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REVIEW

Yield Monitoring System for a Head-Feeding Combine

Tadashi CHOSA[1]*, Yoichi SHIBATA[1,4], Kyo KOBAYASHI[1,5], Masamichi DAIKOKU[1,6], Masaaki OMINE[1], Kazunobu TORIYAMA[2,7], Kan ARAKI[3] and Hisashi HOSOKAWA[1]

[1] Department of Hokuriku Lowland Farming, Hokuriku Research Center, National Agricultural Research Center (Joetsu, Niigata 943–0193, Japan)
[2] Department of Hokuriku Farming System Research, Hokuriku Research Center, National Agricultural Research Center (Joetsu, Niigata 943–0193, Japan)
[3] Media Information Department, C’s Lab Co., Ltd. (Sapporo, Hokkaido 060–0807, Japan)

Abstract

This paper introduces a yield-monitoring system that was developed for a head-feeding combine. If yield variations could be measured during harvesting, data could be used to evaluate management history and provide useful information for planning fertilizer applications and management for the following year. First, we studied the yield-monitoring system and used a hybrid yield-monitoring method that involved an optical sensor and load cell. This monitoring method reduced the measurement error, and was useful in practical applications of site-specific crop management. We then assessed the gap between harvesting and yield-monitoring positions. Yield measured in the grain tank could be converted into yield at the harvesting position by correcting the measured yield with a constant that was determined by the relative position (weighted proportional distribution method) based on the experimental results. Finally, an efficient yield-monitoring system for a head-feeding combine was developed, incorporating our sensing and analyzing methods. It was possible to obtain yield data when normally operating a head-feeding combine that was equipped with our system. The resulting map was equivalent to a yield map generated through quadrate sampling. The estimated error of the system was about 10%.

Discipline: Agricultural machinery/ Information technology
Additional key words: paddy rice, precision agriculture, site-specific management, yield map

Introduction

Consolidation by joining several small fields to form a large tract of land to increase the efficiency of farm management has recently been carried out in Japanese rice production. However, there have been variations in fertility, growth, and yield in these large fields that have become serious problems. Moreover, it is possible for direct seeding and diversification in cropping style, which are supposed to be accelerated by increasing the size of paddy fields, to cause more variable yields within fields.

An understanding of yield variations within or between fields has been used to evaluate growth and management history, and this provides important information to determine site-specific management for the following year. Sites where lodging has been observed

Present address:
[4] Department of Food Production Science, Obihiro University of Agriculture and Veterinary Medicine (Obihiro, Hokkaido 080–8555, Japan)
[5] Department of Farm Mechanization and Engineering, National Agricultural Research Center (Tsukuba, Ibaraki 305–8666, Japan)
[6] Department of Hilly Land Agriculture, National Agricultural Research Center for Kinki Chugoku Shikoku Region, Shikoku Research Center (Zentsuji, Kagawa 765–0053, Japan)
[7] Development Research Division, Japan International Research Center for Agricultural Sciences (JIRCAS) (Tsukuba, Ibaraki 305–8686, Japan)
*Corresponding author: fax +81–25–524–8578; e-mail tchosa@affrc.go.jp
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should have reduced amounts of fertilizer applied and sites where yield has been low should have increased amounts of fertilizer.

We aimed to develop a yield monitoring combine to monitor yield at each site during harvesting. It does not require special operation as in monitoring fertility or crop growth. Although we can understand yield variations through routine farm work, the yield monitoring combine is expected to play an important role in establishing site-specific crop management and spreading related technology to farmers. This paper discusses the yield monitoring system we developed for a head-feeding combine.

Development of yield monitoring method for a head-feeding combine

1. Necessity for unique method for a head-feeding combine

Although combines with yield monitors installed as standard equipment and those that have them installed as an after-sales accessory are marketed throughout Europe and the U.S., they are still not sufficiently accurate[1,6]. Several examples have been reported where yield monitors, marketed in the U.S., on head-feeding combines have been installed. However, these are difficult to apply to a head-feeding combine directly[2] because the sensor and system have usually been designed for a conventional combine. The detecting signal (e.g., grain flow or change of mass in the grain tank) gets relatively smaller in a head-feeding combine. This is because the combine's operating width is narrower than that in a conventional combine, and kernels are continuously fed to the grain tank by the grain auger, while kernels are intermittently fed to the grain tank by a bucket conveyer in a conventional machine. Beside, the required accuracy of yield variations is different to that in Japan because of the difference in the grid size.

Consequently, to spread the use of yield monitoring combines throughout Japan, it is necessary to develop an original yield monitoring technique for a head-feeding combine. We therefore developed a yield monitoring method, i.e., a hybrid yield-monitoring system, for a head-feeding combine[3].

2. Sequence yield monitor and batch yield monitor

The optical sensor (Omron E3-SA) attached to the entrance of the grain tank (Fig. 1) consisted of a pair made up of an emitting and a receiving unit, which continuously measured the grain flow rate into the tank. The signal for the optical sensor was varied according to the particle flow rate between the emitting and receiving units (Fig. 2).

A load cell unit was fixed to the bottom of the grain tank (Fig. 1) because it is easy to attach a load cell to existing combines. We did not need to specially reconstruct the combine harvester itself. The load cell did not measure the total weight directly, but the change in vertical load as kernels filled the tank. We varied the signals for the tested load cell (Teac TL-PF12) according to the weight of unhulled rice discharged. The relationship was plotted on the same line even if the field and variety of rice differed (Fig. 3).

3. Hybrid yield-monitoring system

Although the signals for the optical sensor were varied according to the particle flow rate at the top of the grain auger, the regression equation was not stable because coarse particulates or dusty conditions changed as a result of operating conditions, such as field and grain moisture and mixing of weeds and mud due to lodging.

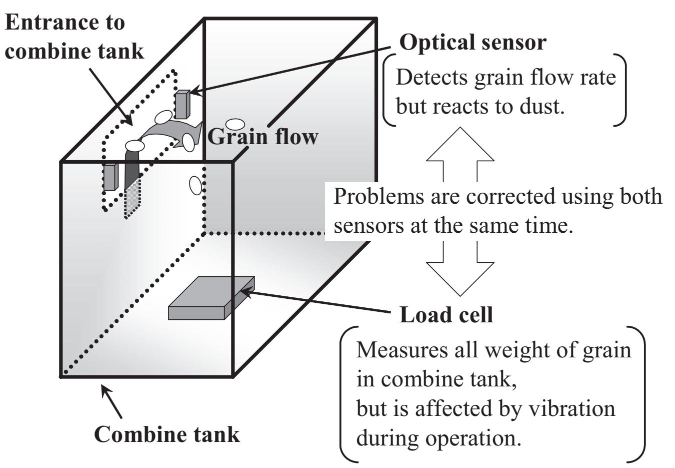

Fig. 1. Principle behind hybrid yield monitoring system using optical sensor and load cell

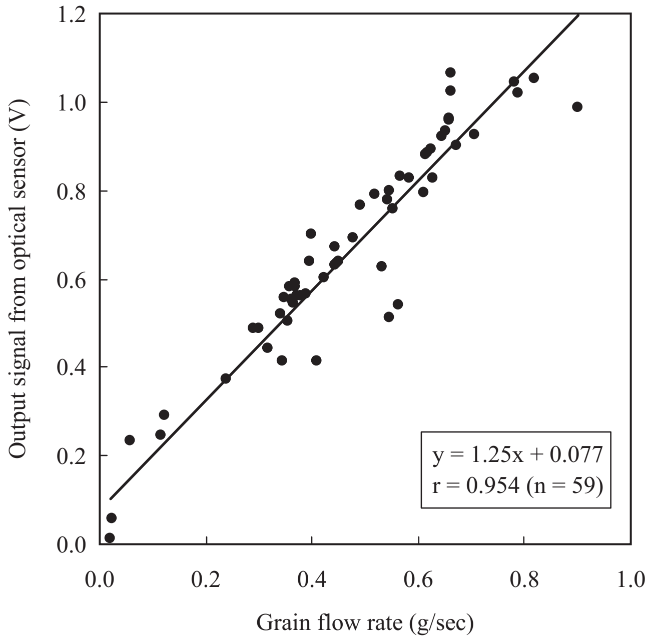

Fig. 2. The relationship between grain flow and output signal from optical sensor

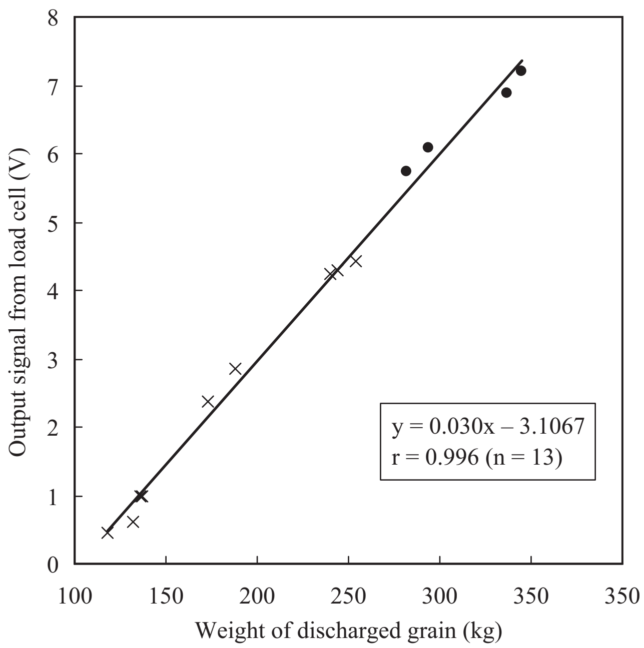

Fig. 3. Relationship between weight of discharged grain and output signal from load cell
● : Field 1 variety, kinuhikari,
× : Field 2 variety, dontokoi.

Because the load-cell signal varied according to the weight of discharged grain, we did not adopt it for the sequence yield monitor due to the effects of vibration. We consequently devised a hybrid yield-monitoring system, where the regression equation was calculated for each stroke. First, the batch yield monitor measured the

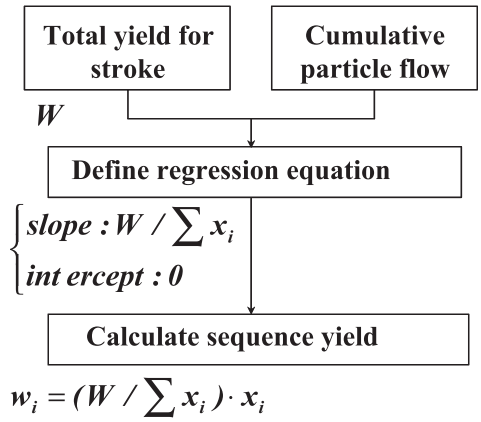

Fig. 4. Algorithm to determine calibration line by hybrid yield monitoring system

grain weight at each stroke. Then, accumulated variations in the particle flow sensor were calculated. Next, the regression equation was defined by comparing the total grain weight and the accumulated variations in the particle flow sensor. Finally, sequence yield variations were calculated using the regression equation (Eq. 1, Fig. 4):

$$w_i = (W / \sum x_i) \cdot x_i \qquad (1)$$

where w_i is the measured yield in position i, W is the sum of yield in a stroke, and x_i is the measured signal of the optical sensor in position i.

Analysis of gap between harvesting position and yield monitoring position

1. Problems caused by tailings return

By measuring the quantity of grain flowing into the grain tank of the combine, we found the harvesting position and measurement position for yield were not the same. This is because a time delay is introduced by conveying, threshing and sorting in a combine harvester. We need to point out that this becomes an error factor, which cannot be disregarded when drawing a yield map[1,6]. Therefore, it is necessary to rectify the gap between harvesting position and grain flow detecting position in drawing a yield map. The delay in time is due to four reasons. The first is the conveying time to the threshing unit after harvesting, the second is the threshing time, the third is the sorting and the time to eliminate rachis-branches, grains with rachis-branches and very light husks. The fourth is due to the length of time to convey the threshed grain to the grain tank as it is cleaned through the grain auger and tailings auger. Although the first, second, and fourth reason can be expressed as simple time delay, the third cannot. This is because it is based on tailings return and grain is circulated several times through the combine harvester. We clarified the gap between harvesting position and yield monitoring position caused by tailings return, using a weighted proportional distribution method that converts detected yield to yield from the harvesting position[4].

2. Gap between harvesting position and yield monitoring position

We cultivated a uniform area of "koshihikari" paddy rice for the field experiment, and a 10-m width of purple-grained "okunomurasaki" rice as a marker to evaluate harvesting (Fig. 5). All grain was collected every 10 m during usual harvesting. Purple-grained rice could easily be distinguished from general kernels after husking, because the husked surface was black. We clarified how the gap between the harvesting position and yield monitoring position occurred by continuously collecting harvested rice. Fig. 6 compares the detection rate for purple-grained rice due to the difference in speed. It plots the positions where purple-grained rice was detected, which was grown from 30 to 40 m. As harvesting speed increased, the positions where purple-grained rice was detected increased even more. Although the gap changed because of harvesting speed, purple-grained rice was detected more than 30 m from the harvesting position in some situations. The same tendency was confirmed in a platform experiment, which was conducted by supplying measured grain into the threshing unit of the combine harvester and monitoring grain flow into the grain tank.

3. Weighted proportional distribution method

Based on the above, we devised a method of converting measured yield at the grain tank into yield in the harvesting position in order to draw a yield map. Our concrete method of calculation distributed detected yield proportionally according to constant a_k, which expresses the gap between harvesting position and yield-monitoring position with the following formulas (Fig. 7).

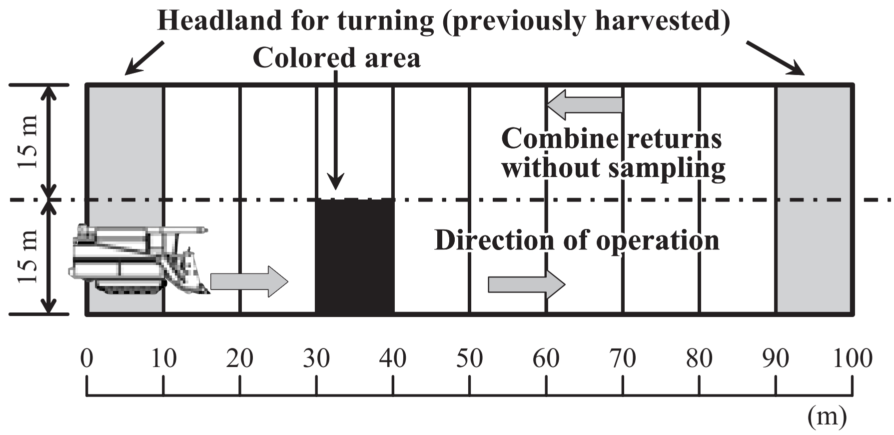

Fig. 5. Test field to analyze gap between harvesting position and yield monitoring position

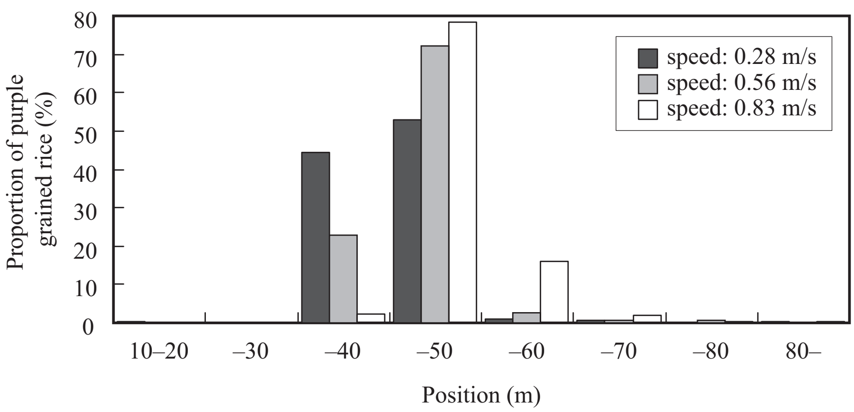

Fig. 6. Proportion of purple grained rice at each sampling location, comparing variations in speed

$$\begin{cases} y_1 = \dfrac{a_1 \cdot M_1}{a_1} + \dfrac{a_2 \cdot M_2}{a_1 + a_2} + \dfrac{a_3 \cdot M_3}{a_1 + a_2 + a_3} + \dfrac{a_4 \cdot M_4}{a_1 + a_2 + a_3 + a_4} + \ \cdots \\ y_2 = \dfrac{a_1 \cdot M_2}{a_1 + a_2} + \dfrac{a_2 \cdot M_3}{a_1 + a_2 + a_3} + \dfrac{a_3 \cdot M_4}{a_1 + a_2 + a_3 + a_4} + \dfrac{a_4 \cdot M_5}{a_1 + a_2 + \ldots + a_5} + \ \cdots \\ \quad \vdots \\ y_n = \dfrac{a_1 \cdot M_n}{a_1 + a_2 + \ldots + a_n} + \dfrac{a_2 \cdot M_{n+1}}{a_1 + a_2 + \ldots + a_{n+1}} + \dfrac{a_3 \cdot M_{n+2}}{a_1 + a_2 + \ldots + a_{n+2}} + \ \cdots \end{cases} \quad (2)$$

$$y_n = \sum_{i=1} \left(a_i \cdot M_{n+i-1} \Big/ \sum_{k=1}^{n+i-1} a_k \right) \quad (3)$$

where M_n is detected yield at the n-th grid, y_n is harvested yield at the same grid, and a_k is the distribution constant of the grid of the k-th relative position from harvesting. The values of constants a_k were determined through the field and platform experiments.

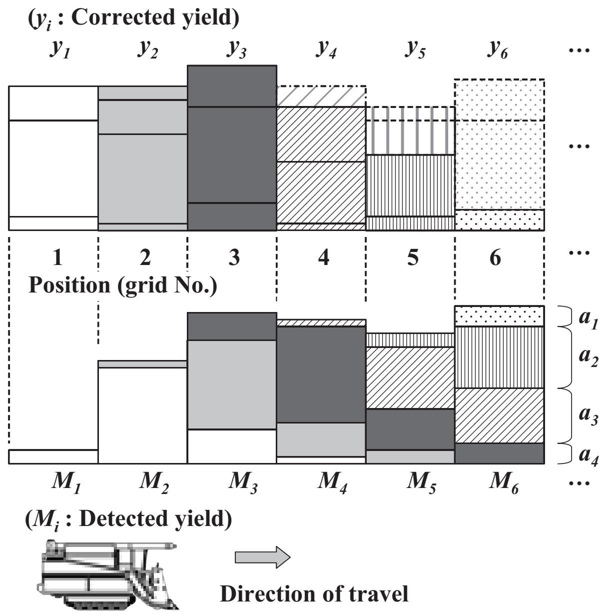

Fig. 7. Outline of weighted proportional distribution method

Systemization of data acquisition, analysis and mapping

1. Development of yield monitoring system for a head-feeding combine

We developed a yield measurement system for a head-feeding combine harvester that included a hybrid yield monitoring system and weighted proportional distribution method[5] (Fig. 8).

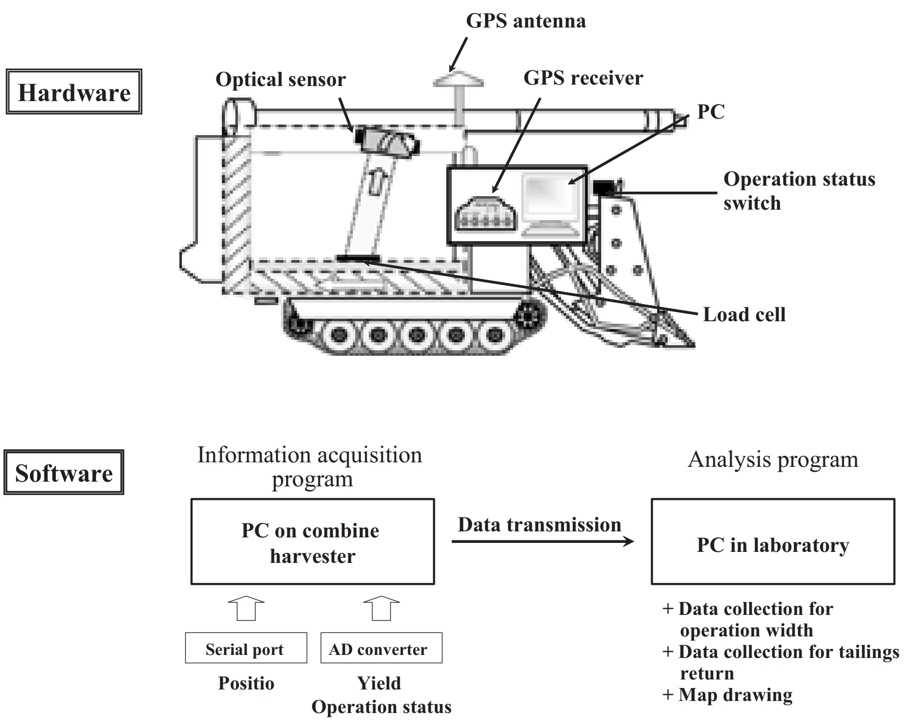

Fig. 8. Schematic of developed system

The hardware for the system we developed consisted of a paired optical sensor and load cell, a work state switch, a GPS (an antenna and receiver), a personal computer, and a power supply. The optical sensor measured grain flow rate during harvesting, the load cell measured the weight of grain within the combine tank when its state did not change, such as during revolutions and stoppages. Work status such as stoppages, revolutions, and harvesting were distinguished by an experimental operational status switch. Position information was acquired by GPS.

The software for the developed system consisted of an information acquisition program that extracted and equalized yield, position, and work state simultaneously during operation. An analysis program did various compensations by post-processing. The information acquisition program, which acquired position information through a serial port and analog signals through an AD translation card, worked on a personal computer. The analysis program also worked on a personal computer, and post-processed data obtained during work. A yield map was drawn by the analysis program after these processes had been done using collected data on tailings returns and operation width. Detected yield was converted to yield at the harvesting position following the weighted proportional distribution method. Operation width was calculated using the distance between each harvesting locus obtained from the GPS.

2. Evaluation of developed system

The system was embedded in a head-feeding combine (Yanmar CA355-GH, four-row harvesting, 27.5 kW (35 HP), tank capacity 850 L). The developed system was then evaluated through the usual operation of harvesting "koshihikari" rice.

Fig. 9 has yield maps, which were created by quadrate sampling and the developed system. Yield was taken to be the equivalent of rough rice, which disregarded the difference in moisture content. Both maps were drafted with linear interpolation between each grid. The tendency of variation in yield was the same in both maps. The results obtained from quadrate sampling were the average of the two investigation points (total area: 2.7 m^2) within each grid (10 × 10 m). The results from the developed system were the average value for the whole grid (100 m^2). Therefore, we could not compare the results. However, if they had been based on the results of quadrate sampling as the only actual measurement, yield measurement error in the developed system may have been less than 5% with about 50% probability, and less

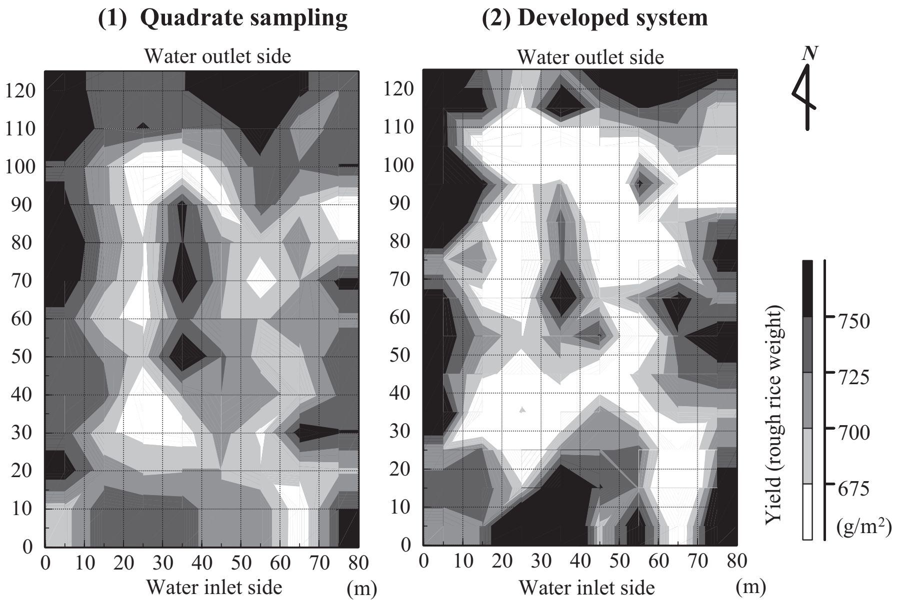

Fig. 9. Comparison of yield maps

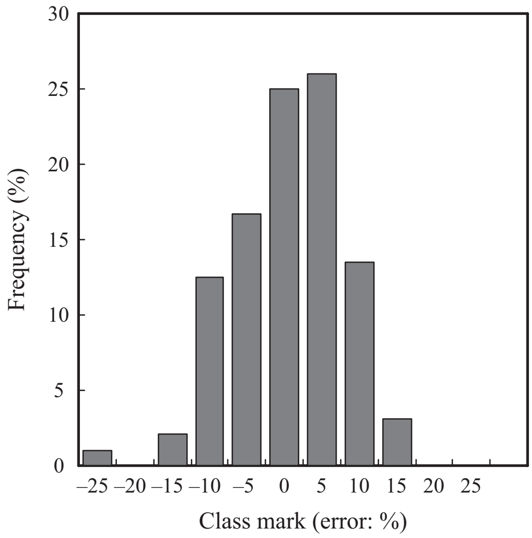

Fig. 10. Error distribution with developed system

than 10% with about 80% probability (Fig. 10).

When the average yield was assumed to be 600 g/m^2 (600 kg/10 a) based on rough rice weight, the measurement error ranging from 5 to 10% was equivalent to 30 to 60 g/m^2 (30 to 60 kg/10 a). This value was sufficiently accurate to understand yield variations, because those within fields that were previously reported[8] have been much bigger than that. Furthermore, when this error was converted into the amount of absorbed soil origin nitrogen, the estimated value was less than 1 g/m^2. Because this value was smaller than the annual change in nitrogen absorption in paddies[7], the accuracy of the developed system was also acceptable for carrying out site-specific management concerning local fertilization design.

Further studies to spread use of developed system

The system we developed was used in an area of more than 15 ha from 2001 to 2004 and achieved stable measurement. We next intend to establish not only a more accurate monitoring method but simplify the measuring apparatus to popularize the system.

Some researchers on precision agriculture in rice paddies have reported that it is possible to decrease yield variations and achieve consistently high quality through site-specific management following fertility and growth[9]. The role of a yield monitoring system for a head feeding combine would be more important when techniques of the precision agriculture and site specific management are discussed for really popularizing this farming system.

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