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# ADOPTION AND PRODUCTIVITY IMPACT OF MODERN RICE VARIETIES IN NEPAL

HARI K. UPADHYAYA
CRISTINA C. DAVID
GANESH B. THAPA
KEIJIRO OTSUKA

## I. INTRODUCTION

As in other Asian countries where the Green Revolution took place, the adoption of modern rice varieties (MVs) has increased considerably in Nepal since the early 1970s. At present, almost 40 per cent of rice crop area is planted to MVs. Yet, the yield growth in Nepal has been the lowest among Asian countries [3].

MVs have diverse characteristics. MVs developed by the International Rice Research Institute (IRRI type) since the mid-1960s are characterized by short stature, short growth duration, superior fertilizer responsiveness, and high yield. The yield potential of IRRI-type MVs, however, is constrained by the availability and timeliness of irrigation water [1]. In Nepal, only 23 per cent of total rice area is irrigated. Moreover, the inefficient operation and maintenance of existing irrigation systems have led to unstable supply of irrigation water in many areas [16]. Therefore, the adoption rate of IRRI-type MVs is generally low even in irrigated areas. Much of the rain-fed rice areas, on the other hand, are either hilly or drought-prone lowland areas. Because of these adverse environmental conditions, the more popular MVs in Nepal are medium statured, longer growth duration, less fertilizer responsive, and lower-yielding modern varieties, such as *Mahsuri*.[1]

The purpose of this paper is to analyze the determinants of MV adoption and its effects on fertilizer use, rice yields, and cropping intensity. A unique feature of our analysis is the attempt to distinguish the determinants of adoption and impact of the two different types of MVs. This contrasts with the existing studies of MV technology adoption, which implicitly assume identical characteristics of MVs.[2] We demonstrate that the yield advantage of IRRI-type MVs over *Mahsuri*

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[1] In Nepal, *Mahsuri* is known as *"Masuli."*

[2] Exceptions are [7] and [10], which distinguish between first- and second-generation IRRI-type MVs. See Feder et al. [4] for a survey of the literature on the adoption of MVs in less developed countries.

is substantial in favorable areas, but insignificant in the poorly irrigated and moderately favorable rain-fed areas.

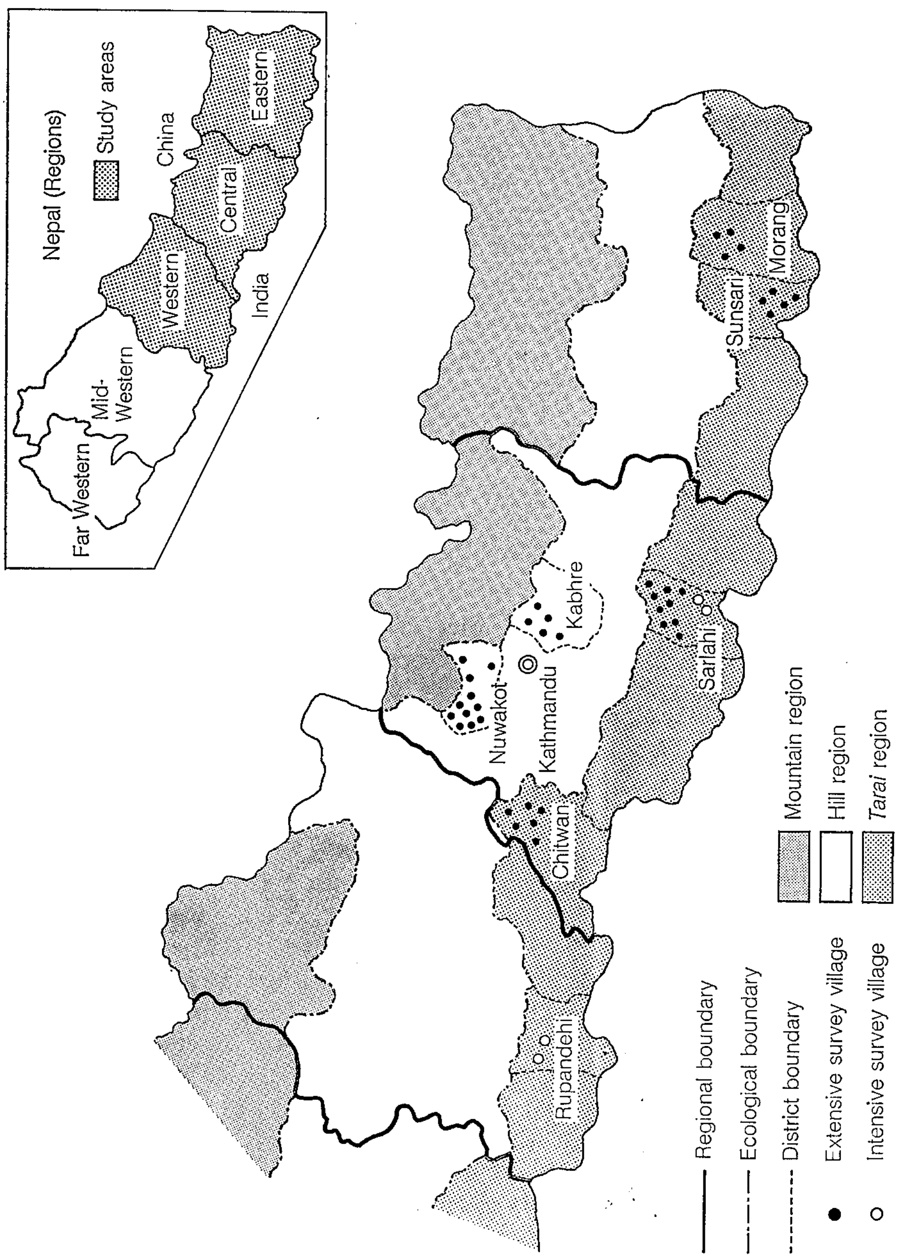
## II. SURVEY DESIGN AND SAMPLING PROCEDURE

In Nepal, the availability of official data on MV adoption is extremely limited. This study is based on surveys by Upadhyaya [15] and Thapa [13]. Upadhyaya conducted a survey of forty-two villages in the Central and Eastern regions which together account for nearly two-thirds of the paddy areas and rice production in the country (see Figure 1). The villages surveyed were selected from the two largest rice-growing *tarai* districts in the Eastern Region and the leading four rice-growing districts in the Central Region (two each in the hills and the *tarai* or lowland area, respectively). The *tarai* region of Nepal is the granary of the country owing to its flat, low-lying topography which is favorable for rice production. It accounts for about three-fourths of the rice-growing area and production of Nepal. In order to select the villages with representative production environments, Upadhyaya applied a stratified random sampling procedure based on the presence of irrigation using information obtained from district agricultural officers. Village-level data on characteristics of the production environment, technology adoption, farm size, tenure, rice and factor prices, yields, and cropping patterns for the 1987 wet season were then obtained by interviewing a group of knowledgeable farmers in each village.

Upadhyaya also conducted an intensive survey of farm households in two *tarai* villages in the Central Region, which were selected from his survey villages. These two villages are "typical" rain-fed and irrigated villages in the Central Region. On the other hand, Thapa conducted an intensive survey of farm households in two *tarai* villages in the Western Region, which are considered to be representative rain-fed and irrigated villages in this region. For our analysis of village-level data covering wide areas in this study, we combined the survey of forty-two villages by Upadhyaya and the intensive survey of two villages by Thapa. We called these forty-four villages the "extensive survey villages."

While village-level extensive data is useful to identify broadly the role of production environments in the adoption of MVs and the achievement of higher yields, they do not provide sufficiently accurate information on separate adoption rates of IRRI and non-IRRI varieties. Thus, we also examine technology adoption and yield data by variety collected through intensive surveys of farm households in four *tarai* villages with different environmental characteristics. The two villages each in the Central and Western regions, which are adjacent to each other, were deliberately chosen with a view to controlling for market and natural environment besides the presence of irrigation (see Figure 1 for their locations). In all these villages, after a census of all households, fifty-five sample households were randomly selected and interviewed using the same set of questionnaires.

Fig. 1. Location of Survey Villages



## III. MV ADOPTION AND PRODUCTIVITY IN EXTENSIVE SURVEY VILLAGES

For the purpose of descriptive analysis, the sample villages have been classified according to three environmental categories depending on the degree of water control. Irrigated villages are those where the majority of paddy area is served by a run-off-the-river gravity irrigation system, managed either by a government agency or by farmers themselves. Favorable rain-fed villages are in the lowland areas which are basically rain-fed (except a small proportion that is irrigated by shallow tube wells or natural springs) and not prone to severe drought throughout the crop season. Unfavorable rain-fed villages are generally located in sloped areas where farmers reported frequent droughts resulting in significant yield losses.

The socioeconomic and production characteristics of the sample villages classified by production environment are presented in Table I. The average farm size is similar between the irrigated and favorable rain-fed villages, but smaller in the unfavorable rain-fed villages. The average size of a rice farm also follows the same pattern as average farm size. The proportion of owner-cultivators is lower in the irrigated villages but similar in the two categories of the rain-fed village.

Nearly two-thirds of paddy areas were actually irrigated in the irrigated villages. Only a small proportion was irrigated in the favorable rain-fed villages, while irrigation facilities were almost nonexistent in the unfavorable rain-fed villages. As expected, the proportion of rice area planted to MVs followed the same pattern as the ratio of irrigated rice area, suggesting a strong positive relation of MV adoption to irrigation. However, about half of the rice area in favorable rain-fed villages was planted to MVs. In the unfavorable rain-fed villages, the rate of MV adoption was very low.

The most widely planted modern variety was *Mahsuri,* which was developed in Malaysia in 1965 [8] and introduced to Nepal in 1973. Compared with modern high-yielding varieties originally bred at IRRI, *Mahsuri* is medium-statured, less responsive to chemical fertilizer application, and lower-yielding under favorable production environments. Accordingly its yield advantage over traditional varieties (TVs) is relatively small compared with IRRI-type MVs under such environmental conditions. However, *Mahsuri* has more stable yields under moderately adverse environmental conditions, which largely explains the sustained popularity of *Mahsuri* in Nepal, particularly under rain-fed conditions.[3]

The village-level survey, however, failed to obtain reliable data on the proportion of area planted to IRRI versus non-IRRI (predominantly *Mahsuri*) type of MVs because of changing proportions of planted area to these varieties from year to year. However, it was possible to identify the villages which adopted only non-

[3] Another major advantage of *Mahsuri* over IRRI varieties is that due to its late-maturing characteristic it can avoid infestation by the Gandhi bug, which is a serious pest in rice growing causing significant yield loss. This is because the heading in *Mahsuri* starts at the time when the pest infestation has already declined, whereas the shorter growth duration IRRI-type varieties usually suffer from heavier infestation.

TABLE I

SOCIOECONOMIC, TECHNOLOGICAL, AND RICE PRODUCTIVITY INDICATORS ACCORDING TO PRODUCTION ENVIRONMENT BASED ON EXTENSIVE VILLAGE SURVEYS, NEPAL, 1987 WET SEASON

| | Irrigated | Favorable Rain-fed | Unfavorable Rain-fed |
|---|---|---|---|
| Number of villages | 23 | 12 | 9 |
| Farm size (ha) | 1.7 | 1.6 | 1.0 |
| Rice farm size (ha) | 1.3 | 1.1 | 0.6 |
| Percentage of owner-cultivators among farm households | 58 | 80 | 81 |
| Irrigation (%, area) | 65 | 13 | 1 |
| MV adoption (%, area) | 74 | 53 | 7 |
| MV adoption (%, villages) | 100 | 90 | 33 |
| IRRI- and non-IRRI-type MVs | 27 | 24 | 0 |
| Non-IRRI-type MVs only | 73 | 70 | 33 |
| Fertilizer use (N, kg/ha) | 22 | 14 | 8 |
| Average paddy yield (ton/ha): | | | |
| IRRI- and non-IRRI-type MVs[a] | 4.1 | 2.9 | — |
| Non-IRRI-type MVs only[b] | 3.2 | 2.7 | 2.8 |
| TVs[c] | 2.0 | 1.8 | 1.6 |
| Total cropping intensity (%) | 217 | 188 | 193 |

[a] Average yield of MVs in villages planting both IRRI- and non-IRRI-type MVs.
[b] Average yield of MVs in villages planting only non-IRRI-type MVs.
[c] Average yield in villages planting only TVs.

IRRI-type MVs and both two types of MVs. Invariably, non-IRRI-type MVs also existed in villages where IRRI-type MVs were adopted. An interesting pattern can be observed if we compare the proportion of sample villages across all three production environments adopting IRRI-type MVs. About one-fourth of irrigated villages adopted IRRI-type MVs, while the proportion of favorable rain-fed villages adopting IRRI-type MVs was slightly less. None of the unfavorable rain-fed villages adopted IRRI-type MVs. Though inaccurate, the ratio of IRRI-type MV adoption area is estimated to be generally higher in irrigated villages. In contrast, non-IRRI-type MVs were observed to be adopted more widely across all three production environments. Apparently, the adoption of IRRI varieties is more strongly constrained by the degree of water control than is the adoption of non-IRRI varieties.

The application of chemical fertilizer should have increased with the adoption of MVs, since MVs, particularly the IRRI type, are characterized by higher yield response to fertilizer application. Moreover, lower production risks in more favorable areas will also affect farmers' incentive to invest in fertilizer and other inputs. It is, therefore, not surprising to find that fertilizer use per hectare, as measured by nitrogen application, was higher in the irrigated areas where the adoption of MVs, including the IRRI type, was higher and yields more stable. The use of chemical fertilizers was largely limited to the portion planted to MVs in favorable rain-fed areas. Similarly, the application of fertilizer in unfavorable rain-fed areas was limited to areas where *Mahsuri* varieties were planted, particularly in the hill regions.

The choices of IRRI- or non-IRRI-type varieties combined with fertilizer use per hectare across all three production environments resulted in the differences in productivity, as reflected in the differential yield per hectare. Since the separate estimates of yields of IRRI- and non-IRRI-type MVs were difficult to obtain in those villages where both types of MVs were planted, we have included in Table I the average yield data for villages planting both types of MVs and those planting only non-IRRI-type MVs.[4] The yield difference between irrigated and favorable rain-fed villages adopting IRRI varieties is significant. In contrast, the yield difference across all three environments adopting only non-IRRI-type MVs is quite small. It seems clear that the yields of IRRI-type MVs are significantly higher than those of non-IRRI-type MVs only in irrigated environments. This suggests that IRRI varieties, in general, have higher yield potential than non-IRRI-type MVs; but unlike non-IRRI-type MVs, their performance significantly decreases as the degree of water control declines. The yields of TVs are lowest and largely similar across all three production environments.

As expected, the total cropping intensity is higher in the irrigated villages than in both categories of rain-fed villages. In Nepal, rice is a major crop only during the wet season; other crops such as wheat and lentil, which do not require as much irrigation water as rice, are grown during the dry season. The higher cropping intensity in irrigated areas is explained mostly by the availability of irrigation water during the dry season. IRRI-type MVs, however, are characterized by shorter growth duration than *Mahsuri* and even more so than TVs. As Barker and Herdt [1] emphasize, the adopiton of MVs, particularly those of the IRRI type, may also contribute to an increased cropping intensity of non-rice crops.

## IV. DETERMINANTS OF MV ADOPTION, FERTILIZER USE, PADDY YIELDS, AND CROPPING INTENSITY IN NEPALESE VILLAGES

Having discussed briefly the socioeconomic and technological characteristics of "extensive survey villages," we will present estimations of MV adoption, fertilizer use, paddy yield, and cropping intensity functions. Previous MV adoption studies in Nepal have identified several socioeconomic and institutional factors affecting a farmer's decision to adopt MVs such as education, exposure to extension, tenure, and availability of institutional credit [5] [11]. Following the previous studies of MV adoption in Nepal as well as in other countries, we constructed a reduced-form MV adoption function, while specifying as independent variables those exogenous variables possibly affecting the rational choice of varieties by rice-

[4] At present the adoption rates of new rice varieties have reached the "ceiling" (i.e., the long-run equilibrium level) in the sense of Griliches [6]. Thus, various types of varieties coexist within a village largely because their yield levels are not significantly different. This seems to be particularly true in the case of rain-fed areas.

growing farmers, such as the percentage of irrigated rice area, farm size, proportion of owner-cultivators, distance from the nearest commercial center, and a *tarai* dummy. Both farm size and owner-cultivator proportion variables are supposed to account for better accessibility by larger owner-cultivators to technology information and institutional credit.[5] The *tarai* dummy is included to control for other socioeconomic and physical environmental factors, such as topography, which are not captured by the percentage of irrigated area variable. The price of fertilizer was not included as an explanatory variable because fertilizer prices were uniform, since they were controlled and the cost of transportation was subsidized by the government. Similarly, paddy price was excluded because paddy prices were noticeably different only between the hill region and the *tarai* region, a fact that would be accounted for by the *tarai* dummy. Since the percentage of rice area planted to MVs is zero in some sample villages, we used the Tobit regression method, which is most appropriate to deal with truncated data such as ours. The linear specification is adopted because most variables are percentage and dummy variables. The estimation results are presented in Table II.

None of the factors, except irrigation, is significant in the MV adoption function. These results are consistent with accumulated evidence that environmental factors, particularly irrigation conditions, are the major factors affecting regional differences in MV adoption rates and that neither tenure nor farm size significantly affects MV adoption [12].[6] The estimated coefficient of the irrigation variable suggests that the rate of MV adoption in a completely irrigated village is approximately 80 percentage points higher than in a completely rain-fed village.

Because of this strong effect of irrigation on MV adoption, it is difficult to isolate the effects of these variables on fertilizer use, paddy yields, and cropping intensities. Furthermore, MV adoption is endogenous in our framework and, hence, should not be used directly as an independent variable in other functions. Ideally, simultaneous regression techniques should be applied. As in other village studies, however, such a procedure is inapplicable to our case because of the lack of appropriate exogenous variables which affect MV adoption, but not paddy yields, fertilizer use, or cropping intensity. In this study we included two dummy variables representing the adoption of two types of MVs as explanatory variables, i.e., villages where both IRRI- and non-IRRI-type MVs were planted, and villages where only non-IRRI-type MVs were planted, with villages where only TVs were planted as the control variable. Strictly speaking, these variables are endogenous since they are presumably affected by the favorable physical environments, among other things. Thus, an implicit assumption here is that these dummy variables capture not only the "pure" effects of improved varieties, but also the effects of exogenous environmental factors on the choice of varieties unaccounted for by the percentage of irrigation variable. Since fertilizer and paddy prices did not vary across our sample villages, prices do not appear as explanatory variables in

[5] As in other developing countries, larger owner-cultivators in Nepal are shown to have better access to cheap credit from institutional sources [18].

[6] Essentially the same qualitative results have been obtained by a recent MV adoption study in the Philippines by David and Otsuka [2], which is also based on village-level information.

TABLE II

ESTIMATION RESULTS OF MV ADOPTION, FERTILIZER USE, PADDY YIELD, AND TOTAL CROPPING INTENSITY FUNCTIONS BASED ON THE EXTENSIVE VILLAGE SURVEY, NEPAL, 1987 WET SEASON

| | MV[a] | Fertilizer[a] | Paddy Yield | Total Cropping Intensity |
|---|---|---|---|---|
| Irrigation percentage | 0.79** | 11.86 | 1.01* | 0.50** |
| | (4.01) | (0.63) | (2.15) | (2.91) |
| Farm size | 0.01 | 0.82 | −0.06 | −0.03 |
| | (1.6) | (0.31) | (−0.62) | (−0.96) |
| Percentage of owner-cultivators | 0.38 | 12.28 | 0.17 | 0.25 |
| | (1.45) | (0.57) | (0.41) | (1.62) |
| Distance | 0.01 | 0.19 | −0.01 | 0.00 |
| | (0.48) | (0.13) | (−0.57) | (0.40) |
| *Tarai* dummy | 0.13 | −6.33 | 0.06 | 0.00 |
| | (1.13) | (−0.77) | (0.23) | (0.02) |
| IRRI- and non-IRRI-type MV dummy | — | 52.80** | 1.52** | 0.06 |
| | | (3.78) | (3.40) | (0.35) |
| Non-IRRI-type MV dummy | — | 41.17** | 0.64* | 0.04 |
| | | (3.59) | (1.94) | (0.31) |
| Intercept | −0.15 | −26.08 | 1.42** | 1.68** |
| | (−0.64) | (−0.92) | (2.75) | (8.83) |
| $R^2$ | — | — | 0.60 | 0.31 |
| (Log-likelihood) | (−1011) | (−166.93) | — | — |
| $F$-value | — | — | 7.74 | 2.30 |
| (Chi-square) | (24.86) | (17.14) | — | — |

Note: $t$-values are in parentheses. ** and * indicate significance at the 1 per cent and 5 per cent levels, respectively.

[a] Tobit regression.

the fertilizer use function. Given that a number of villages did not apply chemical fertilizers on their rice crops, we used the linear rather than log-linear specification to avoid possible sample bias caused by the omission of observations with zero fertilizer application, and employed the Tobit regression method.

Only the MV dummy variables are significant in the fertilizer use function. Yield response of MVs to fertilizer application is higher than that of TVs, so that it becomes more profitable to use larger doses of fertilizer on MV than on TV rice. The estimated coefficients of the two MV variables suggest that villages growing both IRRI- and non-IRRI-type MVs apply larger doses of fertilizer than those growing non-IRRI-type MVs only, even though the difference between the two coefficients is not statistically significant. It should be emphasized that the coefficients of these variables are expected to capture not only the effects of the type of MVs, but also the effects of the environmental factors. In fact, the estimated coefficient of irrigation percentage is not significant, presumably because the MV variables capture the impact of irrigation on fertilizer use.

Again, the two types of MV dummy variable are significant in the paddy yield function estimated by ordinary least squares method. Paddy yields in villages growing both types of MVs are higher than in those growing TVs by about 1.5 tons per hectare, as implied by the estimated coefficient of the IRRI-type MV dummy. The coefficient of the non-IRRI-type MV dummy is only 0.64, which is significantly smaller than the coefficient of the IRRI-type MV dummy. As expected, irrigation also contributes positively to yield. In a completely irrigated village, the average paddy yield is higher by about 1 ton per hectare compared to a completely rain-fed village, regardless of the type of rice variety grown. These results clearly suggest a higher yield potential of IRRI varieties than non-IRRI varieties or TVs, and a positive yield effect of irrigated production environments. Farm size, tenure, and distance variables do not show any effect on intervillage differences in yield levels.

Intervillage differences in total cropping intensities expressed as ratios are explained significantly only by irrigation. The presence of irrigation allows farmers to grow non-rice crops during the dry season when rainfall is inadequate to meet water requirements. The estimated coefficient suggests that the development of irrigation in a rain-fed village can increase the total cropping intensity by 50 percentage points, meaning that about a half of the cultivated area of the village can be planted to an additional crop. While it was expected that the adoption of short-maturing IRRI varieties may enable farmers to grow more crops per year, we did not obtain a significant coefficient of the corresponding village dummy, though the estimated coefficients are positive.[7] This may be partly because the ratio of rice area planted to IRRI varieties is yet quite small to cause any significant increase in total cropping intensities, and partly because the availability of irrigation water is, in general, too limited to grow additional crops even in favorable areas adopting IRRI-type MVs.

Major findings in this section indicate that a lack of irrigation constrains the adoption of MVs in general and IRRI-type MVs in particular, because the yield advantages of IRRI-type MVs over non-IRRI-type MVs and TVs are positively associated with more favorable production environments. Since the extensive village survey did not provide accurate information on the proportion of paddy area planted to IRRI-type MVs, intensive farm household survey data of four *tarai* villages representing different production environments have been used to supplement the above analysis.

## V. DETERMINANTS OF MV ADOPTION, FERTILIZER USE, AND PADDY YIELDS IN *TARAI* VILLAGES

Table III presents the socioeconomic and production characteristics of the four *tarai* villages covered by the intensive household survey. The two villages in the Western Region are designated as WR1 and WR2, and the two villages in the

[7] It is important to note that the percentage of total cropped areas planted to rice during the wet season is significantly higher in irrigated villages and in rain-fed villages growing IRRI-type MVs.

TABLE III

SOCIOECONOMIC, TECHNOLOGY, AND RICE PRODUCTIVITY INDICATORS BASED ON INTENSIVE FARM HOUSEHOLD SURVEY OF FOUR TARAI VILLAGES, NEPAL, 1987 WET SEASON

| | Irrigated | | Favorable Rain-fed | Unfavorable Rain-fed |
|---|---|---|---|---|
| | (WR1) | (CR1) | (WR2) | (CR2) |
| Number of households | 55 | 55 | 55 | 55 |
| Farm size (ha) | 2.0 | 1.6 | 2.1 | 2.1 |
| Rice farm size (ha) | 2.0 | 1.6 | 2.0 | 1.3 |
| Percentage of share tenancy | 23 | 22 | 14 | 27 |
| Percentage of leaseholders | 22 | 27 | 4 | 20 |
| Irrigation (%, area) | 100 | 89 | 11 | 9 |
| MV adoption (%, area): | | | | |
| Total | 100 | 85 | 80 | 5 |
| IRRI-type MVs | 41 | 5 | 6 | 0 |
| Non-IRRI-type MVs | 59 | 80 | 74 | 5 |
| Average fertilizer use (N, kg/ha) | 30 | 15 | 9 | 8 |
| Paddy yield (ton/ha): | | | | |
| Average | 2.88 | 2.45 | 2.22 | 1.90 |
| IRRI-type MVs | 3.25 | 2.80 | 2.58 | — |
| Non-IRRI-type MVs | 2.55 | 2.40 | 2.31 | — |
| Traditional varieties | — | 2.12 | 1.80 | 1.90 |
| Total cropping intensity (%) | 203 | 193 | 170 | 196 |

Central Region as CR1 and CR2. As was mentioned earlier, we assume that these villages represent typical irrigated and rain-fed environments in the *tarai* region, where non-IRRI-type MVs were relatively prevalent and IRRI-type MVs were planted only in the favorable irrigated environments. Except for CR1, average farm size is similar across all four villages. The incidence of tenancy is generally high in the irrigated villages.

Although both WR1 and CR1 have gravity irrigation systems, the irrigation was more reliable and complete in WR1 than in CR1. As a result, MVs were fully adopted in WR1 during the wet season, while TVs were still prevalent in small pockets of rice areas in CR1. The adoption of MVs was found to be as high as 80 per cent even in favorable rain-fed village, WR2. Interestingly, however, the adoption of IRRI-bred MVs was limited to the fully irrigated part of WR2. The adoption of IRRI-type MVs was 41 per cent in WR1 compared to only 5 per cent in CR1.

Consistent with findings of the extensive survey analysis, the average fertilizer use and paddy yields were higher in the irrigated than in the rain-fed villages. Looking at the two irrigated villages, the average level of chemical fertilizer application and paddy yields were higher in WR1 due mainly to a higher rate of adoption of IRRI-type MVs corresponding to a more assured water supply in this village than in CR1. Note that the yield difference between IRRI- and non-IRRI-type varieties becomes smaller as the degree of water control declines; the per-

TABLE IV

DETERMINANTS OF MV ADOPTION BY TYPE OF VARIETY BASED ON THE INTENSIVE SURVEY OF TARAI VILLAGES, NEPAL, 1987 WET SEASON (TOBIT REGRESSION)

| | MV Adoption | |
|---|---|---|
| | IRRI Type | Non-IRRI Type |
| Farm size | 0.02 | −0.01 |
| | (1.15) | (−0.44) |
| Education | 0.12 | −0.01 |
| | (0.76) | (−0.27) |
| Fixed-rent tenancy dummy | −0.09 | −0.04 |
| | (−0.65) | (−0.63) |
| Share tenancy dummy | −0.06 | 0.01 |
| | (−0.37) | (0.13) |
| IRG×CENT | −0.05 | 1.16** |
| | (0.00) | (8.51) |
| IRG×WEST | 0.88** | −0.20** |
| | (5.44) | (−2.59) |
| WEST dummy | 1.51 | 1.27** |
| | (0.00) | (9.44) |
| Intercept | −2.23 | −0.41** |
| | (0.00) | (−3.94) |
| Log-likelihood | −49.04 | −65.11 |
| Chi-square | 125.76 | 162.83 |

Note: *t*-values are in parentheses. ** and * indicate significance at the 1 per cent and 5 per cent levels, respectively.

formance of IRRI varieties deteriorates considerably in less favorable environments, whereas the performance of non-IRRI-type varieties is more stable across production environments. Rice is grown only once per year in our survey villages, and non-rice crops tend to be grown more extensively in the well-irrigated village, WR1, as reflected in higher total cropping intensity.

We will now analyze statistically the factors affecting the adoption of IRRI- and non-IRRI-type MVs using the household-level intensive survey data. The estimation results of the MV adoption functions by type of variety are presented in Table IV. Since the quality of irrigation is different between the Western and Central regions, we specified two irrigation variables, i.e., interaction terms between the percentage of irrigated area and Western and Central Region dummies (IRG×WEST and IRG×CENT). We also included one regional dummy variable, WEST, which is expected to capture the effects of climatic and other regional differences. Rain-fed areas in the Central Region serve as a control. In this regression, we are able to include an education variable, which is defined as the proportion of family members between fifteen and sixty years old receiving more than three years of compulsory schooling, as one of the explanatory variables to account for a family's decision-making ability. The tenancy variable has been specified as two dummy variables to distinguish the effects of share tenancy and fixed-rent tenancy on technology adoption and productivity.[8]

The results show that, consistent with the extensive survey findings, environmental factors are the most important constraints to the adoption of MVs. The adoption of IRRI-type MVs in particular is constrained by the quality of irrigation, as suggested by the significant coefficient of only the IRG×WEST term in the IRRI-type MV adoption function. All of the environmental and regional dummy variables are significant in the non-IRRI MV adoption function. Unlike the adoption of IRRI-type MVs, the presence of irrigation in the Western Region reduced the adoption of non-IRRI-type MVs in favor of the IRRI type. The results also show that presence of irrigation is critically important for the adoption of non-IRRI-type MVs in the Central Region, but not so in the Western Region. The farm size, education, and tenancy variables do not significantly affect the level of MV adoption regardless of variety.

In order to identify the pure effects of varieties on fertilizer use, paddy yield, and cropping intensities, it is desirable to formulate simultaneous equation systems, while treating the IRRI- and non-IRRI-type MV adoption rates as endogenous variables. It is extremely difficult, however, to estimate such equation systems because of the absence of exogenous variables which significantly affect the choice of varieties, but not fertilizer use, yield, or cropping intensity. Theoretically, we expect that all the variables affecting the former would affect the latter. That is to say, MV adoption and other dependent variables should be considered as functions of the same set of exogenous variables ($x$). To illustrate, the relevant functions may be expressed as

$$MV_{\text{IRRI}} = \sum \alpha_i x_i + e_{\text{IRRI}}, \tag{1}$$

$$MV_{\text{Non-IRRI}} = \sum \beta_i x_i + e_{\text{Non-IRRI}}, \tag{2}$$

$$Y = \sum \gamma_i x_i + aMV_{\text{IRRI}} + bMV_{\text{Non-IRRI}} + e_Y, \tag{3}$$

where $MV_{\text{IRRI}}$ and $MV_{\text{Non-IRRI}}$ are adoption rates of IRRI-type MVs and non-IRRI-type MVs, respectively; $\alpha$, $\beta$, $\gamma$, $a$, and $b$ are regression parameters; $Y$ represents fertilizer use, paddy yield, or total cropping intensity; and $e$ is an error term. Because of the common exogenous variables, equation (3) is under-identified and, hence, it is not feasible to apply simultaneous equation estimation methods.

An alternative is the estimation of the reduced-form equations, which can be obtained by substituting equations (1) and (2) into equation (3). Although this approach is econometrically appropriate, this method does not enable us to distinguish the differential effects of IRRI- and non-IRRI-type MVs. In this study, we applied a two-stage regression procedure in which the predicted values of the adoption rates of the two types of MVs based on the regression results of the MV adoption functions (equations (1) and (2)) are used as independent

[8] Owing to the availability of reliable data on the incidence of share and leasehold tenancy, we used the two tenancy variables to test the possible inefficiency of share tenancy. See Otsuka et al. [9] for a recent review of the share tenancy literature.

TABLE V

ESTIMATION RESULTS OF FERTILIZER USE, PADDY YIELD, AND CROPPING INTENSITY FUNCTIONS, NEPAL, 1987 WET SEASON, INTENSIVE SURVEY

| | Fertilizer Use[a] (N, kg/ha) | Paddy Yield (Ton/ha) | Total Cropping Intensity (%) |
|---|---|---|---|
| Farm size | 0.31 | −0.04* | −0.03** |
| | (0.32) | (−2.31) | (−3.45) |
| Education | −3.59 | −0.05 | −0.01 |
| | (−0.95) | (−0.59) | (−0.43) |
| Fixed-rent tenancy dummy | 10.14 | 0.33** | 0.05 |
| | (1.75) | (2.81) | (0.78) |
| Share tenancy dummy | −6.96 | −0.12 | −0.01 |
| | (−1.51) | (−1.07) | (−0.19) |
| IRRI-type MVs | 45.60** | 0.97** | 0.38** |
| | (8.62) | (8.32) | (6.08) |
| Non-IRRI-type MVs | 10.63* | 0.44** | −0.06 |
| | (2.07) | (4.51) | (−1.23) |
| WEST dummy | −88.67** | −0.20** | −0.79** |
| | (−6.93) | (−7.73) | (−5.80) |
| Intercept | 100.72** | 4.44** | 2.82** |
| | (8.23) | (16.09) | (19.30) |
| $R^2$ | — | 0.34 | 0.21 |
| (Log-likelihood) | (−642.49) | — | — |
| $F$-value | — | 14.78 | 7.89 |
| (Chi-square) | (84.66) | — | — |

Note: $t$-values are in parentheses. ** and * indicate significance at the 1 per cent and 5 per cent levels, respectively.
[a] Tobit regression.

variables in the second-stage regressions. Due to the identification problem, however, the two irrigation variables (i.e., IRG×WEST, and IRG×CENT) are excluded in the second-stage regressions. That is to say, we estimated a variant of equation (3), in which predicted values of two MV adoption variables obtained from equations (1) and (2) and exogenous variables other than two irrigation variables are used as explanatory variables. In this specification, while the predicted values of MV adoption reflect the effects of irrigation as well as other variables, the direct effects of irrigation on fertilizer use, paddy yields, and cropping intensity are not taken into account. This implies that the estimated coefficients of the MV variables in the second-stage regressions will capture not only the effects of rice varieties but also the effects of irrigation.

It is quite interesting to note the differential effects of adopting the two types of MVs on fertilizer use, paddy yield, and cropping intensities (Table V). The Tobit regression for the fertilizer use function suggests that although the adoption of both types of MVs will cause an increased use of fertilizer, the IRRI-type MVs induce much higher levels of fertilizer use than the non-IRRI-type MVs, judging from the relative magnitudes of their coefficients. This is to be expected since IRRI-type MVs are more responsive to fertilizer application than non-IRRI-type MVs. Consistently, the yield regression also indicates that the yield advantage of IRRI-type MVs over TVs is much higher than that of non-IRRI-type MVs.

The share tenancy dummy has negative coefficients, but none of them are significant. The results also indicate that compared to owner-cultivators, fixed-rent tenants tend to apply more fertilizer and obtain higher yields per hectare. Theoretically, one may expect that because of the disincentive effects of output sharing on the application of inputs, share tenants apply less fertilizer and obtain lower yields than owner-cultivators and fixed-rent tenants.[9] There is, however, no a priori reason to assume that the behavior patterns of the latter two categories of farmers are different, since they are influenced by common undistorted incentives [9]. Therefore, it is likely that fixed-rent tenants obtain higher yields for reasons other than the difference in tenure *per se*.

Other things being the same, farmers in the Western Region apply smaller doses of fertilizer on rice, obtain lower yield levels, and grow fewer crops than in the Central Region. This may be due to less access to markets or less favorable climatic and other physical environments in the Western Region, but there is no way to identify precise factors affecting the regional differences in fertilizer use, yields, and cropping intensity in our analysis.

The differential effect of IRRI- and non-IRRI-type MVs on total cropping intensity is quite evident. Adoption of IRRI-type MVs seems to have increased the total cropping intensity considerably, meaning that it allows second non-rice crops to be grown.[10] This seems to imply that the combined effect of IRRI-type MVs and irrigation is conducive to multiple cropping. On the other hand, total cropping intensity is not significantly higher in environments where non-IRRI-type MVs are grown than in environments where TVs are grown. Larger-scale farmers cultivate their land less intensively than smaller farmers, as reflected in the significantly negative coefficient of the farm size variable in the total cropping intensity function.

The statistical evidence based on the intensive farm household survey substantiates findings obtained from the extensive survey analysis; the degree of water control is the critical factor affecting the adoption of new rice varieties across villages and across farms within a village. This is particularly true for the IRRI-bred semi-dwarf rice varieties, which are more responsive to fertilizer

9 According to a recent survey of the empirical literature by Otsuka et al. [9], share tenants tend to apply inputs and obtain yield as much as fixed-rent tenants and owner-cultivators. They argue that the probability that opportunistic behavior under share tenancy contracts will be detected is likely to be high and that the penalty on such behavior, once detected, would also be high in less developed agrarian economies where social interaction among members of social groups is intense.

10 This result is inconsistent with the earlier finding based on the extensive survey data. The inconsistency may be resolved, however, if we consider the fact that (1) we used only village dummy adopting IRRI-type MVs in the extensive survey analysis due to the unavailability of variety-specific adoption data and (2) WR1 is particularly well irrigated.

application and potentially higher yielding than other MVs. The adoption rate of such IRRI varieties in Nepal is generally low and concentrated in more favorable production environments, thus contributing to the widening productivity gap between favorable and unfavorable rice-growing areas. The relatively longer duration non-IRRI-type MVs are still more popular in less favorable production environments because their performance is more stable than the shorter duration IRRI varieties.

## VI. CONCLUDING REMARKS

In spite of a rising rate of MV adoption over time, increases in paddy yields in Nepal have not been as significant as in other countries of Asia. The most popular modern variety in Nepal is *Mahsuri,* which is relatively taller and less responsive to fertilizer application than MVs developed by IRRI. Thus yield gains over TVs are modest. Yet, *Mahsuri* is relatively more tolerant to drought and performs uniformly in a wider range of production environments than IRRI varieties, which explains its wide adoption in Nepal. Thus, our analysis indicates that both low irrigation level and the poor irrigation facilities have constrained the adoption of high-yielding MVs developed by IRRI.

There are two alternative strategies to improve the productivity performance of the rice-growing sector in Nepal. One is to develop higher-yielding varieties suitable for less favorable environments, which will eventually replace *Mahsuri.* Considering the overwhelming importance of less favorable environments in this country, a larger allocation of the country's research resources for such a research effort may be warranted. However, it must be recognized that the scientific knowledge to develop such varieties is limited, as evidenced by the efforts made by IRRI for the last three decades.

An alternative strategy is to invest in irrigation and research to develop varieties suitable to favorable production environments. Such a strategy is more promising on efficiency grounds, partly because MVs are by nature more suitable to favorable irrigated environments and partly because more low-cost and high pay-off irrigation projects can be implemented, particularly in the *tarai.* Yet such strategy may widen the unequal distribution of income between the favorable and unfavorable areas. According to a recent study by Upadhyaya et al. [17], however, the regional wage differential in Nepal has been significantly reduced by interregional migration from less favorable to favorable areas. Even if wage income can be largely equalized, an income gap may arise from increased returns to land. Thapa et al. [14] found based on the farm-level data in WR1 and WR2, however, that the income distribution between the landed and landless, or near landless, agrarian classes was not substantially worsened because of hired-labor-using effect of MV technology. In other words, benefits associated with MV adoption accrue not only to the wealthy landlords and owner-cultivators but also to the poor laborers and marginal farmers. Therefore, we may conclude that the strategy to develop higher-yielding MVs suitable for favorable areas can be strengthened for the sake of higher production efficiency in the rice-growing sector of Nepal without entailing larger social injustice.

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