shows that fully charge soils (i.e., 200 mm) are capable of producing acceptable yield if the probabilities of growing season rainfall are low. Yet, the probability of achieving acceptable yields rapidly diminishes as the plant-available soil water declines from 200 to 100 mm and again from 100 to 50 mm. Furthermore, grain yields increase for each soil condition as the probability of growing season rainfall increases.

The farmer and/or his advisor obtains information on the soil water content each field prior to sowing by collecting and examining soil cored to the maximum rooting depth or by estimating the plant available soil water with crop-soil water balance software from the Agricultural Production Systems Research Unit, Toowoomba, Qld (www.apsru.gov.au/apsru/). They obtain seasonal climate outlook forecasts, based on the ENSO (El-Nino Southern Oscillation) phenomenon from websites maintained by the Queensland Department of Primary Industries (www.longpaddock.qld.gov.au/SeasonalClimateOutlook/OutlookMessage/index.html) or from software (Rainman, http://dpi.qld.gov.au/rainman/) developed by scientists of the Queensland Department of Primary Industries to estimate rainfall probabilities for the coming growing season. Armed with this information, the farmer knows the quantity of water he has on hand for his crop and rainfall probabilities for the growing season. Rainfall forecasts are not ironclad, but the farmer has knowledge of the production risk at hand and can make an informed decision on whether to sow or if they should delay sowing until the next growing season or delay sowing until their soil water condition or seasonal rainfall forecast improves.

Summary

The development of crop and farming system simulation models over the last quarter century has enabled scientists to gain knowledge essential to understanding the complex biophysical process that influence crop productivity. It has enabled them to quantify the impact of complex biophysical processes on crop production impact and effectively pass this understanding on to farmers in the form of new tillage, residue management and sowing configurations that more effectively use the scarce water supplies that too often occurs in the major cropping regions of Australia and the USA.

While drought has not been conquered, agriculture's scientist and farmers will continue finding new ways to mitigate its effects on crop production and profitability. Australians have taken the first step in implementing decision aids that help farmers know their production risk before placing seed in the ground by tying together programs in crop/farming system simulation modeling with weather forecast/modeling and on-farm soil water monitoring. The US Government has implemented subsidized crop insurance programs to protect farmers from losses incurred by adverse weather or unstable commodity markets. Could the next opportunity for easing the impact of drought on farmers be a combination of these two approaches?

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