ALABAMA AGRICULTURAL EXPERIMENT STATION AUBURN UNIVERSITY
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CIRCULAR 258 DECEMBER 1981

Predicting Machine Performance Rates for Specific Field and Operating Conditions

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ACKNOWLEDGMENT:

The author wishes to express thanks to W. T. Dumas and the staff at the Marvyn Agricultural Engineering Research Unit for their help in providing machines and crops. The assistance of agricultural engineering students Wayne Fowler and Lee Coon with data collection and analysis is gratefully acknowledged.

First Printing 4M, December 1981

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PREDICTING MACHINE PERFORMANCE RATES for SPECIFIC FIELD and OPERATING CONDITIONS

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INTRODUCTION

As farm machinery becomes larger, more complex, and more expensive it is important that it be used effectively in order to make maximum contribution to agricultural production.

No piece of farm machinery is used for productive work 100 percent of the time. Time spent making field adjustments and repairs, adding seed, fertilizer, chemicals, water, and turning at row ends is lost production time and reduces machine capacity.

Agricultural engineers and other scientists have long been interested in concepts and procedures for more efficient farm machinery use and have used many approaches in these studies.

A systems approach for machinery budgeting and programming has been used by several researchers. Von Bargen (8) used it in his hay harvest work. Stapleton and Barnes (7) also applied the systems analysis concept in their work with cotton harvesting machines.

Renoll (3,4) at Auburn University used systems analysis to study machine operations in the field in an attempt to gain insight into the interaction between machine use and the physical and geometrical characteristics of the field. This work indicates that field machine efficiency is related to row length, turn condition, and terrace system among other things.

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Field machine efficiency is defined as the ratio of the productive machine time to the sum of productive machine time plus the row-end turning time. Productive time is the actual time a machine is doing its specific job. For a planting operation, this would be the time actually spent placing seed in the ground.

Some additional approaches have been used by other engineers. Sowell and Link (6) used a network analysis concept in their machinery selection studies. A mixed integer programming model was used by I. Amir et al. (1) for selection and economic evaluation of hay drying systems.

Bowers (2) used a "rule of thumb" along with many years of experience when developing his procedure for efficiently matching machines to large tractors. The key to this approach was to avoid oversizing the equipment for a specific tractor.

Information in this publication came from a study designed to identify and analyze some of the factors that influence machine performance rates. They include machine and field factors as well as managerial ability.

The study included 4-row, 6-row, 8-row, and 12-row machines operating in fields up to 200 acres in size having row lengths ranging from 400 to 2,500 feet in length. Machine operators were typical of those found on Alabama farms. Data were obtained by time-record methods including manual observations and self-recording clocks.

SOME INITIAL PERFORMANCE RATE CONCEPTS

Scientists as well as farm operators have long been interested in methods and procedures for determining or estimating machine capacity. Such information has numerous obvious benefits.

Approximate Machine Performance Rates

For some conditions, extremely accurate machine capacity values are not needed. For such conditions, the following formula is commonly used.

$$D = W \times S$$

where:
D = capacity (acres/day)
W = machine width (feet)
S = machine speed (miles/hour)

Two assumptions are made in this approach. Nonproductive time such as adjustments, adding seed, and stops is assumed to

FIG. 1. Field size and row length are important factors in determining machine capacity. Rows less than 400 feet greatly decrease performance rates.

be about 18 percent. The assumed work day is 10 hours. This is a quick and easy way to get a rough estimate of machine capacity but it also has some obvious limitations.

For field operations that have very little nonproductive time, such as harrowing or mechanical cultivating, the capacity from the formula is too low. For operations such as planting that have large amounts of nonproductive time the formula would greatly overestimate the capacity. Another problem with the formula is that machine width is used rather than the actual effective working width.

Performance Rates for Average Conditions

In many situations more accuracy is desired than can be obtained with the previous formula. Such accuracy can be obtained by using the following formula:

$$C = \frac{S \times W \times E_f}{8.25}$$

where:
C = capacity (acres/hour)
S = speed (miles/hour)
W = machine width (feet)
E_f = field efficiency (decimal)

Field efficiency is the ratio of time a machine is actually performing its function to the total time required to do the job. It includes the effect of time lost in the field as well as failure to utilize the full width of the machine.

The value E_f takes into account all kinds of support function time, including such things as minor breakdowns, adjustments, turning at row ends, adding seed and fertilizer, and other nonproductive delays. Together they result in a field efficiency of less than 100 percent. Since E_f is influenced by many factors it is difficult to obtain a reliable value.

In an attempt to find a solution to this problem, Renoll (5) proposed a minutes-per-acre concept. It is based on the idea that if the time to cover one specific acre can be determined then the time needed to handle any number of similar acres can be predicted. It differs from other capacity determination methods in that it attempts to use field efficiency values for an acre under its specific field conditions rather than for average conditions.

PRECISE MACHINE PERFORMANCE RATES

During the past few years much interest has developed and considerable effort has been spent in seeking more accuracy in estimating machine capacity rates.

FIG. 2. Physical condition and width of row-end turning space have great influence on machine capacity rates. Reasonably smooth turn space as above is desired.

FIG. 3. Farm machinery that is well serviced and correctly adjusted can reduce field delays and excessive down time thus increasing acre per hour capacity.

Much of this effort has been spent in examining in detail the relative importance of the individual items included in E_f. Some research efforts at Auburn have been along this line. This effort has resulted in a proposed machine capacity prediction formula having more accuracy than those discussed earlier in this circular.

The Concept

The time required for a farm machine to cover an acre includes the down-the-row time plus the additional time needed for turning, adjustments, delays, and other nonproductive activities. In this concept, time for each of these is determined individually and then totalled for the acre. From this information machine capacity can be determined. Some 14 input items, including both field and machine conditions, are used and expressed as follows:

$$T = A + B$$

$$C = \frac{1}{T}$$

where:

A = time spent actually performing the specific operation. Sometimes called down-the-row time. (hours/acre).

B = time used for support functions including row-end turning, adding seed, etc. (hours/acre).

T = total time (hours/acre)

C = performance rate (acres/hour)

Values for A are determined as follows:

$$A = \frac{8.25}{SW} \text{ (hours/acre)}$$

where:

S = machine ground speed (miles/hour)

W = effective machine width (feet)

Effective machine width is the actual width the operator covers in one machine pass.

Item B covers row-end turning, adjustments and other necessary time delays commonly associated with support functions. The B values are obtained from the following:

$$B = \frac{12\ P}{WL} + [(f_1 + f_2 + f_3 + f_4 + f_5) \times \frac{8.25}{SW}]$$
(hours/acre)

The expression $\frac{12\ P}{WL}$ is used to determine the total turning time in hours per acre

where:

P = average time per turn (seconds)

L = average or representative row length for the field (feet)

The term $[(f_1 + f_2 + f_3 + f_4 + f_5) \times \frac{8.25}{SW}]$ indicates the support functions time in hours per acre. Each f value is an input coefficient representing a specific support function. They are as follows:

f_1 = coefficient for adding seed

f_2 = coefficient for adding fertilizer

f_3 = coefficient for adding water and chemicals
f_4 = coefficient for adjustments
f_5 = coefficient for other field delays

Numerical coefficients for individual support functions are expressed as a percentage of the down-the-row time. Some suggested values are found in table 1.

In many farming operations some fields are located away from the farm headquarters. While this does not influence the capacity of a machine on a specific field it does have influence on the number of acres a machine can cover in a growing season or other time period and would be very important in some situations.

The effective capacity of a machine on a field remote from the headquarters can be determined by adding $\frac{VU}{60D}$ to B above.

V = time for round trip, barn to field and return (minutes)
U = number of round trips, barn to field and return required to complete the field operation
D = field size (acres)

If the fields involved are in close proximity to the farm headquarters this item can be omitted.

As suggested earlier T = A + B is used to calculate the hours per acre. If the component items for A and B are substituted in the above expression it becomes:

$$T = \frac{8.25}{SW} + \frac{12\ P}{WL} + [(f_1 + f_2 + f_3 + f_4 + f_5) \times \frac{8.25}{SW}]$$

(hours/acre)

By substitution of T from above in $C = \frac{1}{T}$ the capacity in acres per hour can be determined.

Application Example

Using the formula to predict machine performance rates requires two kinds of input information. The first is "firm data" and includes all information about the operation that is known or has been measured. The other is "estimation data" and includes those items not actually measured. A specific input item might fall in the firm data category for one field and in estimation data for another.

Obtaining the "firm data" information about the machine operation is not difficult. Most of these items are common knowledge to the farmer or can easily be measured. Included would be such things as row spacing, ground speed, row lengths, turning time, and available labor. Coefficients for the "estimation data" are not so easily obtained. Estimates for many of these coefficients can be obtained from previous machinery-use data and from personal experience. If reliable coefficients material is not available from other sources, the information in table 1 can be used. Values in the table are from field research data obtained on efficient and well managed farms.

The following example illustrates how to estimate the capacity for a 4-row planter. Specific operating conditions are as follows:

Firm data
1. Planter—tractor mounted 4-row, 13.3 feet (W)
2. Row spacing—40 inches
3. Planter speed—4.2 miles/hour (S)
4. Seeding rate—16 pounds/acre
5. Fertilizer rate—300 pounds/acre
6. Chemical spray rate—8 gallons chemical and water/acre
7. Time per turn—12 seconds, average (P)
8. Row length—1,017 feet, average (L)
9. Field size—37 acres, adjacent to headquarters

Estimation data
1. Coefficient for adding seed, f_1—.04
2. Coefficient for adding fertilizer, f_2—.12
3. Coefficient for adding chemicals, f_3—.08
4. Coefficient for adjustments, f_4—.04
5. Coefficient for stops and other delays, f_5—.04

The formulas $T = A + B$ and $C = \frac{1}{T}$ are used to determine machine capacity.

$A = \frac{8.25}{SW}$ and by direct substitution becomes

$$A = \frac{8.25}{4.2 \times 13.3} = 0.15 \text{ hours/acre}$$

$B = \frac{12\ P}{WL} + [(f_1 + f_2 + f_3 + f_4 + f_5) \times \frac{8.25}{SW}]$ and by direct substitution becomes:

$$B = \frac{12 \times 12}{13.3 \times 1017} + [(.04 + .12 + .08 + .04 + .04) \times \frac{8.25}{4.2 \times 13.3}]$$
$$= 0.06 \text{ hours/acre}$$

From the above A = 0.15 hours/acre and B = 0.06 hours/acre. Substituting in T = A + B this becomes T = 0.15 + 0.06 = 0.21 hours/acre. By substitution in $C = \frac{1}{T} = \frac{1}{0.21}$ hours/acre = 4.8 acres/hour.

Accuracy of the prediction formula is greatly influenced by coefficient selection. This selection is not always easy since some coefficients vary appreciably as indicated in table 1. However, familiarity with field operating procedure and experience with the specific machine involved is helpful and can result in proper coefficient selection.

Benefits From Its Use

An accurate method for determining or predicting machine performance rates is badly needed and has a number of important benefits. It would enable a farmer to more accurately determine machine time per acre and thus more accurately determine the number of acres his specific machines could handle under his conditions.

FIG. 4. Effective machinery use planning along with proper operator training and instruction help maximize machine capacity.

TABLE 1. SOME TYPICAL COEFFICIENTS FOR PREDICTING FARM MACHINERY CAPACITY[1]

Machine operation	Coefficient values				
	Adjustments	Other delays[2]	Add seed	Add fertilizer	Add chemicals[3]
Plant (4-row)	.03-.07	.03-.04	.03-.05	.10-.14	.07-.09
Cultivate (4-row)	.05-.07	.03-.04			
Plant (6-row)	.05-.09	.03-.06	.04-.06	.12-.16	.08-.11
Cultivate (6-row)	.06-.09	.03-.06			
Spray (12-row)	.03-.05	.02-.03			.06-.10
Disk harrow	.01-.03	.00-.01			
Harrow and apply chemicals	.02-.04	.00-.01			.10-.12
Plow (4-bottom)	.02-.05	.01-.03			
Plow (6-bottom)	.03-.06	.01-.03			

[1] Expressed as decimal percent of time the machine actually spent performing its function.
[2] Includes such items as: idle field travel, field obstructions, operator instruction, and short rest stops.
[3] Can vary considerably depending on the amount of chemical and water applied per acre.

The concept is valuable to economists and others interested in estimating machine cost per hour prior to machine purchase or in comparing per hour costs for two different size machines.

It will be helpful to more accurately determine correct size and machines needed for a specific cropping system.

SUMMARY

A method to predict machine capacity for row-crop machines under specific field and operating conditions is presented. It uses individual input coefficients to represent such things as row length, adjustment time, breakdown time, and other conditions that influence capacity. Fourteen such input coefficients are used.

This report also includes a table of typical coefficient values that can be used if actual values are not available.

The capacity concept was applied to various row-crop machines during its development. The predicted capacity values were compared with actual field measured capacity values and were found to vary less than 5 percent. The formula uses some input coefficients which are derived from in-the-field measurements as well as by estimation and thus is subject to these limitations.

The prediction formula as presented here has application to row-crop machines. Modification for use with nonrow-crop machines should be possible.

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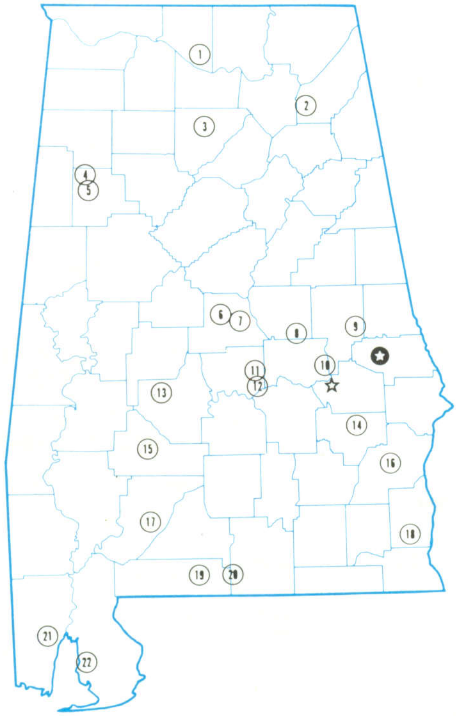

Research Unit Identification

⊛ Main Agricultural Experiment Station, Auburn.
☆ E. V. Smith Research Center, Shorter.

1. Tennessee Valley Substation, Belle Mina.
2. Sand Mountain Substation, Crossville.
3. North Alabama Horticulture Substation, Cullman.
4. Upper Coastal Plain Substation, Winfield.
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