Durability of a Japanese Type Combine Harvester Discussed from the Viewpoint of Energy Economy

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Summary

Twenty years have passed since a Japanese type combine harvester was developed and came into general use in the Japanese farming. It has been used twice a year for the harvest of rice, wheat and barley in the southern half of Japan.

Informations on parts and times of failures, and also on the areas between the failures were obtained by questionnaire from the users of 35 combine harvesters of the same model in Saga district. Total working area by these combines was 2,976.4 ha. The failure rate of each malfunctioning part was calculated periodically and plotted on a Weibull probability diagram. Wear-out failures were remarkable in V belts, endless gum tracks, hydraulic devices, grain augers and so on.

Energy consumption was calculated to find out the way for increasing the durability of the combine. To use strengthened and/or more durable parts was more advantageous than to increase the frequency of repairs or maintenance, from the viewpoint of energy economy.

Suitable timing of renewal can be predicted from the energy consumption thrown into production, circulation, and utilization of the combine. The operating limit is assumed to be 125 to 140 ha, from the steep rising point on the energy consumption curve.

But this limit is thought to be greatly influenced by the repair service, repair cost, maintenance, and operation of respective machine.

Introduction

Though purchasing power of farmers has been reduced because of political restrictions on rice cultivation and suppression of the rice price, over one million Japanese type combines are in use according to a 1982 statistical report by the Ministry in charge. Hardly any fluctuation has been noticed in the widespread use of other farm machinery. Naturally the combines must be periodically renewed and repaired, so farmers must consider the depreciation and integrated repair cost. It is not always economical for them to use their machines as long as they like.

We considered how to use or renew the combine from the viewpoint of global energy cost. Using data on their utilization and repair, we could predict lifespan of parts which malfunctioned in several sets. At the time of renewal, we were interested in the depreciation and the actual condition of the parts and the machines themselves. Most of them had been purchased for group use, but some had become a single farmer's possession, and this transition was also of interest to us.

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Methods

A combine harvester is a representative farm machinery, we thought, because of its seasonal use and the machine contains abrasive parts. So 35 combines, the same type and the same maker, were selected at random near the Saga University. They had been developed and made for leading and large-sized farmers in Japan, and could be said to be the best machine available at the time they were bought. Every year, we inquired of the operators about the harvesting areas and actual conditions of operation, and investigated repaired parts from bills of the service stations that were in charge of the maintenance. All of the operators belonged to the Saga Agricultural Co-operative Association.

For each main part, failure rate was calculated periodically as harvest area increased. The rate, which followed up each curve, was plotted on a Weibull probability diagram[1]. From the diagram, the root causes of failure, the mean times of failure of the parts and the weak points of the combine were predicted[2].

Cost of maintenance and repair were converted into energy, with the aid of energy intensities[3] which had been calculated from Input-Output analysis. The ideal chance of renewal of the combine was examined with the increasing curve of energy consumption.

Results and Discussion

Records of Utilization and Repair

Fig. 1 shows the harvesting area and repair records of the combines. The most heavily operated machine harvested 139.7 (ha) of rice, barley and wheat in 9 years, average 85 (ha) per 7.6 years. Twenty machines harvested over 80 (ha), which is far more than individual farmers in general. The mean operating area in a year has been decreasing : 12.1 (ha) in 1978, 11.8 (ha) in 1979, 11.2 (ha) in 1980, 10.6 (ha) in 1981, 10.1 (ha) in 1982. This downward tendency has been caused by political suppression of rice cultivating area and by the transition of ownership.

From Fig. 1, which also shows when and what parts were repaired, integrated failure rates for main parts were calculated respectively. Figures 2 and 3 show trends of increasing failure of each part. There is an indication that endless gum tracks, hydraulic devices, bearings in chassis, grain auger, straw binder, straw cutter shaft, straw cutter blades, V belts and sickle bars caused wear-out failures. To insure longer lives of these parts, it will be necessary to change the design or materials of which they are made, with the exception of those parts that are inexpensive or consumptive. It seemed that endless gum tracks had

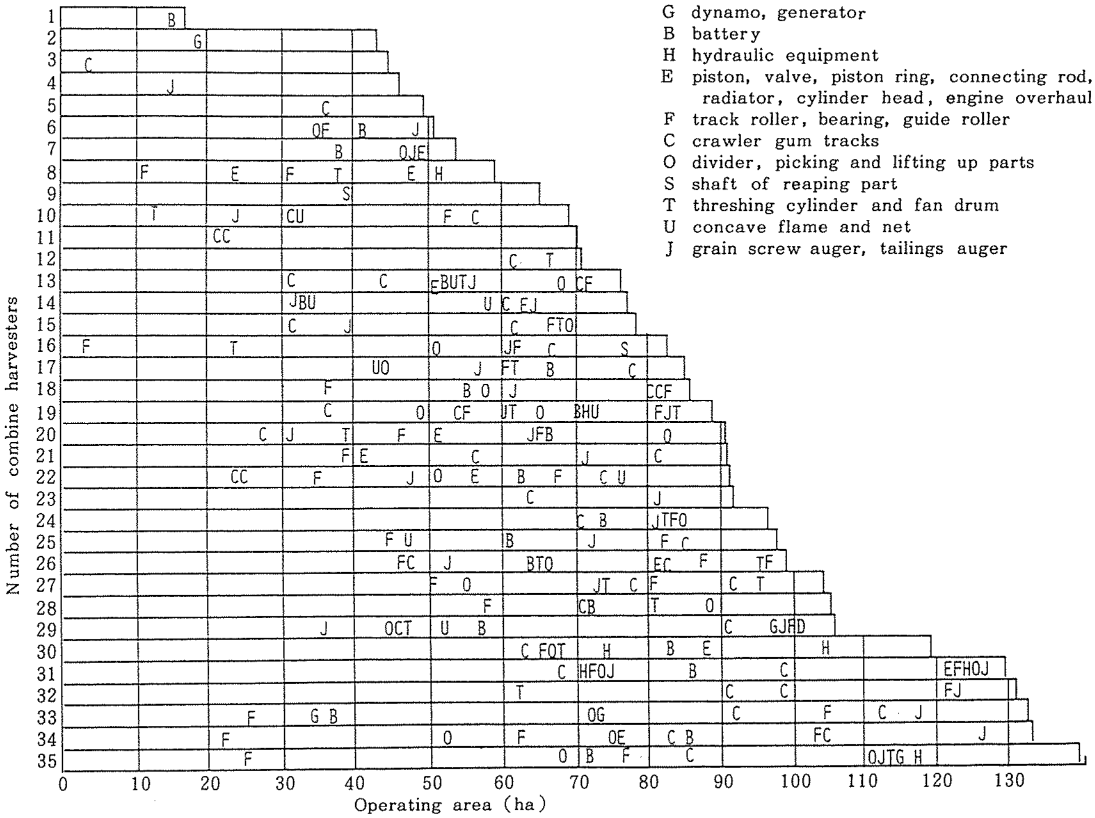

Fig. 1 Cumulative harvesting records and the failure records of each combine.

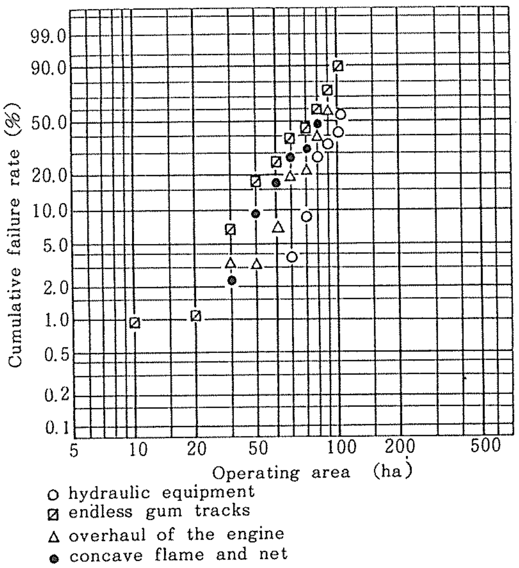

Fig. 2 Cumulative failure rate for the heavy maintenance of combine harvesters on Weibull probability graph.

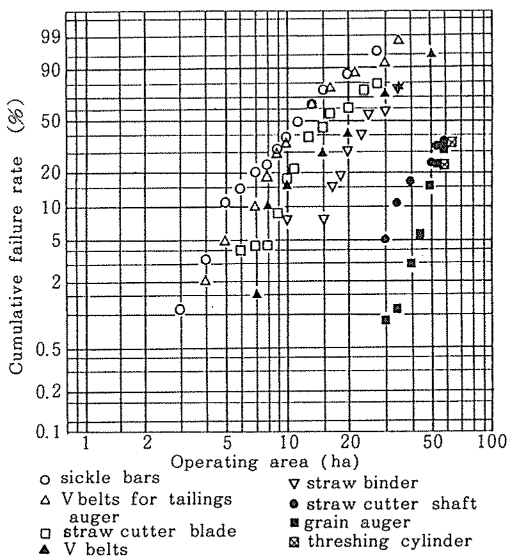

Fig. 3 Cumulative failure rate of miscellaneous parts of the combine.

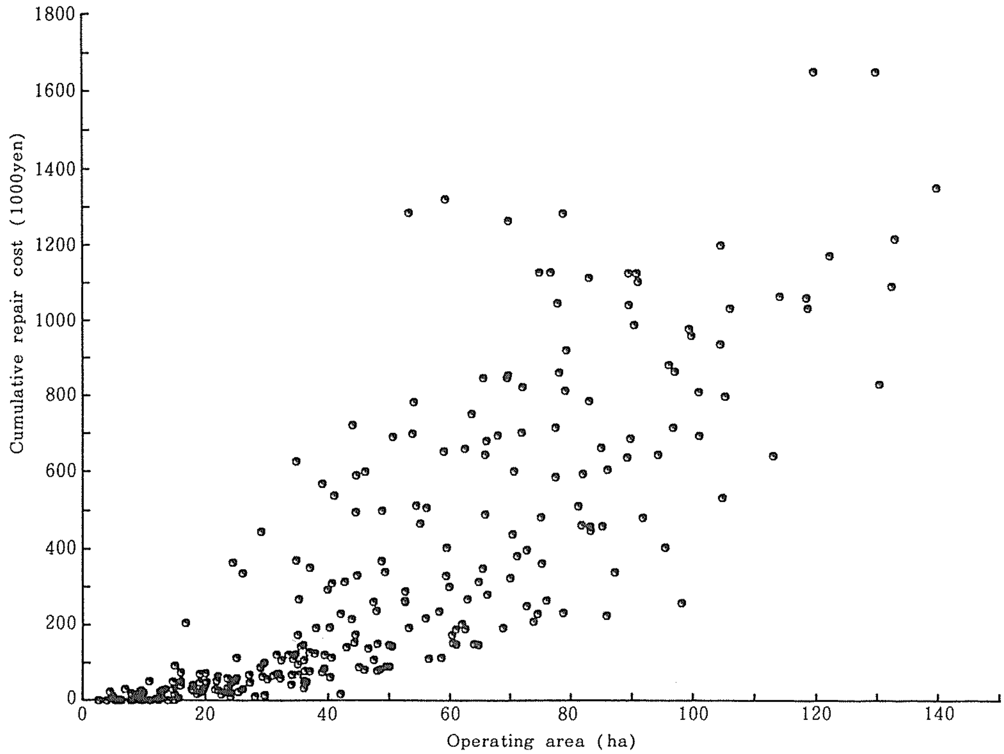

Fig. 4 Cumulative repair cost of each combine as a function of operating area.

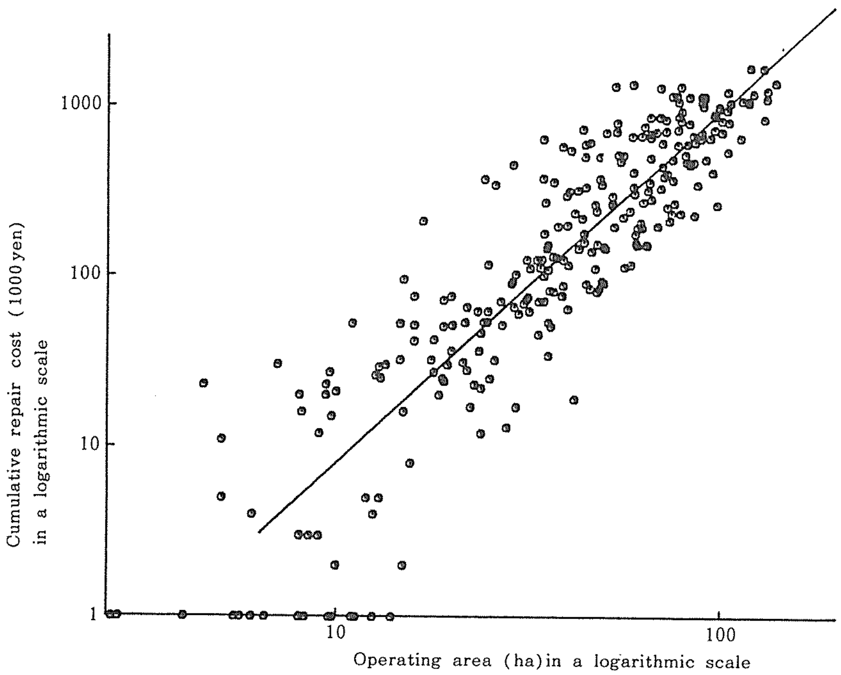

Fig. 5 Cumulative repair cost of each combine as a function of operating area in a log-log. graph.

Table 1 Scale of the repair or maintenance derived from annual cost on each combine.

No.	1974	1975	1976	1977	1978	1979	1980	1981	1982
1	----	----				V	V	V	
2	----	----			V		V	V	$\overline{V}$
3	----	V	V	$\overline{V}$		V		V	V
4	----	----	----		V	V	V	V	V
5	----	V	V	V	V	X	V	$\overline{V}$	V
6	----	V	V	V	V	X	XXX	V	$\overline{V}$
7	----	----		V	V	V	$\overline{V}$	V	XXXX
8		V	V	V	XX	XX	$\overline{V}$	XXXXX	V
9	----	V	V	V	$\overline{V}$	V	V	$\overline{V}$	V
10	----		$\overline{V}$	XX	$\overline{V}$	XX	$\overline{V}$	Scr	Scr
11	----	----	V	V	XXX	V	V	V	V
12	----	----	V	V	V	V	V	V	XX
13	----		V	V	XX	XX	XX	XXXX	
14	----		V	V	X	V	XXXX	$\overline{V}$	V
15	----	V	V	V	XXX	$\overline{V}$	V	XXXXX	V
16		V	V	V	$\overline{V}$	$\overline{V}$	$\overline{V}$	XXXXX	XX
17	----	V	V	V	$\overline{V}$	$\overline{V}$	$\overline{V}$	V	XX
18	----	----	V	V	V	V	$\overline{V}$	$\overline{V}$	XXX
19	----	----	V	V	X	$\overline{V}$	XXX	X	XX
20	----	----	V	V	XX	X	XXX	$\overline{V}$	V
21		V	V	V	V	X	XX	$\overline{V}$	XX
22	----	----	V	V	XXX	V	XX	XX	$\overline{V}$
23	----	V	V	V	V	V	XX	$\overline{V}$	V
24		V	V	V	$\overline{V}$	XX	$\overline{V}$	X	$\overline{V}$
25	----	V	V	V	V	$\overline{V}$	$\overline{V}$	V	$\overline{V}$
26	----		V	V	X	X	XXXX	$\overline{V}$	$\overline{V}$
27	----	V	V	V	V	X	$\overline{V}$	XXXX	XX
28	----	V	V	V	$\overline{V}$	$\overline{V}$	$\overline{V}$	X	$\overline{V}$
29	----		V	$\overline{V}$	XXXX	X	$\overline{V}$	XX	$\overline{V}$
30	----	V	V	V	V	XXX	XXX	V	XXXX
31	V	V	V	V	$\overline{V}$	XXXXX	$\overline{V}$	X	XXXXXS
32	V	V	V	$\overline{V}$	$\overline{V}$	V	X	XX	X
33	V	V	$\overline{V}$	X	$\overline{V}$	XXXXX	XX	XX	V
34		V	$\overline{V}$	$\overline{V}$	$\overline{V}$	XXX	XX	XX	X
35		V	$\overline{V}$	V	$\overline{V}$	X	X	XXXXX	V

---- : before introduction of the combine
empty column : no repair
V : less than 50 thousand yen
$\overline{V}$: 50- 99 thousand yen
X : 100-199 thousand yen
XX : 200-299 thousand yen
XXX : 300-399 thousand yen
XXXX : 400-499 thousand yen
XXXXX : 500 thousand yen or more
S or Scr : scrapped

caused early stage failure, at less than 20(ha).

Repair Cost

As shown in Fig. 4, cumulative repair cost, which includes service charge, preventive maintenance and repair of breaks, is expressed as a function of harvesting area. The relationship is expressed by a straight line in log-log. graph, as given in Fig. 5. The grade of the curve was 1.95, or nearly 2. So the curve in Fig. 4 was approximated as a quadratic polynomial function of operating area. The information is scatteringly plotted, especially at the points of 60−80(ha), the difference is 5 or 6 times the minimum. The big difference was mainly a result of the way of keeping, using, and maintenance.

Annual repair scale or cost of each combine is shown in Table 1. For 2 or 3 years at the beginning, they required little cost, but after that they occasionally needed high cost repairs or heavy maintenance. Generally, 2.5 % of the combines required over 500 thousand yen per year for maintenance and repair, 8.7 % required over 300 thousand yen, 17.8 % required over 200 thousand yen, 25.0 % required over 100 thousand yen, and 44.2 % of them exceeded 50 thousand yen. Every year, 60 % of the farmers paid 50 thousand yen for preventive maintenance and 10 thousand yen for repair after breakdown.

Energy Cost

Let us figure how much energy is needed to increase durability. Energy intensity on the purchase price in 1978 was abstracted as follows from Energy Intensity Figures[3] based on the 1975 Input-Output Tables and the 1965−1970−1975 Link Input-Output Tables prepared by Ministry of International Trade & Industry, Japan. Energy intensity of hot rolled steel (ordinary steel) was 82.8 kcal/yen, hot rolled steel (special steel) was 85.9 kcal/yen, forged steel was 95.3 kcal/yen, and cast and forged materials for machinery (iron) was 56.5 kcal/yen. Unit price of steel was 45 yen/kgf in case of ordinary steel and 107 yen/kgf for special steel. So energy intensity per physical unit of ordinary steel was 3,730 kcal/kgf, and that of forged steel was 10,200 kcal/kgf. Energy intensity of prime mover or boiler was 17.2 kcal/yen, agricultural machinery was 13.0 kcal/yen, combine harvester was 20.7 kcal/yen (especially calculated), repair of a precision instrument was 11.2 kcal/yen, repair of aircraft was 11.6 kcal/yen, repair of a general machinery was 12.6 kcal/yen, repair of a motor vehicle was 14.8 kcal/yen, repair of a building was 21.0 kcal/yen. Energy intensity per physical unit of manual labor was 16,600 kcal/hour (Gross national energy product)/(The working hours)/(The total working force).

If weak parts of the machine are strengthened or replaced, use of a larger quantity or stronger materials which consume more energy in producing and processing is unavoidable. Using the data mentioned above, let us figure the energy needed to increase durability. If the maker changes the material weighing 100 kgf from ordinary steel to special steel, the maker must pay 0.647 million (kcal) more, which is calculated by multiplying the weight and difference of energy intensity.

If the combine increases 100 kgf in weight due to reinforcement of its durability, the energy requirement increases 1.93 million (kcal), which is counted by multiplying energy intensity, ratio of price to weight, and increased weight of machine (13.0 kcal/yen × 1,483 yen/kgf × 100kgf).

Repair of a machine at a cost of 200 thousand yen is not unusual and requires 3.34 million (kcal) in energy, multiplying energy intensity and repair cost (16.7 kcal/yen × 200 thousand yen). Supposing that the repair is in a busy farming season, operator, assistant and carrier must inactively wait for repair to be completed. This may take 3 hours or more. For this, more energy 0.20 million (kcal) is required (16,600 kcal × 4 person × 3 hours).

Clearly, strengthening parts or increasing their durability is more advantageous than increasing the frequency of repair services.

Timing of Renewal

Suitable timing of renewal can be presumed by using Fig. 6 and Fig. 4 inserted in the figure from the viewpoint of energy consumption. The line in Fig. 4 was drawn to correlate the points, which shows the increase in repair cost vs. operating area. Because the energy intensity of combine repair was calculated to be 16.7 kcal/yen, the energy consumption of repair and maintenance increased, as Fig. 5 shows. The purchase price of the combine was 3.01 million yen. So, the comparable energy consumption was 6230×10^4 (kcal), multiplying energy intensity and the price (20.7 kcal/yen$\times$3.01 million yen). Thereupon, as Fig. 6 shows, the total energy consumption is obtained as the sum of energy consumed in production, circulation, and utilization.

The total energy curve in this figure seems to increase rapidly at point C which is the contact point by straight line from the origin O. When the operating area exceeds this point, the total energy increases by a steeply rising gradient. So, this point is thought to be the maximum usable limit from the standpoint of energy economy. It is read at a little under 140(ha). Considering that the purchase price was subsidized at half this amount, the point is at about 125(ha).

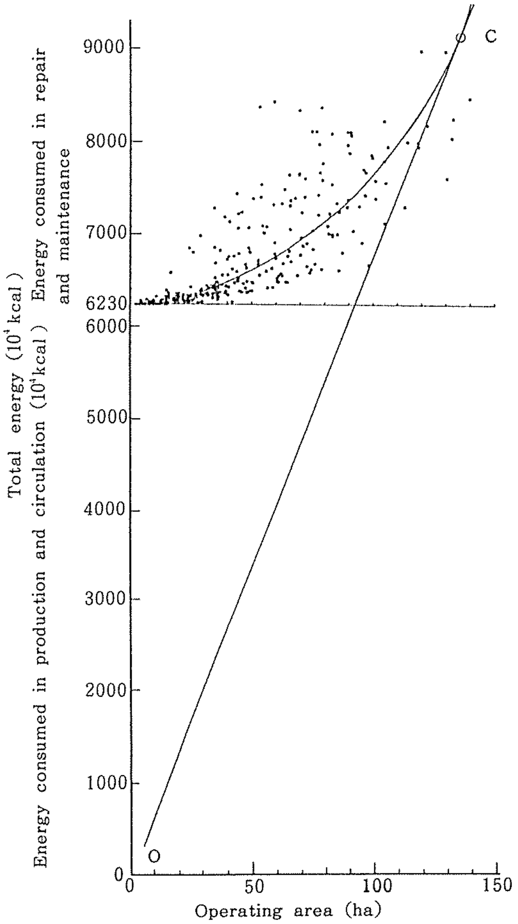

Fig. 6 Total energy consumed in production, circulation, and maintenance.

Anyway from the viewpoint of energy economy, the combine can be used until when the operating area come up to 125–140(ha), but that is conditioned upon nearly the same circumstances as this research.

References

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エネルギー消費の面からみた 自脱コンバインの耐久性について

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摘 要

自脱コンバインが開発され，広く利用されるようになっておよそ20年が経過し，収穫機械としても不動の地位を占めている．この研究は1970年代中頃から，コンバインの形態がほぼ定着した時点において稲麦収穫機として改善を要する点を見つけるために始めたもので，約7年を経過した．

佐賀地方で稼働している代表的な自脱コンバインのうちから一機種を選び，その35台について不具合を起こした部品や時期並びにそれまでの使用面積を調査した．総調査面積は35台で2976.4haにのぼった．

交換あるいは故障した部品について，一定時期ごとに故障率を算出し，その増加状態をワイブル確率紙上に描いた．寿命故障はVベルト，クローラ履帯，油圧装置，揚穀機などにみられた．

エネルギー消費の面からみて，耐久性の向上を目指すためには，部品の寸法や強度の増大及び材料の変更が，修理や整備の回数増よりも有利であることを実証した．

コンバインの製造，流通，使用の各段階で投入されるエネルギー消費量から自脱型コンバインの更新適期を推定できた．すなわちコンバインの使用実態を踏まえ，単位面積当りエネルギー消費曲線が急増する点を読みとって，コンバインの消費エネルギーの経済性からみた耐用限度は125～140haであると予想した．最近の水田転換政策に伴ない，水稲作，麦作ばかりでなく，雑穀類が増えたこともあってコンバインは多目的の収穫機械として，構造面も含め反省期に入ったとも考えられる．以上の意味からコンバインを見直す一資料になれば幸いである．

なお，本研究は文部省科学研究費のエネルギー特別研究として取りあげられた「農業におけるエネルギーの有効利用の研究（代表 木谷 収 東京大教授）」の一部をなし，3年間補助を受けた．記して謝意を表わす．