An overview of traction research at University of California, Davis

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Experiments using a specially designed device were conducted to determine the performance characteristics of tractor tires under various conditions. Radial ply tires showed superior performance over bias ply tires. Soil had a greater influence on traction capabilities than did tire design. Traction prediction equations for radial ply tires were developed.

Over the past few decades, tractor sizes have steadily increased. With the growth in power, performance is restricted mainly by the limitations of the traction device (wheels or tracks) imposed by the terrain over which tractors operate. The power efficiency of pneumatic tires ranges from about 90% when operating on concrete to less than 50% on loose or sandy soils. A conservative estimate of the annual fuel loss due to the poor tractive efficiency (ratio of drawbar power to axle power) of agricultural tractors in the United States alone is 152 million gallons. Since the drawbar is the most commonly used power outlet of agricultural tractors, the ability to provide draft to pull various types of implements is a primary measure of a tractor's effectiveness. The tractive efficiency with which the pull is achieved is also of importance.

Experimental evidence indicates that the soil has a greater influence on traction capabilities than do tire design features. On pavement, vehicles can develop a high pull, but when operating on soil, they may develop only a fraction of that pull because of adverse soil conditions. Within a given soil type and condition, however, tire design has a significant effect on tractive performance.

We have conducted extensive field tests over the past four years at the University of California, Davis, to determine the effects of tire geometry, tire type (radial vs. bias), lug design, inflation pressure, axle loading, and soil type and condition. Using a unique, mobile, single-wheel traction testing machine developed specifically for the purpose, we compared radial and bias ply tires in a tilled Yolo loam soil and studied the effect of tread design on the tractive performance of 18.4-38 tires in a tilled and in an undisturbed Capay clay soil. These studies enabled us to develop a formula to predict the tractive performance of radial ply tires. Moreover, we have developed models of low-pressure pneumatic tire interaction with the soil.

Traction testing machine

The traction testing device, developed at the Department of Agricultural Engineering, UC Davis, is essentially a mobile soil bin that can be used to conduct controlled experiments in the field. With it, we can test tires of diameters ranging from 18 inches (0.46 m)(rim ID) to 79 inches (2 m)(OD) and widths up to a maximum of 39 inches (1 m).

The system is designed to provide an infinitely variable vertical load up to a maximum of 6,000 pounds (26.7 kN) and a draft load up to a maximum of 3,000 pounds (13.3 kN). The device can be operated in a draft control or a slip control mode.

Tire testing procedure

Each tire test consisted of several (typically 8 to 10) runs. For a given run, vertical load on the tire and either draft or slip were controlled.

The first few runs were conducted in slip control mode (that is, slip was held constant at a preselected value during the run). The first of these runs was conducted at approximately zero slip and was used to obtain the (zero slip) tire rolling radius (the effective tire radius that results in zero slip when the draft on the tire is zero, r). The next few runs (typically 3) were conducted at successively higher levels of slip. The remaining runs in a given test were conducted in draft control mode (draft was held constant during the run) at successively higher levels of draft. A test was considered complete when either the wheel slipped excessively or the system torque limitations were reached. Between successive runs, the tester was rotated about its rear support wheels by about 5 degrees.

During each run, vertical load (axle load, W), input torque (T), net traction (draft, D), wheel speed, and forward travel were recorded with a digital data logger. Figure 1 shows a typical test result—the variation of draft, input torque to the axle, and tractive efficiency with slip. We obtained the predicted traction performance curve in this figure by statistical methods (performing a nonlinear regression analysis through the experimental data). Although draft increased with increasing slip, the tractive efficiency peaked at about 5% slip for this tire, soil, and loading condition.

We also obtained several values of soil cone index in each test site using a hydraulically operated standard cone penetrometer mounted on the test machine. In addition, several readings of soil bulk density and surface moisture content were taken with a neutron probe.

Radial vs. bias ply

Four tires (18.4R38, 18.4-38, 14.9R28, 14.9-28) were each tested at two levels of inflation pressure and three different vertical loads in a well-tilled Yolo loam soil (table 1). Two performance characteristics were compared: (1) average tractive efficiency in the 0 to 30% slip operating range; (2) net traction ratio, (net traction)/axle load, at 20% slip. We found that: (1) radial ply tires performed better than bias ply tires; (2) large tires performed better than small tires; (3) increased vertical load improved performance; and (4) tire inflation pressure did not influence performance under the test conditions.

The large radial ply tires resulted in an average value of tractive efficiency in the 0 to 30% slip range of 27.23% vs. 25.37% for the large bias ply tires. This 1.86 percentage point difference in tractive efficiency translates to a 6.8% savings in energy usage. The energy-savings implications of this difference are of interest. We estimated that using machinery equipped with radial ply rather than bias ply tires would save 290,000 barrels of oil equivalent, or approximately $5 million per year, in California alone.

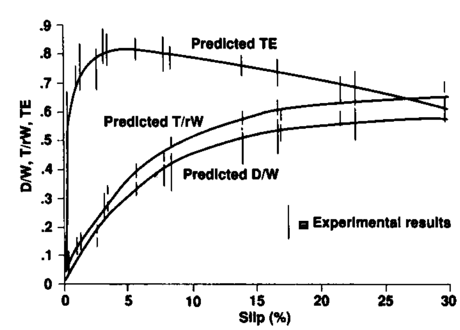

Fig. 1. Predicted traction performance curves and typical test results for an 18.4R38 tire with 24.5 kN applied load and 124 kPa inflation pressure in a firm Yolo loam soil.

Jack Kelly Clark

A unique, single-wheel traction testing device developed by Shrini Upadhyaya and design engineers at the Department of Agricultural Engineering, UC Davis, measures performance of different types of tractor tires under varying conditions. In field tests, the single wheel travels along a 60-foot track under controlled degrees of load and slippage.

Jack Kelly Clark

Effects of tread design

Five 18.4-38 tires with various tread designs were tested at an inflation pressure of 18 pounds per square inch (psi) and two levels of vertical load in an undisturbed and in a tilled Capay clay soil. Three of the tires had a "long bar-short bar" tread pattern (tires T-1 to T-3) and the other two (T-4 and T-5) had conventional tread patterns. There were shape differences among the long bar-short bar tires and between the conventional tires since they came from several tire manufacturers. Unfortunately, the data logger did not record data for the T-4 tire in tilled Capay clay. This tire was therefore tested in a tilled Yolo loam soil along with the T-3 tire.

Tread design T-4 developed relatively good traction and resulted in the highest tractive efficiency of all the tires in the undisturbed Capay clay soil (table 2). Tread design T-2 also developed relatively good traction but had the poorest tractive efficiency in the undisturbed soil. The tractive characteristics of the five tread designs tested did not differ from each other significantly in the tilled Capay clay soil. Tread design T-3 resulted in better tractive characteristics than tread design T-4 in the tilled Yolo loam soil.

Radial tire traction prediction

Because of the superior tractive performance of radial ply tires, we performed field tests to obtain traction prediction equations for such tires under various soil and loading conditions. Three radial ply tires (18.4R38, 16.9R38, and 24.5R32) were tested in two soils (Capay clay and Yolo loam). Each soil received five different treatments: (1) undisturbed; (2) disced twice with a heavy stubble disc to a depth of approximately 6 inches (150 mm); (3) disced twice with the heavy stubble disc, then twice with a finishing disc; (4) stubble-disced twice, followed by four passes with the finishing disc; and (5) the same treatment as (4) and then flood-irrigated to create a crust.

Before the tillage treatments, the Capay clay was flood-irrigated and allowed to dry. The Yolo loam field was not flood-irrigated before treatment. As a result, the two fields had distinctly different moisture contents. The tire tests were thus conducted in ten soil conditions. Within each condition, each tire was tested at two inflation pressures—12 (83) and 18 (124) psi (kPa)—and three vertical loads—approximately 3,000 (13.3), 4,500 (20), and 6,000 (26.7) pounds (kN)—

TABLE 1. Summary of tractive characteristics of test tires in Yolo loam soil

Tire and inflation pressure	Axle load	Tractive efficiency: Max. value	Tractive efficiency: % slip at max. value	Tractive efficiency: Avg over 0-30% slip range	D/W* at 20% slip
kPa	kN	%	%	%	
18.4R38:					
100	11.2	55.3	12	24.0	0.303
100	14.2	61.7	10	26.8	0.328
100	22.7	66.9	10	29.5	0.398
125	13.5	66.5	10	28.1	0.342
125	16.1	61.3	10	27.3	0.342
125	27.1	62.4	10	27.7	0.363
18.4-38:					
110	10.8	46.2	12	20.2	0.257
110	13.6	58.5	10	25.3	0.308
110	22.5	64.8	10	28.7	0.346
135	12.9	52.6	13	23.0	0.276
135	17.2	60.7	10	26.4	0.321
135	26.0	66.0	8	28.6	0.352
14.9R28:					
180	11.1	43.3	14	18.0	0.245
180	14.9	41.0	16	17.8	0.253
180	21.8	48.6	12	21.4	0.288
205	12.7	42.9	14	18.5	0.234
205	17.1	43.7	12	20.1	0.251
205	24.4	47.8	12	20.8	0.287
14.9-28:					
180	9.4	35.9	16	15.3	0.233
180	12.5	38.3	14	16.5	0.233
180	16.5	44.4	12	19.3	0.280
220	11.1	34.2	18	14.5	0.227
220	15.1	39.4	12	16.9	0.227
220	18.5	39.7	14	17.2	0.240

* D = draft. W = axle load.

TABLE 2. Summary of tractive characteristics of five 18.4-38 tires

Soil, tire	Axle load	Cone index	Tractive efficiency: Max. value	Tractive efficiency: % slip at max. value	Tractive efficiency: Avg over 0-30% range	D/W* at 20% slip	Max D/W
	kN	kPa	%	%	%		
Capay clay, undisturbed:							
T-3	16.85	1121	68	10	60.94	0.421	0.639
T-1	16.79	1006	70.1	8	62.53	0.440	0.615
T-4	16.60	868	77.8	8	69.29	0.443	0.74
T-5	16.5	992	68.5	10	60.75	0.419	0.63
Capay clay, undisturbed:							
T-3	25.65	1121	71.8	8	63.84	0.432	0.473
T-1	25.61	1006	75.3	8	66.61	0.454	0.556
T-2	25.52	802	68.1	11	61.32	0.493	0.64
T-4	25.30	868	83.4	8	72.91	0.487	0.674
T-5	25.3	992	71.4	10	63.87	0.450	0.586
Capay clay, tilled:							
T-3	16.67	746	59.8	14	53.74	0.320	0.556
T-1	16.69	629	71.0	8	62.86	0.328	0.458
T-2	16.76	325	64.1	12	57.35	0.357	0.582
T-5	16.6	—	60.7	12	54.08	0.325	0.501
Capay clay, tilled:							
T-3	25.43	746	68.3	10	60.72	0.392	0.462
T-1	25.57	629	72.4	8	63.11	0.366	0.456
T-2	25.57	325	66.0	10	58.58	0.392	0.443
T-5	25.3	—	68.2	8	60.67	0.385	0.453
Yolo loam, tilled:							
T-4	21.56	665	60.2	10	53.49	0.352	0.383
T-5	21.50	700	48.0	12	41.96	0.286	0.328

* D = draft. W = axle load.

resulting in 180 tests consisting of over 1,500 runs.

We analyzed the data and developed prediction equations using traction mechanics as a guide. Model simulations were conducted to determine the effects of soil cone index (72.5 vs. 145 psi), soil moisture content (8% vs. 16%), tire size, tire inflation (12 vs. 18 psi), and vertical loading (4,500 vs. 5,600 pounds) on tire performance.

The simulations indicated that changes in soil conditions influence tire performance much more than changes in tire loading and dimensions. Within a given soil condition, the 24.5R32 tire would perform better than both the 18.4R38 and 16.9R38 tires. The performance of the 18.4R38 tire was similar to that of the 16.9R38 tire, but at lower soil cone index values, the 18.4R38 performed slightly better than the 16.9R38 tire. Increased vertical load led to a slight increase in performance. Increased tire inflation pressure led to slightly decreased performance.

In the range of conditions tested, performance was better in the soil with a higher moisture content. This improvement in traction is probably due to an increase in soil cohesion. At high enough moisture contents, the angle of soil friction would drop and tractive performance would become poorer.

Mathematical models

We have developed mathematical models to predict the soil deformation and soil-tire interface stresses due to interaction between soil and low-pressure pneumatic tires. We are currently implementing these models, using a commercial finite-element modeling and analysis package called MARC. We are also attempting to develop a 3-D displacement measuring device to measure soil deformation under a pneumatic tire.

The information related to soil deformation and soil-tire interface stresses is expected to be useful in designing pneumatic tires to enhance their tractive characteristics and reduce soil compaction. Excessive soil compaction reduces water infiltration, increases soil erosion, decreases biological activity in the soil, increases tillage energy requirements, and reduces crop yield. Traffic-induced soil compaction is of increasing concern because of its detrimental effects on agricultural sustainability.

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