DIVISION S-6—SOIL AND WATER MANAGEMENT AND CONSERVATION

Profile Modification of a Fragiudalf to Increase Crop Production

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ABSTRACT

Root development and crop yields are greatly reduced in soils having fragipan layers because of restricted air and water movement, high bulk densities and soil strength, and high acidity. In the first year after soil profile modification by trenching of a Missouri Typic Fragiudalf, available water storage and yields of grain sorghum (*Sorghum bicolor* (L.) Moench) were increased. Within unmodified areas, sorghum yields averaged 1,841 kg/ha. Deep trenching without chemical or physical additives increased yields to 4,322 kg/ha. Mixing lime, fertilizer, and sawdust with the soil material within the trenches increased grain sorghum yields to 5,987 kg/ha. The sawdust significantly increased water storage and water extraction, resulting in the grain yield increase.

Reexcavation of a pit used by the Soil Conservation Service for soil series identification of the Hobson soil showed no signs of soil density or strength reformation during the 16-year period since the pit was refilled.

Additional Index Words: **root penetration, soil water, water availability, sawdust, subsoiling, liming.**

SOILS WITH FRAGIPAN HORIZONS cover about 2.8 million ha in Missouri, Arkansas, and Oklahoma; the majority is in the Ozark Highland (Land Resource Region 116, Agric. Handb. 296, 1965). Fragipan layers restrict air and water movement, have high bulk densities and soil strengths and are extremely acid. These properties limit root development through the fragipans. Saturated conditions above the fragipan during much of the year also harm root systems of perennials such as trees and vine crops.

Crop yields usually are lower for fragipan than for nonfragipan soils because limited rooting depths cause droughty conditions during the latter part of the growing season. To obtain maximum use of fragipan areas for future agricultural production, the effective rooting depth and water storage must be increased. One approach is to disrupt the fragipan to create a more desirable physical environment and to add soil amendments or fertilizer to create a more desirable chemical environment for biological activity and root growth.

Kardos and Meyers (1968), in Pennsylvania, and Van Doren and Haynes (1961), in Ohio, found that chiseling alone did not cause long-term improvement in the rooting environment of fragipan soils. For long-term effectiveness, chiseling must penetrate through the fragipan and the loosened fragipan must not reform when completely wetted. Fritton and Olson (1972) indicated that the likelihood that the fragipan will reform depends upon the relative mixture of fragipan material with topsoil and organic material. If the fragipan material can be stabilized in the loosened condition, complete mixing might not be necessary (Stout and Ciolkosz, 1974).

This investigation evaluated changes in water storage, water extraction, and crop yield as influenced by thoroughly mixing and chemically altering the Fragiudalf profile.

EXPERIMENTAL PROCEDURE

The experimental site was on a 3% south slope of a predominantly Hobson silt loam soil in Dent County, Missouri. The Hobson Series is a member of the fine-loamy, siliceous, mesic family of Typic Fragiudalfs. These soils typically have brown acid silt loam or loam surfaces and very strongly acid brown clay loam B2t

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[1] Contribution from the Missouri Agric. Exp. Stn. and the North Central Region, ARS—USDA, Columbia, MO. Journal Ser. no. 7515. Received 2 July, 1976. Approved 20 September 1976.

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Table 1—Chemical Analyses of Hobson Silt Loam

Horizon	Depth	Organic matter	pH_w	pH_s	Available phosphorus	Exchangeable Ca	Exchangeable Mg	Exchangeable K	Cation exchange capacity
	cm	%			µg P/g	meq/100 g			
Ap	0-18	1.4	5.9	5.4	6	3.8	3.0	0.23	9.0
B21	18-30	1.0	4.8	4.0	1	2.5	4.0	0.34	15.0
B22	30-53	0.9	4.6	3.8	4	1.3	3.4	0.31	13.5
A'x	53-96	0.7	4.6	3.7	5	0.5	1.7	0.10	8.0
B'x	96-124	0.7	4.8	3.7	4	0.3	0.8	0.05	4.0
Within trench material									
Treatment A†	0-152	0.9	4.9	4.2	3	1.8	1.7	0.18	7.4
Treatment B‡	0-152	0.8	5.5	4.9	3	2.5	2.2	0.20	7.5
Treatment C§	0-152	1.0	5.4	5.2	102	3.4	3.0	0.75	9.4
Treatment D¶	0-152	1.7	5.0	4.8	98	3.4	3.0	0.71	10.1

† Trench only.
‡ Trench + lime (136 kg/24.4 m of trench).
§ Trench + lime + fertilizer (34 kg 6-24-24/24.4 m of trench).
¶ Trench + lime + fertilizer + sawdust (908 kg/24.4 m of trench).

Table 2—Summary of Monthly Rainfall and Temperature in 1975

Month	Atmospheric temperature‡ Average maximum	Atmospheric temperature‡ Average minimum	Atmospheric temperature‡ Extreme maximum	Rainfall total
	°C			cm
May†	27	15	29	0.6
June	28 (29)	16 (17)	33 (41)	10.8 (11.5)
July	32 (32)	17 (18)	36 (44)	5.2 (8.0)
August	32 (32)	18 (18)	38 (44)	18.8 (8.6)
September	23 (27)	11 (13)	34 (40)	8.8 (9.4)

† From planting date 23 May.
‡ Values in parentheses are long-term averages.

horizons underlain by a dense sandy fragipan at about 50 to 70 cm. The thickness of the B2t horizon is about 30 cm and the average clay content is about 25 to 35%. The profile is bisequal since it has two pairs of A and B horizons with the fragipan in both the lower A and B. The fragipan layer varies in thickness from 30 to 80 cm and is underlain by weathered sandstone (about 130 to 160 cm below the surface) or yellowish brown heavy clay loam. Within the fragipan horizon are thick, gray complex coatings associated primarily with vertical surfaces of the large primary polygons about 20 to 30 cm apart. Water movement and rooting through the fragipan horizon are restricted to these vertical cleavage planes. The Hobson soils are formed partly in loess and partly in material weathered from sandstone rocks of the Roubidoux formation, which is of the Ordovician period (Koenig, 1961).

The soils within the study site were quite variable. The soil in the center of the area had thick Hobson-type fragipans, but the soil at the lower, outer edge of the area graded into a fine-loamy, siliceous, mesic Typic Paleudult. The depth to sandstone ranged from 60 to 90 cm; sandstone fragments constitute about 85% of layers below the A horizon.

Table 1 presents some chemical properties of samples taken from Hobson soil profiles within the experimental area. Organic matter was determined by the Walkley-Black method; cation exchange capacity and exchangeable Ca, Mg, and K by the ammonium acetate method. Available phosphorus was measured by extracting 1 g soil with 10 ml of $0.1N$ HCl + $0.03N$ NH_4F for 1 min.

The climate of the study area is fairly humid and is marked by extremes in temperature (Table 2). The average annual precipitation is about 107 cm. One year out of 10 will have monthly rainfall < 1.8 cm for June through September, during which high temperatures cause low soil moisture levels. The 1975 growing season was slightly cooler than average, with July drier, and August much wetter.

The soil profile was modified in October 1974 using a Parsons Model #133 trenchliner[3]. This wheel-type trencher is capable of digging a trench 175 cm deep and 51 cm wide. Although travel speeds varied with type of material in the fragipan, speeds commonly were up to 152 cm/min. A conveyor belt allows the soil from a trench to be deposited about 150 cm from the trench. Thus, after the wheel removed and thoroughly mixed vertical slices of the soil profile, the soil was returned to the adjacent trench. A front-end-loader was used to transport the soil from the first to the last trench within each plot.

The experimental design is shown in Fig. 1. Plots were 7.6 by 24.4 m long, and each had 5 parallel trenches (152 cm deep and 51 cm wide) placed 152 cm apart as measured from centers (Fig. 2). The trench treatments were arrayed in a 4 by 4 Latin square design. A nontrenched area, 7.6 m wide and above each row of treatments, was used to evaluate the effects of the trenches on adjacent areas above and below. Eight 7.6 by 12.2 m long plots at each end of the trenched and nontrenched rows were used to determine crop yield on undisturbed areas.

The four treatments evaluated were:

A) trench only,
B) trench + lime (136 kg/24.4 m of trench),
C) trench + lime + fertilizer (34 kg 6-24-24)[4] /24.4 m of trench), and[4]
D) trench + lime + fertilizer + sawdust (908 kg/24.4 m of trench).

The soil additives were applied along a straight line (immediately over the soil volume to be trenched) and thoroughly mixed with the soil profile during trenching. Chemical analyses were made on bulk samples taken within the trenches after the four treatments were applied (Table 1).

After modification, the plots were leveled and 750 kg 6-24-24[4] /ha and 18 tons/ha of lime was surface applied. On 8 November, 1974, the site was seeded to 95 kg/ha wheat as a winter cover crop. On 5 May, 1975, the wheat *(Triticum aestivum)* was killed with paraquat. Because a N deficiency became apparent on the sawdust plots during the winter and early spring, an additional 23 kg of ammonium nitrate was added to each of these plots (equivalent to 1,240 kg/ha) on 21 May, 1975; an additional 757 kg/ha of ammonium nitrate was then surface applied to the entire study area. After disking, grain sorghum (*Sorghum bicolor* (L.) Moench) hybrid 'G-522'' was seeded on 23 May at 8 kg/ha in 38-cm rows. No weed control was required throughout the growing season.

Volumetric soil water content was determined twice weekly by the neutron probe method along a transect across the plots. Access tubes for moisture measurement were centrally located in the trenches, in the 102 cm between the trenches, and within the 7.6 m nontrenched areas. Soil bulk density, particle-size distribution, and saturated hydraulic conductivity were determined on trenched and nontrenched Hobson soil at the end of the growing season. Penetrometer resistances were determined on 25-cm diameter natural cores using the penetrometer described by Bradford et al. (1971). Remolded cores were formed in 10-cm diameter brass cylinders. The probe allowed point resistance to be measured separately from wall friction. The included angle of the point was 60°.

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[3] Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the USDA, and does not imply its approval to the exclusion of other products that may also be suitable.

[4] Contains 6% N, 10.5% P, and 20% K.

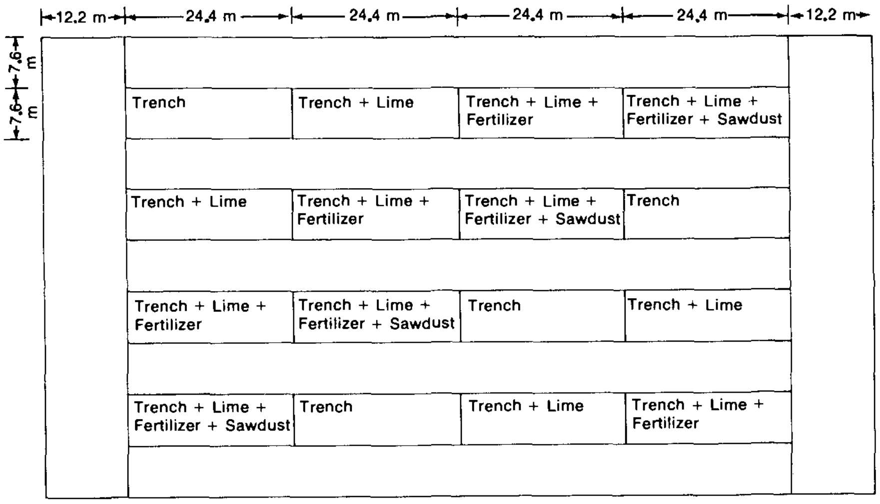

Fig. 1—Experimental design.

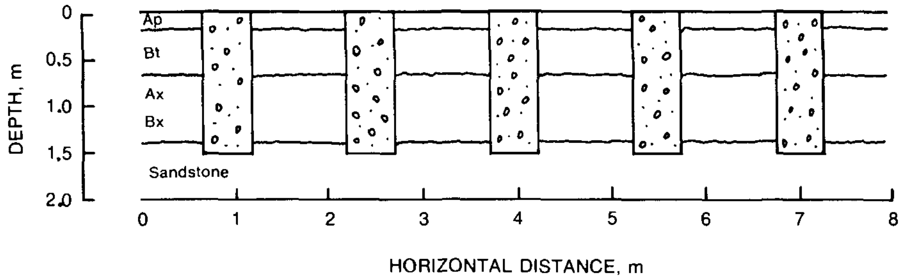

Fig. 2—Schematic representation of a profile modification plot showing the Hobson profile and mixed material.

On 30 September, 1975, grain yields were determined by hand sampling from two 3 by 6 m subplots within each plot.

RESULTS

Yields

Sorghum grain yields were significantly increased during the first year after deep-trenching (Table 3). The four trench treatments were analyzed by a Latin square analysis of variance with two subsamples. The treatment effect was significant at the 1% level, the row effect was significant at the 5% level, and the column effect was nonsignificant. The row effect was due to higher yields in lower positions of the slope. As tested by Least Significance Difference, the trench + lime + fertilizer +sawdust treatment yield of 5,987 kg/ha was significantly greater at the 5% level than all other treatments. Other significantly different treatments are given in Table 3. As a uniformity test, a 4 by 4 Latin square analysis of variance was conducted on the nontrenched areas within the experiment; this analysis showed a nonsignificant column, row, and treatment effect (at the 5% level). A comparison among the nontrench area and trench soil treatment means was made with a LSD test using a pooled error variance from the two separate Latin square analyses. Yields in the 7.6-m nontrenched areas (between the parallel trenched plots) were significantly higher than those in the area outside the trenched area. This effect was attributed in part to the additional 8 cm of topsoil added during the soil leveling operation. Yields outside the tenched area were 1,841 kg/ha which were much lower than the other yields.

Differences in sorghum yields resulted from a change in the chemical as well as physical soil environment (Table 3). Adding lime and fertilizer together significantly increased yields. Adding lime alone to the trenches did not significantly increase yield (at the 5% level), nor did adding fertilizer alone to the trench + lime plots significantly increase sorghum yields. Adding lime + fertilizer + sawdust significantly increased yields over all other treatments tested. This increase was due, in part, to the effect of sawdust on increased available water within the soil profile. Surface applications of an additional 23 kg of ammonium nitrate to each sawdust plot was necessary to eliminate nitrogen deficiencies created by the sawdust. All plots received at least 340 kg N/ha as ammonium nitrate as a broadcast treatment which was assumed to have eliminated nitrogen as a yield-limiting factor.

Soil Water Storage and Depletion

Soil water storage and utilization differed markedly within the trenches, between trenches within the deep-trenched plots, and within the 7.6-m nontrenched areas.

Table 3—Effects of Profile Modification and Chemical Amendments on Grain Yield of 'G-522' Hybird Grain Sorghum

Modification treatment	Yield, kg/ha
Outside trench area	1,841
Nontrench area	3,229 a†
Trench (A)‡	4,322 b
Trench + lime (B)	4,906 bc
Trench + lime + fertilizer (C)	5,145 c
Trench + lime + fertilizer + sawdust (D)	5,987 d

† Means followed by the same letter are not significantly different at the 5% level.
‡ Treatment number.

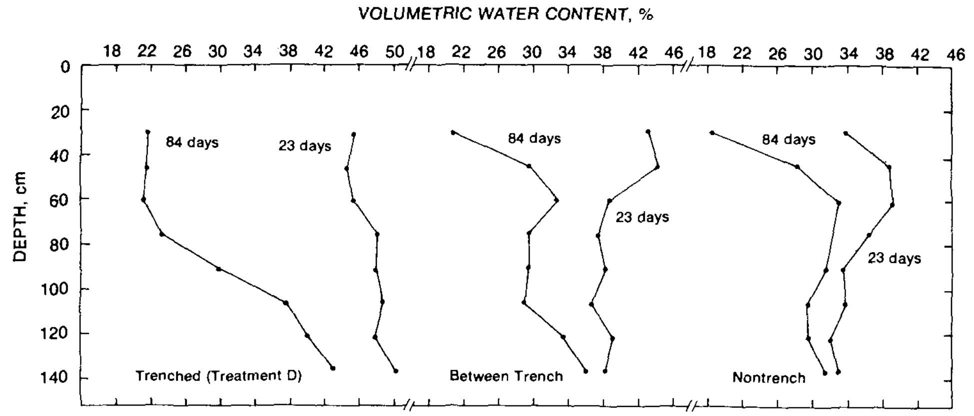

Fig. 3—Soil water content in early season and late season of trenched, between trench, and nontrenched profiles.

Figure 3 shows volumetric water contents plotted as a function of depth for typical soil profiles tested. On 14 June, 1975 (23 days after planting), the trenched soil profile (Treatment D) had more water stored within the profile than nontrenched areas (Fig. 3). The volumetric water content at saturation was about 48%. Since there was a perched water table above the fragipan horizon at the beginning of the growing season, depths below 60 cm can be assumed to be at or near saturation. There were slight differences in the volumetric water contents between the nontrench and between-trench areas at the beginning of the growing season, but these seemed to be within the variation expected due to differences in soil profile morphology.

On 14 August 1975 (84 days after planting), the upper 46 cm of the soil profile reached its minimum volumetric water content; rains were heavy (18.4 cm in August) after this date. For the 84-day period after planting, the sorghum plants utilized more water from the trenched soil profiles than from the between-trench and nontrenched soil profiles. The changes in volumetric water contents for the two dates at a 76-cm depth (about 15 to 30 cm below the B22t-A'1 interface) for trenched, between-trench, and nontrenched areas were 24.9%, 8.1%, and 3.9%, respectively. Greater differences in the undisturbed zones between the trench areas, than between the nontrench areas, were attributed to lateral water movement from the between-trench areas to roots growing in the trench area. Upon excavation of the trenched areas, massive amounts of roots were found to 120-cm depths and were concentrated along the trench walls. No roots penetrated the fragipan horizon either from above or laterally from the trench areas.

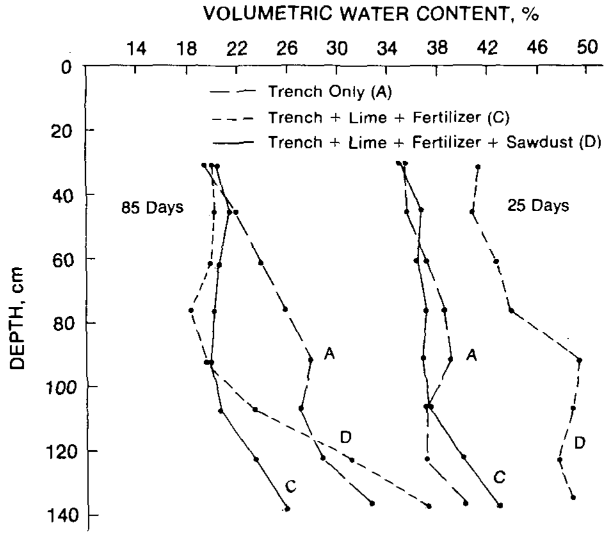

Fig. 4—Soil water content in early and later season as affected by profile modification.

Differences in the volumetric water content profiles within the trenched treatments resulted from the lime, fertilizer, and sawdust. The water content in early season was much greater in the sawdust trenched treatment (Fig. 4) than in the other trench treatments, whereas there were no differences between the other trenched treatments. After 84 days, differences were noted in water content in profiles of the trenched plots. In the trenched-only treatments, a smaller amount of water had been extracted. In all cases, more water had been extracted at the 140-cm depth in the lime + fertilizer trenches, and less water at low zones in the sawdust trenches. The volumetric water content of profiles were the same between trenches amended with lime and those amended with lime + fertilizer.

Soil Physical Environment

The profile modification increased storage of water available to the plant roots by increasing total pore space (decreasing bulk density), by increasing the saturated hydraulic conductivity, and by decreasing the mechanical resistance to plant root growth. Table 4 shows changes in physical properties due to deep trenching, as determined from core samples (12.0 cm in diameter and 10.2 cm long) taken from the sawdust plot in row 2 (Fig. 1). Figure 5 compares the

Table 4—Physical Properties of a Hobson Silt Loam in its Natural or Modified Conditions.

Sample depth	Horizon	Hydraulic conductivity	Texture			Porosity
			Sand	Silt	Clay	
cm		cm/day	%			
		Natural Hobson				
15-23	Ap	70	28	58	14	0.39
30-38	B22	57	14	54	32	0.49
53-61	B23	14	38	33	29	0.50
76-84	A'x	0.07	48	34	17	0.37
		Modified Hobson				
20-28		554	58	27	15	0.46
43-51		612	64	22	14	0.46
78-86		799	66	19	15	0.45

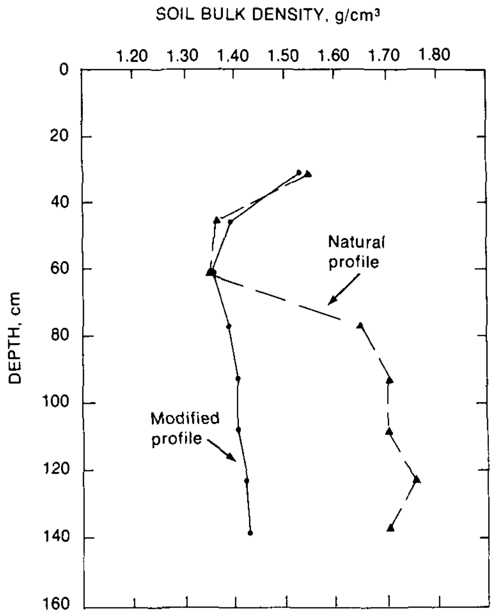

Fig. 5—Bulk densities of natural and modified profiles.

soil bulk density profile of the Hobson soil in its natural and modified states. Trenching reduced the initial bulk density of 1.7 to 1.4 g/cm³ at the fragipan depth. Penetrometer resistances at 1/3 bar suction on the Hobson B2x horizon ranged from 150 to 200 bars, whereas the Ap horizon was between 20 to 30 bars. Reformed Hobson B2x horizon with bulk densities of 1.45 to 1.55 at 1/3 bar suction had penetrometer resistances ranging from 3 to 9 bars. When a vertical wall was dug into the trenched material, it collapsed, indicating a very weak shearing resistance.

DISCUSSION

The striking increase in sorghum yield from 1,841 to 5,987 kg/ha is attributed to the impact of soil modification on increased available water stroage and root proliferation. The most important factor was the decreased density and strength of the fragipan layer, which allowed roots and water to penetrate the soil profile. Another significant factor was the modification of the rooting zone by lime + fertilizer + sawdust, which promoted the massive root development and increased the sorghum yield from 4,322 to 5,987 kg/ha.

Sorghum roots utilized little moisture from below the fragipan layer unless the layer was fractured. The added water storage due to trenching enabled the plant roots to extract more water from the soil profile. Adding fertilizer and lime corrected a chemically poor root environment and adding sawdust further increased the water storage. Ample water was available near the end of the growing season (84 days) in the sawdust trenches below the 120 cm depth (Fig. 4). In this study, we assumed that little, if any, water moved upward in the profile from below the 160 to 180-cm depth because of the presence of sandstone rock.

To gauge the possible extent of increased packing and fragipan reformation with time, in December 1975, we reexcavated and reexamined a Hobson series site that was dug and refilled in 1959. The site was approximately 50 m from the sorghum plots and is described in Soil Survey Investigations Report No. 6 (1966) under S59M1-33-3. There was little indication of reformation during the 16 years. Upon excavating across the 1959 pit, the back-filled soil collapsed in an alcove-type failure (Lutton, 1969), indicating little shearing strength. Roots were present below 120 cm within the back-filled fragipan material. The material appeared very similar, in soil strength and bulk density, to the material taken from the sorghum plots. Using a Pilcon[3] hand vane device, we found vane shear strengths in various horizons of the natural Hobson adjacent to the back-filled material to be: B_1-460 g/cm²; B_{21t}-700 g/cm²; B_{22t}-700 g/cm²; B_{23t}-770 g/cm². The high strength and brittleness of the fragipan zone prevented any vane shear readings in this zone. Vane shear strengths in the back-filled material ranged from 100 to 200 g/cm²; bulk density varied from 1.54 to 1.61 g/cm³; however, approximately 10% of the material in the 12 cm diameter density rings was coarse, sandstone fragments. Thus we concluded that there were no signs of reformation over a 16-year period.

ACKNOWLEDGMENT

This work was supported in part by Project No. 7025-5500 from Title 5 Funds, Rural Development, Missouri Agric. Exp. Stn. and by a special assistance grant from the Director of the Missouri Agric. Exp. Stn. The support and encouragement of Daryl Hobbs, Director for Rural Development, is gratefully acknowledged. The authors thank Leonard Johnson, Community Development Specialist, Salem, Missouri, for his local support in all areas of this project and Steve Johnson for performing and analyzing portions of the field study.

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