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Fuel consumption of gasoline and diesel tractors when used with selected implements in West Tennessee

Roger Garland Carpenter

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To the Graduate Council:

I am submitting herewith a thesis written by Roger Garland Carpenter entitled "Fuel consumption of gasoline and diesel tractors when used with selected implements in West Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering.

Fred D. Tompkins, Major Professor

We have read this thesis and recommend its acceptance:

J. I. Sewell, B. L. Bledsoe

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

October 29, 1976

To the Graduate Council:

I am submitting herewith a thesis written by Roger Garland Carpenter entitled "Fuel Consumption of Gasoline and Diesel Tractors When Used With Selected Implements in West Tennessee." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Mechanization.

Fred D. Tompkins, Major Professor

We have read this thesis
and recommend its acceptance:

B. L. Bledsoe

John Sewell

Accepted for the Council:

Hilton A. Smith
Vice Chancellor
Graduate Studies and Research

FUEL CONSUMPTION OF GASOLINE AND DIESEL TRACTORS WHEN USED WITH SELECTED IMPLEMENTS IN WEST TENNESSEE

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Roger Garland Carpenter
December 1976

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ABSTRACT

The rate of fuel consumption was measured for both gasoline and diesel tractors in size classes for use with two-, four-, and six-row implements. Tractors were operated at four different speeds with various sizes of the following implements: moldboard plow, tandem disc, planter, and cultivator.

Fuel meters were designed and constructed to measure the amount of fuel consumed for gasoline and diesel tractors during field operations. The fuel consumption was measured volumetrically by using systems of electrically-actuated solenoid valves to control the flow of fuel into and out of graduated cylinders.

The moldboard plows in almost every instance required the most energy both per hour and per unit area with each tractor type. As a rule, the moldboard plow was followed in fuel consumption by the tandem disc, the cultivator, and the planter. As implement size increased fuel consumption per hour increased as did field capacities. An increase in operating speed resulted in an increase in fuel consumption per hour. However, the fuel consumed per unit area decreased as speed increased from 3.2 to 8.1 kilometers per hour (2.0 to 5.0 miles per hour). This suggests that certain implements with high field capacities plus high operating speeds may result in substantial energy savings.

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CHAPTER I

INTRODUCTION

I. Statement of Problem

In the last decade, the price and availability of energy (gasoline and diesel fuel) used to operate most farm machinery was of little concern to farmers of the United States, since it was readily obtained at a relatively low cost. However, with the advent of the "energy embargo" of 1974, cost of this same energy approximately doubled compared with 1967 prices. The United States Department of Agriculture Statistical Reporting Service noted that in 1967 the prices paid by farmers for gasoline and diesel fuel were 28.3 and 16.3 cents per gallon, respectively. By 1973, the prices had only risen to 33.9 and 23.0 cents per gallon, respectively. However, at the end of 1974, the prices paid by farmers had ballooned to 46.5 cents per gallon for gasoline and 36.5 cents per gallon for diesel fuel. As of January, 1976, the prices paid by farmers for gasoline and diesel fuel were 52.5 and 41.4 cents per gallon, respectively.

These rising costs have created widespread concern in the agricultural industry since large tractors (over 60 kilowatts or 80 horsepower) comprise over 50 percent of the farm tractors manufactured (Casterton and Smith, 1971). This strongly indicates that the rate of fuel consumption of farm tractors on a hourly basis has increased. As a result, rising fuel consumption and fuel prices have added greatly to the production costs of farmers.

Corresponding to increases in tractor size, tillage implement size has grown proportionally. An increase in field capacity and savings in time and labor are realized with the larger systems. However, the increase in fuel consumption may offset these advantages.

Since most farm energy is expended during tillage, a need for analyzing fuel consumption of farm tractors engaged in tillage operations was apparent. Also, an inexpensive and accurate method of monitoring fuel consumption was needed to facilitate research activities. Moreover, field capacities warranted investigation to determine if any savings result through use of larger tractor-implement systems.

II. Objectives

The purpose of this study was to investigate the fuel requirements of gasoline and diesel farm tractors while performing selected tillage operations.

Specific objectives included:

1. Design and construct systems for accurate measurement of the fuel consumption rate of gasoline and diesel tractors operating in the field.
2. Measure fuel requirements of selected tractors and implements.
3. Obtain an energy requirement both per hour and per unit area for each type of implement and tractor at various operating speeds.

4. Compare the fuel requirements of comparable tractor and implement systems.

CHAPTER II

REVIEW OF LITERATURE

I. Reasons for Measuring Fuel Consumption

The approximate two-fold increase in the price of gasoline and diesel fuel in less than a decade has sharply increased the production costs of most farmers (Statistical Reporting Service, USDA, 1976). The increased cost of most agricultural tractors has also pushed production costs upward.

Pimentel et al. (1973) reported that fossil fuels have become so vital to modern agriculture that any energy crisis would have a significant effect upon food production. A careful analysis is needed to measure the energy inputs in the United States' crop production techniques.

Steinhart and Steinhart (1974) commented that modern agriculture is so dependent on fossil fuel energy that even a small increase in energy prices may make it profitable to increase labor input. In other words, a small increase in energy prices might make it profitable to "demechanize" farm production to some extent.

Cook (1975) also discussed the effect of fuel shortages on agriculture. He stated that the agricultural economy of the United States would be drastically affected by severe fuel shortages and that field crop production would be virtually impossible in the United States' agricultural system without petroleum.

Vaughn (1976) and Wittmuss (1975) determined the fuel needed for a diesel tractor in two corn production systems--conventional and minimum tillage. However, neither investigator considered in his calculations such pertinent variables as drive wheel slippage, tractor condition, and other factors that effect fuel consumption. These omissions reduced the utility of their results. The need still exists for effective measurement of fuel consumption for determining energy requirements of tillage operations.

II. Methods of Measuring Fuel Consumption

Measuring the flow rate of a liquid can be troublesome at times. However, it can be relatively simple. Several ways are available to measure the flow of liquids (Doebelin, 1966). Some of the more commonly used methods are:

1. Constant area, variable-pressure-drop flowmeters, commonly called "obstruction" meters.
2. Constant-pressure-drop, variable-area flowmeters, or "rotameters."
3. Turbine flowmeters.
4. Positive displacement flowmeters.
5. Metering pumps.
6. Electromagnetic flowmeters.
7. Gross-Mass-Volume flow rate.

In measuring fuel consumption for motor vehicles, Kieling (1962) reportedly used a positive displacement fuel meter, Model FM-200. As one piston received fuel, a second piston discharged fuel into the engine. An electric solenoid which was connected to a counter was activated for each fuel discharge. Since the volume of each cylinder was known, the number on the counter, when multiplied by the cylinder volume, produced the amount of fuel used by a particular engine.

Saal (1955) also used a positive displacement type fuel meter in measuring the fuel consumption of passenger cars. He employed the fuel meter to determine the relationship between fuel consumption, forward speed, and degree of gradient.

In other motor vehicle tests, a computer was employed to monitor variables in two engines (Sutherland, 1974). The fuel consumption was measured by instruments using voltage or frequency output (turbine flowmeters). The readings were recorded by the computer every 504 milliseconds, thus, computing the average fuel flow.

Sawhill and Firey (1962) conducted tests of fuel consumption and travel time on large semi-trucks. To measure the fuel consumption in this situation, a system of burettes was used. The burettes were modified slightly by adding a graduated scale behind each one. This scale, in addition to the scales already on the burettes, allowed easier reading of the liquid level, especially while the vehicle was in motion. An assistant was assigned the task of observing the burettes during the actual tests and recording the fuel consumption at specific points. Since the semi-trucks were powered by diesel engines, a special device, called a "day tank," was inserted in the fuel line between the transfer pump and the burettes. The purpose of the "day tank" was to account for the fuel returned to the supply tank which occurs in most diesel systems.

The primary disadvantage of burette systems was the need to stop the tests and refill the burettes. Also, the burettes required constant observation for accurate fuel readings. Michalowicz (1970) developed a fuel meter employing the burette system which allowed continuous operation with both gasoline and diesel powered vehicles. The fuel meter was basically a series of burettes with the addition of several "devices" which allowed the system to refill and switch burettes when in operation. An opaque float rested on the surface of the fuel column in each burette. A series of light sources with contrasting photoelectric sensors were strategically placed at precise distances apart, i.e., 5 cc, 10 cc, etc., on each burette. As fuel was used from one burette, the float interrupted the light beam, actuating an electric relay which in turn actuated an impulse counter. The number of impulses and the "distance" between light beams translated into fuel consumption.

When a float reached the last light beam in a burette, a series of electric valves were activated and the next burette went into operation as the first burette began to refill. To prevent overflowing, the refilling process stopped when the rising float interrupted the topmost light beam.

A comparison of fuel measuring methods was performed by Saal (1955). He compared a positive displacement flowmeter with a burette to check for any variation in the two methods. After several tests using both methods, he concluded that results obtained with the fuel meter did not vary significantly from those obtained with the burette.

Koertner (1975) and others, discussed a technique for measuring fuel and energy requirements for tillage and other machinery operations.

They stated that any agricultural machine could be attached to an instrumented tractor making fuel and energy requirements readily available in the field. The technique consisted of determining the position of the metering valve in the injector pump. Using the rpm and the metering valve position, a resulting power output prediction was made. However, analysis of the data disclosed inconsistencies in the method, which rendered the results unacceptable. One factor thought to be a cause of the poor test was the temperature of the fuel. Relatively high fuel temperatures possibly caused premature expansion of the metering valve, resulting in erratic valve position readings.

In measuring the fuel requirements of farm tractors in the laboratory, Leviticus (1976) reported that the measurement method he employed was gravimetric and not volumetric. A large main tank was permanently located on a scale. Fuel was pumped to a second tank which supplied fuel to the tractor, such that an overflow into the main tank occurred continuously. The weight differences were measured precisely every ten minutes. When the time came for measurement, the pump was stopped; the overflow stopped; and the weight was taken while the tractor continued to run. One big advantage of this method was its independence of fuel temperature.

Measuring fuel consumption by volume in gasoline tractors has been relatively simple. Deere and Company (1972) and Gulvin (1953) indicated that a metering device need only be placed in the fuel supply line directly between the fuel supply tank and the carburetor if the gasoline is gravity fed; or between the supply tank and the fuel pump for engines with such devices.

The measurement of fuel consumption for diesel engines has been much more complex (Crumbley, 1960; Kates, 1954; Long, 1975). Most diesel engines have a fuel return system which carries surplus fuel back to the supply tank. Also, preventive measures must be taken to prevent air from entering the fuel system. Diesel fuel systems should be airtight for proper operation and performance.

III. Alternatives to Increased Energy Use

Energy use in U. S. Agriculture can be reduced economically if farmers will perform specific alternatives. Pimental et al. (1973) suggested that one method to reduce fuel use would be to operate machinery precisely scaled for its task at efficient speeds. Another alternative mentioned was increasing the number of acres tended by tractors and other machinery.

Cook (1975) stated that fuel consumption could be directly reduced by using chemicals for weed control, thus eliminating some trips through the field. However, since herbicides require petroleum for their manufacture, the total energy consumption may not be reduced significantly.

Vaughn (1975) and Wittmuss (1975) reported that fuel can be conserved by reducing tillage operations using minimum tillage techniques. As indicated by their calculations, fuel consumption was directly reduced using minimum tillage; it may remain unchanged due to the heavy dependence on herbicides manufactured from petroleum.

Wilkins and Coleman (1971) stated that energy requirements for farm tractors tend to increase with speed. They also noted that farmers are not primarily concerned in minimizing energy use. Considering the dramatic cost increases for farm fuels, these statements may not hold true presently. Any savings in fuel use today would seem to result in larger profits for farmers.

Hirst (1974) discussed farmers' alternatives to high rates of fuel consumption. He stated that farmers could save fuel by combining field operations, reducing tillage practices, increasing labor inputs, and employing more tractors with diesel engines. Also, a partial return to organic farming would not significantly reduce petroleum consumption immediately, but would tend to reduce petroleum usage in the future.

CHAPTER III

DESIGN OF FUEL METERS

I. Component Selection

Two methods of flow measurement were investigated for this analysis: the gross-mass-volume flow rate and the turbine flowmeter. The former method was chosen since a fuel meter could be constructed easily and inexpensively, and accurate data could be acquired with relative simplicity. The method employing turbine flowmeters was discarded due to the high cost of system components.

The gross-mass-volume flow rate method involved placing a known volume of fuel into a container, such as a graduated cylinder, and operating the tractor on fuel from this container for a given time interval or travel distance. Therefore, determining the maximum cylinder volume required for field operation was necessary. Nebraska Tractor Test results provided fuel consumption data for the largest gasoline and diesel tractors selected for use in this study (the International Harvestor 766 and 966, respectively). The time required to travel across the field at the slowest test speed was projected to be four minutes. Using this time and the fuel consumption data obtained earlier, the maximum anticipated gasoline consumption totaled 1850 milliliters, while diesel fuel consumption amounted to 956 milliliters. As a result, graduated cylinders with capacities of 1000 and 2000 milliliters were selected for the diesel and gasoline tests, respectively. An advantage was inherent with the 1000 milliliter cylinder. Since the graduations were smaller (10 milliliters as compared to 20 milliliters with the 2000 milliliter cylinder), the fuel level could be read with greater precision.

With the fuel metering method selected, a system was needed for controlling fuel flow from the graduated cylinder to the tractor engine and when the tractor was operated independent of the fuel meter. Therefore, a system of valves and conduits were designed to accompany the graduated cylinder.

Various types of flow control valves were investigated. One type considered was manually operated, while the second type was electrically actuated by a solenoid. The electrically actuated valve was selected over the manual type because of the ease in operation. The electric valves could be actuated from the tractor seat without dismounting. The solenoid valves also provided instantaneous operation in controlling flow, which aided in the measurement accuracy.

The components of both fuel meters were mounted on plywood boards which were easily mounted on the tractors for field operation. The gasoline fuel meter, shown in Figure 1, was constructed in two sections. The solenoid valves were installed on a separate board and were located close to the engine fuel line connections due to a limited supply of the recommended rubber hose. The diesel fuel meter, shown in Figure 2, was constructed as a single unit since all construction materials were readily available. The single-unit construction made the meter easier to handle and install.

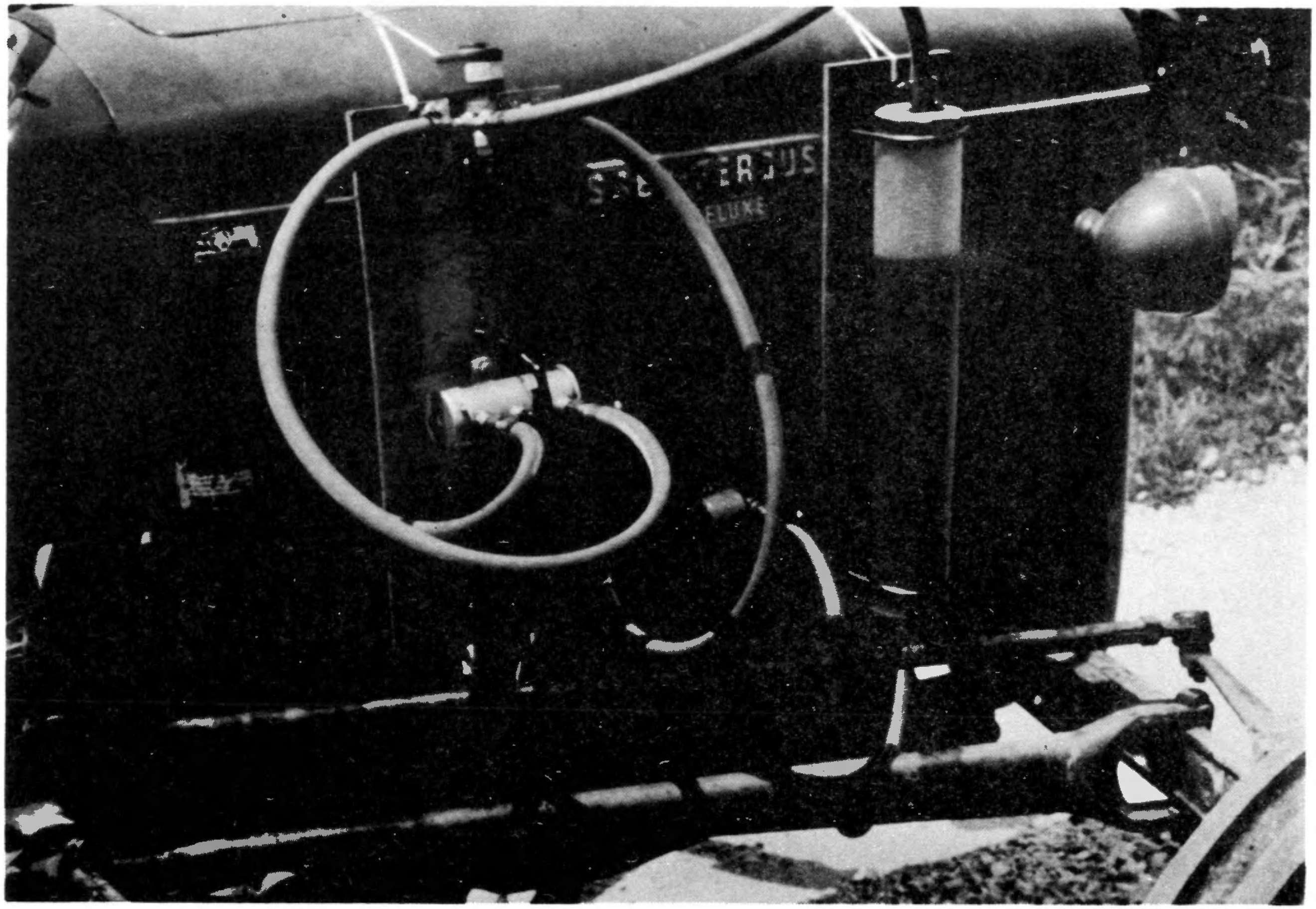

FIGURE 1. Gasoline fuel meter mounted on Massey-Ferguson 35 tractor.

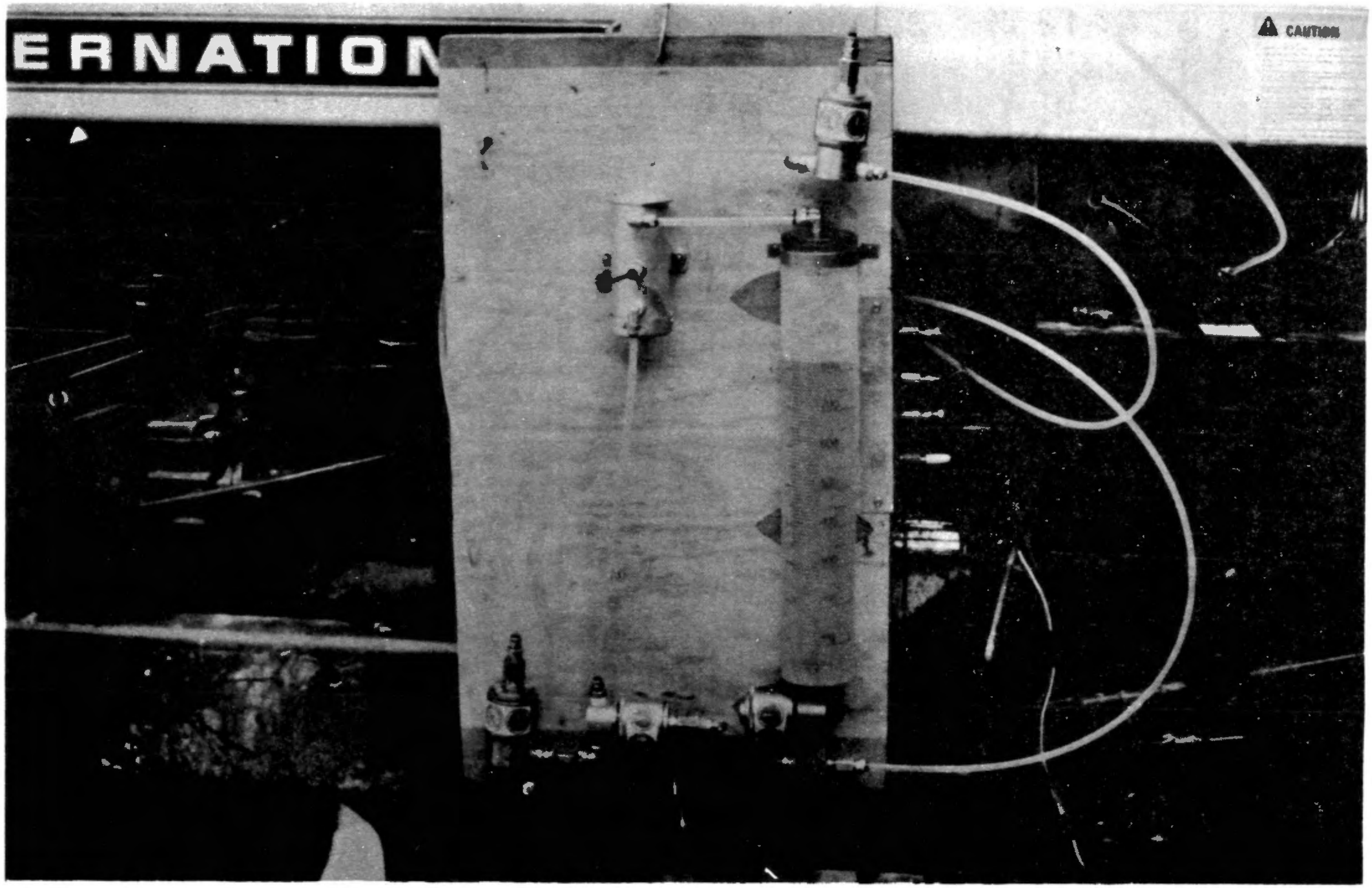

FIGURE 2. Diesel fuel meter mounted on International Harvestor 966 tractor.

II. Fuel Meter Operation

The operation of the gasoline fuel meter is shown schematically in Figure 3. The fuel meter was installed in the fuel line between the supply tank and the carburetor. In preparation for measuring fuel consumption, the graduated cylinder was filled to the desired level by means of an electric fuel pump (2) which carried fuel from the supply tank through solenoid valve 1. When the test began, the solenoid valves 1 and 4 were actuated allowing the engine to use only gasoline from the graduated cylinder. Upon completion of the test, the solenoid valves were switched "off" allowing the engine to use gasoline from the supply tank once again. The volume of fuel consumed during the given interval was then computed based upon the volume of fuel remaining in the cylinder.

Diesel fuel systems presented more problems when attempts were made to measure fuel consumption by the previous method. Precautions were necessary to account for the excess fuel from the injector pump and the fuel injectors. Also, air could not be allowed to enter the supply line between the supply tank and fuel filters.

The diesel fuel meter in Figure 4 was very similar in construction to the gasoline meter shown in Figure 3. The difference lay in the extra solenoid valve (6) at the top of the graduated cylinder (4). Also, with most diesel tractors, the graduated cylinder could be refilled with the return fuel, therefore, eliminating the need for the electric fuel pump (3) and solenoid valves (1 and 2). When the return fuel volume was not adequate, the fuel pump along with the solenoid valves 1 and 2 were required for refilling.

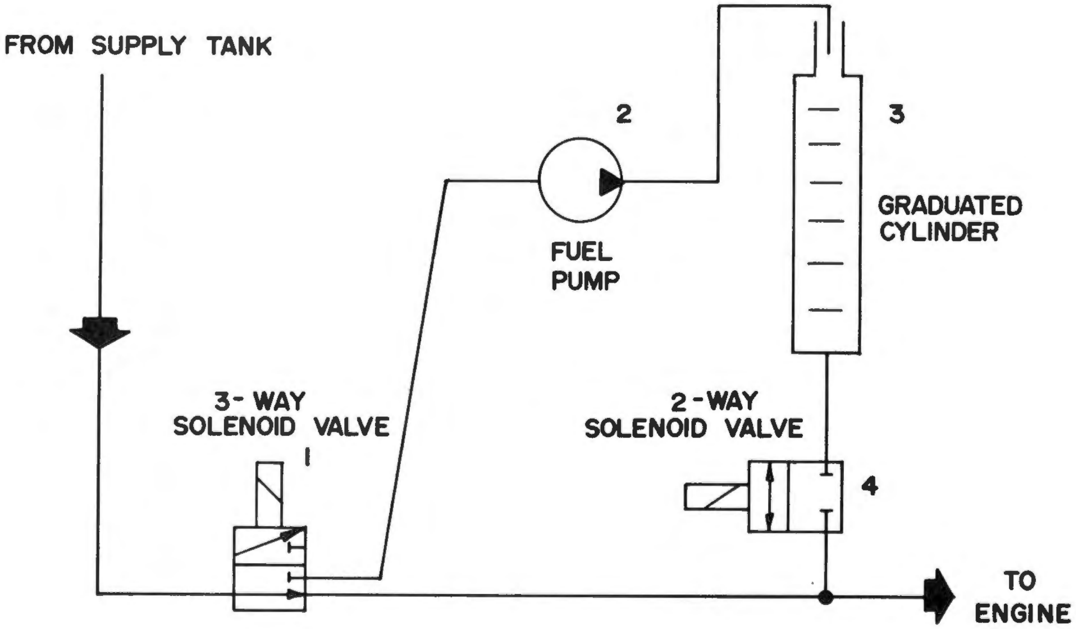

FIGURE 3. Schematic diagram of gasoline fuel meter.

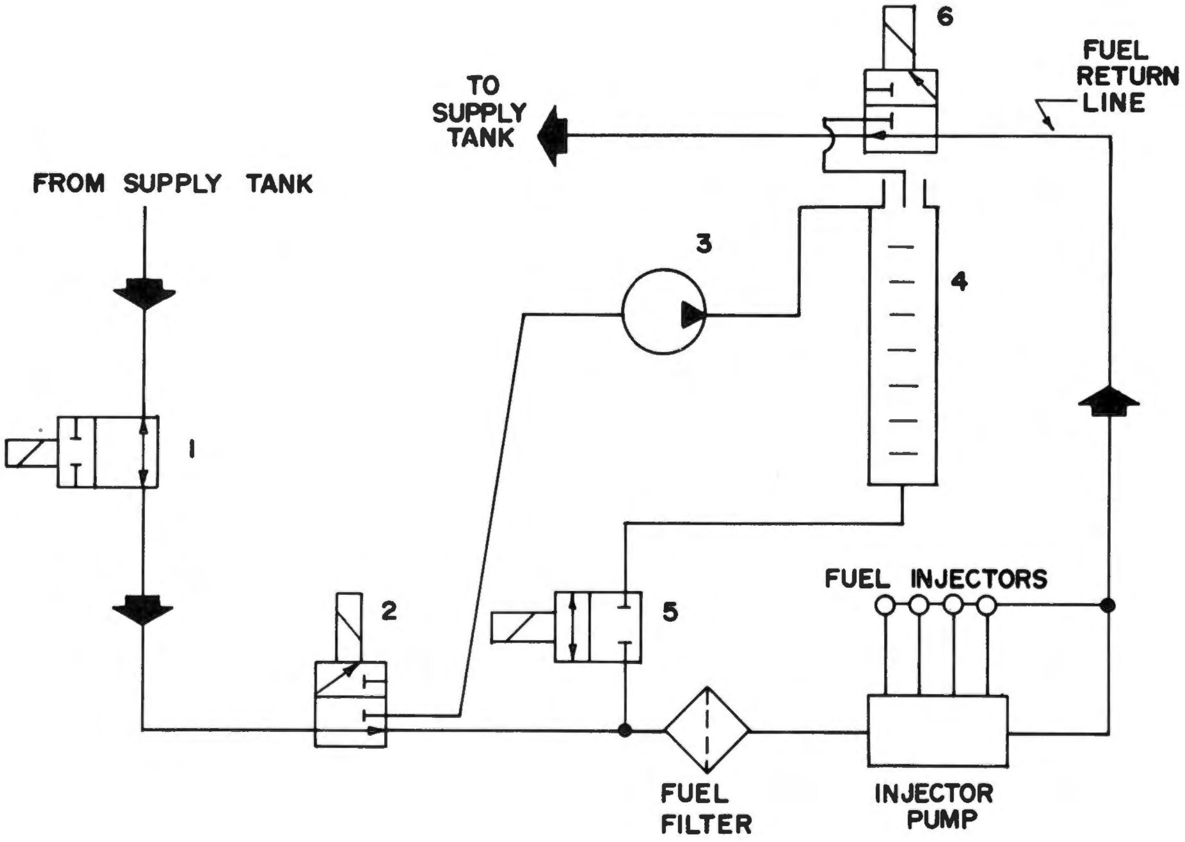

FIGURE 4. Schematic diagram of diesel fuel meter.

The diesel fuel meter operated in the same manner as the gasoline meter. The solenoid valves (1, 2, 5, and 6) were activated for a given test, and deactivated when the test was completed, allowing for observation and recording of the fuel level with the tractor engine operating.

A "built-in" error was incorporated in both fuel meters. As previously noted, the graduations of the gasoline cylinder were at 20-milliliter intervals while the diesel cylinder was graduated into 10 milliliters. Thus, the fuel consumption during a given interval for gasoline and diesel tractors could be read only to the nearest 20 milliliters and 10 milliliters, respectively.

CHAPTER IV

DATA ACQUISITION AND ANALYSIS

I. Machinery Systems Tested

Fuel consumption measurements were obtained over a two-year period from 1975 to 1976. Tests involving gasoline tractors were performed the first summer and diesel tests during the second year. However, the experiments of each year were not performed in the same manner, as the experimental design was changed the second year to strengthen the statistical analysis.

Three tractors of different sizes were used in each of the gasoline and diesel consumption experiments. A Massey-Ferguson 35, an International Harvestor 464, and an International Harvestor 766 were used in the gasoline tests. These tractors had power ratings of approximately 22 kilowatts (30 horsepower), 37 kilowatts (50 horsepower), and 60 kilowatts (80 horsepower), respectively. An International Harvestor 544, an Allis-Chalmers 190, and an International Harvestor 966 were employed for the diesel trials. These tractors were rated at approximately 37 kilowatts (50 horsepower), 56 kilowatts (75 horsepower), and 75 kilowatts (100 horsepower), respectively. All tractors were inspected prior to performing any measurement trial and found to be in good operating condition.

Three size classes of tillage implements were used in this study. Two-row, four-row, and six-row equipment were matched with the three tractors of each type. Four tillage implements were associated with each size class: a moldboard plow, a disc, a planter, and a cultivator. Measurements were also made using a "do-all" and a chisel plow with the six-row tractor. Table 1 describes each implement with respect to size and use.

The tillage tools were operated at four speeds obtained through various gear selections. The engine speed was maintained as closely as possible to the manufacturers rated RPM. Fuel measurements were made at ground speeds of:

Speed 1 - 3.2 kph (2 mph)
Speed 2 - 4.8 kph (3 mph)
Speed 3 - 6.5 kph (4 mph)
Speed 4 - 8.1 kph (5 mph)

All tillage operations were performed in Memphis silt loam soil when the moisture content was in the range considered suitable for tillage. This soil has moderate texture and structure with excellent drainage, which allows for good workability. The length of the test area was 183 meters (600 feet) with relatively level topography. The plowing depth was approximately 20 centimeters (8 inches), and all other tillage operations were maintained at a 10 centimeter depth (4 inches).

II. Fuel Consumption Measurements

Gasoline consumption measurements were made at the West Tennessee Experiment Station, Jackson, Tennessee. At the beginning of the tests, a gasoline tractor was selected at random (from the three tractors designated for the study) and equipped with the gasoline fuel meter.

TABLE 1. Implement Types and Sizes Used for Determining Fuel Requirements.

Implement	Size Class	Tractor Type
MF 2-12 Moldboard*	2-row	gasoline
AC 3-16 Moldboard	2-row	diesel
AC 4-16 Moldboard	4-row	diesel
AC 3-16 Moldboard	4-row	gasoline
IH 4-16 Moldboard	6-row	gasoline
IH 5-16 Moldboard	6-row	diesel
IH 122 Light Tandem Disc	2-row	gasoline
IH 132 Light Tandem Disc	2-row	diesel
JD Medium Tandem Disc	4-row	gasoline
IH 370 Medium Tandem Disc	4-row	diesel
IH 470 Heavy Tandem Disc	6-row	gasoline
IH 48 Heavy Tandem Disc	6-row	diesel
IH Planter 38"/row	2-row	gasoline
IH Planter 38"/row	2-row	diesel
AC Planter 38"/row	4-row	diesel
AC Planter 38"/row	4-row	gasoline
"Do-all"	6-row	gasoline
AC Planter 38"/row	6-row	diesel
MF Cultivator 38"/row	2-row	gasoline
MF Cultivator 38"/row	2-row	diesel
MF Cultivator 38"/row	4-row	gasoline
AC Cultivator 38"/row	4-row	diesel
IH Cultivator 38"/row	6-row	gasoline
Chisel Plow	6-row	diesel

*Two 12-inch bottoms.

The tillage implements, compatible with that tractor, were used in sequence as in a conventional cropping system (plow, disc, plant, and cultivate). The operating speeds were selected at random from the designated ground speeds.

At the beginning of each gasoline test, the fuel level in the graduated cylinder was observed and recorded. Usually the fuel cylinder required refilling to the 2000 milliliter mark. The tillage operation was started outside of the test area. When the rear wheels of the tractor entered the test area, the fuel meter and a stop watch were switched "on." After travelling the given distance, the fuel meter and stop watch were switched "off," and the fuel level and travel time were recorded. Another speed was selected, and the tillage operation was repeated. This process was performed until all four speeds were replicated four times. Another implement was selected and employed in the manner previously described. When all implement operations were completed, the fuel meter was removed and installed on another tractor. The entire experiment was repeated in this manner until all three gasoline tractors were used.

The diesel experiment, performed at the Milan Field Station, Milan, Tennessee, was arranged in a slightly different manner. A tractor was randomly selected and equipped with the diesel fuel meter. However, upon completion of two replications of speeds with each implement, the fuel meter was installed on another tractor. This procedure was continued until all tractors were employed. At this point, the entire sequence was repeated. This procedure yielded two replications of each tractor with speeds sampled twice within tractors.

III. Data Analysis

The Statistical Analysis System (SAS) computer program, developed by the Statistics Department at North Carolina State University, was used for statistical calculations. The SAS program computed analyses of variance for fuel consumed per hour and fuel consumed per unit area for each tractor-implement system. Means were calculated for the speeds, implements, implements at each speed, tractors at each speed, and tractors with each implement.

A nested design was used to analyze data from the diesel test. Tractors, implements, and speeds were the main effects of the analyses with all combinations as interactions. Replications were nested within tractors, while the other main effects, when combined with replications, were nested within tractors, also.

The gasoline experiment contained four replications of speeds. However, tractors and implements were not replicated, rendering the nesting of replications, as performed in the diesel analysis, invalid. Therefore, the analyses for the gasoline test consisted of tractors, implements, and speeds as main effects with interactions of the three factors. The variation normally attributed to replications was confounded in the residual.

CHAPTER V

RESULTS AND DISCUSSION

I. Diesel Fuel Consumption

The data collected during the tests using diesel tractors were subjected to analyses of variance. These analyses are summarized in Table 2. The various error terms used as tests of significance for the main effects and their interactions were examined first. If soil conditions varied greatly, or, if the data collection procedures were not well executed, error terms with a large number of degrees of freedom could be expected. If, on the other hand, these error terms were small and statistically insignificant, confounding of soil factors within the experimental data could be considered inconsequential; and the error terms could be pooled. Such pooling, however, would make tests of significance less rigorous. Therefore, the decision was made not to pool error terms if there was as little as a 75 percent chance of a given error term being significant.

The residual was used to test the three-way interaction nested within tractors in analyses involving both fuel consumed per hour and per unit area. As shown in Table 2, this source of variation was significant at the 75 percent level of probability for both dependent variables. Therefore, this interaction was employed to test the remaining error terms without being pooled in the residual. The resulting "F" tests revealed that the remaining error terms were

TABLE 2. Analyses of Variance for Diesel Fuel Consumption.

Source of Variation	Degrees of Freedom	Mean Square	F Value
Liters per Hour			
Tractor	2	691.366	246.592*
Rep/Tractor	3	2.804	1.260
Implement	3	140.457	53.388*
Tractor X Implement	6	48.826	18.559*
(Rep X Implement)/Tractor	9	2.631	1.182
Speed	3	244.210	472.838*
Tractor X Speed	6	29.860	57.815*
(Rep X Speed)/Tractor	9	0.516	0.232
Implement X Speed	9	5.695	2.559**
Tractor X Implement X Speed	18	5.104	2.294**
(Rep X Implement X Speed)/Tractor	27	2.225	1.586**
Residual	96	1.403	
Liters per Hectare			
Tractor	2	156.702	72.507*
Rep/Tractor	3	2.161	0.678
Implement	3	2357.935	1399.710*
Tractor X Implement	6	164.236	97.493*
(Rep X Implement)/Tractor	9	1.684	0.528
Speed	3	174.339	104.311*
Tractor X Speed	6	5.206	3.112**
(Rep X Speed)/Tractor	9	1.673	0.524
Implement X Speed	9	14.909	4.674*
Tractor X Implement X Speed	18	3.982	1.248
(Rep X Implement X Speed)/Tractor	27	3.189	2.536*
Residual	96	1.258	

*Significant at $\alpha = .01$.

**Significant at $\alpha = .25$.

nonsignificant, rendering the error terms capable of being pooled. However, in order to achieve more rigorous "F" tests, the pooling was not performed, and the tests of significance were conducted as indicated in Table 2.

The diesel experiment contained an irregularity which may adversely affect the results. As discussed in Chapter IV, a chisel plow was employed in the six-row tractor tests. This particular implement was substituted for a six-row cultivator, which was not available for use. The chisel plow was somewhat similar to a cultivator, but the draft force required to operate the chisel plow was greater. The chisel plow was operated at a depth of 20 centimeters (8 inches); the same depth as the moldboard plow.

The effect of tractors was significant for both diesel fuel consumed per unit area and per hour (Table 2). However, as indicated by Table 3, the tractor means responded differently with each of the previously mentioned variables. For diesel fuel consumed per hour, the mean of the six-row tractor was statistically different from the other means. The six-row tractor mean, on the other hand, was significantly different from the mean of the two-row tractor only for diesel fuel consumed per unit area. One reason for these differences was the effect of the chisel plow which was embedded within the six-row tractor response. Since the chisel plow required more draft force than the cultivator, the diesel fuel consumed by the six-row tractor was higher. If the effect of the chisel plow was omitted from the analysis, the following six-row tractor means would result:

TABLE 3. Fuel Consumption Means for Two-, Four-, and Six-Row Diesel Tractors Operated with Four Implements at Four Field Speeds.

Make of Tractor	Rated Size	Fuel* Consumption	
		Liters/Hr	(Gal/Hr)
IH 544	2-row	9.86	(2.60)^{a}
AC 190	4-row	10.83	(2.86)^{a}
IH 966	6-row	15.97	(4.22)^{b}
		Liters/Ha	(Gal/Ac)
IH 544	2-row	11.50	(1.23)^{ab}
AC 190	4-row	9.85	(1.05)^{a}
IH 966	6-row	12.98	(1.39)^{b}

*Means followed by the same superscript are not significantly different at $p <.05$.

15.27 liters/hour (4.03 gallons/hour)

11.99 liters/hectare (1.28 gallons/acre)

When these means were compared with the six-row means of Table 3, the six-row tractor mean decreased as much as 0.99 liters while the other means increased. This indicates that the chisel plow required more diesel fuel to operate since the six-row means decreased when the chisel plow effect was excluded.

Another factor considered to have affected results was the soil condition. The diesel experiment was conducted over a span of one week. At the beginning of the week, the soil in the test area was "moist," but suitable for tillage. Toward the week's end, the hot weather had dried the soil somewhat excessively, indicated by unusually high levels of dust created by the tillage operations. However, these tillage machines seemed to perform well under this condition. The moisture effects were probably reflected in the significance of the three-way interaction nested within tractors.

Table 3 also shows no significant difference between two-row and four-row tractors for both diesel fuel consumed per hour and per unit area. This may have resulted from the type of tractor and size of the engines. As previously discussed, the two-row tractor was an International Harvestor 544 and the four-row tractor was an Allis-Chalmers 190. Both tractors were equipped with four cylinder engines; the former having a displacement of 3.92 liters (239 cubic inches) and 4.93 liters (301 cubic inches) for the latter. Since these engine displacements are relatively close, the difference in diesel fuel consumption may be small. On the other hand, the mechanical condition of the tractors could not be verified and slight differences in diesel fuel consumption may have resulted from some mechanical problem.

Table 4 discloses that moldboard plows consumed significantly more diesel fuel per hour than the planter or cultivator. This response was obvious in that implements of heavy draft, such as the moldboard plow, consumed more fuel per hour than the light draft implements, such as the planters. The tandem discs revealed no significant difference in fuel consumed per hour over the cultivators, probably because the response of the chisel plow was contained within the cultivator effect, raising the mean value. The two-row and four-row cultivator means were 9.47 and 8.47 liters per hour, or, 2.50 and 2.24 gallons per hour, respectively, while the chisel plow exhibited a mean of 18.08 liters per hour (4.78 gallons per hour). This comparison clearly shows that the chisel plow required double the diesel fuel of the two-row and four-row cultivators.

The analysis for fuel consumed per unit area disclosed that each implement was significantly different from the other (Table 4). The moldboard plows covered the least area for a single trip across the test area and possessed the greatest draft of all implements, resulting in the relatively high mean values as shown in Table 4. The tandem discs were actually next to the moldboard plows for diesel fuel consumed per unit area, even though Table 4 indicates that cultivators were second in diesel fuel consumption. This may be explained by the response of the chisel plow within the effect of cultivators. The mean for the chisel plow was 15.95 liters per hectare (1.71 gallons per acre). When this mean was compared with the two-row and four-row cultivator mean values

TABLE 4. Mean Diesel Fuel Requirements for Implements Employed with Two-, Four-, and Six-Row Tractors at Four Field Speeds.

Implement Type	Fuel* Consumption	
	Liters/Hr	(Gal/Hr)
Moldboard Plow	14.00	(3.70)^{a}
Tandem Disc	12.20	(3.41)^{ab}
Planter	9.96	(2.63)^{c}
Cultivator	12.01	(3.17)^{b}
	Liters/Ha	(Gal/Ac)
Moldboard Plow	21.70	(2.32)^{a}
Tandem Disc	7.87	(0.84)^{c}
Planter	6.24	(0.67)^{d}
Cultivator	9.95	(1.06)^{b}

*Means followed by the same superscript are not significantly different at $p < .05$.

of 9.20 and 4.70 liters per hectare (0.98 and 0.50 gallons per acre, respectively), a relative difference of 9.0 liters per hectare (0.96 gallons per acre) was obtained. Since a six-row implement is capable of covering more area in one pass than smaller implements, the diesel fuel consumed per unit area is expected to be lower for certain six-row equipment. Therefore, if the appropriate cultivator had been available for the six-row test, the mean for this implement was estimated at 4.50 liters per hectare, or 0.48 gallons per acre, producing a mean for the cultivator effect similar to the planter mean for diesel fuel consumed per unit area.

The effect of operating speed is shown in Table 5. The rates of diesel fuel consumption both per hour and per unit area at the two slower speeds (3.2 and 4.8 kilometers per hour, or, 2.0 and 3.0 miles per hour, respectively), were statistically different from each other, and from the high field speeds of 6.4 and 8.1 kilometers per hour (4.0 and 5.0 miles per hour). No significant difference was exhibited between the two high speeds. The tests at slow operating speeds required more fuel and time relative to high speeds to complete one observation. At a slow field speed, 3.2 kilometers per hour (2.0 miles per hour), the average time required to traverse the trial distance was four minutes, producing a relative field capacity of 0.9 hectares per hour (2.2 acres per hour). One and one-half minutes were required for the tests at 8.1 kilometers per hour (5.0 miles per hour), resulting in a field capacity of 2.0 hectares per hour (5.0 acres per hour). Therefore, more diesel fuel was expended per hour at the high operating speed, since more area was covered in one hour than at the low operating speed. This increase

TABLE 5. Mean Diesel Fuel Consumption for Field Speeds of Two-, Four-, and Six-Row Tractors Operated with Each Implement Type.

Speed		Fuel* Consumption	
Km/Hr	Mi/Hr		
		Liters/Hr	(Gal/Hr)
3.2	2.0	9.33	(2.46)^{a}
4.8	3.0	11.62	(3.07)^{b}
6.4	4.0	13.49	(3.56)^{c}
8.1	5.0	14.44	(3.82)^{c}
		Liters/Ha	(Gal/Ac)
3.2	2.0	14.09	(1.51)^{a}
4.8	3.0	11.46	(1.23)^{b}
6.4	4.0	10.52	(1.13)^{bc}
8.1	5.0	9.70	(1.04)^{c}

*Means followed by the same superscript are not significantly different at $p < .05$.

in field capacity at high speeds resulted in less diesel fuel consumed per unit area. Means of speeds associated with diesel fuel consumed per unit area are shown in Table 5.

The variables for both diesel fuel consumed per hour and per unit area revealed a significant interaction between tractors and implements (Table 2, page 25). Figure 5 displays this interaction for diesel fuel consumed per hour. With the cultivator and planter, the four-row tractor consumed the least amount of fuel per hour. As discussed earlier, the type of tractor may be the reason for this response. Most of the interaction, however, may be due to the sharp upturn in fuel consumed per hour for the six-row tractor operated with the chisel plow. As indicated in Figure 5, the fuel consumed per hour for the six-row cultivator (chisel plow) was 18.08 liters per hour (4.77 gallons per hour). The mean effect of the two-row and four-row cultivators was only 8.97 liters per hour or 2.37 gallons per hour. Comparison of the chisel plow mean with the cultivator mean revealed that the chisel plow consumed more than twice the diesel fuel of the two cultivators. With reference to the two-row and four-row tractors, the cultivators and planters consumed similar amounts of diesel fuel. Since equipment systems with high field capacities consume more fuel per hour, a six-row cultivator was estimated to consume 11.36 liters or 3.00 gallons per hour. This estimate is represented by the dotted line in Figure 5.

The interaction of tractors and implements for fuel consumed per unit area is shown in Figure 6. For the moldboard plow, tandem discs, and cultivators, the six-row tractor consumed the most diesel fuel per unit area. It, however, consumed the least diesel fuel per unit area

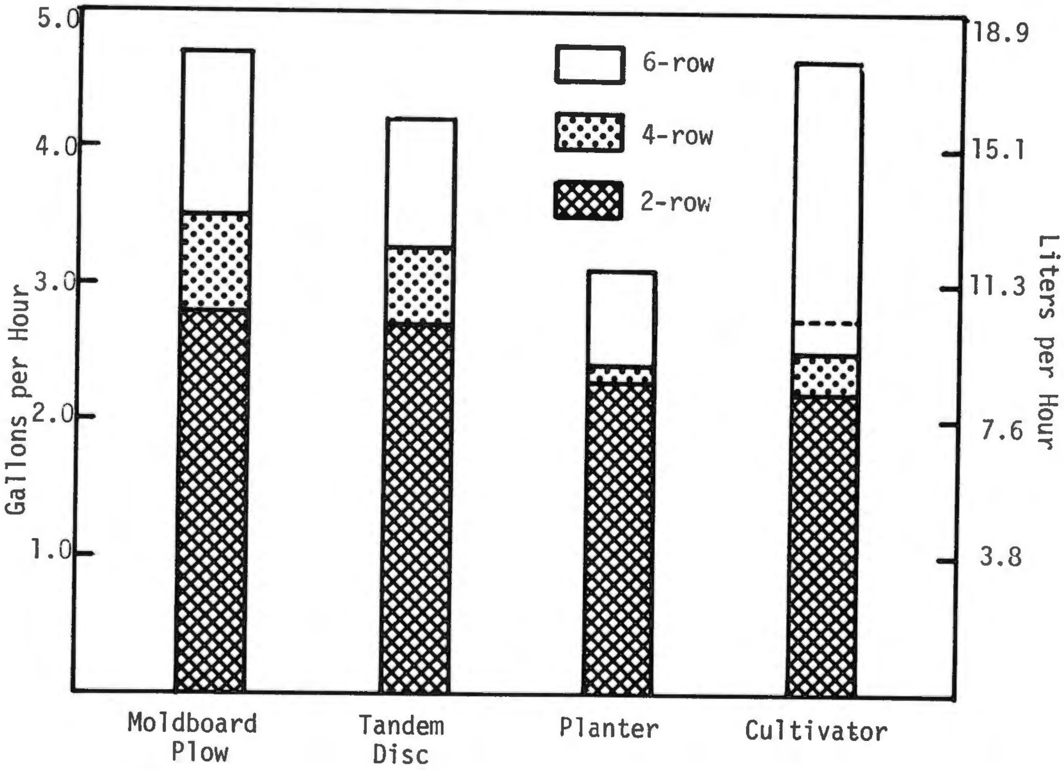

FIGURE 5. Average diesel fuel requirements per hour for each implement type when employed with two-, four-, and six-row tractors at four field speeds.

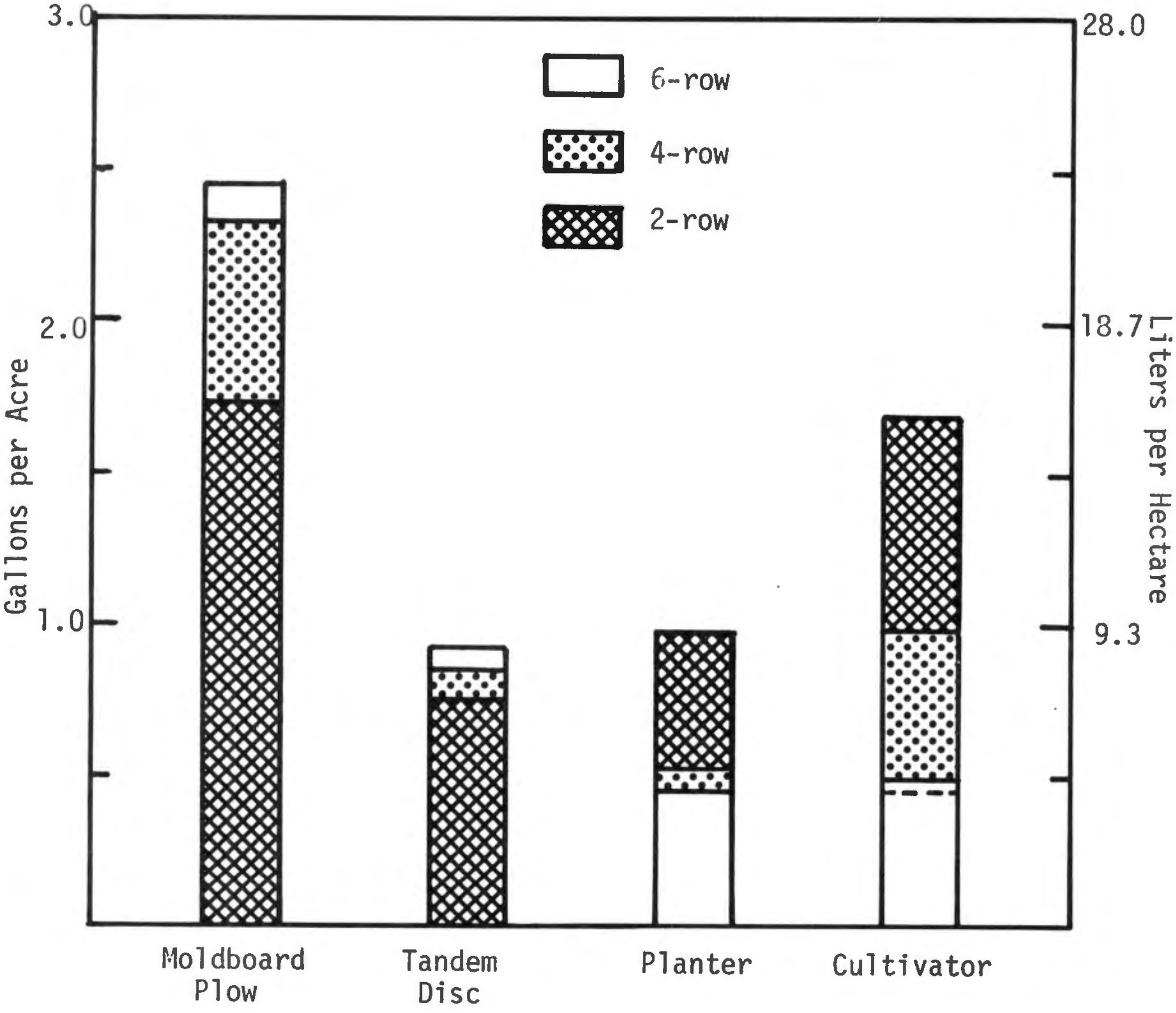

FIGURE 6. Average diesel fuel requirements per unit area for each implement type when employed with two-, four-, and six-row tractors at four field speeds.

for the planters. The moldboard plows did not possess high field capacity and they had more draft than the tandem discs, planters, and cultivators. This resulted in more diesel fuel consumed per unit area for each moldboard plow. On the other hand, with the planters and cultivators, the six-row tractor-implement system covered three times more area per pass over the test plot than the two-row system, resulting in lower diesel fuel consumption per unit area for the six-row system. Figure 6 displays this response with the planters, but the chisel plow produced high fuel consumption, as in previous discussion, for the six-row tractor. In this instance, the chisel plow possessed a mean of 16.00 liters per hectare (1.71 gallons per acre) as compared to 9.20 liters per hectare (0.98 gallons per acre) for the two-row cultivator and 4.70 liters per hectare or 0.50 gallons per acre for the four-row cultivator. With the two-row and four-row tractors, the fuel consumption per unit area for the cultivators was lowest of all implements. Also, as previously discussed, a large physical implement size allowed for high field capacities producing low fuel consumption per unit area. Therefore, an estimate of 4.2 liters per hectare (0.45 gallons per acre) was established for a six-row cultivator. The dotted line in Figure 6 represents this estimate in relation to the two-row and four-row cultivators.

The tractor-speed interaction was significant for diesel fuel consumed per hour and not significant for fuel consumed per unit area. These results are clearly shown in Figures 7 and 8. Figure 7 discloses that diesel fuel consumption per hour increased for each tractor as operating speed rose. The curve associated with the six-row tractor increased much more rapidly than the two-row and four-row tractors. It

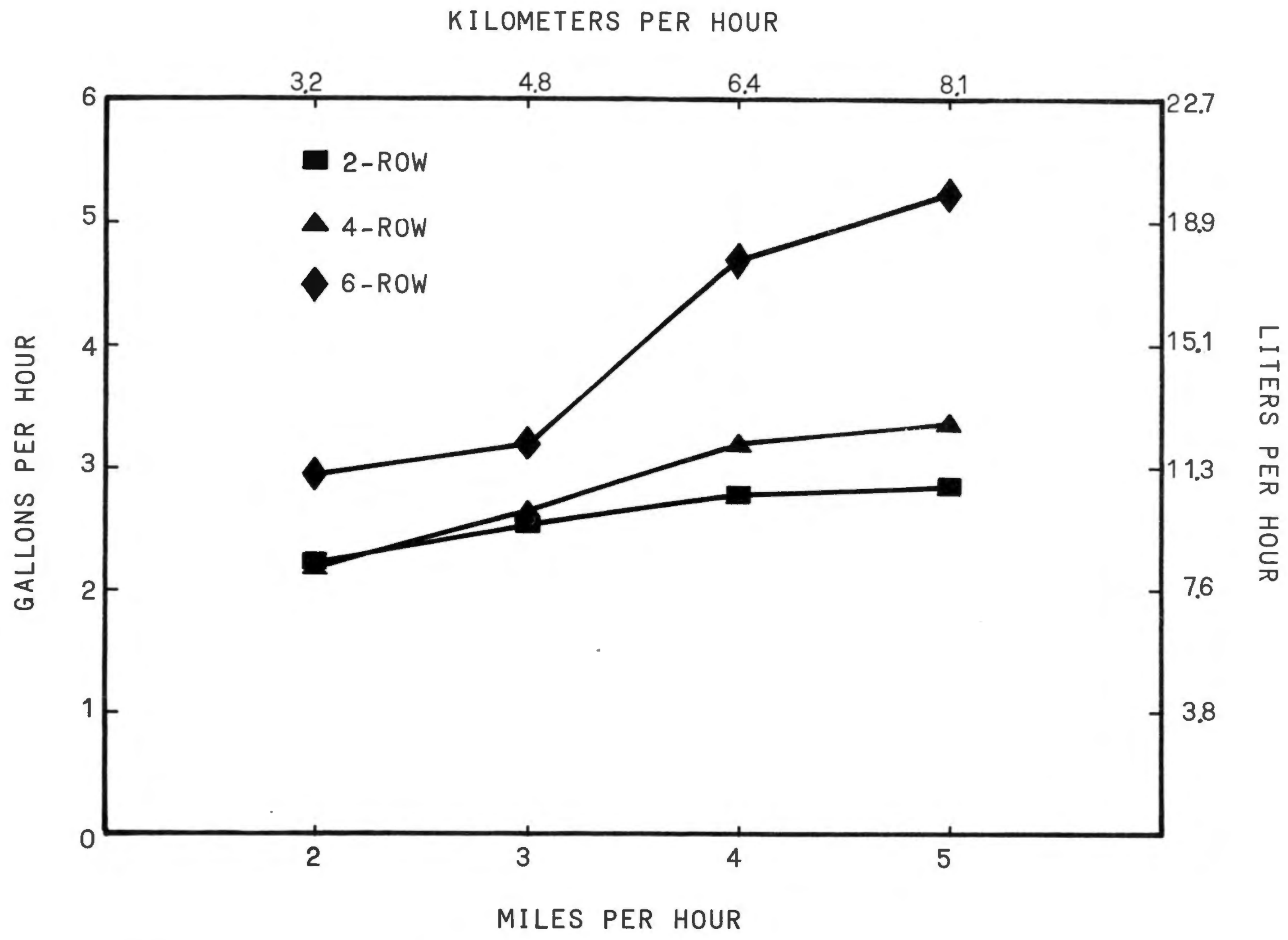

FIGURE 7. Average fuel consumption per hour for two-, four-, and six-row diesel tractors operated at four field speeds with four implement types.

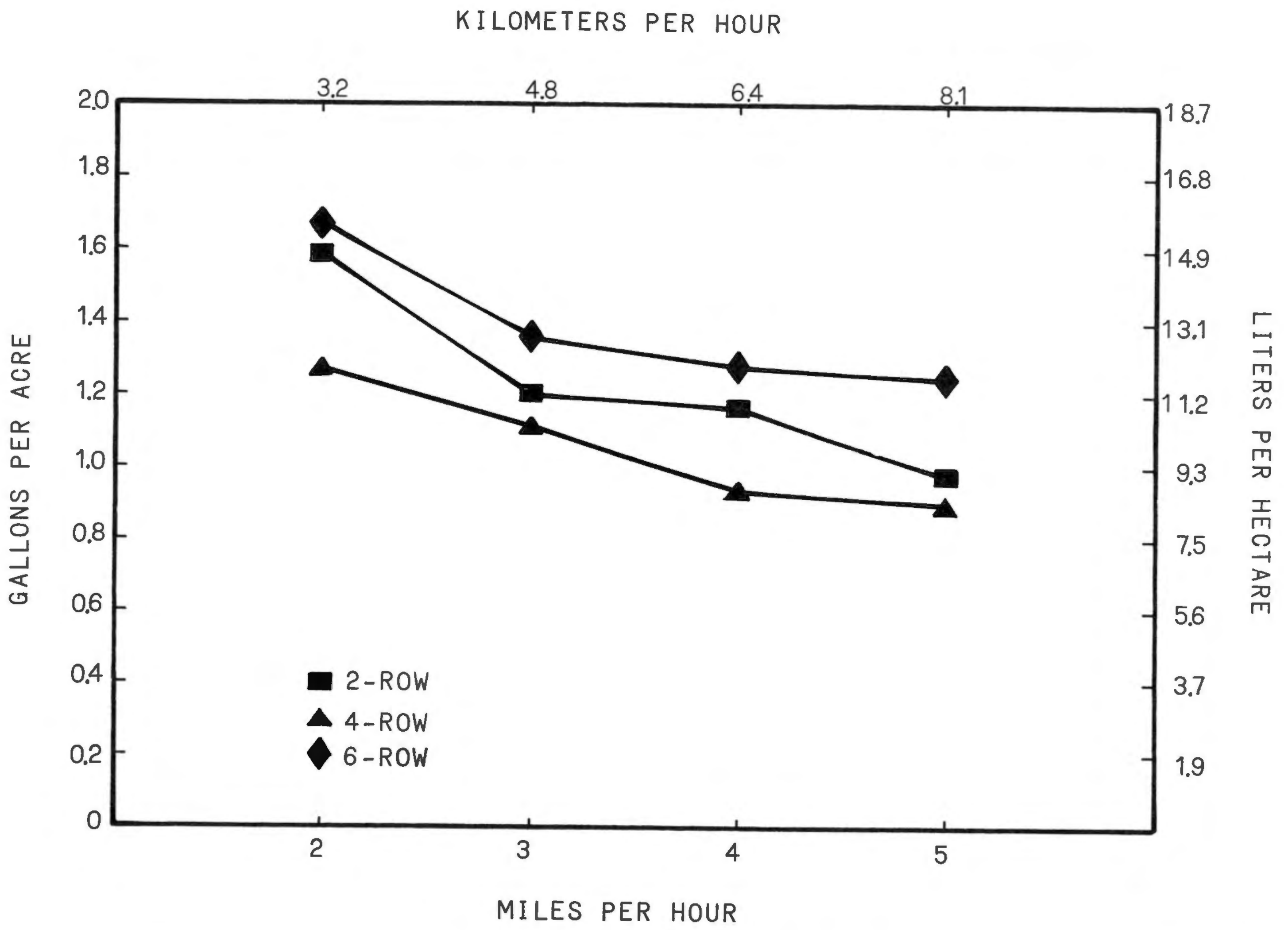

FIGURE 8. Average fuel consumption per unit area for two-, four-, and six-row diesel tractors operated at four field speeds with four implement types.

also indicates that large tractor-implement systems, such as the six-row system, consume more diesel fuel per hour at operating speeds between 3.2 and 8.1 kilometers per hour (2.0 and 5.0 miles per hour, respectively).

Upon inspection of Figure 8, no interaction was apparent for diesel fuel consumed per unit area, as the curves are nearly parallel. As operating speed rose, fuel consumption per unit area was reduced. This decline was relatively equal for all tractors at each speed.

The implement-speed interaction was significant for fuel consumed per unit area as indicated in Table 2, page 25. In previous discussion, the moldboard plow produced the greatest diesel fuel requirements. As shown in Figure 9, the moldboard curve decreases more rapidly than the others and becomes closer, which defines interaction.

Figure 10 displays a slight interaction between implements and speeds for diesel fuel consumed per hour. Table 2, however, indicates that this interaction was not significant. In this instance, the response of each implement was relatively equal for increases in operating speed.

The large tractor-implement systems required the most fuel for operation for a given time interval. However, large pieces of equipment, such as a six-row planter, have relatively high field capacities as shown in Figure 11. This figure also shows that when planting at a speed of 8.1 kilometers per hour (5.0 miles per hour), the six-row system consumed the least amount of diesel fuel per unit area. This suggests that large tractor-implement combinations, such as the six-row planting and cultivating systems, are more economical to operate at high field

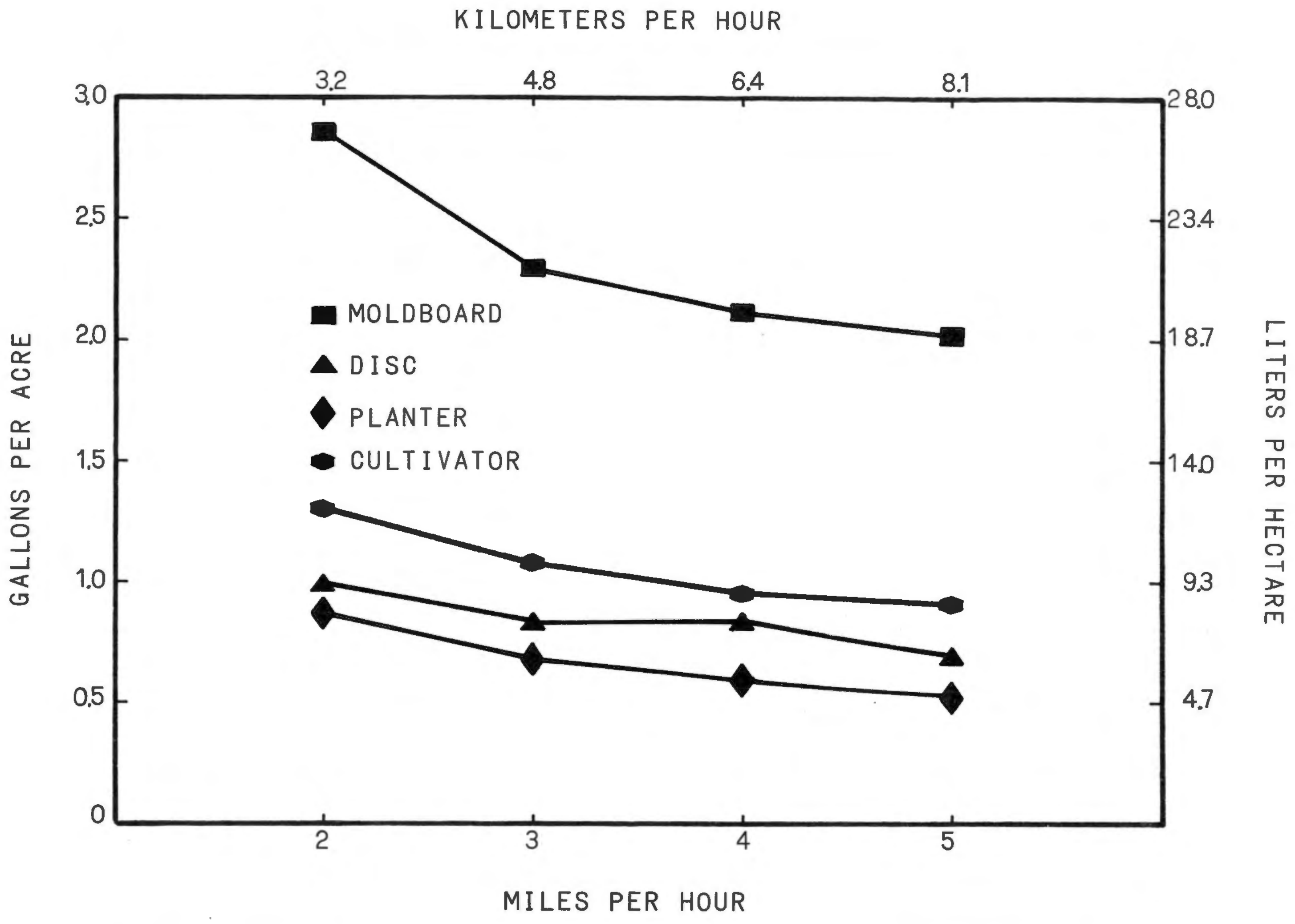

FIGURE 9. Average diesel fuel requirements per unit area for two-, four-, and six-row implements when operated at each field speed.

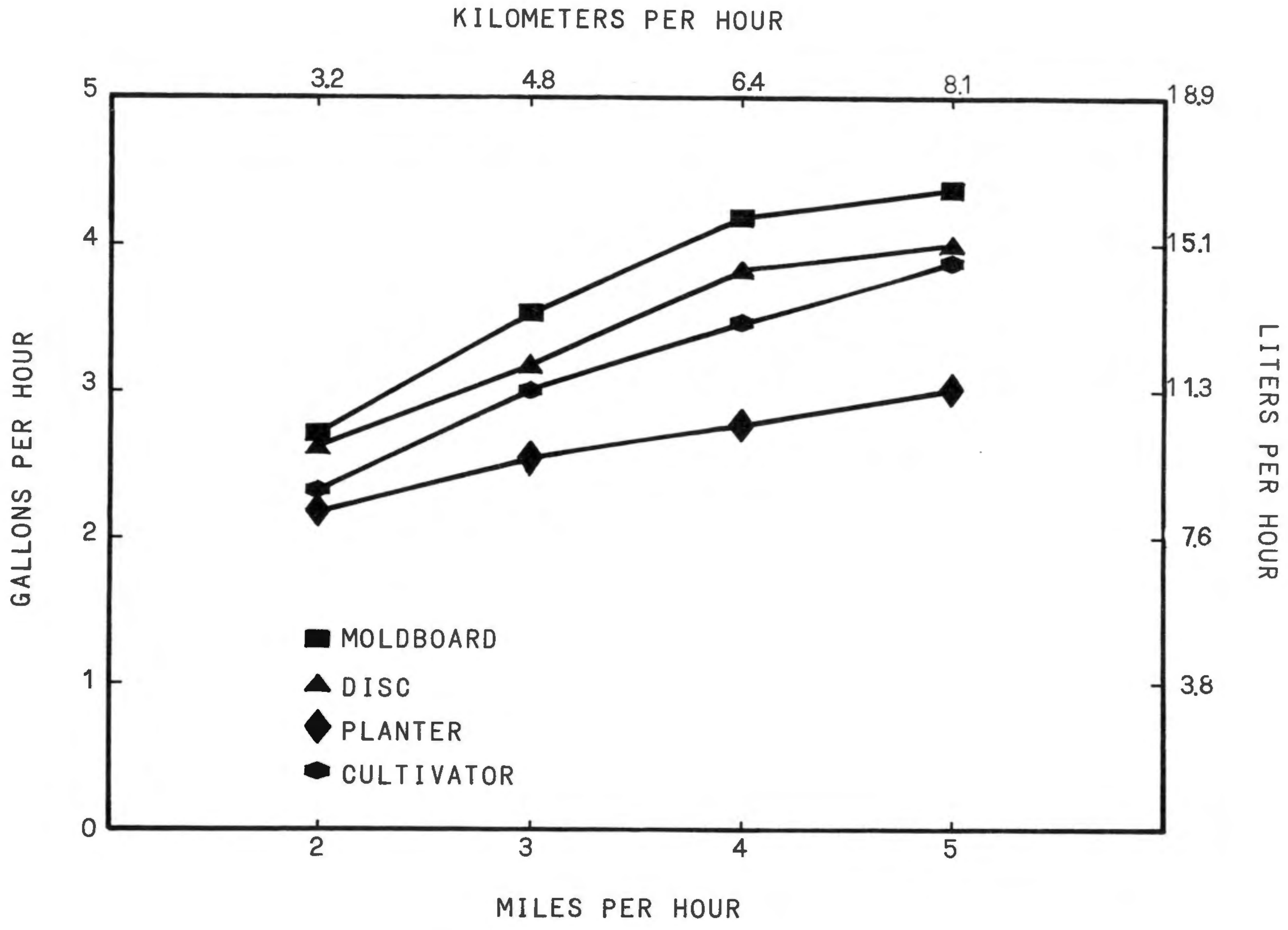

FIGURE 10. Average diesel fuel requirements per hour for two-, four-, and six-row implements when operated at each field speed.

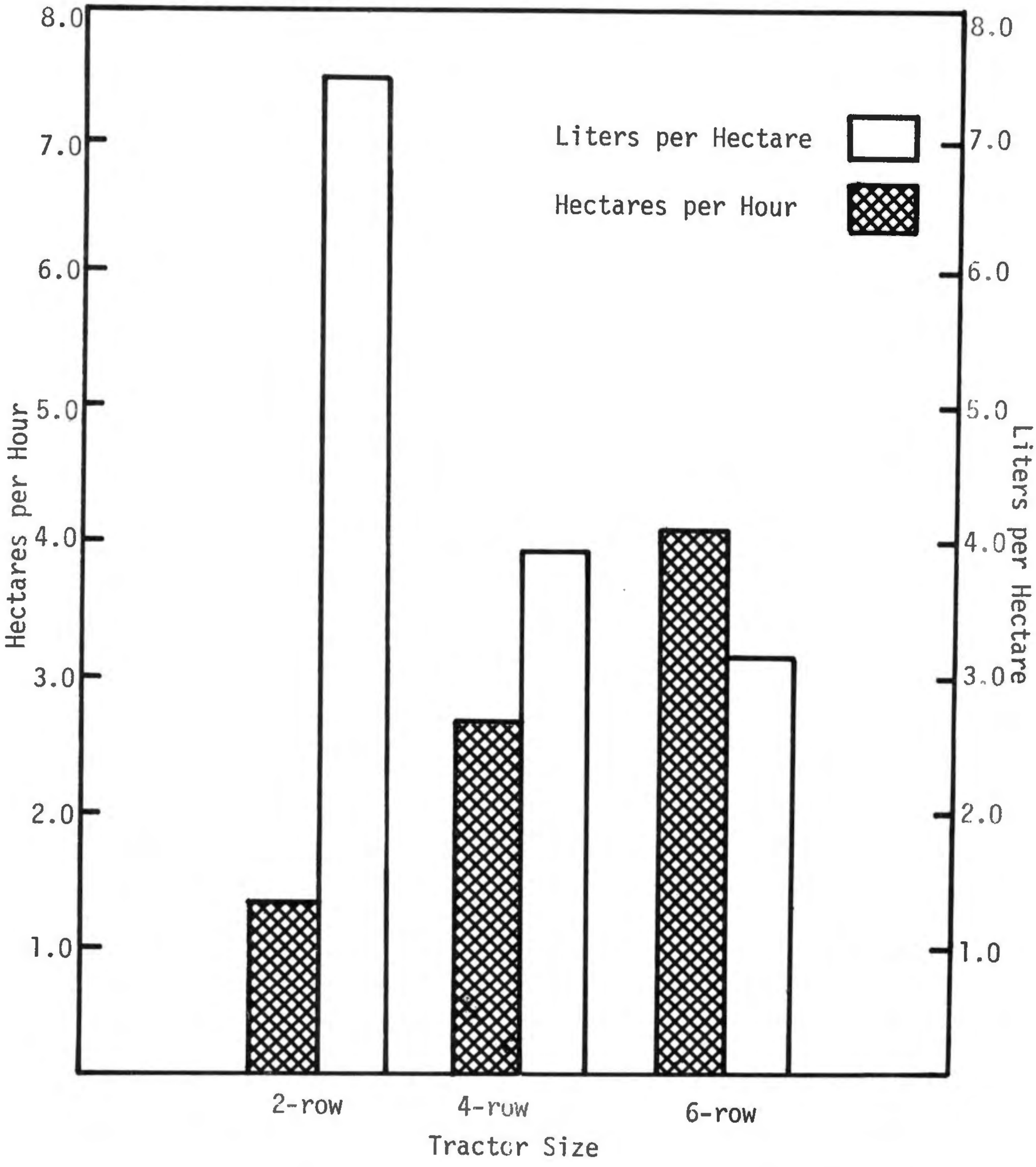

FIGURE 11. Mean diesel fuel consumption per unit area and field capacities for diesel tractors operated with various size planters at 8.1 kilometers per hour (5.0 miles per hour).

speeds, since less fuel was expended per unit area and more hectares were completed per hour.

II. Gasoline Consumption

The gasoline analysis, as shown in Table 6, was similar to the diesel analysis. However, the gasoline experiment was performed with replications of speed only. Thus, the effect due to replication could not be subdivided as in the diesel analyses. Since replication was confounded in the residual, all tests of significance were conducted using the residual as the error term. If, on the other hand, the gasoline experiment had been replicated correctly, the gasoline analyses may have produced the same results as the diesel experiment. A brief comparison of the analyses indicates this may be the case.

The gasoline experiment produced essentially the same information as in the diesel experiment. Also, each analysis contained the same number of observations and degrees of freedom. The gasoline experiment, however, contained no true replications, as stated in the previous discussion. This resulted in a large experimental error which contained confounding of such effects as replications of operating speeds and soil conditions. Moreover, the large number of degrees of freedom contained in the experimental error produced significant "F" values for each term in the gasoline analyses. Some terms, on the other hand, may have actually been insignificant had the experiment contained true replication. Likewise, difficulty was experienced in attempting to explain the true response of these terms. Therefore, when reviewing the entire gasoline analysis, one should recognize that the results and

TABLE 6. Analyses of Variance for Gasoline Consumption.

Source of Variation	Degrees of Freedom	Mean Square	F Value
	Liters per Hour		
Tractor	2	3107.570	7185.584*
Implement	3	96.957	224.193*
Tractor X Implement	6	41.216	95.302*
Speed	3	93.148	215.384*
Tractor X Speed	6	9.593	22.182*
Implement X Speed	9	5.536	12.801*
Tractor X Implement X Speed	18	2.922	6.756*
Residual	144	0.432	
	Liters per Hectare		
Tractor	2	359.436	354.803*
Implement	3	3265.414	3223.325*
Tractor X Implement	6	222.005	219.144*
Speed	3	367.483	362.746*
Tractor X Speed	6	3.175	3.134*
Implement X Speed	9	56.387	55.661*
Tractor X Implement X Speed	18	4.489	4.431*
Residual	144	1.013	

*Significant at $\alpha = .01$.

conclusions made were limited to the soil type, soil conditions, and type of equipment employed in the tests. These results would not necessarily be applicable to future experiments of this nature. However, based upon the diesel analyses, confidence may be placed upon the gasoline results to a limited extent.

Four implements were employed for each gasoline tractor test. In performing the six-row tests, however, a six-row planter was not available. Therefore, a "do-all" was substituted in this instance since it was the only implement of "six-row-size" at disposal which had not been used already. This "do-all" was a trailed implement, hydraulically actuated, which combined the operations of a spring tooth harrow and a mulcher. It is normally employed prior to planting for smoothing and firming the soil surface.

Tractors, obviously, had a significant effect upon gasoline consumption. Table 7 reveals the difference between the individual tractors. Each tractor was significantly different for both gasoline consumed per hour and per unit area. The six-row tractor consumed over 10 liters (2.60 gallons) more gasoline per hour than the four-row tractor. The four-row tractor consumed only 3 liters (0.80 gallons) more gasoline than the two-row tractor. For gasoline consumed per unit area, the two-row and four-row tractors consumed more gasoline while maintaining their previous difference. The six-row tractor consumed the most gasoline, but this was less than the gasoline consumption per hour.

The relatively high gasoline consumption per hour for the six-row tractor may be attributed to the use of the "do-all." This may be seen through the mean values of each tractor calculated without

TABLE 7. Fuel Consumption Means for Two-, Four-, and Six-Row Gasoline Tractors Operated with Four Implements at Four Field Speeds.

Make of Tractor	Rated Size	Gasoline* Consumption	
		Liters/Hr	(Gal/Hr)
MF 35	2-row	5.72	(1.45)[a]
IH 464	4-row	8.92	(2.36)[b]
IH 766	6-row	19.07	(5.04)[c]
		Liters/Ha	(Gal/Ac)
MF 35	2-row	8.31	(0.83)[a]
IH 464	4-row	11.41	(1.22)[b]
IH 766	6-row	12.97	(1.39)[c]

*Means followed by the same superscript are not significantly different at $p < .05$.

the effect of the planters and the "do-all." The means are shown below:

	Liters/Hr	(Gal/Hr)	Liters/Ha	(Gal/Ac)
Two-row	6.05	(1.60)	9.44	(1.01)
Four-row	9.64	(2.55)	13.01	(1.39)
Six-row	18.70	(4.94)	14.89	(15.93)

When these means were compared with those in Table 7, the six-row tractor mean for gasoline consumed per hour decreased approximately 0.37 liters (0.10 gallons). The two-row and four-row means increased 0.33 liters (0.09 gallons) and 0.72 liters (0.20 gallons), respectively. This indicates that the "do-all" required more gasoline than the planters. The means for gasoline consumed per unit area increased for all tractors because removal of the cultivators and the "do-all" from the calculations decreased the mean field capacity. This allowed the gasoline consumption per unit area to rise. However, the six-row tractor had the greatest increase of 1.92 liters (0.20 gallons) as compared to increases of 1.13 liters (0.12 gallons) and 1.60 liters (0.17 gallons) for the two-row and four-row means, respectively.

The resulting gasoline consumption means for implements, as displayed in Table 8, were somewhat peculiar. This statement was made because the tandem discs consumed more gasoline per hour than the moldboard plows. In the gasoline tests, the moldboard plows may not have been "matched" with the tandem discs. For example, a 1.83 meter disc (6 feet) and a 2-0.3 meter (12 inches) moldboard plow was employed for

TABLE 8. Mean Gasoline Requirements for Implements Employed with Two-, Four-, and Six-Row Tractors Operated with Each Implement Type.

Implement Type	Gasoline* Consumption	
	Liters/Hr	(Gal/Hr)
Moldboard Plow	11.04	(2.92)^{b}
Tandem Disc	13.17	(3.48)^{a}
Planter	10.55	(2.79)^{bc}
Cultivator	9.88	(2.61)^{c}
	Liters/Ha	(Gal/Ac)
Moldboard Plow	23.02	(2.46)^{a}
Tandem Disc	8.33	(0.89)^{b}
Planter	6.25	(0.67)^{c}
Cultivator	5.84	(0.62)^{c}

*Means followed by the same superscript are not significantly different at $p < .05$.

the two-row test. The four-row test included a 3.05 meter disc (10 feet) and a 3-0.35 meter (14 inches) moldboard plow. These tandem discs covered 1.23 meters (4 feet) and 2.00 meters (6.5 feet), respectively, more than the moldboard plows. Therefore, the draft of the tandem discs may have been greater and, as a result, the gasoline required per hour to operate these tandem discs may have been greater.

The effect of this size difference, however, was readily apparent for gasoline consumed per unit area. With a large physical implement size, more area was tilled per pass over the test plot as compared with smaller implements. This resulted in relatively low gasoline consumption per unit area. However, the increase in gasoline consumed per unit area for moldboard plows may have been caused by the limited field capacity coupled with the high draft force associated with moldboard plows.

Planters and cultivators consumed approximately the same amount of gasoline as indicated in Table 8. On the other hand, the planter consumed about the same amount of gasoline per hour as the moldboard plows. The relatively small size of the moldboard plows may have been the reason for this response. The effect of the "do-all" was expected to be of no consequence in this instance since the planters exhibited no difference in gasoline consumption over the cultivators.

Operating speeds, in addition to tractors and implements, had an important effect upon gasoline consumption. These speeds responded equally for both gasoline consumed per unit area and per hour (Table 9). The two slowest speeds, 3.2 and 4.8 kilometers per hour (2.0 and 3.0 miles per hour, respectively), exhibited a definite significant difference ($p \leq 0.01$) in their effect upon gasoline consumption. The two fast

TABLE 9. Mean Gasoline Consumption for Field Speeds of Two-, Four-, and Six-Row Tractors Operated with Each Implement Type.

Speed Km/Hr	Speed Mi/Hr	Gasoline* Consumption	
		Liters/Hr	(Gal/Hr)
3.2	2.0	9.42	(2.49)^a
4.8	3.0	10.91	(2.88)^b
6.4	4.0	12.02	(3.17)^c
8.1	5.0	12.29	(3.25)^c
		Liters/Ha	(Gal/Ac)
3.2	2.0	14.82	(1.59)^a
4.8	3.0	10.78	(1.15)^b
6.4	4.0	9.37	(1.00)^c
8.1	5.0	8.47	(0.91)^c

*Means followed by the same superscript are not significantly different at $p < .05$.

operating speeds, 6.4 and 8.1 kilometers per hour (4.0 and 5.0 miles per hour, respectively), apparently, had the same response. Also, the effect of operating speed can be seen in two ways. First, as speed rises, the gasoline consumption per hour increases. This rise in operating speed produces an increase in the field capacity. More gasoline is consumed per hour since more area is being covered per hour. The increase in gasoline consumption per hour becomes insignificant at high operating speeds as revealed in Table 9. Secondly, a decrease in gasoline consumed per unit area was realized with a rise in operating speed which increases field capacity. This allows for more area covered with a specific volume of gasoline. Table 9 also shows that the decrease in gasoline consumed per unit area becomes insignificant at the high speeds.

An interaction occurred between tractors and implements; Figure 12 illustrates this interaction for gasoline consumed per hour. The majority of the interaction may be attributed to the increased gasoline consumption due to the "do-all." At the same time, the two-row and four-row planters experienced a drop in gasoline consumption per hour. Also, the hourly gasoline consumption of the two-row and four-row planters was very similar to the gasoline consumption of the cultivators; the cultivators being slightly higher. As a result, an estimate for the six-row planter was made and is represented by the dotted line in Figure 12.

Figure 13 displays the tractor-implement interaction for gasoline consumed per unit area. The graph indicates that interaction occurred due to the relatively high gasoline consumption of the moldboard plows.

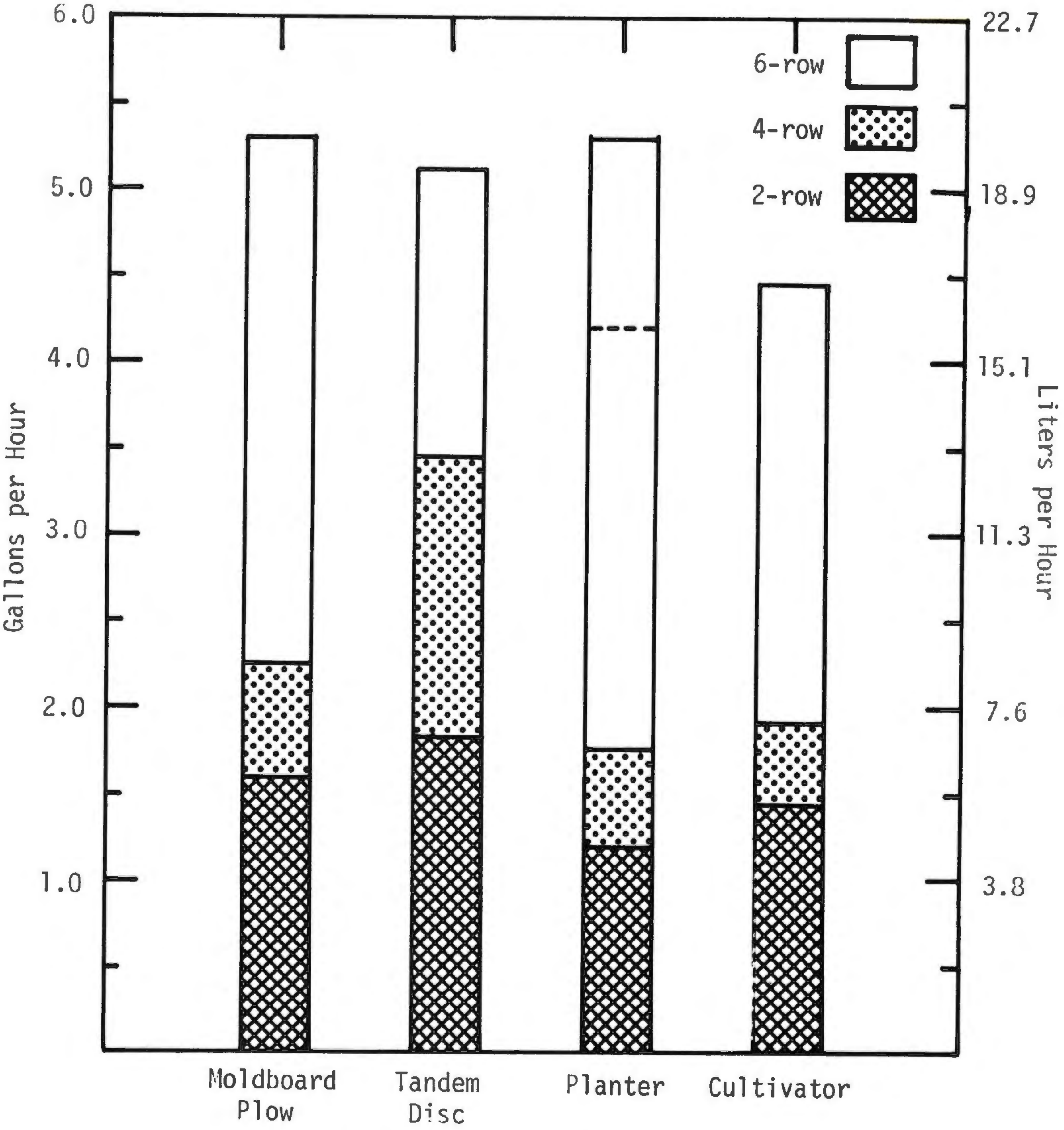

FIGURE 12. Average gasoline requirements per hour for each implement when employed with two-, four-, and six-row tractors at four field speeds.

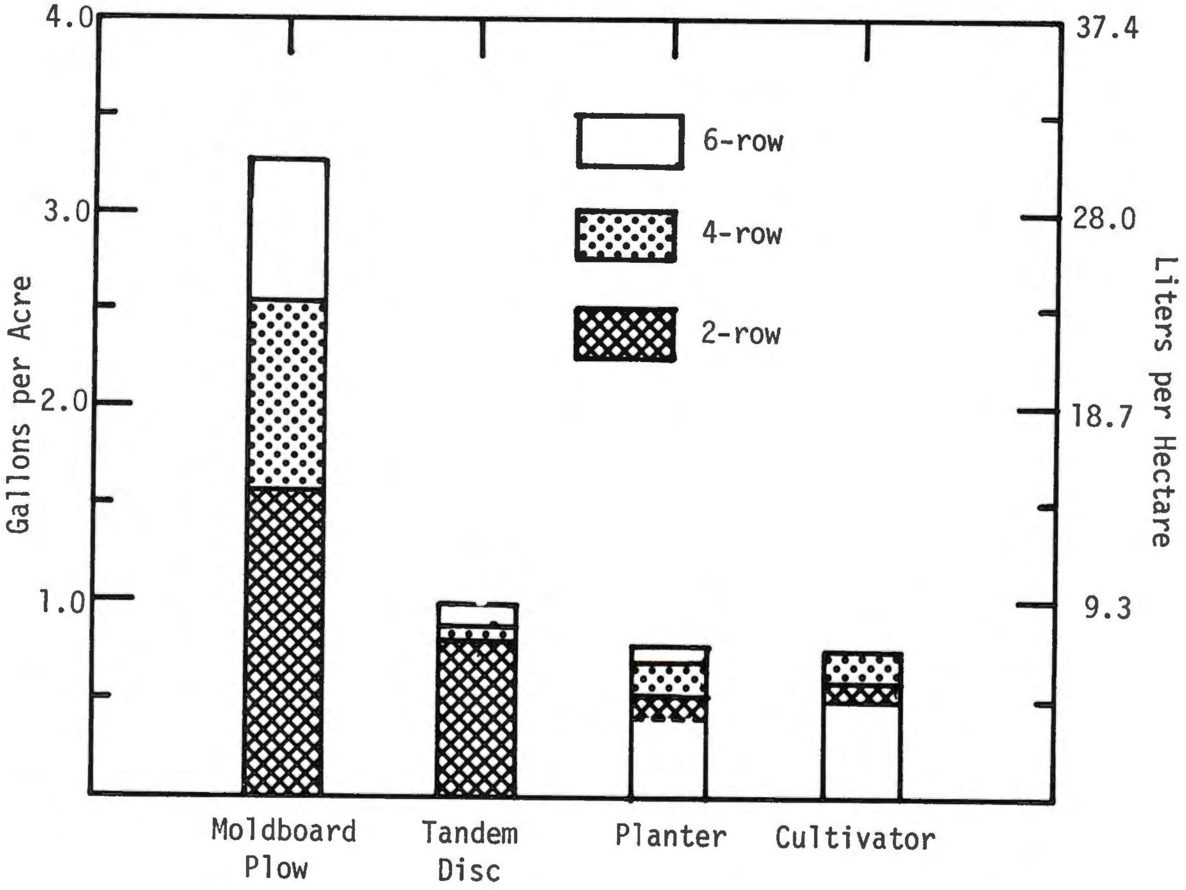

FIGURE 13. Average gasoline requirements per unit area for each implement when employed with two-, four-, and six-row tractors at four field speeds.

These plows possessed the highest draft force and the lowest field capacity as mentioned in previous discussion. This resulted in relatively high gasoline consumption per unit area. Also, some interaction may be due to the planter response of the six-row tractor. At this point, the "do-all" required the most gasoline, while the six-row planter would have consumed approximately 1.70 liters per hectare (0.45 gallons per acre), represented by the dotted line in Figure 13. This estimate was made under two conditions. The six-row equipment allowed for higher field capacities, which reduced the gasoline consumption per unit area. In addition, the gasoline consumption for the two-row and four-row cultivators and planters was very similar. The six-row cultivator mean was 1.90 liters per hectare (0.50 gallons per acre); thus, the planter mean was estimated as stated above.

Tractors interacted with speeds for gasoline consumed per hour as shown in Figure 14. Most of this interaction was due to the response of the six-row tractor. A similar response was noted in Figure 7, page 37, of the diesel analysis. In both instances, the six-row tractor consumed a higher rate of gasoline at each operating speed than the two-row or four-row tractors. Also, the two-row gasoline tractor responded opposite to the four-row gasoline tractor at 8.1 kilometers per hour (5.0 miles per hour); therefore, some interaction may have occurred. The gasoline consumption per hour for the two-row tractor decreased 0.21 liters (.05 gallons), while the four-row tractor exhibited an increase of 1.25 liters (0.3 gallons) of gasoline.

Figure 15 shows a slight interaction between tractors and speeds for gasoline consumption per unit area. Tractors and speeds exhibited

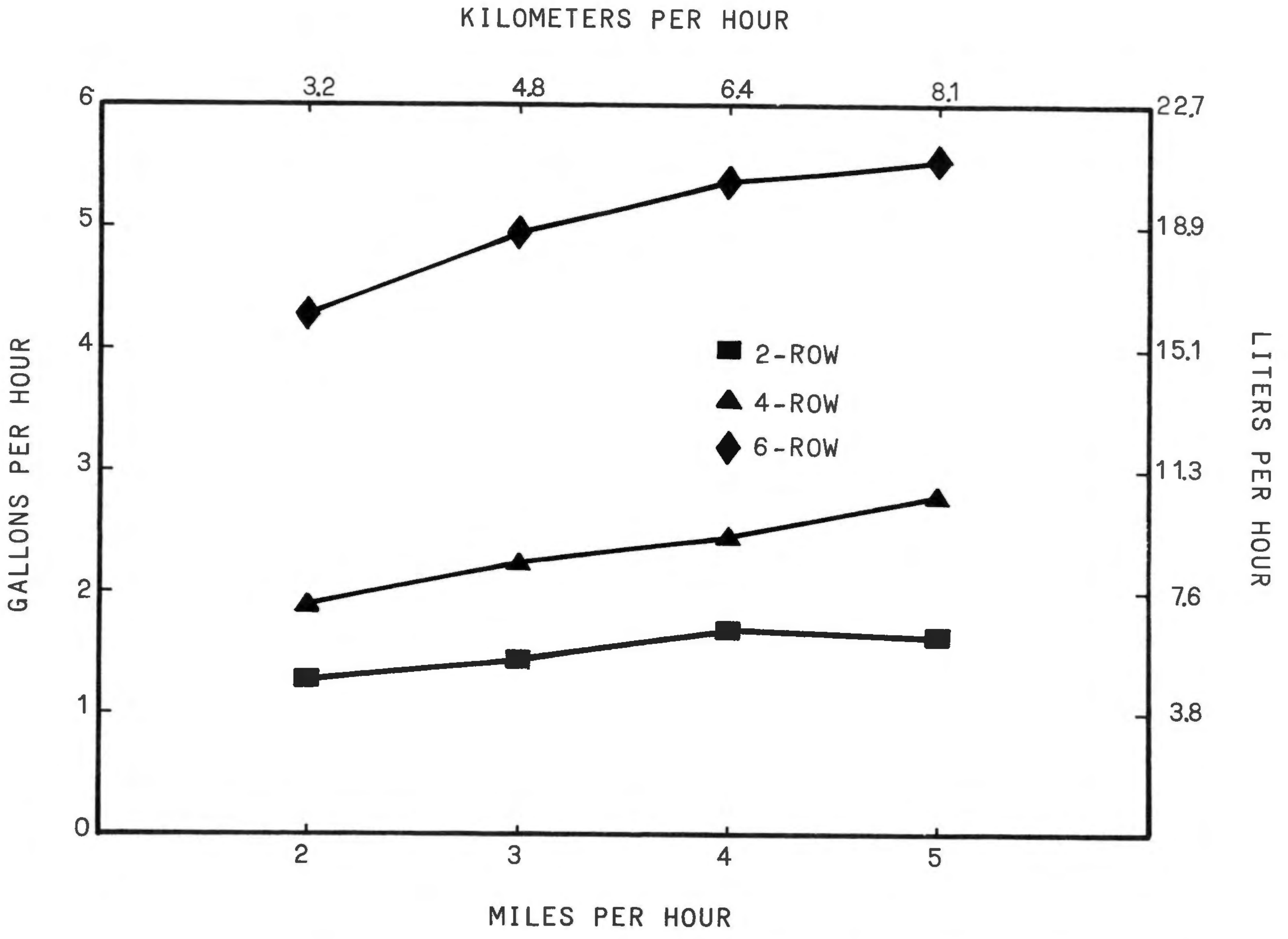

FIGURE 14. Average fuel consumption per hour for two-, four-, and six-row gasoline tractors operated at each field speed with four implement types.

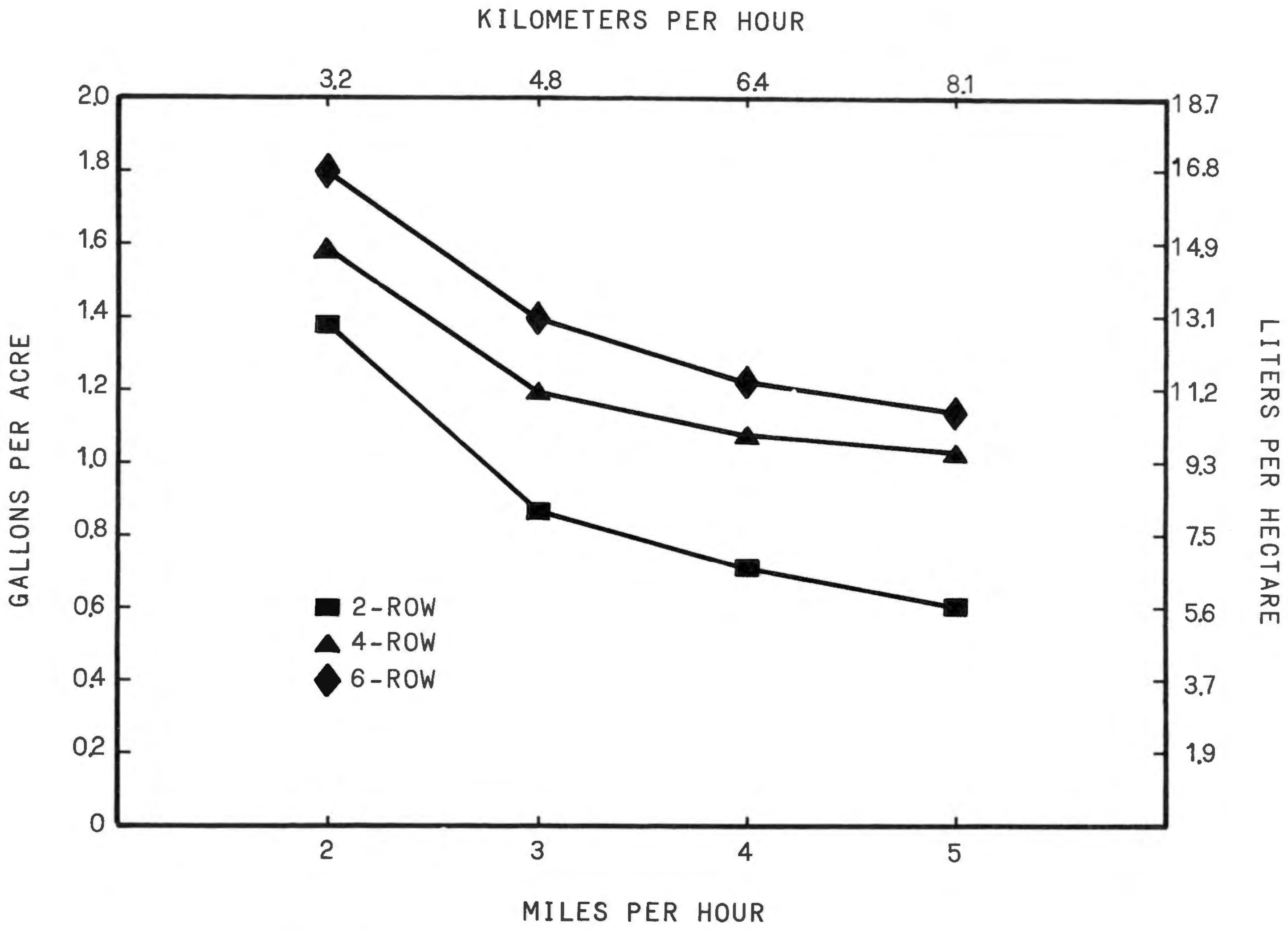

FIGURE 15. Average fuel consumption per unit area for two-, four-, and six-row gasoline tractors operated at each field speed with four implement types.

a slight interaction for diesel fuel consumption per unit area as shown in Figure 8, page 38, but this interaction was insignificant. The same situation may exist for this portion of the gasoline analysis. Figure 15 indicates that the gasoline consumed per unit area declined at a greater rate for the two-row tractor. This rate of reduction in gasoline consumption appeared to be significant when compared to Figure 8.

Review of Figure 16 reveals a definite interaction between implements and speeds for gasoline consumed per hour. The curves associated with the implements used in the gasoline tests responded upward, as did the implements in the diesel analyses. However, Figure 10, page 41, shows a much different response for the diesel analysis. A slight interaction occurred, but it was not significant.

As discussed earlier, the tandem discs did not "match" the moldboard plows, such that these discs possessed a much greater field capacity. The gasoline consumed per hour was higher in this instance for the tandem discs. The majority of interaction was due to the "do-all" response. This "do-all" had a mean value of 20.17 liters (5.33 gallons) of gasoline per hour. The four-row planter (closest size to six-row) produced a mean of only 6.76 liters (1.79 gallons) per hour. Therefore, the "do-all" had an "inflated" effect upon the planter response. Also, interaction may be involved at the high operating speeds. From a speed of 6.4 to 8.1 kilometers per hour (4.0 to 5.0 miles per hour), the gasoline consumed per hour for the moldboard plow increased at a greater rate than for the other implements.

Interaction occurred between implements and speeds for gasoline consumed per unit area as indicated in Figure 17. This interaction

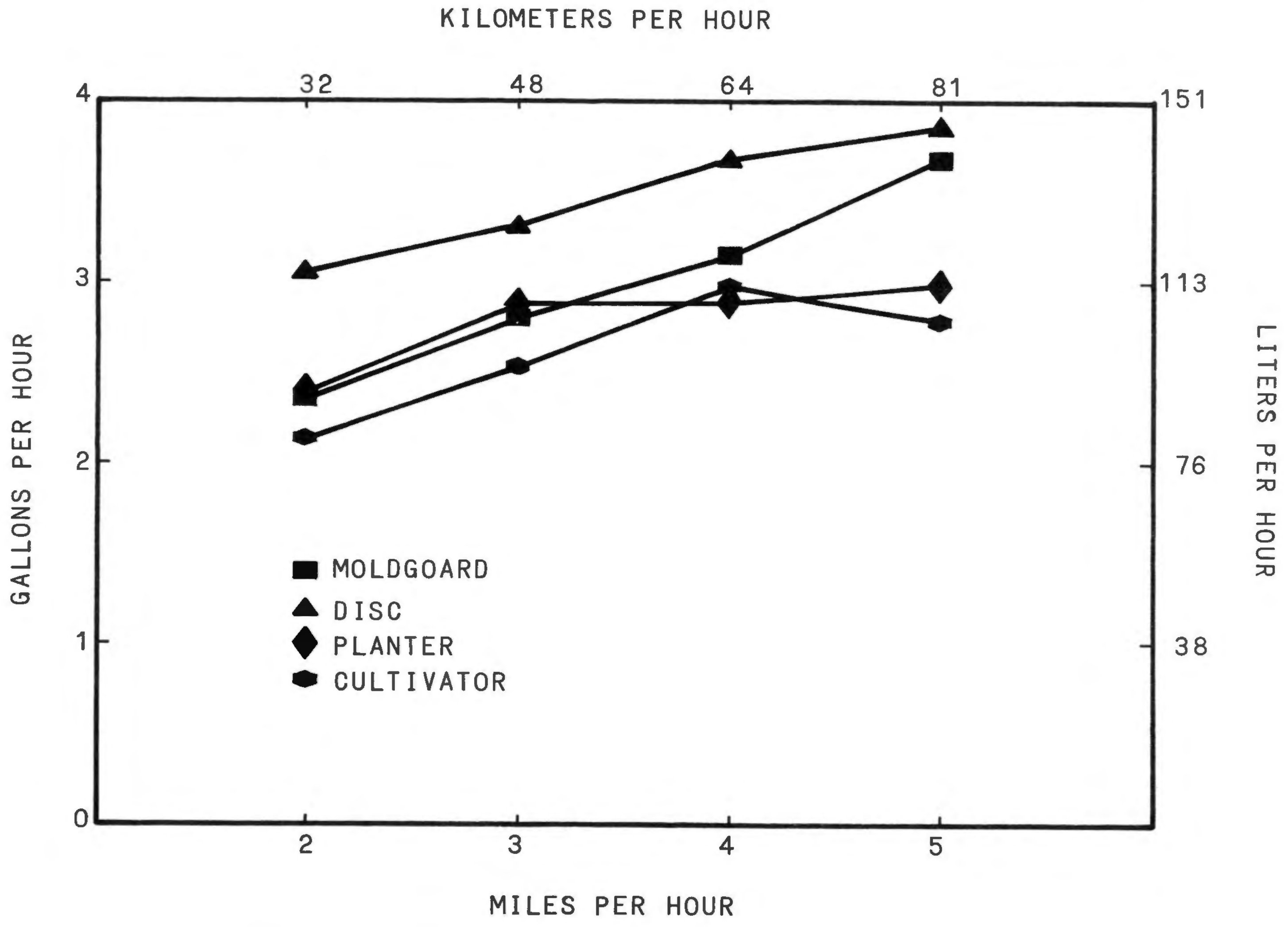

FIGURE 16. Average gasoline requirements per hour for two-, four-, and six-row implements when operated at each field speed.

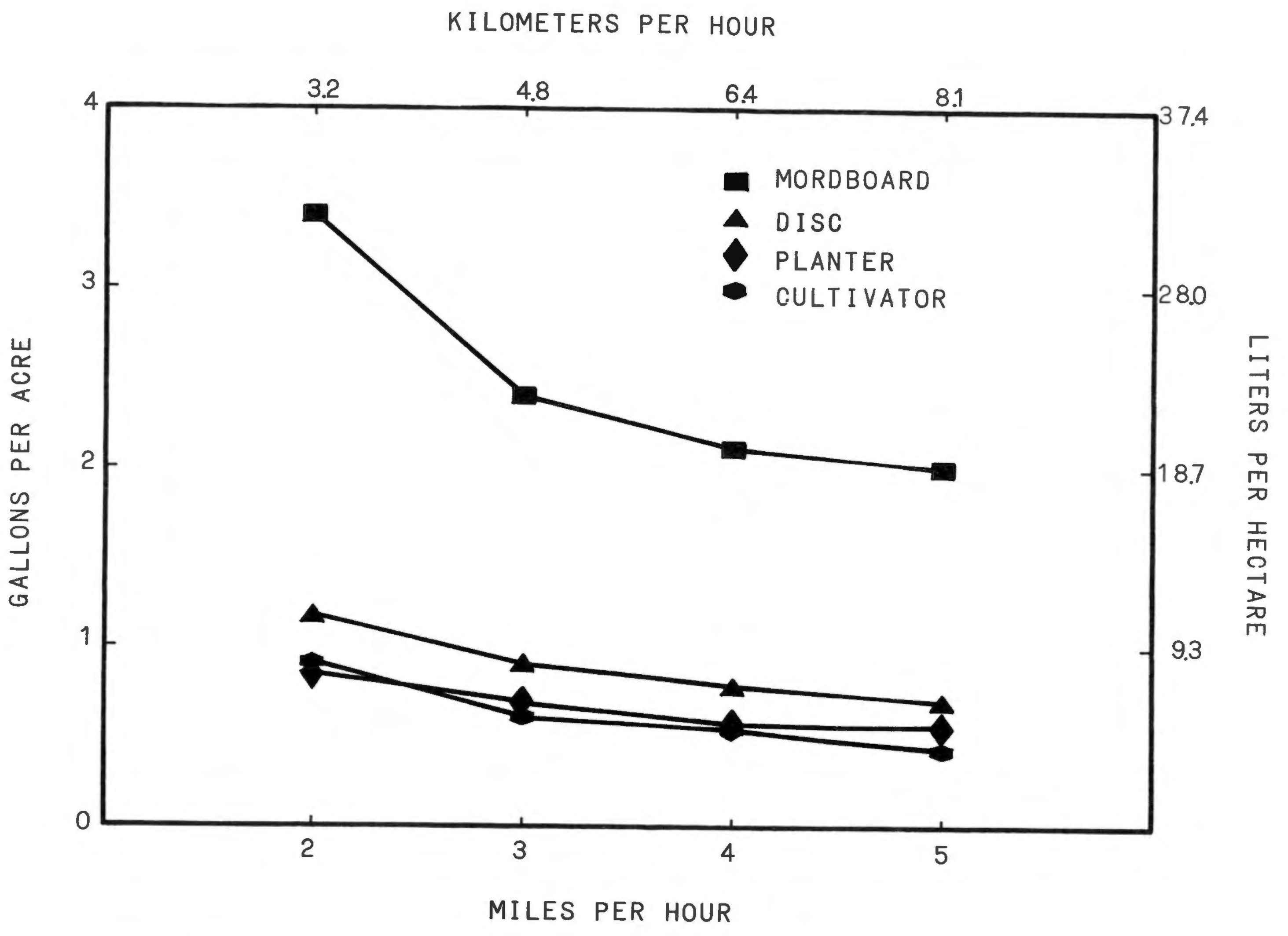

FIGURE 17. Average gasoline requirements per unit area for two-, four-, and six-row implements when operated at each field speed.

was due to the relatively high rate of decline in gasoline consumption for moldboard plows. The gasoline consumption of the other implements was about equal. Figure 9, page 40, reveals a similar response for the diesel analysis. At each operating speed, the implement employed in the diesel tests responded in much the same manner as those of the gasoline analysis. This indicates that the gasoline experiment may have been as reliable as the diesel experiment.

6. The six-row primary and secondary tillage tools operated at 8.1 kilometers per hour (5.0 miles per hour) yielded the highest performance efficiency which was subjectively evaluated by inspecting the soil pulverization and surface smoothness. Also, this efficiency was relatively high for the smaller implement sizes at the above speed. A marked reduction in soil pulverization resulted as the speed was reduced to 3.2 kilometers per hour (2.0 miles per hour), especially with the two-row size class. The quality of work achieved, however, was not considered in the analyses.

III. Recommendations for Future Study

Fuel consumption measurements could be made using new types of tillage equipment and other conventional tillage implements not included in this study. Also, the fuel consumed by self-propelled machines, such as cotton pickers and combines, could be measured. This should give more accurate estimates of energy costs during harvest.

Some benefit may be derived by reducing the length of the test area. This would allow for a smaller graduated cylinder in the fuel meter. The graduations would be smaller, producing more accurate results. Also, less area would be required for the fuel tests and more area would be available for starting and stopping.

Another field of study might be the determination of fuel conversion ratings (kilowatt-hours per liter or horsepower-hours per gallon) for various tractor and implement systems. This would require measuring horsepower in addition to the fuel consumption. Likewise, an accurate method for measuring horsepower in the field would be essential.

CHAPTER VI

SUMMARY AND CONCLUSIONS

I. Summary

The objective of this study was to measure the fuel consumption for both gasoline and diesel tractors while operating various tillage implements in the field. Tractors were selected in size classes to accommodate two-, four-, and six-row equipment. The tractors were operated at four different speeds with appropriate sizes of the following implements:

1. Moldboard Plow
2. Tandem Disc
3. Planter
4. Cultivator

In two instances, the implement planned for use was not available: a six-row planter for gasoline tests and a six-row cultivator for diesel tests. A "do-all" was substituted for the planter, and a chisel plow was used rather than the six-row cultivator.

A fuel meter was designed and constructed in the summer of 1975 for measuring gasoline consumption. The following year, the gasoline meter was modified to facilitate diesel fuel measurement. These modifications included accommodations for the return fuel which comes from the fuel injectors and injector pump.

All tillage operations were performed in Memphis silt loam soil when the moisture content was considered suitable for tillage. The plowing depth was approximately 20 centimeters (8 inches) while all other tillage operations were maintained at a 10-centimeter depth (4 inches).

The diesel tractors, generally, consumed less fuel than the gasoline tractors. The six-row tractors, on the average, consumed the most fuel per hour while the two-row tractors expended the least amount of fuel both per hour and per unit area. With the row-crop implements (the planters and cultivators) the six-row tractors consumed the least amount of fuel per unit area. The two-row tractors consumed the most fuel per unit area with these same implements.

The moldboard plows used in the diesel tests resulted in the highest rate of diesel fuel consumption in every instance when compared with the other implements. The tandem discs were second, followed by the cultivators and planters. The implements used with the gasoline tractors responded in the same manner, with the exception of the moldboard plows. In this instance, the moldboard plow required less gasoline per hour than the tandem discs.

The slowest operating speed resulted in the highest rate of fuel consumption per unit area in both gasoline and diesel analyses. However, less fuel was consumed per hour at the lowest speed, 3.2 kilometers per hour (2.0 miles per hour). The highest operating speed required the most fuel per hour and the least fuel per unit area.

II. Conclusions

The following conclusions were drawn from the results of this study:

1. Diesel tractors consumed less fuel than the gasoline tractors for each size class to accomplish a given tillage operation at a given operating speed.

2. Moldboard plows, generally, required more fuel both per hour and per unit area than any other implement since they produced the highest draft force.

3. More fuel was consumed per hour at the highest operating speed (8.1 kilometers per hour or 5.0 miles per hour) than at the lowest operating speed (3.2 kilometers per hour or 2.0 miles per hour). However, more fuel was consumed per unit area at 3.2 kilometers per hour (2.0 miles per hour) than at 8.1 kilometers per hour (5.0 miles per hour).

4. Large row-crop implements, including the six-row planters and cultivators, possessed high field capacity capabilities, but produced high fuel consumption per hour. However, when fuel consumption was measured on a per unit area basis, less fuel was used when these large implements were employed. The six-row moldboard plows and tandem discs required much more fuel per hour than the smaller sizes; but on a per unit area basis, the fuel required for the largest implements was only slightly greater than the requirements for the smaller tillage machines.

5. The six-row tractors with each implement type at all operating speeds consumed the most fuel on an hourly basis. However, they consumed the least fuel per unit area when operating with cultivators and planters. The two-row tractors consumed the least amount of fuel per hour, but, in some cases, they consumed the most fuel per unit area due to their low field capacity.

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VITA

Roger Garland Carpenter was born in Athens, Tennessee, on August 16, 1953. He attended Decatur Elementary School and was graduated from Meigs County High School in 1971.

In September of 1971, he enrolled in Tennessee Technological University at Cookeville, Tennessee, and in August, 1974, he received a Bachelor of Science degree in Agricultural Science. He immediately enrolled in The University of Tennessee in September, 1974, as a graduate research assistant working toward a Master of Science degree in Agricultural Mechanization. He is a student affiliate member of the American Society of Agricultural Engineers and a member of Gamma Sigma Delta (Agricultural Honorary Society).

He is married to the former Julia Ann Jones of Big Springs, Tennessee.