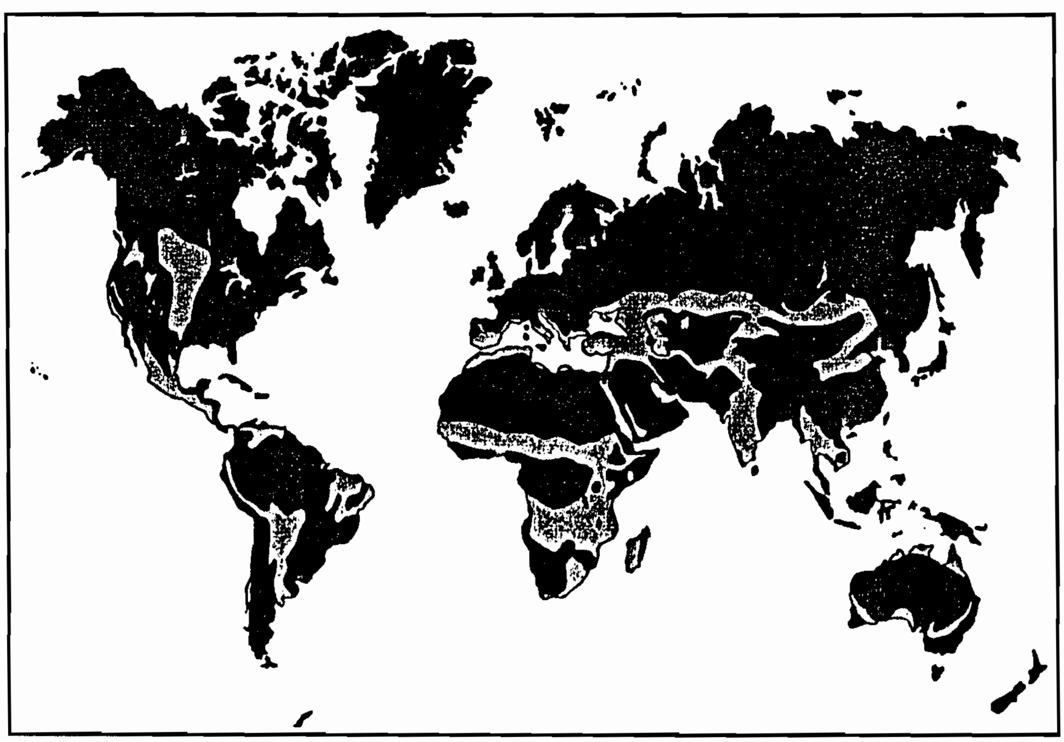
Proceedings of the

International Conference on Dryland Farming

CHALLENGES IN DRYLAND AGRICULTURE

A GLOBAL PERSPECTIVE



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Proceedings of the International Conference on Dryland Farming

August 15-19, 1988
Amarillo/Bushland, Texas U.S.A.

128 Soil Fertility and Water Use Efficiency

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Water use efficiency (WUE) is of concern to farmers when they must deal with suboptimal water resources and they wish to utilize each increment received to the fullest extent. Under these conditions, it is necessary to make as much of the water resource available to the crop as possible and subsequently to have the crop utilize that water with maximum efficiency to produce desired commodities. Depending upon its intended use, WUE may be defined in several way as follows:

$$WUE_P = Y/PPT;\ WUE_{ET} = Y/ET;\ WUE_T = Y/T \qquad [1]$$

where: Yield (Y) can be total biomass or usable product such as grain, PPT is total precipitation received per crop, ET is evapotranspiration, and T is transpiration. WUE_P is a measure of water use efficiency based upon total precipitation available including all ways in which water is lost and/or remains unused in the soil. This definition is useful in long-term agronomic studies where evaluation of cultural practices includes their effectiveness in making the water resource available to the crop. WUE_{ET} is a measure of water use efficiency based upon evapotranspiration and is useful in agronomic studies to evaluate the effects of cultural practice on efficient use of water lost from the system by evaporation (E) and transpiration. WUE_T is a measure of water use efficiency based upon transpired water and is important in physiology studies where information is sought relative to basic metabolic functions and relationships between plant growth and water use.

Thus, factors having a disproportionate effect on yield and plant water use will affect WUE. For example, Black et al. (1981) found that replacing crop-fallow production systems with more intensive cropping systems resulted in increased average annual crop yields with subsequent increases in WUE_P (Table 1). The annual cropping sequences used 81% of the precipitation, while the 3-year rotation used 59% and the crop-fallow 51% of the precipitation received. Nitrogen application resulted in additional yield increases without affecting water utilization which resulted in an additional increase in WUE_P. Excellent reviews of the effects of soil fertility on water use and WUE_{ET} and WUE_T have been published (Briggs and Shantz, 1913; Viets, 1962, 1967; Power, 1983). These reviews provide more detail than will be possible to discuss here. However, we will briefly address the main principles since they apply to current problems of maximizing use of available water resources in crop production through optimization of inputs.

Data in Figure 1a illustrates the effects of the interaction between available water and nutrient levels on grain sorghum [*Sorghum bicolor* (L.) Moench]. As available water increased, yield responses to applied N increased. For the medium (W_2) and high (W_3) water levels, ET and Y where independent (Fig. 1b), with the expected linear relationship between WUE_{ET} and yield (Fig. 1c). This may occur, because as nutrient levels increase plant growth, leaf area is increased resulting in greater ground cover and T while reducing incident radiation on the soil surface and E (Power, 1983). Thus,

Table 1. Average precipitation-use efficiency per cropping sequence as influenced by cropping system within a tall wheatgrass barrier system over a 12-year period (Adapted from Black et al., 1981).

Cropping system	Total ppt per crop	Total water[a] use per crop	WUE_P[b]	Average annual grain yield No N	Average annual grain yield +N	WUE_P No N	WUE_P +N
	mm	mm	%	Mg/ha	Mg/ha	kg/ha/mm	kg/ha/mm
Annual cropping							
6WW,B,S,B,WW,S,B	396	222	81	1.33	1.79	3.4	4.5
Three year rotation							
SW-WW-F	569	333	59	1.00	1.42	2.6	3.7
Crop fallow							
WW-F	788	404	51	1.02	1.25	2.6	3.1

[a] Crop water-use per crop is based on soil water use plus precipitation received from seeding to harvest.
[b] Symbols: +N = 34 kg N/ha each crop year; ppt = precipitation; WUE_P = [(total water use/crop) / (total precipitation received/crop)] x 100; WW = winter wheat (*Triticum aestivum* L.); SW = spring wheat; B = spring barley (*Hordeum vulgare* L.); S = safflower (*Carthamus tinctoris* L.); and F = fallow.

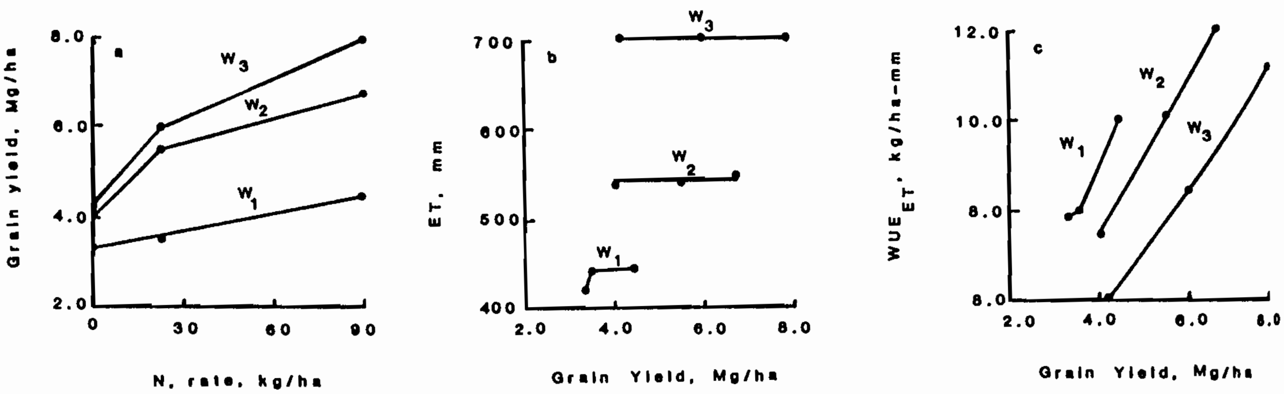

Figure 1. Relationships between sorghum grain yield, ET, and WUE_{ET}. All plots preplant irrigated to fill soil profile. Growing season: W_1 = rainfed, W_2 = 50% of ET replaced weekly, and W_3 = 100% of ET replaced weekly. ET replacement began approximately six weeks after planting. (Onken, A.B. and C.W. Wendt. Unpublished data.)

Table 2. Fertilizer effects on grain yield and WUE_{ET} of grain sorghum and millet in Niger and Mali (Wendt, C.W., Z. Kouyate, and W.A. Payne, unpublished data).

Location	Ferti-lity[a]	Grain sorghum Yield	Grain sorghum WUE_{ET}	Grain sorghum % of control	Millet Yield	Millet WUE_{ET}	Millet % of control
		Mg/ha	kg/ha/mm	%	Mg/ha	kg/ha/mm	%
Kdia Pate', Niger	0	0.27	0.83	100	0.65	2.01	100
ET (321 mm)	F	0.53	1.66	200	0.84	2.62	130
N'Dounga, Niger	0	1.20	4.40	100	1.14	4.18	100
ET (273 mm)	F	1.73	6.35	144	1.44	5.27	126
Chikal, Niger	0	0.24	1.12	100	0.48	2.24	100
ET (214 mm)	F	0.35	1.62	144	0.56	2.64	118
Cinzana, Mali	0	1.31	3.52	100			
ET (372 mm)[b]	F	2.05	5.52	157			
ET (390 mm)[c]	0	1.51	3.88	100			
	F	2.62	6.72	173			

[a] Niger: 0 = control; F = 10 kg P + 45 kg N/ha - 1985.
Mali: 0 = control; F = 20 kg P + 45 kg N/ha - 1986.
[b] Tillage = No till.
[c] Tillage = Deep plowing + tied ridges.

with a moist soil surface these two processes may affect each other such that little change in ET occurs. At the lowest water level (W_1), the relationship between ET and Y and WUE_{ET} and Y was non-linear due to a significant increase in ET with applied N.

Fertilizer applications have been found to have substantial effects on yield and WUE_{ET} for sorghum and millet [*Pennisetum americanum* (L.) Leeke] grown in dryland systems in the Sahelian zones of Niger and Mali on soils that were very low in N and P (Table 2). Amounts of ET were low, indicating yield restricting levels of available water. Increases in grain yield and WUE_{ET} were dramatic, ranging from 18 to 100%. Changes in WUE_{ET} were less for millet than for sorghum due to a lesser response to fertilizer. These data confirm that under very deficient soil fertility conditions, responses to applied fertilizer can be obtained even at low levels of available water.

Under similar levels of ET, N fertilization significantly increased WUE_{ET} of winter wheat (*Triticum aestivum* L.), corn (*Zea mays* L.), and sorghum produced dryland in the central Great Plains of the United States (Table 3). Data in Table 4 illustrate the effects of the degree of crop responsiveness to available and applied nutrients on WUE_{ET}. Available water and soil fertility were low as can be seen from the low values for ET and the magnitude of the response to applied N. While there were significant differences in yield with no applied N, there were no differences in WUE_{ET}. However, due to a larger yield response, the WUE_{ET} of SC630 was greater than 77CS1 and SC325, and the WUE_{ET} of R6956 was greater than SC325 when N was applied. Thus, since one of the primary effects of fertilizer on WUE_{ET} is its effect on yield, maximum benefits from applied fertilizer will be achieved only when the most responsive cultivars are utilized.

Research to define the relationships between plant nutrition and WUE_T has been conducted in containers such that E can be controlled and T measured. Briggs

Table 3. Influence of N fertilization on grain yield and WUE_{ET} of winter wheat, corn, and sorghum grown in a three year dryland wheat-corn (or sorghum)-fallow rotation at Akron, Colorado (A.D. Halvorson, unpublished data).

N rate	Winter wheat Yield	Winter wheat WUE_{ET}[a]	Corn Yield	Corn WUE_{ET}	Sorghum Yield	Sorghum WUE_{ET}
kg/ha	Mg/ha	kg/ha/mm	Mg/ha	kg/ha/mm	Mg/ha	kg/ha/mm
0	2.53	8.8	1.70	7.1	1.06	4.5
28	3.58	12.5	2.64	11.1	1.61	6.8
56	4.18	14.6	3.57	15.0	2.27	9.5
84	4.50	15.7	3.61	15.2	2.38	10.0
112	4.70	16.4	3.77	15.8	1.98	8.3

[a] WUE_{ET} = kg/ha/mm.

Table 4. Water use, grain yield, and WUE_{ET} of four grain sorghum genotypes grown dryland at Lubbock, Texas, 1984 (Onken, A.B. and C.W. Wendt, unpublished data).

Sorghum line	ET No N	ET +N[a]	Grain yield No N	Grain yield +N	WUE_{ET} No N	WUE_{ET} +N
	mm		Mg/ha		kg/ha-mm	
SC630	277	284	2.98 ab[b]	5.84 a	10.8	20.6 a
R6956	366	312	3.11 a	5.47 a	8.5	17.5 b
77CS1	297	348	2.53 ab	4.78 a	8.5	13.7 bc
SC325	305	300	2.35 b	3.21 b	7.7	10.4 c
	N.S.	N.S.			N.S.	

[a] 180 kg N/ha.
[b] Means followed by the same letter in the same column do not differ significantly at the 0.05 probability level.

Table 5. WUE_T and values of "m" for two sorghum genotypes as affected by water and fertility levels (Wendt, C.W. and A.B. Onken, unpublished data).

	WUE_T Tops	WUE_T Tops and roots	"m" values Tops	"m" values Tops and roots
	g/kg			
Genotype				
SC630-11E	3.1 a[a]	3.6 b	30.0 a	34.3 b
77CS1	3.3 a	4.5 a	28.2 a	39.3 a
Water level				
High	3.2 a	3.8 b	28.5 a	34.3 b
Low	3.2 a	4.3 a	29.6 a	38.4 a
Fertility level				
0	3.2 b	3.9 b	28.6 b	35.6 b
10	3.2 b		28.7 a	
20	3.2 b	3.9 b	29.0 a	35.7 b
40	3.2 b		28.3 a	
80	3.4 a	4.3 a	30.7 a	39.2 a

(Wendt, G.W., and A.B. Onken. Unpublished data.)
[a] Means followed by the same letter in the same column do not differ significantly at the 0.05 probability level.

and Shantz (1913) provided an excellent summary of early work in water requirements. The earliest work reported was that of Woodward (1699) which was conducted in solution cultures, which led to the conclusion that, within limits, water requirement of plants was dependent upon the amounts of plant nutrients available. The first reported study in soil was that of Lawes (1850), in which he found reductions in water requirements for wheat and clover (*Trifolium pratense*) due to additions of manure and ammonical salts. Some of the best early work on the influence of fertilizers on WUE_T was conducted by Kiesselbach (1910, 1916). In a study with soils of different inherent fertility, he found the greatest decrease in water requirement occurred when manure was applied to soils of lowest fertility. His data suggest that fertilizer effects on WUE_T are inversely related to the fertility level of the soil.

de Wit (1958) suggested that in arid and semiarid areas, water requirement depends on plant species and evaporative demand with the following relationship:

$$Y = mT/E_o \qquad [2]$$

where Y is total dry matter, T is total transpiration, E_o is mean daily free water evaporation, and m is a proportionality constant characteristic of the crop. Thus, there is a correction for evaporative demand. Research by Hanks (1983) supports this relationship; however, "m" values are apparently affected by genotype and year-to-year climatic variability. Use of vapor pressure deficit for E_o rather than evaporation has been proposed by Tanner and Sinclair (1983). They suggest that through such corrections, "m" values will be the same in all climates.

In an effort to more carefully define the relationship between sorghum genotypes, water level, and nutrient levels on WUE_T, a controlled study was conducted under a rainout shelter in mini-lysimeters sealed to prevent evaporation (Table 5). Differences in WUE_T and "m" were not well delineated based on shoot weight alone. However, when root weights were included, significant differences were found between cultivars, fertility levels, and water levels. The "m" values were lower than those of Howell and Musick (1985) and higher than those of Hanks (1983) and de Wit (1958).

The foregoing discussion indicates that fertilizer affects WUE through its effect on yield. Improvement of WUE is only of value if the fertilizer application makes economic sense. Yield potential influences the nutrient requirement of a crop. Many factors influence dryland crop yield potentials. Among the most important are cropping systems (Table 1) and amount and distribution of available water (Fig. 1). Thus, as a first step in determining fertilizer needs, some realistic estimate of yield potential must be available.

Since crops obtain nutrients from the soil as well as from fertilizers applied in the current season, the nutrient supplying power of the soil needs to be assessed. This can best be accomplished through the use of soil tests that have been correlated to crop yield and fertilizer application rates (Halvorson and Kresge, 1982; Onken and Sunderman, 1972; Onken et al., 1980; and Onken et al., 1985). The objective is to simultaneously make the most efficient use of the available water resource and applied fertilizer.

References

Black, A.L., P.L. Brown, A.D. Halvorson, and H.D. Siddoway. 1981. Dryland cropping strategies for efficient water-use to control saline seeps in the northern Great Plains, U.S.A. Agricultural Water Management 4:295-311.

Briggs, L.J., and H.L. Shantz. 1913. The water requirements of plants. II. A review of literature. United States Department of Agriculture, Bureau of Plant Industry, Bulletin 285.

de Wit, C.T. 1958. Transpiration and crop yields. Versl. Landbouwk. Onkerz. 64.6. Institute of Biological and Chemical Research on Field Crops and Herbage, Wageningen, The Netherlands.

Hanks, R.J. 1983. Yield and water-use relationships: an overview. p. 393-412. *In* H.M. Taylor, W.R. Jordan, and T.R. Sinclair (eds.). Limitations in efficient water use in crop production. Madison, WI: American Society Agronomy, Crop Science, and Soil Science Society of America.

Halvorson, A.D., and P.O. Kresge. 1982. FLEXCROP: A dryland cropping system model. U.S. Department of Agriculture Production Research Report No. 180. Washington, D.C.: U.S. Government Printing Office.

Howell, T.A., and J.T. Musick. 1985. Relationship of dry matter production of field crops to water consumption. Les besions en eavdes cultures. Conference Internationale, Paris. 11-14 Sept. 1984. INRA, Paris. p. 247-269.

Kiesselbach, T.A. 1910. Transpiration experiments with the corn plant. Nebraska Agricultural Experiment Station 23rd Annual Rep. p. 125-139. Lincoln.

Kiesselbach, T.A. 1916. Transpiration as a factor in crop production. Nebraska Agricultural Experiment Station Research Bulletin No. 6, Lincoln.

Lawes, J.B. 1850. Experimental investigation into the amount of water given off by plants driving their growth; especially in relation to the fixation and source of their various constituents. Horticulture Society, London. V. 5, p. 38-63.

Onken, A.B., R.L. Matheson, and D.M. Nesmith. 1985. Fertilizer nitrogen and residual nitrate-nitrogen effects on irrigated corn yield. Soil Science Society of America Journal 49:134-139.

Onken, A.B., R.L. Matheson, and E.J. Williams. 1980. Evaluation of EDTA-extractable phosphorus as a soil test procedure. Soil Science Society of America Journal 44:783-786.

Onken, A.B., and H.D. Sunderman. 1972. Applied and residual nitrate-nitrogen effects on irrigated grain sorghum yield. Soil Science Society of America Proceedings 36:94-97.

Power, J.F. 1983. Soil management for efficient water use: soil fertility. p. 461-470. *In* H.M. Taylor, W.R. Jordon, and T.R. Sinclair (eds.). Limitations to efficient water use in crop production. Madison, WI: American Society Agronomy, Crop Science, and Soil Science Society of America.

Tanner, C.B., and T.R. Sinclair. 1983. Efficient water use in crop production: research or re-search? p. 1-27. *In* H.M. Taylor, W.R. Jordon, and T.R. Sinclair (eds.). Limitations to efficient water use in crop production. Madison, WI: American Society Agronomy, Crop Science, and Soil Science Society of America.

Viets, F.G., Jr. 1962. Fertilizers and efficient use of water. p. 223-264. *In* A.G. Norman (ed.). Advances in Agronomy. New York: Academic Press.

Viets, F.G., Jr. 1967. Nutrient availability in relation to soil water. *In* R.M. Hagen et al. (ed.). Irrigation of Agricultural Lands. Agronomy 11:458-471. Madison, WI: American Society of Agronomy.

Woodward, John. 1699. Some thoughts and experiments concerning vegetation. Philosophical Transactions (Royal Society, London 21(253):193-227.