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"Soil Water Constraints for Dryland Corn and Sorghum Production in Venezuela"

I. Pla Sentis
Universidad Central de Venezuela
Instituto de Edafologia
Facultad de Agronomia
Apartado 1131
Maracay
Venezuela

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36 Soil Water Constraints for Dryland Corn and Sorghum Production in Venezuela

I. Pla Sentis
Universidad Central de Venezuela, Facultad de Agronomia,
Apartado Postal 1131 - Las Acacias Maracay 2131, Venezuela

Introduction

Corn (*Zea mays* L.)(400,000 ha) and grain sorghum [*Sorghum bicolor* (L.) Moench] (300,000 ha) are, together with rice (*Oryza sativa* L.), the most important food grains produced in Venezuela. They are grown under rainfed conditions in semiarid to subhumid areas with highly mechanized practices. Yields are generally very low (less than 2 Mg/ha), although cultivars of high genetic potential are used and the practices of fertilization, weed control, and crop protection are good. The principal feature of the rainfall is high seasonal and annual variability (Pla et al., 1979). Rainstorms of high intensity (60-100 mm/hour) and volumes (>60mm) are very frequent (Pla, 1980). At the beginning of the growing season, rainfall is more variable in amount and very irregular in frequency. The characteristics of the rainfall and soils generally result in the breaking up of surface aggregates of tilled bare soils, followed by sealing of the soil and a decrease in water infiltration accompanied by runoff and erosion in sloping lands (Pla, 1980).

Irregularities in rainfall distribution during the growing season have to be buffered by water reserves in the soil, which depend both on the soil water retention characteristics and on the depth of the soil profile to which roots extend. Soil erosion losses may reduce the soil depth, and this is particularly serious when a shallow topsoil overlies an argillic horizon. Williams et al. (1981) recognized the loss of plant available soil water capacity as the "first and foremost" mechanism by which erosion reduces soil productivity. Tillage operations, frequently with heavy equipment and in soil too wet at the onset of the rainy season, generally result in soil compaction, and in the development of shallow layers with high mechanical resistance to the penetration of roots. These layers prevent the utilization of water reserves stored in the deeper soil profile, and frequently also restrict the downward movement of water. Roth et al. (1988) reported that in an Oxisol in Brazil under no tillage, higher bulk densities developed in the top 20 cm, whereas conventional tillage led to the development of a plow pan at the 20- to 30-cm depth. Swan et al. (1987) found a significant interaction effect on corn yield between climate and soil water holding capacity, dependent on soil depth to the impeding layer.

According to Stewart et al. (1985), the interaction between precipitation and evaporation, and the resulting water regime, is undoubtedly the predominant factor which affects productivity and management of crops and soils in the dryland agricultural environment. This is particularly true in the corn and sorghum producing areas of Venezuela (Pla et al., 1985, 1987). Therefore, any attempt to control the quantity and availability of soil water to plants must be based on a thorough understanding and a quantitative knowledge of the dynamic balance of water in the soil. Based on that, the objectives of this study were: (1) to determine the effect of soil surface sealing and effective rooting depth in relation to the amount and distribution of rainfall on the soil water regime during the different crop growth periods of selected seasons; (2) to assess the amount of rainfall available for crop production, and to estimate the amount of water surplus or water deficit and their duration for each growing period of corn and grain sorghum in a particular season; and (3) to suggest the best possible alternatives for management of crops and soils to increase the amount of rainfall available for crop production, minimizing the amount and duration of water surplus or deficit, in order to increase productivity.

Materials and Methods

Two sites in the semiarid (9°30'N 66°E) and subhumid (9°N 69°E) regions of Venezuela, where most of the corn and grain sorghum is grown, were selected for this study. The rainfall pattern (Fig. 1) and the soils (Table 1) in those sites are representative of the respective regions.

The site of the Chaguaramas soil has a rolling topography, and has been mostly cultivated with grain sorghum since 1976. The soil shows a moderate degree of erosion, and has an effective rooting depth of 20 to 30 cm on top of an argillic horizon that no roots are able to penetrate. Three plots 10 x 5 m^2 along the slope, belonging to a larger experiment on soil management (Pla et al., 1985, 1987), were used to monitor the soil water content during the growing seasons of 1980 and 1981. The plots had a system to collect and measure runoff water and eroded soil at regular intervals. Soil water change was followed through measurements in three regularly spaced places along the slope in the middle of the plots with tensiometers at a 15-cm depth, and soil sampling at the same depth when it was too dry for the tensiometers.

Table 1. Physical characteristics of the soils at the experimental sites.

Soil	Depth	Particle size µm				Bulk density	Water retention				K^bsat.	K^cseal
		<2	2 to 50	50 to 250	250 to 2000		FC[a]	Suction (MPa) 0.01	0.15	1.5		
	cm	g/kg				Mg/m^3	Volume fraction				m/s	m/s
CHAGUARAMAS (Typic Haplustalf, 6% slope)	0-26	200	180	500	120	1.51	0.26	0.24	0.13	0.09	3×10^{-5}	3×10^{-6}
	25-53	480	250	200	80	1.50					6×10^{-7}	
FANFURRIA (Fluvaquentic Ustropept, < 1% slope)	0-23	250	580	150	20	1.21	0.34	0.32	0.20	0.15	4×10^{-6}	7×10^{-7}
	23-38	240	650	60	50	1.52					10^{-6}	

[a] Field capacity 48 hours after saturation, without evaporation.
[b] Values determined in undisturbed cylindrical cores (5 cm diameter, 5 cm height) water saturated.
[c] Values determined following the method of Pla (1985).

Grain sorghum (hybrid Chaguaramas III) adapted to the area was sown at a density of 300,000 seeds/ha in rows 50 cm apart, across the slope at the start of the wet season. In 1981, with earlier rains, a sorghum ratoon could be harvested in the last part of the rainy season. Fertilizers and herbicides were applied according to the recommendations for the area. Close to the experimental plots, measurements of water infiltrability, runoff, and soil erosion losses were made on plots 3 x 1 m^2 along the slope by using a drop-former type of portable rainfall simulator (Pla, 1981). The surface soil was air-dryed and tilled, bare or completely covered by crop residues, before the application of a simulated rainfall at 100 mm/hour for 60 minutes.

The Fanfurria soil is completely flat and has been cultivated since 1972, mostly with corn, followed in some years by grain sorghum at the end of the rainy season. At the 20- to 25-cm depth, the soil in the experimental site has a compacted layer 10 to 15 cm thick, which impedes deeper root penetration. The soil water conditions were followed by daily monitoring in three 10 x 5 m^2 (subdivided in two) plots belonging to a larger experiment on soil management (Pla et al., 1987), using direct observations for water-logging and the same kind of measurements of Chaguaramas soil for the other water levels. Corn (hybrid Obregon) was sown every 20 cm in rows spaced 1 m apart, resulting in a population of 50,000 plants/ha. Grain sorghum (hybrid Pioneer) was sown like in the Chaguaramas site. Fertilization and weed control practices followed the standards for the area. The sowing dates for corn, earlier than in Chaguaramas, were at the beginning of the rainy season each year. Sorghum did not follow corn immediately because of planting difficulties in soils that were too wet or water-logged. Infiltrability of rainfall water was measured in the field, simultaneously in three 1 x 1 m^2 plots with the same rainfall simulator used in Chaguaramas, on surface air-dry tilled soil, bare or covered by plant residues.

The data obtained in the laboratory and under field conditions close to the experimental sites were used to feed a water-budget model to predict the soil water regimes under different simulated surface soil conditions (bare or completely covered by plant residues), effective rooting depths (20 and 50 cm), and surface drainage (with or without), for the rainfall patterns of particular seasons. Evapotranspiration rates, calculated from average pan evaporation data for the rainy season, were taken as 5 mm/day for all situations when the soil water potential (SWP) in the root zone was higher than -1.50 MPa. Days with excessive (ESM), adequate (ASM), deficient (DSM), and very deficient (VDSM) soil water (moisture) for the crops were considered the ones with an average water content in the effective rooting depth above field capacity (FC), between FC and a SWP of -0.15 MPa, between SWP of -0.15 MPa and -1.50 MPa, and below SWP of -1.50 MPa, respectively. In the flat and not drained Fanfurria site, water-logged days (WL) were considered the ones when the relation between rainfall amount and intensity, and infiltrability of water in the soil results in a surplus of free water standing on the soil surface for at least 12 hours.

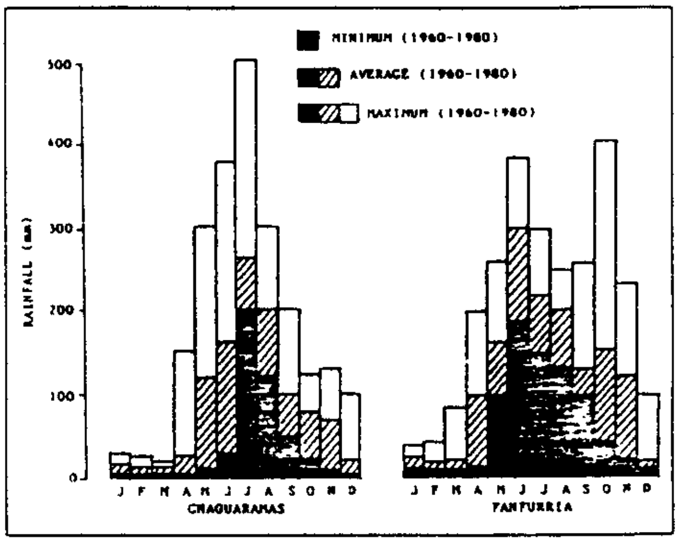


Figure 1. Monthly rainfall (minimum, average, and maximum values) for the period 1960-80 at Chaguaramas and Fanfurria sites.

Results and Discussion

The rainfall amounts and distribution (Fig. 1) show their variability from year to year, and a high irregularity and concentration during the rainy season. These characteristics of the rainfall pattern are much more marked in the Chaguaramas semiarid soil site than in the subhumid Fanfurria site.

There are abrupt changes from the upper soil to the shallow argillic (Chaguaramas) or compacted (Fanfurria) layers, and very low hydraulic conductivities (K) of these horizons (Table 1). The sealing effect on the soil surface gives the very low values of K in the formed seal. These effects correspond with the change of infiltration rates (IR) of simulated rainfall in bare soils as compared to protected ones, under field conditions (Fig. 2). The high soil erosion losses in the bare Chaguaramas soil follow the decrease in IR due to soil surface sealing.

The actual soil water regimes on the experimental plots compared to the respective rainfall patterns during the growing seasons of 1980 and 1981 (Fig. 3) show a good correspondence with the grain yields of corn and sorghum (Table 2). In the relatively dry growing seasons of 1980 and 1981 in Chaguaramas, the yields of grain sorghum in the first harvest were limited by the number of days with water deficits, especially during the vegetative and reproductive periods. The comparatively good yield of the sorghum ratoon in the last portion of the 1981 growing season may be explained by the adequate soil water conditions during the whole season. The higher yield of 1979 was due to shorter periods of water stress (Fig. 4) than in 1980 and 1981. In Fanfurria, the yields were mostly limited by the days with water-logging and excessive soil water, especially when they occurred in the vegetative period with shallower roots. This situation led to the almost complete loss of the initial corn crop in 1981, and of the complementary sorghum crop in 1980. It is shown that even in the relatively wetter season of 1980, there were a few days with soil water deficits due to the very irregular rainfall distribution.

From the calculated results (Fig. 4), it is clear that in shallow Chaguaramas soils, the soil water conditions and, consequently, the crop yields will be highly dependent on rainfall distribution during certain critical growing periods much more than on deeper soils. Therefore, when erosion decreases the upper soil depth, the dependence of the water-supplying capacity of the soil on the rainfall amount and distribution will increase. The reduction of the high evaporation losses and the prevention of sealing by mulches of crop residues (Unger and Jones, 1981) or treatments with asphalt emulsions (Pla et al., 1987) have proved to increase the efficient use of the limited water resources, especially in the initial part of the vegetative growing period when the plant canopy does not provide a good soil cover. According to our results, the benefits of this and other soil conservation practices like furrow diking, bench terraces, strip cropping, etc., which are effective for controlling erosion by preventing runoff, will only be effective in providing additional water for crop production if the soil rooting depth is maintained or increased to some minimum value, depending on soil characteristics and climate. Their contribution to reduce erosion losses would indi-

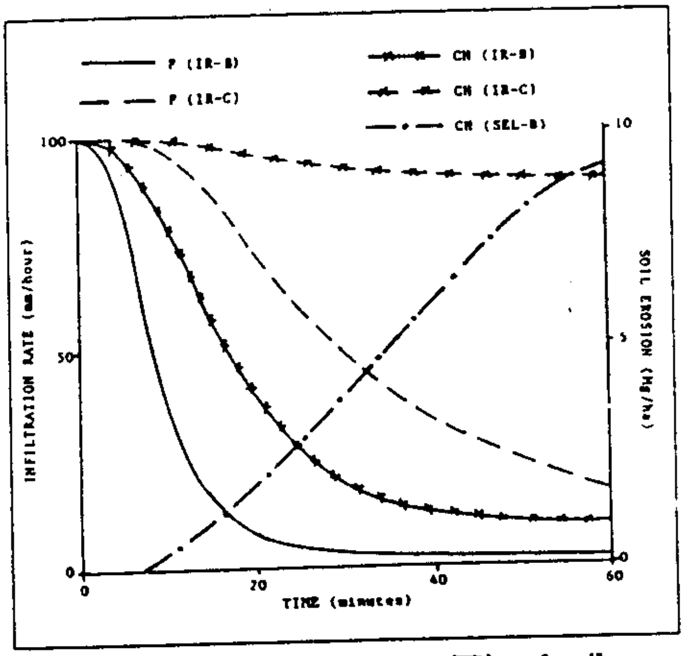


Figure 2. Water infiltration rates (IR) and soil erosion losses (SEL) under simulated rainfall at 100 mm. hour-1, in an initially air dry tilled soil, bare (B) or completely covered (C) by crop residues. (CH: Chaguaramas soil; F: Fanfurria soil).

Table 2. Crops, grain yields, and soil erosion losses (Chaguaramas) during the growing seasons of 1979 (Chaguaramas), 1980 and 1981, with no soil protection, and no surface drainage (Fanfurria), in experimental plots 10 x 5 m² along the slope.

Soil	Year	Crop	Seedling emergence	Yield	Crop	Seedling emergence	Yield	Soil erosion
			Date	Mg/ha⁻¹		Date	Mg/ha	Mg/ha
Chaguaramas	1979	Sorghum	June 1	6.3	-	-	-	45
	1980	Sorghum	May 3	4.0	-	-	.	13
	1981	Sorghum	March 13	2.8	Sorghum*	July 15	3.3	2
Fanfurria	1980	Corn	March 26	3.3	Sorghum	Sept. 21	0.6	-
	1981	Corn	March 17	0.7	Sorghum	Aug. 11	3.5	-

* Ratoon.

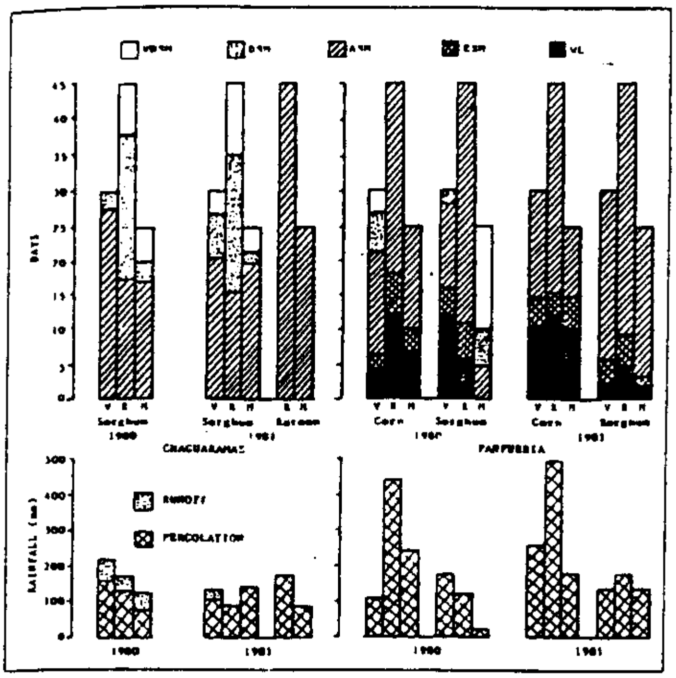


Figure 3. Monitored soil water (moisture) conditions (WL: Water-logging; ESM: Excessive Soil water; ASM: Adequate soil water; DSM: Deficient soil water; VDSM: Very deficient soil water) and rainfall distribution during the growing periods (V: Vegetative; R: Reproductive; M: Maturity) of corn and grain sorghum during the growing seasons of 1980 and 1981 in experimental plots 10 x 5 m² along the slope in Chaguaramas and Fanfurria soil sites.

rectly contribute to preserve this depth. To increase it, the thorough mixing of the restricting horizon with the upper soil layer has proved to increase water storage and crop yields in some cases (Bradford and Blanchar, 1980), but the effects may be very different according to the soils and climatic conditions.

The calculated soil water regime for Fanfurria soil shows that the predicted periods with water-logging and excessive soil water would be mostly solved either by the provision of surface drainage or by the protection of the surface soil against the sealing effect of raindrops, together with increase of the effective rooting depth of the soil profile. The provision of surface drainage, through broad or cambered beds, for rapid disposal of all excess water accumulating on the soil surface may be very effective to avoid water-logging and excessive soil water in humid years like 1980, and for improving yields (Marcano, 1980), but in drier years, it may increase the danger of drought during prolonged dry spells in the growing season. In some cases, it would be useful to break the compact layers by chiseling or to turn them over by moldboard plowing in order to facilitate soil water infiltration and to help plants to extract greater amounts of water from deeper soil, thus decreasing water-logging in humid years and resulting in higher and more regular grain yields.

The correspondence between the measured and predicted soil water regimes for critical periods of the same growing seasons shows that it is possible to get fairly good estimates when the correct assumptions are made, particularly with respect to infiltrability, runoff, surface drainage, and deep percolation of rainfall water, as well as the effective available soil water storage capacity. These estimates could be very useful to diagnose for each soil and rainfall pattern the main factors responsible for the present and future soil water limitations and the amount and timing of water stress strongly affecting crop yields, and to preview the effects of different management practices in order to select the most appropiate ones for each case.

It may be concluded that for the rainfed corn and sorghum producing areas of Venezuela, and probably for many other similar areas in the semiarid to subhumid tropics, the management efforts have to be mainly directed to maintain or to increase the effective plant available water holding capacity of the soil, by giving the conditions for a non restrictive root growth, together with providing sufficient protection or stabilization of the surface soil to prevent strong reductions in infiltrability by sealing, and to reduce erosion losses.

References

Bradford, J.M., and R.W. Blanchar. 1980. The effect of profile modification of a Fragiudalf on water extraction and growth by grain sorghum. Soil Science Society of America Journal 44:374-378.

Marcano, F. 1980. Improvement of surface drainage in heavy soils for corn production. (Latin American Journal of Agricultural Sciences). ALCA, Caracas, Venezuela 15(1):23-42.

Pla, I. 1980. Soil characteristics and erosion risk assessment in some agricultural soils of Venezuela. p. 123-138. *In* R.P.C. Morgan (ed.) Soil conservatian, problems and prospects. Chichester, U.K.: John Wiley & Sons.

Pla, I. 1981. Rainfall simulators for the study of soil-water relationships under tropical rainfed agriculture. Journal of the Agronomy School. Maracay, Venezuela XII(1-2):81-93.

Pla, I., A. Florentino, and T. Perez. 1979. Relation between soil physical properties and problems of soil management and conservation in agricultural soils of Venezuela. p. 184-196. *In* R. Lal (ed.) Soil tillage and crop production. Ibadan, Nigeria: IITA.

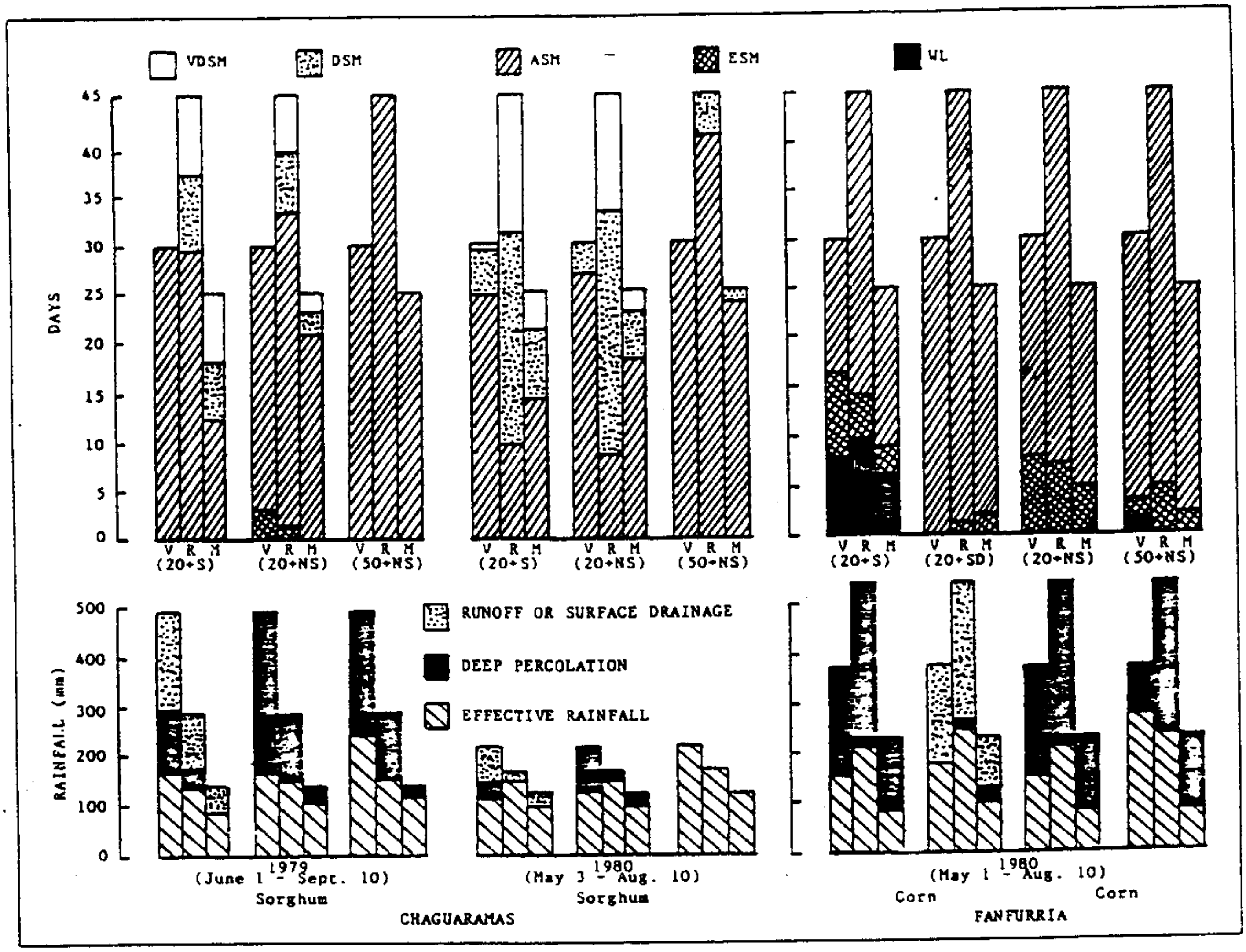
Pla, I., A. Florentino, and D. Lobo. 1985. Soil and water conservation problems in the Central Plains of Venezuela. p. 66-78. *In* S.A. El-Swaify, W.C. Moldenhauer, and A. Lo (ed.) Soil erosion and conservation. Ankeny, Iowa: Soil Conservation Society of America.

Pla, I., A. Florentino, and D. Lobo. 1987. Soil and water conservation in Venezuela through asphalt mulching. p. 481-495. *In* I. Pla (ed.) Soil conservation and productivity. Caracas, Venezuela: Universidad Central de Venezuela.

Roth, C.M., B. Meyer, H.G. Frede, and R. Depsch. 1988. Effect of mulch rates and tillage systems on infiltrability and other soil physical properties of an Oxisol in Parana, Brazil. Soil & Tillage Research 11:81-91.

Stewart, B.A., P.W. Unger, and O.R. Jones. 1985. Soil and water conservation in semiarid regions. p. 328-337. *In* S.A. El-Swaify, W.C. Moldenhauer, and A. Lo (eds.) Soil erosion and conservation. Ankeny, Iowa: Soil Conservation Society of America.

Swan, J.B., M.J. Shaffer, W.H. Poulson, and A.E. Peterson.



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1987. Simulating the effects of soil depth and climatic factors on corn yield. Soil Science Society of America Journal 51:1025-1032.

Unger, P.W. and O.R. Jones. 1981. Effect of soil water content and a growing season straw mulch on grain sorghum. Soil Science Society of America Journal 45:129-134.

Williams, J.R., R. Allmaras, K.G. Renard, L. Lyles, W.C. Moldenhauer, G.W. Langsdale, L.P. Meyer, and W.G. Rawls. 1981. Soil erosion effects on soil productivity: a research perspective. Journal of Soil and Water Conservation 36:82-90.