COMBINED HOUSEHOLD AND GIS ANALYSIS OF FARMER STRATEGIES: AN APPLICATION TO FEEDING PRACTICES ON SMALLHOLDER KENYAN DAIRY FARMS

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ABSTRACT
Traditional studies of agricultural technology adoption have long been constrained by a limited ability to include spatially-differentiated data. Typically, crude proxies or location dummy variables are used to approximate spatial effects. GIS tools, however, now allow spatially explicit data to be included in household econometric models of technology adoption. This paper describes a study that combined GIS and survey variables to examine the cattle feeding strategies on farms in highland Kenya. Data from a large geo-referenced household survey were combined with GIS-derived variables to comprehensively evaluate the spatial, agro-ecological, market and farm resource factors that determine variability of feeding strategies on smallholder dairy farms. Roads, urban populations, milk collection and processing facilities were digitised, and integrated with spatial coverages of agro-ecology. These were then combined, using econometric methods, to quantify the main spatial and local determinants of the probability of adoption of: a) stall feeding or zero-grazing, and b) planted fodder in the form of Napier grass. The results show the influence not only of agro-ecology, but also of market infrastructure and support services on the adoption of improved feeding strategies. A comparison of predicted uptake using GIS and household variables shows that after first calibrating GIS-derived variables through a household survey, broad but reliable predictions of technology uptake in other areas may be possible.

1. INTRODUCTION
Household-level statistical analyses of farm practices in developing countries have long suffered from having to use poor proxies variables to represent spatially-related factors. Distance or time to market outlets or service providers are often based only on farmer judgement and recall in survey questionnaires. Agro-ecological zones are generally only roughly differentiated. All other spatially-related effects are usually captured by simple “location” dummy variables. The crude nature of these proxies has limited the ability of researchers to quantify the effects of spatially-related factors on farmer choice of technology and allocation of resources. Examples of studies employing these methods

without including spatial factors include Adesina et al (2000), and Polson and Spencer (1991)

Conversely, GIS-based analyses typically ignore the socio-economic and other household-specific factors that may vary markedly even within a relatively small zone of analysis. This is often due to the practical reason that spatial data for these variables cannot easily be obtained. Income levels, level of education, access to credit, and the number of a household's dependents are just a few of many variables that are critical to determining farmer choices and constraints. Analyses that rely heavily on remote-sensed data may poorly predict outcomes in which individual household resources play an important role.

Smallholder dairy farming is an intensifying activity in highland East Africa, with cut-and-carry strategies and planted fodder playing an increasing role as the size of land holdings shrink due to human population growth. Besides the attraction of good returns to milk sales, this process is driven by the role manure plays in meeting the demand for intensive cropping. There remains, however, wide variability in observed feeding strategies employed by small-scale farmers. This variability is influenced not only by local agro-ecological and farming system conditions, but also by access to input and output markets, availability of support services, and the nature of the human and other resources available within the farm household. In spite of this great variability, dairy development programs have promoted standard "zero-grazing" strategies, and have not always adapted strategies to suit local circumstances. Better local targeting of strategies is likely to lead to more sustained success of dairy development efforts.

This study attempts to improve on traditional studies of farmer strategies and technology adoption by combining GIS-derived data with those obtained from a large household survey in Central Kenya. Two strategies are examined that are linked to intensification of the land-use and production system: 1) stall-feeding of cattle, sometimes called "zero-grazing", and 2) planting of cultivated fodder, in this case Napier. The data are combined in a standard logit model that evaluates effects of spatial and household determinants on the probability of adoption of the strategy.

2. BACKGROUND TO SMALLHOLDER DAIRY FARMING IN KENYA

Smallholders are an important factor in Kenyan dairy development. Unlike some countries in southern Africa, in Kenya smallholder dairy farmers produce some 56% of total milk production and 80% of the total marketed milk (Peeler and Omore, 1997). In the study area, which comprises the main milk producing regions of the country, about 74% of all households were farms, and of these 73% had dairy cattle.

Dairy production in this region is typically conducted on a small farm of a few acres landholding, with a herd of 1-3 crossbred cows plus heifers and calves, generally a cross of local Zebu with European dairy breeds. Production is based on the close integration of dairy cattle into the mainly maize-based farms. Although varying locally, other important food crops are potatoes and sweet potatoes, beans, kales, and in some areas, wheat. Cash crops may include coffee, tea, pyrethrum, market vegetables, and cut flowers. An important element of this system is the use of the manure to fertilize food and cash crops, allowing sustained multiple cropping on the small landholdings. Labour for dairy production is provided mainly by family members, although some 60% of households surveyed were found to hire labour, with 20% retaining permanent labourers in the household (Staal et al., 1998).

Cows are often fed planted fodder (*Pennisetum purpureum*, an elephant grass, also called Napier grass), maize stover, weeds and grass, and grain millings or compounded dairy feed. In many cases where landholdings are small, cattle at not allowed to graze at all, but are instead stall-fed (zero-grazing, based on cut-and carry of fodder). The level of intensity of feeding, with only grazing at one extreme, and zero-grazing at the other, varies in close inverse relationship with the size of land holdings. Overall the main feeding systems in the area are zero-grazing in the case of some 40% of smallholder dairy farms, and only grazing for 25%, with the remainder employing some combination of the two. Milk production per animal is low, typically 4-7 litres per day (Staal et al. 1998).

Fundamental to understanding milk production and marketing in Kenya is the recognition of the role of the informal, or raw milk, market. Estimates have suggested that about 80% of marketed milk is not ever processed or packaged, but instead is bought by the consumer in raw form (Omore et al, 1999). The factors driving the continued importance of the informal market are traditional preferences for fresh raw milk, which is boiled before consumption, and unwillingness to pay the costs of processing and packaging. By avoiding pasteurising and packaging costs, raw milk markets offer both higher prices to producers and lower prices to consumers. Surveys in the Kenyan highlands consistently show some 15% higher farm-gate prices and 25-50% lower retail prices through the raw milk market compared to the formal packed milk market (Staal et al., 1998). The informal market consists of direct sales of raw milk from producer to consumer, typically through farmer delivery to nearby households, but also of sales to small milk traders and who deliver milk to consumers or other retail outlets. In the more formal market, dairy farmer cooperatives are the largest players while private dairy processors capture the smallest share.

Spatial factors are important in dairy farming: a perishable product (milk) requires good market access, and agro-climate determines base productivity. However, individual household resources such as land and labour resources also influence farmer strategies. An important question for researchers and dairy development planners introducing improved livestock practices is thus: how do these different factors influence the uptake of improved feeding strategies? Specifically, how can the spatial factors be differentiated from others?

3. DATA SOURCES

3.1 Household survey

A diagnostic survey to characterize the smallholder dairy system was conducted in Central, Eastern and Rift valley provinces of Kenya by a collaborative team from the Ministry of Agriculture, the Kenya Agricultural Research Institute (KARI), and ILRI. Eight districts were selected so as to provide contrasting agro-ecological production potential and market access. Within those districts, a stratified sampling method was used to select a sample of sublocations, the smallest administrative units. Based on the agro-ecological zones described by Jaetzold and Schmidt (1983) and field knowledge, six major land use systems, namely coffee/dairy, horticulture/dairy, tea/dairy, sheep/dairy, wheat/dairy and urban Nairobi were identified. Three population density classes were identified within each[1], resulting in twelve stratification groups due to missing density groups in some zones. The number of households surveyed in each sub-location was then weighted by existing household number estimates from the 1989 census figures, and a sample size was obtained from a chosen confidence level of 95%, a coefficient of variation for main parameters derived from previous studies, and a level of difference of 20%. The resulting sample size was 1,389 in 82 sub-locations, with some heterogeneity between the sample sizes in each division. Random transects were then drawn in each sub-location, and every 5th household along the transect was selected until the desired samples was obtained, whether a farm household or not. Each household was geo-referenced using a GPS unit. All main milk processing and collecting centres in the study area were also geo-referenced.

3.2 GIS layers and analysis

The primary new GIS coverage developed for the analysis was a detailed road network of the area, for which digitised maps at the level of resolution required were not available. Topographic map sheets at a scale of 1:50,000 were acquired from the Survey of Kenya and three classes of roads were digitised: 1) all weather, bound surface, 2) all weather, loose surface, and 3) dry weather only. This network of roads was supplemented with a 4-kilometer grid to fill in the areas between existing roads. These auxiliary routes are referred to as "feeder roads or trails" (Deichmann 1997) and are necessary additions because they allow access to the network by farms or facilities that are not on the actual road network. GIS software (workstation ARC/INFO, ESRI, 1998) was then utilized to assign farm or facility information to the nearest node or intersection in the network.

Networks are made up of road sections (lines) and nodes (intersections of 2 or more sections, that also represent farms, towns, facilities etc). In this case, the major urban areas such as Nairobi, and other towns were added to the network as nodes, as were the farm households and milk processing facilities. The road sections in the network were then assigned assumed mean travel speeds, with values of 40 km/hr in the case of dry weather only roads (type 3), 60 kms/hr for all weather loose surface roads (type 2), and 80 kms/hr for hard surface roads (type 1). The GIS was then used to calculate travel times based on each section's length and its associated travel speed, which then were used to identify least-travel time routes. To do this, the Arc/Info GIS Network module (ESRI 1998) was used, and for each node on the network were obtained: a) distance to largest urban area (Nairobi) by least travel-time path, broken down by road type, b) distance to the 2 other nearest urban areas by least travel-time paths, by road type. Since the Network module summarized these least cost paths for all nodes in the network, it was possible to interpolate these points to produce smoothed accessibility surfaces for the whole study area. Arcview 3.1 Spatial Analyst (ESRI 1999) was used to accomplish these interpolations, which utilizes a simple inverse weighted distance algorithm.

[1] The density classes were: a) < 200 inhabitants per Km^2, b) >200 but < 500, and c) > 500.

The human population density layer was developed at ILRI and is based on the 1989 Kenya census. This information is attached to sub-location boundaries for the whole country. Using Arcview Spatial Analyst, focal neighbourhood functions were used to evaluate the mean population density within a 5 km radius for every point in the study area. The agro-climatic information (precipitation / potential evapotranspiration - PPE) was taken from the database contained in the Almanac Characterization Tool (Corbett 1999).

4. METHOD

4.1 Conceptual framework

Particularly in the high population density areas of central Kenya, feed resources form a primary constraint to dairy farming. Addressing this constraint through adopting improved feeding strategies in the form of zero grazing or planted fodder exposes a farmer to risk, such as those resulting from required investment of capital in a zero-grazing cattle stall, or of land into fodder production at the expense of food production.

Any adoption decision by a smallholder farmer is the outcome of a process during which the risk-adjusted benefits are weighed against the constraints and alternatives at his/her disposal. The choice can be explained by a set of factors that influence the welfare criterion of expected utility. These factors are related to both the characteristics of the technology, its environment and the potential adopter. The set of factors that influence the technology choice can be broadly categorised into four major groups, namely, technology attributes; farmer's resources; policy and institutional environment; and farmer's attributes, including preferences, risk profile, and ability to use information. In this case specific attributes of the technology are assumed to be uniform across the sample. The decision variable is a simple representation of feeding strategy technology uptake, and takes a value of 1 if the farmer reports using that technology, and 0 otherwise. The variables needed to explain that decision are thus those related to individual farmer expertise and risk profile (human-capital variables), the farm resource available, land, labour and capital, including the agro-climatic conditions of the locale, and access to markets and services. This form of adoption analysis is commonly employed using only survey data plus dummies variables to capture locational effects (Adesina et al 2000, Polson and Spencer 1991). This analysis uses the same adoption model but combines both household survey and GIS-derived variables.

4.2 Model development for feeding strategy adoption analysis

The dependent variable is defined as 1 if the technology is employed, and 0 otherwise. Explanatory variables were chosen from the household survey and GIS-derived data sets.

Human capital: Several human capital variables were included that refer specifically to the head of the farm household. These were the years of dairy farming experience, and years of formal education. Higher levels of either of these would be expected to raise farmer ability to successfully manage improved feeding strategies.

Household resources: These were represented by the total agricultural land available to the household per cattle unit (stocking density), the number of adults and the proportion of female adults. The latter two describe potential family labour resources, with women thought to bear the greatest burden for the dairy activities. Annual PPE is included as an indicator of the quality of the land resource due to agro-climate. Further, human population density is included to represent potential sources of information on dairy management from neighbours. The latter two are GIS-derived variables.

Access to market and services: Several GIS-derived distance measures are used to represent access to markets, including distance by road type to the main urban areas. See de Wolff et al (2000) in these proceedings for a detailed analysis of these market access measures. That study shows that simple distance measures may be more useful market access indicators than more complex composite measures. A variable was also included here to reflect access to livestock services, measured by the proportion of households locally that report availability of veterinary services.

Given the presence of non-adopters in the sample, the distribution is censored with respect to the decision to adopt improved feeding strategies: for those households that did not adopt, we can only observe that decision as zero, and so cannot observe the contribution of the explanatory variables that affected that decision. Using an ordinary linear OLS estimation in this case will produce biased parameter estimates, even if the non-adopting households are dropped. In this case, limited-dependent variable estimation methods must be used if unbiased estimates are to be obtained, and so a logit model is employed. The estimated parameters are then transformed to reflect the marginal effect on the probability to adopt of an incremented change in the independent variable. The estimate is made using a maximum likelihood procedure.

5. RESULTS

5.1 Analysis of adoption of zero-grazing technology

The significant results of the logit analysis of uptake of zero-grazing are shown in Table 1, where the estimated coefficients have been converted into marginal effect on the probability of uptake. The survey-derived variables with significant effect on the probability of zero-grazing are the number of adults in the farm household, the cattle stocking density, and the availability of veterinary services locally. An increase in adults in the household reduces the probability, which may be related to access to off-farm employment. As expected, increased cattle density raises the probability of zero-grazing, which is designed as a strategy for intensification as land-holdings shrink. However, the relationship is only marginally significant at the 10% level, indicating that other variables are more important. The strong positive effect of availability of vet services on zero-grazing uptake shows the importance of such livestock services for sustained improved dairy farming. A non-significant variable of note is the education level of the household head, suggesting that low human capital levels may not be a barrier to uptake of this technology, thus widening its availability.

The GIS-derived variables are generally significant in explaining uptake of zero-grazing strategies. The effect of distance to market is consistently negative, but differs by road type. The results suggest that a farm 10 km further on poor seasonal road (type 3) from the main urban area, or even from a main road, is more than 15% less likely to take up stall-feeding. An estimated 7% reduction in probability occurs with an addition of 10 km to the 2 other nearest urban centres, indicating the importance of urban markets in general. These effects occur through reduced access to milk markets and input markets, as well as reduced reliability of such markets (deWolff et al, 2000). The GIS-derived PPE variable is also important in explaining uptake of zero-grazing, showing that where agro-climatic conditions are more favourable (higher PPE), there is significantly higher probability of adoption of this intensive feeding strategy.

Variable	Estimated mean marginal effect of base change	Base change
Survey-derived variables		
Number of adults in farm household	-3.6%***	1 unit
Cattle stocking density (dairy cattle/acre on farm)	4.3%*	1 unit
Local presence of vet services (% hh's locally)	1.4%***	10%
GIS-derived variables		
Avg annual precipitation/evapotranspiration	4.2**	10%
Kms to largest urban centre, road type 1	-0.3%***	1km
Kms to largest urban centre, road type 2	Not significant	
Kms to largest urban centre, road type 3	-1.6%**	1km
Avg kms to 2 other nearest urban centres, road type 1	-0.7%**	1km
***=significant at 1%, **=significant at 5%, *=significant at 10%		

Table 1: Estimated impact on probability of practicing stall-feeding (zero-grazing), significant variables.

5.2 Analysis of adoption of planted fodder technology

Similar results are obtained in the analysis of reported uptake of planted Napier grass for fodder (Table 2). In this case however, the most important of the survey-derived variables are those related to human capital: years of farming experience and education of the household head. The significance of these explanatory variables suggests that this technology has characteristics that require higher levels of human capital to achieve success. Access to veterinary services is again significant and positive. Of note is the fact that stocking density is not apparently related to uptake of planted fodder, even though the technology is aimed towards land-scarce dairy farming systems.

Variable	Estimated mean marginal effect of base change	Base change
Survey-derived variables		
Years of farming experience	0.4%***	1yr
Years of education	1.6%***	1yr
Local presence of vet services (% hh's locally)	1.3%**	10%
GIS-derived variables		
Avg annual precipitation/evapotranspiration	4.5%***	10%

Kms to largest urban centre, road type 1	-0.1%***	1km
Kms to largest urban centre, road type 2	-0.4%**	1km
Kms to largest urban centre, road type 3	Not significant	
Avg kms to 2 other nearest urban centres, road type 1	-0.6%***	1km
***=Significant at 1%, **=significant at 5%, *=significant at 10%		

Table 2: Estimated impact on probability of planting fodder (Napier grass), significant variables.

As with the previous analysis, the GIS-derived measures of market access and agro-climatic potential are strong predictors of uptake of planted fodder. As expected, the distance to market effects are negative, and average distances to urban areas have the strongest effect on uptake. In this case, the poorest roads have a less significant effect than main roads. A 6% reduction in probability of uptake could result from an increase in 10 km of main road between a farm and two other urban areas. Agro-climatic potential as measured by the PPE index is significantly and positively related to uptake of this intensive farming practice.

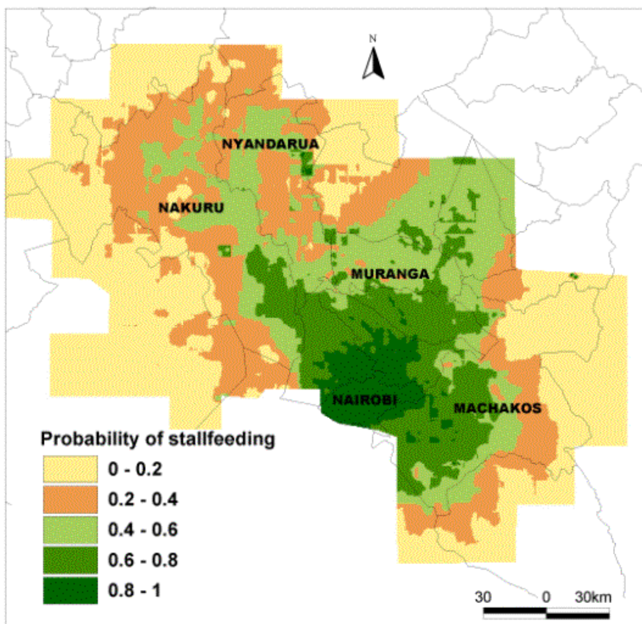

Figure 1: Map of predicted probability of uptake of stall-feeding (zero-grazing) in central Kenya using only GIS-derived variables (other variables held constant at mean).

5.3 Predicting technology uptake

The strength of the GIS-derived variables allows good spatial predictions of uptake. Using only the GIS-derived variables for market access and PPE, predicted probability values are obtained for each node in the GIS, holding all survey-derived variables fixed at their observed means. Interpolated probability surfaces were then generated for uptake of the two feeding strategies studied. These are shown in Figures 1 and 2 for stall-feeding (zero-grazing) and planted fodder, respectively, and cover only the districts where surveys were conducted.

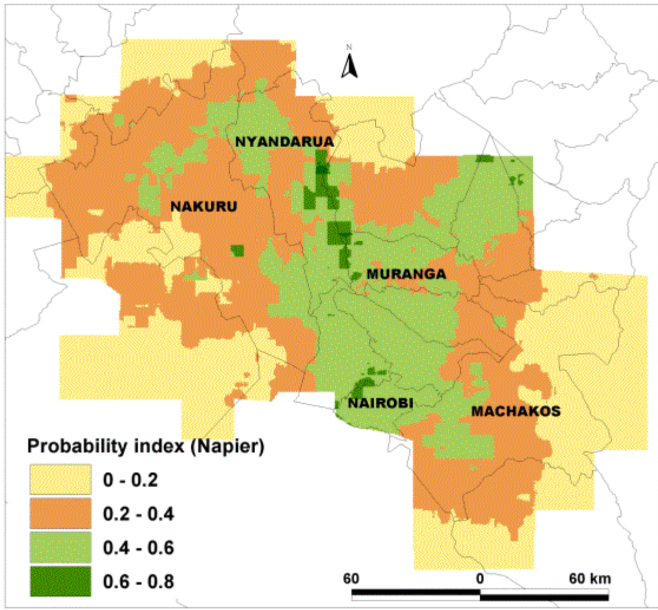

Figure 2: Map of predicted probability of uptake of planted fodder (Napier) in central Kenya using only GIS-derived variables (other variables held constant at mean).

In order to test the potential accuracy of predictions made using only the GIS-derived data, they were compared with predictions made using the full data set including both survey and GIS-derived variables. Tables 3 and 4 show the results of those comparisons, made on the basis of whether the predicted probability of a given farm taking up the target feeding strategy is greater or less than 0.5. Table 3 shows that, in the case of stall-feeding, predictions made using only the GIS-derived variables matched 90% of those using the full data set. This relatively good match is further illustrated by a scatter-gram of the predicted points shown in Figure 3. The variation away from the axis is due to variation captured through the survey-derived variables that is not contained in the GIS variables.

	Probability of adoption	Using only GIS-derived variables p<0.5	Using only GIS-derived variables p>0.5	Total
Using complete household and GIS-derived variables	p<0.5	316 (87.5)	45 (12.5)	361 (100)
	p>0.5	25 (6.8)	343 (93.2)	368 (100)
Total number of observations		341	388	729
Matched predictions: (316+343)/729 = 90%				

Table 3: Comparisons of predicted probabilities of stall-feeding using household and GIS variables. Percent of observations in parentheses.

	Probability of adoption	Using only GIS-derived variables		Total
		p<0.5	p>0.5	
Using complete household and GIS-derived variables	p<0.5	492 (93.4)	35 (6.6)	527
	p>0.5	136 (75.6)	44 (24.4)	180
Total number of observations		628	79	707
Matched predictions: (492+44)/707 = 76%				

Table 4: Comparisons of predicted probabilities of planting fodder using household and GIS variables. Percent of observations in parentheses.

In the case of predictions of planted fodder uptake (Table 4), the GIS-derived variables do not perform as strongly as in the first case, yielding matched predictions in only 76% of cases. This may be due to the relatively more important effect of household and human capital variables for this technology. Again, Figure 4 illustrates the poorer fit of the two sets of predictions.

These comparisons are useful when thinking of regions where GIS coverages of infrastructure and agro-climate exist, but where no household specific data are available. The results strongly suggest that if technology adoption parameters can be calibrated in one area with the use of a combination of survey and GIS-derived variables, then predictions can be made using only GIS variables in those areas where household data are not available.

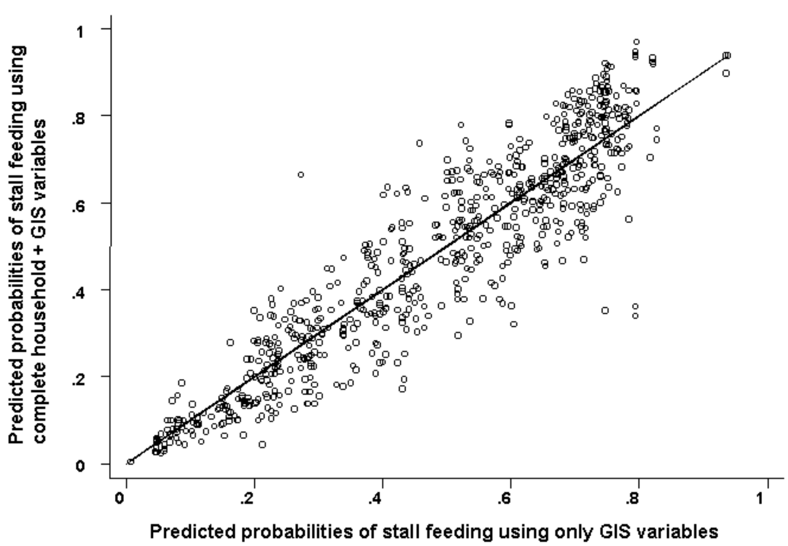

Figure 3: Comparison of predicted probabilities of uptake of stall-feeding using GIS-derived and survey variables.

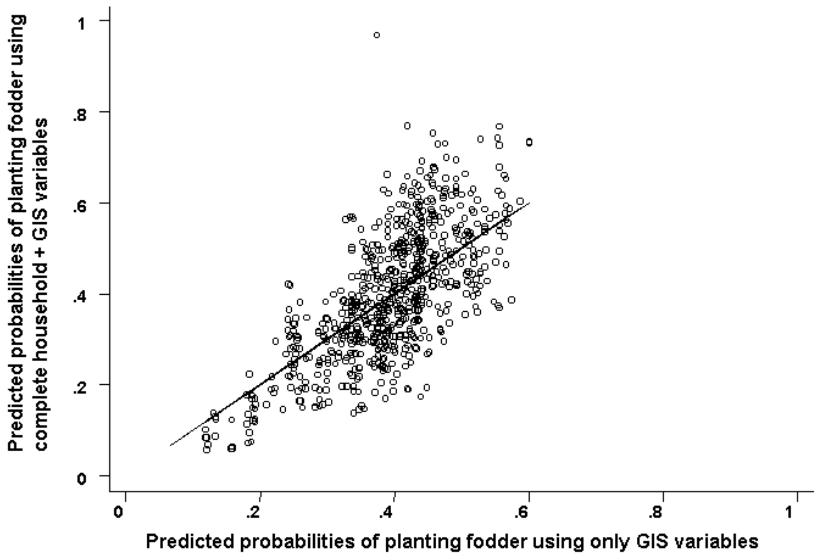

Figure 4: Comparison of predicted probabilities of uptake of planted fodder using GIS-derived and survey variables.

6. CONCLUSIONS

This study demonstrates a potentially powerful tool for better understanding technology uptake, and then further towards planning tools through making more accurate predictions of that uptake. The improvement over traditional uptake or adoption analysis is the inclusion of GIS-derived variables emanating from a geo-referenced household survey combined with independently developed GIS layers. The results show that this combination is able to differentiate spatial effects from those due to individual household factors such as human capital levels.

Overall, the results of the two sets of analyses quantify the important role of spatial factors for smallholder milk production technology, a result which is likely to be relevant for other types of market-oriented smallholder agriculture. Infrastructural factors are seen to play a more important role in livestock production than traditional notions of farm size and stocking rate. Spatially-accurate agro-climatic measures allow better assessment of the potential trade-offs between agriculture potential and market incentives. These results are relevant for planners in dairy development, for better spatial targeting of development efforts.

Finally, comparisons of GIS-only predictions with those made using the full data set show close approximations. This suggests that, once calibrated to control for individual household variation, GIS-derived predictions can usefully indicate the spatial patterns of uptake of some farmer technologies even in areas where detailed household data are not available. Using this technique, technology recommendation domains can be feasibly broadened beyond national boundaries.

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