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Farmers' perceptions of benefits and factors affecting the adoption of improved dual-purpose cowpea in the dry savannas of Nigeria

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Abstract

This study links participatory research methods, geographic information systems (GIS) techniques, village and household-level surveys, and a tobit analysis to examine the adoption and impact issues related to a new technology, improved varieties of dual-purpose cowpea (IDPC), developed by International Institute of Tropical Agriculture (IITA) and International Livestock Research Institute (ILRI) and recently released in Nigeria. The article analyzes factors affecting the adoption and impact of the technology across different socioeconomic domains as defined by degree of market access and population density. The results show multiple benefits from this flexible leguminous crop, many of which relate to the fodder and soil fertility-enhancing aspects of IDPC rather than higher grain yields *per se*. The intensity of adoption was affected by different village- and household-level factors in each socioeconomic domain, allowing more sharply defined recommendation domain-targeting strategies. The multiple research approaches taken also provided useful lessons at different system levels regarding the benefits of, and perceived problems with, this technology for researchers, development practitioners, and policy makers. The collaborative research approaches taken in this study are helping to close the "feedback loop" from farmers back to researchers and others attempting to disseminate the technology, and by doing so, should contribute to faster and more widespread uptake of this technology.

Keywords: Impact; Adoption; Cowpea; Food security; Tobit

1. Introduction

The leguminous crop cowpea (*Vigna unguiculata* [L.] Walp.) is viewed by many as an appropriate option for increasing food and feed production in the dry savannas (31–210 growing days) of West Africa for multiple reasons (summarized in Section 1.2). Dual-purpose cowpea (IDPC) varieties have been developed by International Institute of Tropical Agriculture (IITA) and International Livestock Research Institute (ILRI) that produce both more food as well as high quantities of nutritious fodder for livestock. Widespread uptake of these new varieties appears to have good potential to occur across the dry savanna region of West Africa. This study addresses factors influencing the adoption and impact of the new varieties.

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Participatory research approaches were combined with formal surveys of 80 communities and 462 households in northern Nigeria and recommendation domains were defined using geographical information systems (GIS). A tobit model was used to analyze household characteristics influencing the intensity of adoption of the new varieties. This assessment was undertaken to provide information for researchers and policy makers for research priority setting, technology targeting, and dissemination efforts.

1.1. The place of cowpea in evolving crop-livestock systems in West Africa

Cowpea, known as black-eyed peas in North America, is an important crop in West Africa. Ortiz (1998) reported that in the mid-1990s the cowpea production area of Nigeria and Niger together accounted for 87% of world cowpea production area. While cowpea grain is an important product—it has been estimated that from 1961 to 1995 cowpea grain production in Nigeria increased by over 400%—productivity levels remain very low, typically less than 500 kg/ha (Ortiz, 1998). In view of such low yields, the popularity of cowpea may be considered paradoxical. Researchers working with the crop attribute its popularity with farmers to the multiple roles that cowpea plays within these farming systems. Cowpea fodder is a much higher protein source of animal feed than sorghum or millet fodder, is easily stored and sold during the dry season for much needed cash, and farmers do not mind sacrificing some grain yield in order to be sure that they will have fodder for their livestock. Well-fed livestock in turn provide meat, milk, and traction, as well as serving as an emergency cash source. They also produce manure that contributes toward the sustainability of the farming system. This manure may in many cases be the only input used to replenish fragile soils. As a legume, cowpea also contributes to soil fertility directly through nitrogen fixation, and even though the above-ground biomass is removed for fodder, the roots and any fallen leaves can make a significant difference to subsequent cereal yields (Bagayoko et al., 1998; Carsky and Berner, 1995; Carsky and Vanlauwe, 2002; Manu et al., 1994). Rotation with cowpea also helps to reduce the seedbank of *Striga hermonthica*, a parasitic weed of cereals that can cause up to 100% loss of grain yield (Berner et al., 1996).

These roles become increasingly important as agriculture intensifies and crop and livestock production become more closely integrated (Tarawali et al., 2003). Driven by rapid population increases and dramatic rates of urbanization, the process of agricultural intensification is occurring and evolving in West Africa. In 2000, 38% of sub-Saharan Africa's (SSA) population was found in West Africa (240 million people). By 2050, West Africa's population is projected to increase by 139% to 574 million (Kristjanson et al., 2003; Thornton et al., 2002). It is anticipated that livestock numbers will also increase dramatically (Delgado et al., 1999). With the increasingly popular view that crop-livestock integration and integrated natural resources management provide some of the best options for sustainable productivity increases, the trends in human and livestock population and the imperative agricultural intensification point to the fact that cowpea is likely to become more popular and to play even more crucial roles in agricultural production systems in the near future. This vision supports the need for research to develop and disseminate cowpea varieties that continue to respond to the food-feed as well as the soil fertility needs of the region.

1.2. Research toward improved dual-purpose cowpea varieties

In view of cowpea's multiple roles and contributions to both human and livestock production, one of the opportunities recognized during the mid-1990s was to develop dual-purpose cowpea varieties—types that would yield both grain and fodder. This is in contrast to farmers' local varieties, which are usually grown in roughly equal proportions of grain and fodder types, intercropped with cereals (Singh and Tarawali, 1997). If such dual-purpose cultivars could be identified, then farmers would have the opportunity to replace both their traditional grain and fodder types with a variety that would give both superior grain yield and more fodder.[1] In this way farmers would in the end get more

[1] Observations of farmer risk management strategies in the dry savanna zone suggest that there will still remain niches for traditional crop varieties (see Chavas et al., 1991), so biodiversity loss due to adoption of improved varieties within these complex systems and harsh environments is not as great a concern as it is in higher potential areas.

grain, because the area usually under fodder type cowpea would now produce grain. They would also end up with more fodder because the area usually under grain type cowpea would now produce fodder. It was on this basis that IITA and ILRI scientists began working together to include fodder quantity and quality, along with grain parameters among the selection criteria in the cowpea breeding program (Tarawali et al., 1997). Some promising dual-purpose varieties—with good grain and fodder yields for the dry savannas—were identified (Singh et al., 1997; Singh and Tarawali, 1997). These varieties also exhibit pest and disease resistance and mature in only 75–80 days (Okike et al., 2003).

Programs aimed at extending the results of cowpea research in Nigeria, largely emanating from research by IITA and partners, have been underway for the last 20 years. Three major phases have been described by Kristjanson et al. (2002b), namely: an introductory "training and demonstration" phase (1982–1987); a "farmer participatory trials" phase (1992–1997) when 10 improved varieties, including two IDPC varieties (IT-90K-277-2 and IT-89KD-288), were released with no emphasis on seed multiplication; and the current "farmer-to-farmer seed diffusion" phase (starting from 1997) during which 36 primary farmers multiplied seeds that reached 2,458 secondary and tertiary farmers by 1999.[2] More recent strategies have focused on introducing dual-purpose cowpea varieties in a systems context (Tarawali et al., 2003). Recognition of the potential of dual-purpose cowpea stimulated a number of studies to investigate the likely adoption and impacts from the farmers' perspectives. The present article describes a linked series of workshops, community discussions, and detailed household surveys, combined with GIS stratification to identify some of the potentials of IDPC.

2. Methods

2.1. Community impact workshops

The adoption and impact research was carried out in Kano and Jigawa States in northern Nigeria since cowpea research and dissemination efforts (led by IITA researchers based at the research station in Kano) have focused on this region over the last 20 years. Before decisions were made regarding stratification of the sample and site selection, community impact workshops were conducted in Bichi and Minjibir villages in Kano (Kristjanson et al., 2002a, 2002b). These villages were chosen as they were considered to represent a spectrum of good and poor market access, in order to capture possible differences in perceptions of the role of cowpea for villagers relatively close to wholesale markets (Bichi) compared to those in more isolated areas (Minjibir). The group discussions elicited information as to the perceived benefits from dual-purpose cowpea. The benefits described by participants occurred at the plot, farm household, and village/community levels, and included economic, environmental, and social benefits. Several useful indicators for further monitoring and evaluation of each type of benefit at the various levels were elicited in this exercise (see Kristjanson et al., 2002a).

2.2. Village survey approach and defining the recommendation domains

From the information gained from farmers in the impact workshops, and other studies of similar crop livestock farming systems (Ehui et al., 1998; Inaizumi et al., 1999; Okike et al., 2001; Weber et al., 1996; Williams et al., 1999), the following stratification criteria were chosen for village-level, followed by household-level, surveys: human population density and access to a wholesale market (for obtaining farm inputs and for sale of produce). Based on these variables, four socioeconomic domains were defined (Manyong et al., 1996; Okike, 1999):

- LPLM—Low human population density (less than 150 people per square km), and poor wholesale market access (market tension indicator, as described below, from 1 to 5).
- LPHM—Low human population density, and good wholesale market access (market tension indicator from 6 to 10).
- HPLM—High human population density (>150 people per square km), and poor wholesale market access.

[2] Primary farmers purchase seed from research/development institutions, secondary farmers purchase seed from primary farmers, and tertiary farmers purchase seed from secondary farmers.

- HPHM—High human population density, and good wholesale market access.

GIS tools were used to overlay georeferenced spatial data on human population density and market accessibility and map out each of these four zones. The human population density (number of persons per square kilometer) the GIS layer used comes from Deichmann (1996). The spatial market access variable used in this study was based on a "market tension" concept developed by Brunner et al. (1995), and essentially accounts for travel time to the nearest wholesale market. Market tension decreases with distance from the market and decreases faster off-road than on-road, and faster along dirt roads than paved roads. Thus it corresponds to economic distance, defined in terms of transport costs, rather than straight-line distance. The market tension indicator ranged from 1 to 10, where 10 is essentially easy year-round access to a wholesale market and 1 corresponds to locations with long travel times to a wholesale market due to both distance and the condition of the roads. Both human population density and market tension measures were derived for 1990, as that was the most recent comparable data available. For each of the four socioeconomic domains, 20 sample points were randomly generated using a computer program that provided their coordinates. Thus a total of 80 points were marked on the map, and the nearest villages to these sample points were located using a GPS instrument (Okike, 1999). Group interviews were conducted in the 80 villages during a 6-week period in August–September, 1999 (for details, see Okike, 1999 and Kristjanson et al., 2002b). Fig. 1 shows the socioeconomic domains, the length of growing period, roads, and the location and relative size of selected towns in Kano and Jigawa States. The study villages are represented by circles, with the smallest circles depicting zero adoption of improved DP cowpea, and the largest circle corresponding to 18–38% of village cropland planted with the new varieties.

The village-level survey addressed issues surrounding farmers' adoption decisions on IDPC and its results highlighted some issues that could only be explored with a household-level survey. These included the need for a deeper understanding of how farmers were getting new information and technologies, and the extent to which the private sector was (or was not) reaching farmers that the public sector is apparently not able

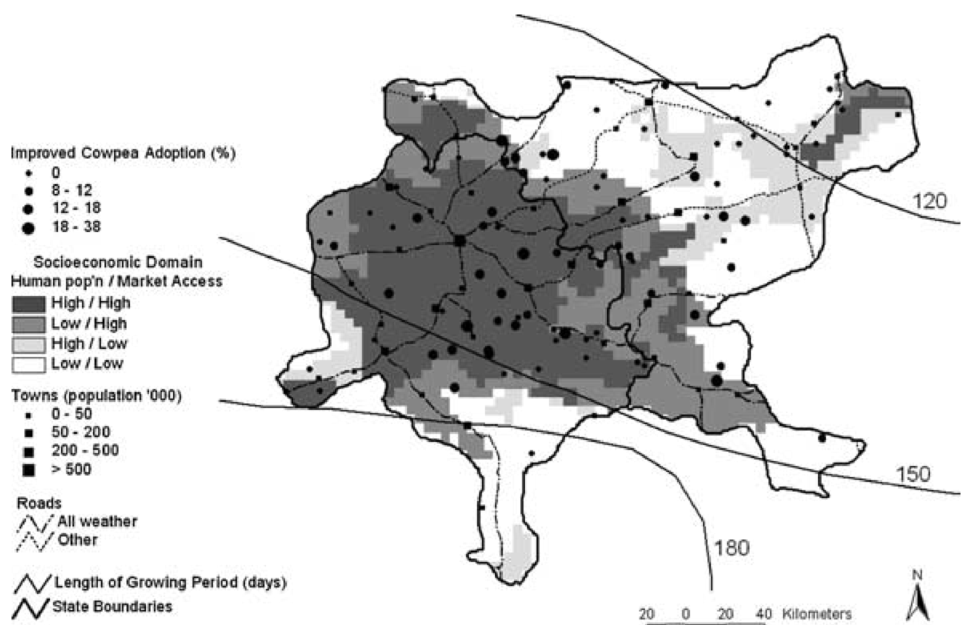

Fig. 1. Socioeconomic domains, length of growing period, and adoption levels for surveyed villages in study area (Kano and Jigawa States, northern Nigeria).

to reach. It also became evident that more information was also needed on within-community variation in adoption patterns. These objectives were pursued in the subsequent household-level survey.

2.3. Household survey

One community that was known to have households using IDPC was chosen from each of the four socioeconomic domains. Though the four villages were chosen purposively in order to ensure a sufficient sample size of households that had adopted IDPC, the actual households interviewed were then chosen randomly. A list of all households in each of the four communities was obtained from the village head—the total number of households in these villages ranged from 350 to 1,500. A sample of 120 cowpea-farming households was then randomly drawn per location, totaling 480 households for the study. After the data cleaning exercise was completed, 462 of the returned household questionnaires were deemed to be useful for the analysis.

In each community, four individuals familiar with every member of the community were asked to conduct a wealth ranking exercise for each of the 120 randomly selected households. Three wealth ranks were preferred, resulting in a score of 3 points for households they classified as relatively wealthy, a score of 2 for those in the middle category, and a score of 1 for the poorest group. The four scores were then averaged for each household, resulting in the following classification: average score of <1.5 = poor, 1.5–2.5 = middle class, and >2.5 = wealthy.

2.4. Analytical model

The tobit model was chosen for this analysis because it can measure the probability and intensity of adoption (McDonald and Moffit, 1980; Tobin, 1958). For the purposes of the household-level analysis, the intensity of adoption of IDPC varieties was defined as the proportion of total cowpea area planted to IDPC varieties (PROPIDPC). In this case, the dependent variable is zero for nonadopters of IDPC and varies between 0 and 1 for adopters (where 1 means 100% of cowpea area is planted to improved dual-purpose varieties).

Given the manner in which improved cowpea varieties (grain or dual-purpose) were introduced to farmers by researchers, the decision to adopt was often made simultaneously with the decision to use chemical fertilizers and insecticide spray. This implies that including chemical fertilizer and insecticide as exogenous variables would have led to biased and inconsistent coefficient estimates, since the covariance between the error term and these variables will be nonzero. Therefore, a three-equation simultaneous equation tobit model was used to determine the factors affecting the adoption of the dual-purpose cowpea technology.

Following McDonald and Moffit (1980) the tobit model may be expressed as

$$\alpha = X\beta + \varepsilon_i \quad \text{if } X\beta > \varepsilon_i, \qquad 0 \quad \text{if } X\beta \leq \varepsilon_i, \quad (1)$$

where α is the solution to the resource use maximization problem of intensity of adoption of IDPC, subject to X, the vector of explanatory variables. The vector of coefficients is β and ε_i is the independently distributed normal random error term with mean zero and variance σ^2.

The above standard model (Eq. [1]) can be embedded in a system of recursive simultaneous equations, such that in a two-equation model:

$$\alpha = X\beta + \varphi_2 y_2 + \varepsilon_1 \text{ (Tobit)} \quad (2)$$

$$y_2 = \eta_2 x_2 + \varepsilon_2, \quad (3)$$

where y_2 is the variable assumed to be endogenous, x_2 is a vector of instrumental variables, and ϕ_2 is the coefficient on y_2, which is included in β in Eq. (1). Eq. (3) is estimated first using ordinary least squares (OLS). Next, Eq. (2) is estimated using a full information maximum likelihood technique. According to Maddala (1983), the derivation of the covariance matrix with two or more endogenous variables is very complicated. However, LIMDEP© version 7.0 (Greene, 1997) easily estimates the two-equation model and gives outputs such as σ_{12} and σ_2^2, which enable the testing of the exogeneity of y_2 through a simple hypothesis that σ_{12}/σ_2^2 equals zero. Blundell and Smith (1986) show how the two-equation model may be extended in a simple three-step procedure to models with many regressions and requiring similar maximum likelihood estimates. They show that by following such a procedure, the result is asymptotically equivalent to a Lagrange multiplier test of weak exogeneity, i.e., that $\mathrm{Cov}[\varepsilon_1, \varepsilon_j]$ equals zero for

$j = 2, 3, \ldots, n$. Following Blundell and Smith (1986), then, the recursive three-equation simultaneous tobit model used for this study is

$$\begin{aligned} \alpha &= \beta X + \varphi_2 y_2 + \varphi_3 y_3 + \varepsilon_1 \text{ (Tobit)} \\ y_2 &= \eta_2 x_2 + \varepsilon_2 \quad \text{and} \\ y_3 &= \eta_3 x_3 + \varepsilon_3, \end{aligned} \tag{4}$$

where y_2 and y_3 are the use of chemical fertilizers and of insecticide spray for cowpea farming, while α is the percentage of cowpea area planted with IDPC.

McDonald and Moffit (1980) decomposed the total change in α associated with a change in an explanatory variable X_i into the change in the probability of being above zero, and the change in the value of α if it is above zero. This was applied to this study to investigate the change in intensity of adoption of IDPC as X_i changes among adopters, as well as in changes in the overall probability of adoption as X_i changes and more farm households adopt IDPC.

2.5. Empirical model

The dependent variable (PROPIDPC), the ratio of the area planted with IDPC varieties to the total area of cowpea (i.e., all varieties), was chosen since discussions with farmers indicated that they were most likely to substitute existing cowpea varieties with the new varieties (rather than substitute IDPC for millet, for example). The group impact discussions and village-level surveys (along with a review of similar empirical studies) led to the choice of independent variables to be included in the regression analysis.

These independent variables are grouped into three categories:

(i) Endogenous variables—use of chemical fertilizers (*FERTLZ*) and use of insecticide spray (*SPRAY*), since these decisions are typically made jointly with the decision whether to adopt IDPC, and the intensity of cultivation once adopted;

(ii) Instrumental variables—used for obtaining the predicted values of *FERTLZ* and *SPRAY* (see Eqs. [5] and [6]). They include the socio-economic domain that the community falls within (*SEDOMAIN*), educational status of the head of household (*EDUHHH*), number of people in the household (*HHSIZE*), total household labor available (*TOTALLAB*), number of different plots owned (*FARMNOS*), average distance of plots from the household (*FARMDIST*), area planted to dual-purpose cowpea (*DPCAREA*), quantity of livestock manure for farming (*MANURE*), expenditures on inputs other than labor, fertilizer, and insecticide (*OTHCOSTS*), amount of credit for farming (*CREDIT*), whether or not the respondent belongs to a farmers' group, e.g., cooperative society (*GROUP*), number of visits by agricultural extension agent (*EXTNVST*), number of varieties of cowpea planted (*VARIETY*), and the amount of hired labor employed per hectare (*HDLBHA*); and

(iii) Exogenous explanatory variables—used in the second stage to compute the maximum likelihood estimates (MLE) of factors affecting the adoption of IDPC. These variables included the predicted value of *FERTLZ* (*PFERTLZ*) and the predicted value of *SPRAY* (*PSPRAY*), and, they structurally incorporated the characteristics of the instrumental variables. Also included were proxies[3] of the relative wealth level of the household such as cultivated farm size per household member (*HAHHSIZ*), the amount of livestock owned by the household—broken into small ruminants (*STLU*) and large ruminants (*LTLU*)—and household labor per hectare (*HHLBHA*). In addition, the residuals of Eq. (5) (*RFERTLZ*) and the residuals of Eq. (6) (*RSPRAY*) are included to enable testing for endogeneity.

From the conceptual model above, a simultaneous equations system is specified to explain *PROPIDPC*. In the first stage, the following equations are used to obtain the predicted values of the endogenous variables *FERTLZ* and *SPRAY*:

$$\begin{aligned} FERTLZ = f(&SEDOMAIN, EDUHHH, HHSIZE, \\ &FARMNOS, MANURE, OTHCOSTS, \\ &CREDIT, VARIETY, GROUP, \\ &HDLBHA, EXTNVST) \end{aligned} \tag{5}$$

[3] Comparison of means of household characteristics for poor, medium, and wealthy households showed highly significant differences among these variables. While the communities themselves gave the relative wealth ranking of each household and this could have been included as an explanatory variable, wealth rank is highly correlated to land and livestock holdings, so these proxies were used to avoid multicollinearity problems.

and

$$SPRAY = f(SEDOMAIN, EDUHHH, DPCAREA, FARMDIST, TOTALLAB, CREDIT, VARIETY, GROUP, HDLBHA, EXTNVST). \quad (6)$$

As discussed earlier, *PFERTLZ, SPRAY, RFERTLZ*, and *RSPRAY* are incorporated into the second stage, which we specify as

$$PROPIDPC = f(SEDOMAIN, FARMDIST, HAHHSIZ, STLUHHSZ, LTLUHHSZ, HDLBHA, OTHCOSTS, CREDIT, VARIETY, GROUP, PSPRAY, RSPRAY, PFERTLZ, RFERTLZ). \quad (7)$$

Eq. (7) was used to first estimate the parameters of the variables in the entire study area irrespective of the socioeconomic domain. The reasoning behind doing it this way is that the socioeconomic domain in which a community falls is exogenous to its farmers, at least in the short term. They are more likely to be able to influence other management-related variables such as herd size. When *SEDOMAIN* proved to be a highly significant explanatory variable, separate regressions were run, by socioeconomic domain, to understand how management variables affect the decision to adopt within a given domain. These results, as well as those from the descriptive analyses and the formal and informal interviews at village and household levels, are presented and discussed in the next section.

3. Results and discussion

3.1. Farmers' viewpoints on IDPC

Table 1 shows the results of our survey of 462 households regarding the status of the farmers' use of IDPC varieties and summarizes some of their viewpoints as stated regarding IDPC. Fifty-five percent of farmers had heard about IDPC varieties. Of these, just over half found out about them from an extension agent, 22% from a neighbor, and 14% from a trader. These three sources of information were also the most important sources of the improved seeds as well (59% of households obtained their seeds from an extension agent, 25% from a neighbor, and 8% from a trader).

Table 1
Characteristics of farm households' adoption of improved dual-purpose cowpea (IDPC) varieties

	Farmers (%)
Sample farmers ($N = 462$) that have heard about IDPC varieties	58
Source of knowledge about IDPC varieties	
Neighboring farm	22
Researcher	7
Field day	2
Trader	14
Extension agent	54
Neighboring village	1
Initial source of IDPC planted by adopting farmers	
Neighboring farm	25
Researcher	5
Field day	1
Trader	8
Extension agent	59
Radio	2
Distribution of farmers by adoption of IDPC	
Adopting farmers	41
Nonadopting farmers	50
Farmers that have abandoned adoption	9
Distribution of farmers by participatory wealth ranking	
Poor farmers	27
Middle class farmers	60
Wealthy farmers	13

In terms of uptake, 41% were adopters (i.e., were currently planting one or more IDPC varieties), 50% had not adopted the new varieties, and 9% had tried and then abandoned IDPC. The results of the wealth ranking exercise showed that 27% of households fell in the poorest group, 60% in the middle class, and 13% in the wealthiest category.

Viewpoints regarding the pros and cons of the new technology (Table 2) highlight that the two most important characteristics of IDPC varieties for these farmers were higher grain yield and their earlier maturity. In the farming systems of the study area, dual-purpose cowpea is usually the last crop to be planted—late in the rainy season—and is, therefore, constantly under the threat of crop failure in the event that the rains stop suddenly. The fact that the IDPC varieties reach

Table 2
Farmers' views on improved dual-purpose cowpea (IDPC) varieties

	Farmers (%)
IDPC varieties have advantages over local varieties	55
Reasons	
Higher grain yield	69
Higher fodder yield	2
Higher cereal yield following IDPC	4
Lower operational costs	4
Two crops per year as against one for local varieties made possible	
Early maturing	19
IDPC varieties have disadvantages compared to local varieties	56
Reasons	
Requires insecticide spray	88
Difficult to obtain pure seeds	6
Capital intensive	4
Labor intensive	1
Intolerant to water-logging; Requires fertilizers initially	1
Relative to last planting season, my IDPC area has increased this season	44
Reasons	
More income	54
High quality food for household	31
Source of employment	9
Fodder for livestock	1
Soil enrichment	1
Improved management practices	1
Other reasons	3
Relative to last planting season, my IDPC area has decreased this season	2
Reasons	
Land shortage	58
Others	42
Impact of IDPC on households is positive	54
Indicators of positive impact on household	
Higher household income	72
Healthier/happier household	12
Active children	1
Household better clothed	9
More livestock	2
Improved housing	2
Others	2
Impact of IDPC on community is positive	54
Indicators of positive impact on community	
Better roads	1
Pumps on communal wells	1
More houses in community	23
More cycles	36
More traders/visitors/commerce	30
More marriages	4
More employment	3
Never tried planting IDPC varieties at all	37
Reasons	
Never heard of them	4
Too risky to plant	29
No access to seeds	45
Local cowpea varieties meet my needs	3
Land is under-utilized with improved varieties	2
Lack of facilities for spraying	10
Other reasons	7

maturity before their local counterparts gives them a head start and a better chance of providing some grain as well as fodder in such "bad" years. In addition, although IDPC varieties yield more grain when sprayed, they are not entirely dependent on insecticide spraying to produce grain. This means that even poor households are able to take advantage of the earlier maturity, higher yields of grain and fodder, and the level of insect resistance achieved through breeding efforts to date and remain in a win-win situation. Even if insect pressure is very high, they will still get some fodder.

The disadvantages of IDPC varieties most frequently cited were: (1) the perception that they require insecticide spray, and (2) that it is difficult to obtain "pure" seeds. The first perceived disadvantage can be attributed to the earlier extension strategies for improved grain type varieties that were introduced in a package that included "mandatory" insecticide spray. The reasons given by the 44% of households that had increased their IDPC area were that IDPC provides more income (54%), high-quality food for the household (31%), and is a source of employment (9%) for women making and selling cowpea snack foods (Table 2).

When nonadopters were asked why they had never tried IDPC, the most common responses were that they had no access to the seeds (45%), it was too risky to plant (29%), and they lacked facilities for spraying (10%). The lesson here for researchers focusing on the constraints surrounding use of insecticide is that many farmers feel it is necessary with IDPC, but it is viewed as problematic for various reasons. Further participatory work could elicit in more detail their concerns and how great a limiting factor they are in terms of uptake of this technology.

3.2. Results of the village-level analysis

The results of the village-level analysis showed that the factors with a significant and positive influence on the area devoted to IDPC were the socioeconomic domain (i.e., LPLM, HPLM, LPHM, HPHM), importance and density of livestock, and the market price received for improved cowpea grain relative to traditional varieties. Communities located in high-population, good market access domains had a higher intensity of adoption than the others, supporting the hypothesis that important "drivers of change" are high population pressure coupled with good market access (Table 3). Intensity of adoption was significantly and positively influenced by both the perceived importance of livestock and by the number of livestock owned (TLU density) within the village. Not surprisingly, the price of the improved cowpea grain relative to traditional varieties had a highly significant influence on the percentage area planted with improved DP cowpea. The fact that intensity of adoption is higher in the more densely populated, better market access domains, despite the fact that DP varieties and livestock are found in higher numbers and are more likely to be judged "very important" by villagers in the other domains, highlights the opportunities for ongoing dissemination efforts. Expanding the availability of information and improved seeds to these more remote areas is the challenge.

3.2.1. Impacts of IDPC varieties on households and communities

Table 3 shows how these variables vary by socioeconomic domain, while Table 4 captures differences across wealth rankings. Almost all of the variables show a significant statistical difference between socioeconomic domains, indicating that human population density and access to a wholesale market are indeed important stratification variables. For example, availability of labor is much higher in HPHM (384 mandays/cropping season) than in LPLM (230 mandays) or LPHM (111 mandays). As is seen elsewhere in Africa, the number of livestock (TLU/household) is also the highest where the most people are found. The ratio of the area of improved dual-purpose varieties to local varieties is also highest in HPHM (0.79, compared to 0.35 in LPLM). In the low population density areas, where labor is scarcer, average farm size and number of plots owned are lower than in the high-density areas. Market access appears to be positively related to higher use of both credit and animal traction.

Looking across wealth rankings (Table 4) gives some insights into household differences between relatively poorer and wealthier households. The wealthy have larger households, more plots, much larger farms (14 ha versus 5 ha for the poor and 7.5 ha for the middle class), and more labor (455 mandays/season compared to 169 for the poor and 219 for the middle class). They use more animal traction and credit and have

Table 3
Characterization of surveyed households and dependent variables, by socioeconomic domain

Variable and level of statistical difference between domains	LPLM $N = 124$ Value (SE)	LPHM $N = 112$ Value (SE)	HPLM $N = 122$ Value (SE)	HPHM $N = 104$ Value (SE)	Dry savanna $N = 462$
Age of head of household (years)***	45.8 (0.97)	45.8 (1.44)	49.5 (1.08)	43.7 (1.31)	46.3 (0.60)
Size of household (number of persons)***	9.4 (0.31)	7.3 (0.30)	10.3 (0.25)	8.8 (0.40)	9.0 (0.16)
Number of plots owned***	4.8 (0.19)	3.8 (0.15)	3.5 (0.15)	5.7 (0.24)	4.4 (0.10)
Average distance of plots from homestead (kilometers)**	1.3 (0.05)	1.7 (0.62)	2.5 (0.17)	1.9 (0.11)	1.8 (0.16)
Total farm size (hectares)***	6.4 (0.50)	4.7 (0.40)	10.9 (0.87)	9.1 (1.17)	7.8 (0.40)
Total labor (mandays/season)***	230 (19)	111 (9)	228 (22)	384 (53)	235 (15)
Total animal traction (days/season)***	4.0 (0.71)	4.2 (0.26)	7.0 (1.09)	6.8 (1.22)	4.5 (0.46)
Amount of credit used ('000 Naira)***	1.8 (0.6)	0.5 (0.2)	3.7 (0.8)	5.0 (1.3)	2.6 (0.4)
Number of cowpea varieties planted***	1.7 (0.06)	1.5 (0.06)	1.8 (0.06)	1.5 (0.08)	1.8 (0.04)
Ratio of area of improved dual-purpose varieties to local varieties***	0.35 (0.03)	0.39 (0.04)	0.07 (0.02)	0.79 (0.03)	0.38 (0.02)
Number of wives in household	1.8 (0.08)	1.7 (0.08)	1.8 (0.07)	1.9 (0.09)	1.8 (0.04)
Number of Tropical Livestock Units owned***	2.2 (0.23)	1.8 (0.22)	2.9 (0.29)	4.0 (0.56)	2.7 (0.17)

***1% level of significance (LOS), **5% LOS, and *10% LOS.

Table 4
Characterization of cowpea farmers in the dry savanna zone of Nigeria by wealth ranking, including variables used in the tobit model

Variable and level of statistical difference between wealth ranks	Poor $N = 126$ Value (SE)	Middle class $N = 278$ Value (SE)	Wealthy $N = 58$ Value (SE)	All $N = 462$ Value (SE)
Age of head of household (years)	45.2 (1.15)	46.7 (0.78)	46.7 (1.70)	46.3 (0.60)
Size of household (number of persons)***	7.9 (0.29)	9.3 (0.21)	10.4 (0.44)	9.0 (0.16)
Number of plots owned***	3.9 (0.16)	4.4 (0.13)	5.5 (0.33)	4.4 (0.10)
Average distance of plots from homestead (kilometers)	2.0 (0.53)	1.8 (0.11)	1.9 (0.21)	1.8 (0.16)
Total farm size (hectares)***	5.4 (0.38)	7.5 (0.45)	14.3 (1.95)	7.8 (0.40)
Total labor (mandays/season)***	169 (14)	219 (13)	455 (93)	235 (15)
Total animal traction (days/season)***	3.1 (0.61)	4.3 (0.54)	8.2 (2)	4.5 (0.46)
Amount of credit used ('000 Naira)**	1.4 (0.52)	2.7 (0.58)	5.3 (1.43)	2.6 (0.42)
Number of cowpea varieties planted	1.5 (0.05)	1.7 (0.04)	1.6 (0.01)	1.6 (0.03)
Ratio of area of improved dual-purpose varieties to local varieties*	0.31 (0.03)	0.40 (0.02)	0.42 (0.06)	0.38 (0.02)
Number of wives in household***	1.5 (0.06)	1.8 (0.05)	2.2 (0.11)	1.8 (0.04)
Number of Tropical Livestock Units owned**	1.7 (0.17)	2.8 (0.23)	4.4 (0.68)	2.7 (0.17)

***1% level of significance (LOS), **5% LOS, and *10% LOS.

more livestock and wives. This is the most important reason why these variables were introduced into the tobit model as proxies for relative household wealth levels, and are expected to affect the dependent variable through positive and significant coefficients.

The difference between the ratio of area of improved dual-purpose varieties to local varieties, however, at 0.42 for wealthy households and 0.31 for poor households, is only statistically different at a 10% level of significance. Table 2 also shows that 54% of participants felt that IDPC has a positive impact on household well-being, and the most important indicator of that is higher household income levels, followed by a "healthier, happier" household that is better clothed, has more livestock, better housing, and more active children. At the community level, impact indicators mentioned were more bicycles, traders and commercial activities and improved housing.

Differences between adopting and nonadopting households with respect to variables that serve as proxies for, or indicators of, household income/welfare, assets/wealth, and food security were examined (Table 5). The explanatory variables included in the analysis of variance were:

- Income or welfare proxies (flows): gross farm revenues (from crops and livestock), gross revenue from sale of cowpea grains, gross revenue from sale of cowpea fodder, gross revenue from sale of non-cowpea crops, percentage of nonfarm income; number of wives in household.
- Food security proxies: number of months the household is typically deficit in cereals or cowpea grains, number of months household has surplus cowpea grains.
- Asset proxies (stocks): livestock holdings (TLU), percentage of children educated up to secondary level, whether the house is cemented, has a zinc roof, is painted, and if the household head owns a bicycle.

With respect to the income or welfare proxies, Table 5 shows that gross farm income, gross revenue from cowpea grain and fodder, gross revenues from other crops, and number of wives were significantly larger for adopters. The percentage of nonfarm income was not significantly different for adopters versus non-adopters, suggesting that income from off-the-farm is not an important driver of technological change on-farm in this instance.

With respect to household food security, the number of months the household was deficit in cereals and cowpea grain was significantly less for adopting households (Table 5). While some may argue that it may be the case that increased food security may have been there first, i.e., within wealthier households that were more able to take risks on a new technology, this contention is not supported by the evidence coming from

Table 5
Comparative assessment of household socioeconomic characteristics of adopters and nonadopters of IDPC varieties showing some impacts of adoption

Variable and level of statistical difference between groups	Adopters $N = 190$ Value (SE)	Nonadopters $N = 229$ Value (SE)	Stopped $N = 43$ Value (SE)	All $N = 462$ Value (SE)
Number of Tropical Livestock Units owned***	3.1 (0.28)	2.2 (0.21)	1.9 (0.32)	2.7 (0.17)
Gross farm revenue (crops + livestock) ('000 Naira)***	175.8 (28.7)	66.7 (18.1)	64.8 (10.3)	125.5 (17.1)
Gross revenue from cowpea grains ('000 Naira)***	33.6 (6.8)	6.7 (0.8)	5.2 (1.0)	21.1 (3.8)
Revenue from sale of cowpea fodder ('000 Naira)***	27.0 (5.7)	4.1 (0.6)	3.1 (0.8)	16.4 (3.1)
Gross revenue from non-cowpea crops ('000 Naira)***	121.9 (27.1)	25.0 (1.7)	42.1 (7.2)	79.0 (14.8)
Percentage of nonfarm income	44.4 (1.4)	47.6 (1.7)	50.8 (3.3)	46.2 (1.0)
Household deficit in cereals (months)***	1.6 (0.15)	2.5 (0.31)	2.2 (0.43)	2.0 (0.15)
Household deficit in cowpea grains (months)***	3.2 (0.24)	5.8 (0.32)	4.8 (0.71)	4.3 (0.20)
Household has surplus cowpea grains (months)	0.4 (0.07)	0.2 (0.10)	0.3 (0.3)	0.3 (0.06)
Number of wives in household**	1.9 (0.06)	1.7 (0.06)	1.8 (0.12)	1.8 (0.04)
Percentage of children in household educated up to secondary level**	55.6 (2.3)	65.4 (2.6)	62.1 (4.6)	59.8 (1.6)
House cemented (%)	23	10	4	37
House has zinc roof (%)	32	20	6	58
House is painted (%)	9	2	2	13
Household head owns a bicycle (%)	24	11	3	38

***1% level of significance (LOS), **5% LOS, and *10% LOS.

the impact workshops or the household-level survey—i.e., poor households are also adopting and benefiting from this technology.

With respect to assets, adopting households had significantly more livestock, with an average of 3.1 tropical livestock units (TLU) compared to 2.2 TLU for nonadopters (Table 5). They also had a higher percentage of better-quality houses (made from cement, with a zinc roof, and painted), and more bicycles, but these asset proxies did not show statistically significant differences between adopters and nonadopters. Unfortunately, we did not collect information as to the dates of asset acquisition, and so cannot definitively say that adoption led to asset investment and not the other way around. Once again, however, the addition to the tobit results of the findings from the participatory work make us quite confident in saying that it is not only the wealthy households that are adopting and benefiting from this new technology, and that adopters are finding their income increases through sales of fodder and cowpea snacks, allowing them to increase their asset base (e.g., by buying livestock).

A result that is not very intuitive was that adopters had a significantly lower percentage of children in the household educated up to a secondary level. This may be explained by the fact that adopters were younger people and therefore had smaller family units, reflected in smaller number of secondary school-age children.

3.3. Tobit model results of the household-level analysis

The instrumental variables used in the ordinary least squares (OLS) regressions to predict fertilizer use (*FERTLZ)* and insecticide use (*SPRAY)* explained 18.6% and 44.6% of their variability, with Durbin-Watson (autocorrelation) statistic values of 2.15 and 1.73, respectively. These intermediate-stage results are not presented in detail here, but it should be noted that in explaining *FERTLZ* as a dependent variable, socioeconomic domain, use of manure, number of plots, whether a group member, and frequency of extension visits were significant at a 5% level and had the expected signs. Similarly, socioeconomic domain, percentage of cowpea area under dual-purpose varieties, available household labor, number of cowpea varieties planted, and frequency of extension visits were significant in explaining *SPRAY*.

Table 6 summarizes the maximum likelihood estimates for the tobit model across all domains, as well as the separate models for LPLM, LPHM, HPLM,

Table 6
Maximum likelihood estimates (MLE) of coefficients of the tobit model for the adoption of IDPC varieties by farmers in different socioeconomic domains in the dry savanna zone of Nigeria

Variables	Socioeconomic domain				
	All domains	LPLM	LPHM	HPLM	HPHM
Constant	0.048535	0.01521	−0.042832	−0.107497	−0.263449
Domains	0.085119***	N/A	N/A	N/A	
FARMDIST	−0.020439**	−0.09856**	0.037427**	−0.005711	−0.031032
OTHCOSTS	0.000013*	0.00012	0.000004	N/A	
CREDIT	−0.000001	0.00001	0.000000	−0.000005*	−0.000002
VARIETY	0.061936***	0.03281	0.030735	0.070357**	0.024486
GROUP	0.058203**	0.04067	0.094277***	0.076959**	0.078210
HA_HHSIZ	−0.012790	−0.03295	0.034628*	−0.075639*	−0.122326
STL_HHSZ	0.101058**	0.13945*	0.069309	−0.022497	0.323987
LTL_HHSZ	0.012868	−0.02170	−0.005039	−0.029479	0.015861
HDLB_HA	0.002861***	0.00532	0.002138***	0.001190	−0.000724
HHLB_HA	0.000642	−0.00074*	0.001678*	0.000087	−0.002620
P_SPRAY	0.000027**	0.000017	−0.0000022*	−0.000080***	0.000254***
P_FERTLZ	0.000000	0.000003	0.000000	−0.000004	0.000007
R_SPRAY	0.000038***				
R_FERTLZ	0.00002***				
Model statistics					
Log likelihood	−82.843	−38.400	−24.882	−9.249	−17.171
Sigma (σ)	0.2135***	0.2657***	0.1631***	0.1522***	0.2111***
R^2 (OLS)	0.30	0.68	0.95	0.36	0.28

Dependent variable (Y) = proportion of IDPC area in total cowpea area (*PROPIDPC*), with mean = 0.2855.

and HPHM domains. To start with, the residuals of equations (9) and (10), i.e., *RFERTLZ* and *RSPRAY* were significant at the 1% level in the overall model (Table 6, column 2). These results justify the use of their predicted rather than observed values to eliminate the simultaneity bias, not only from the overall model, but also from the models for each socioeconomic domain. The overall model shows that statistically significant determinants of the proportion of cowpea area under IDPC, with the expected signs include socioeconomic domain, distance of plots to the household, input costs other than labor, fertilizer and insecticide, number of cowpea varieties planted, whether a group member, small ruminant herd size per household member, hired labor per hectare of farmland, and the predicted values for use of insecticides. It is instructive to note that even though the decisions regarding adoption of IDPC, use of insecticide, and chemical fertilizers have been shown econometrically to be made jointly, the use of chemical fertilizers did not significantly constrain the intensity of adoption of IDPC whereas the use of insecticide spray did. A partial explanation for this finding may be that while insecticide spraying is perceived as a prerequisite for improved cowpea yields (the effect of even a small amount of spray on IDPC is more dramatic than fertilizer application in terms of increasing grain yield), expenditures on chemical fertilizers are made with benefits for a wide range of crops in mind.

Although hired labor per hectare of farmland was a significant factor influencing intensity of adoption, available household labor per hectare was not. In most cases, the spraying of cowpea is done on a contract basis, since most farmers do not own spraying equipment individually, but may get access to labor and a sprayer through group membership (hence the positive sign and significance of this variable). The contractor is regarded as hired labor, thus the higher the proportion of land under IDPC, the more hired labor for spraying is needed. The fact that the availability of household labor was not a significant constraint to IDPC adoption intensity was also not surprising. In practice, the farmers substitute IDPC into existing farm areas that would otherwise have been planted to other cowpea varieties, thus there is no "real" extra demand on household labor due to adoption, especially with spraying contracted out.

The number of cattle per household member, the major wealth proxy variable, was not a significant explanatory variable, which corresponds to observations from earlier informal surveys, i.e., it is not only the wealthiest households that are taking up IDPC. The fact that there is no discernible wealth effect on adoption is not, in fact, surprising, given that seed is a variable input that can be adopted on any farm size. However, it is noteworthy. Investors in research and development efforts aimed at alleviating poverty will be interested to know that it is the poorer households that own more small ruminants per household member and engage in fattening rams for festivals as an off-farm income activity that are the most significant adopters of IDPC, and this appears to be related to the benefits from more fodder (and not just more grain)—since cowpea fodder is the preferred supplement for small ruminants compared to cattle.

Given domain, how do the management variables affect the decision to adopt? The factors that show up as significant do vary across domains. Everywhere in the study area, except in the LPLM domain, adoption intensity is positively and significantly associated with higher levels of insecticide spraying. This spraying is accomplished with the aid of farmers' group activities in the LPHM and HPLM domains. In the HPHM domain, individual ownership of spraying equipment is more prevalent, giving little incentive for resorting to collective action to increase cowpea output. While farmers in HPHM appear to have "outgrown" the need for collective action for cowpea farming, this was not the case of the more isolated villages (LPLM). In these areas, farmers were observed to be organizing themselves to purchase the necessary chemicals as a group, but did not as yet have the spraying equipment. It is, therefore, not surprising that group membership was not a significant explanatory variable in LPLM for IDPC cultivation.

Another interesting result to note is that smaller farm size per household member is associated with higher intensities of adoption in all domains except the low population density, good market access domain (LPHM). This leads to the speculation that with population growth and corresponding shrinking farm sizes per household member, farmers are seeking technologies such as IDPC that are likely to improve, or at least maintain, their output per unit land such that losses in farm size do necessarily translate into losses in output and consequently expose them to food and/or income insecurity.

Other differences across socioeconomic domains include the following. The density of small ruminants is important in explaining the adoption of IDPC only in the LPLM domain, and labor only shows up as a significant factor in the low population density domains.

Following McDonald and Moffit (1980), the maximum likelihood estimates of the coefficients of the tobit models presented above were decomposed to estimate the change in the probability of adoption of IDPC per unit change in the explanatory variables $\{\delta F(z)/\delta x\}$, the total change expected in the dependent variable in the entire study area per unit change in the explanatory variables $\{\delta E(PROPIDPC)/\delta x\}$, and the change in the intensity of adoption among farmers that have already adopted $\{\delta(PROPIDPC^{*})/\delta x\}$. The most interesting results for the entire study area and domains are discussed here but not presented in tables for reasons of shortage of space. However, these results are available on request from the authors. Results of this analysis show that the factor with the largest effect on the proportion of cowpea area under IDPC in the dry savanna zone of Nigeria is the number of small ruminants per household member. Numerically, increasing each household members' small ruminant holding (*STLUHHSZ*) by 1 TLU (or 10 in number, since the average weight of a small ruminant is equivalent to 0.1 TLU) increases the probability of adoption of IDPC by 24.6%. In addition, the same amount of increase in *STLUHHSZ* leads to an increase in intensity of adoption by 0.054 on average for the entire sample and by 0.039 among current adopters.[4] This implies higher relative returns to focusing dissemination efforts on those that have not already adopted, and in domains where adoption is still low, e.g., in the LPLM domain. Other factors influencing the probability of adoption are socioeconomic domain, the number of cowpea varieties, and group membership. Okike et al. (2001) have shown that arranging the domains from LPLM, LPHM, HPLM, to HPHM corresponds to an increasing degree

[4] With an average measure of adoption intensity of 0.28 for the entire sample, an increase in the intensity of adoption of 0.054 implies that the proportion of the IDPC area in total cowpea area would increase to 0.33.

of agricultural intensification and technical efficiency, largely in response to increasing human population density and market access. Assuming that the same order holds here, then improving market access for a LPLM domain, i.e., changing it to an LPHM domain, has the potential to increase the probability of adoption of IDPC by 20.7% and increase the intensity of adoption by 0.046 or by 0.33 among the current adopters. Similarly, planting an additional variety of cowpea or belonging to a farmers' group, increased the probability of adoption by 15.1% and 14.2%, and the intensity of adoption by 0.033 and 0.31, respectively.

Policy implications of these findings include investments in market infrastructure, small ruminant improvement projects (e.g., targeting women since small ruminant management is usually left to the women in the household), increased availability of seeds (e.g., through private–public sector initiatives), and efforts aimed at collective action are ways in which to increase the adoption of this soil fertility and livelihood-enhancing (according to the informal survey results) technology.

The probability of change due to insecticide spraying (*PSPRAY*) was calculated to be 0.0065%, implying that the ability to invest an extra 1,000 Naira (enough to buy 1 liter of standard insecticide spray) will increase the probability of adopting IDPC by 6.5%. This is rather low and suggests returns to efforts made toward encouraging the adoption of IDPC through a message linking its successful cultivation with mandatory insecticide spraying will also be comparatively low. This is especially true for the socioeconomic domain with low population density and poor market access. This same probability increased nearly threefold to 17.1% in the HPHM domain with its stronger population and market access drivers.

4. Conclusions

The results of the household survey supported and enhanced the results of both the group discussions (farmer impact workshops) and the village-level survey. This was encouraging, as it reinforces conclusions drawn earlier—namely that informal group approaches and community-level surveys can provide very useful information regarding both adoption and impact of improved natural resource management technologies, and are faster and cheaper to carry out than household-level surveys (Kristjanson et al., 2002a). Nonetheless, doing the formal survey (aimed at a sufficiently large number of households to allow an extrapolation of the results to a wider area) allowed us to address some of the issues in greater detail.

With respect to the costs versus the benefits of considering different socioeconomic domains in combination with the participatory and formal survey tools, we also learned some lessons. By stratifying our sample by the socioeconomic domain, we were able to show just how important the hypothesized factors of market access and population density are in explaining adoption patterns. Since these data were available, they did not add much to the overall cost of the research. We found that moving from the village-level, more participatory, to household-level, more focused surveys clarified many issues and allowed us to much better focus the household survey. We would not have had as good an understanding, for example, about the different types of impacts perceived by men versus women, or about the types of benefits at different levels (plot, household, village) with only the household-level survey—these were described and debated in detail in the group sessions. The consequence was that the final questionnaire was much smaller than what was drafted before the village-level studies, workshops, and focus group discussions were undertaken. This saved resources in terms of survey time and cost as well as reducing the problem of respondents' fatigue.

While the analysis of the survey data has pointed toward some of the factors affecting adoption that may be useful to ongoing research and dissemination efforts, it is the process of undertaking these workshops and surveys that may in fact lead to the largest impact over the longer run in terms of faster and more widespread uptake of IDPC and related management strategies. This is because the participants in these events (plus others such as farmer field days that researchers are also now involved in) include local policy makers, extension agents, traders, and others that will all play some role in the dissemination of knowledge and improved seeds in the future.

The survey also highlighted areas of caution regarding IDPC. Many farmers perceive the use of insecticide spray as necessary with the new varieties and feel that it poses a constraint for several reasons (including cost and availability of a sprayer). This is a perception that may still linger from earlier grain variety releases, but nonetheless one that researchers/disseminators must address. Availability of seeds was also viewed as a factor-limiting uptake by many. Farmers clearly need more information regarding these issues. It is also evident that these constraints will best be addressed by a concerted effort between researchers and the private sector agents that will ultimately be producing and selling these inputs (which has begun).

Finally, this study has demonstrated the usefulness of linking multiple research approaches to assess adoption and impact, particularly for natural resource-enhancing technologies with multiple benefits that are realized at many different scales (plot, farm/household, community).

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