

availability may lead farmers to forgo such risks by choosing not to buy concentrate. The dependent variable is expressed in binary form, with 1 for the stated use of concentrated feed on farm, 0 otherwise. The analysis is conducted only for dairy farms.

The independent variables are derived from both the household surveys and from the GIS, and are chosen to reflect technology adoption theory, as well as the specific characteristics of the technologies examined, both described earlier. The independent variables, their source, and rationale for inclusion in the models are described in [Table 1](#). The same independent variables are used in all three models.

Given the potential complexity of managing improved dairy animals, greater levels of human capital on farm are expected to increase uptake of all three technologies. Human capital was introduced in the form of years of dairy farming experience, and years of formal education of the household head, which are assumed to proxy level of human capital in the household as a whole. Further, human capital of female-headed households may be constrained through social barriers to information and services, so this is proxied.

Household resources constraining the uptake decisions are expected to include labour, land and feed availability. Labour resources were represented by the number of adults and the proportion of female adults over total adults. Women are thought to supply the greatest proportion of labour for the dairy activities, but in many households the labour burden is shared ([Maarse, 1995](#)). The dependency ratio within the household may reduce labour availability, but may also increase demand for milk consumption. The total agricultural land held by the household is included in acres, a potential constraint to fodder production and cattle keeping. Additional feed resources are available from maize stover, so acres of maize cultivated is included. The measure of agro-climate, average annual PPE, although a GIS-derived spatial variable, should be seen as a measure of the quality of the land resources available to the household. However, it can also be expected to positively reflect availability of common property forage resources locally.

To measure market access, we employ combinations of relatively simple measures of distance to urban areas, differentiated by road type. These allow us to differentiate market effects of different types of infrastructure and destinations, which composite potential

measures cannot do as easily. Also, as will be demonstrated, simple distance measures allow the testing of infrastructure policy scenarios. Further, the composite measures tend to be highly collinear with other measures of development or development potential, such as population density and agro-climate. Access to services is measured by two variables, derived from mean responses in the farm neighbourhood to farmers' stated access to animal health and extension services. Higher levels of both of these are expected to increase and sustain the level of adoption. Recognising the importance and multiplicity of milk markets, as well as markets for inputs and services, one survey variable and a set of GIS-derived variables are included to measure the different dimensions of market access. These are described in [Table 1](#). [Table 2](#) shows the mean values for the variables included in the models.

9. Results and discussion

9.1. *Logit estimates of uptake of dairy cattle, Napier grass and concentrate feeding*

The logit model results are shown in [Table 3](#), under the columns for estimates using both survey and GIS-derived variables, in the form of marginal effects expressed as percent change in probability of uptake with the base change indicated for each variable. The estimates were made using a maximum likelihood procedure.

The results show reasonable explanatory power with percent of overall correct predictions ranging from 69% in the case of Napier grass adoption to 82% in the case of concentrate use. Adopters are more accurately predicted in the dairy cattle and Napier grass cases while non-adoption is better predicted in the concentrate case.

The effects of human capital measures on technology uptake are generally positive. Farming experience is positively significant only for dairy cattle uptake, and is not significantly associated with fodder cultivation or concentrate use. Improved cattle in these systems exhibit mortality rates of between 7 and 15% annually ([Bebe et al., 2002](#)), even among adult animals, and thus present significant risks. The positive role of experience in cattle keeping may be

Table 3
Estimated logit models for adoption of dairy cattle technology, Napier cultivation, and concentrate feeding^a

	Dairy cattle				Napier				Concentrate feeding			
	Estimates using survey and GIS-derived data		Estimates using only survey data		Estimates using survey and GIS-derived data		Estimates using only survey data		Estimates using survey and GIS-derived data		Estimates using only survey data	
	Marginal effect (%)	Base change	Marginal effect (%)	Base change	Marginal effect (%)	Base change	Marginal effect (%)	Base change	Marginal effect (%)	Base change	Marginal effect (%)	Base change
<i>n</i>	2214		2178		1908		1843		908		1787	
No. of adopters	1391		1363		1028		1011		467		457	
Household head characteristics												
Sex (1 = male, 0 = female)	NS		NS		NS		NS		NS		NS	
Years of farming experience (unit)	0.26***	1	0.24**	1	NS	NS	NS	NS	NS	0.15*	1	
Years of formal education (unit)	1.69***	1	1.60**	1	1.47***	1	1.53***	1	1.37***	1	1.65***	1
Household characteristics												
No. of adults	NS		NS		NS		NS		NS		NS	
Ratio of adult female to total adults (%)	1.00*	10	1.10*	10	NS	NS	NS	NS	-1.17**	10	-1.46***	10
Dependency ratio (%)	-1.37***	10	-1.36**	10	-1.22**	10	-1.19*	10	-0.82**	10	NS	NS
Acreage under maize (unit)	NS		3.16*		NS		NS		2.50***		2.18**	
Land size in acres (unit)	0.46***	1	0.74***	1	NS	NS	0.40**	1	NS	NS	NS	NS
Average annual PPE	8.94***	0.1			7.31***	0.1			1.55**	0.1		
Neighbourhood characteristics												
Percentage of local hh with access to animal health services	2.05***		1.8*		NS		NS		5.54***		5.22***	
Percentage of local hh with access to extension services	NS		NS		NS		2.04**		-1.00**		NS	
Percentage of local hh with access to formal milk outlets	1.62***		2.76***		1.40**		2.61***		1.54***		NS	
Market access												
Distance to nearest market centre (km)			5.00*				NS				NS	
Distance to the nearest formal milk collection centre on tarmac (unit)	-0.63***		1		NS		NS		-0.26***		1	
Total distance by road to Nairobi in km	-0.74***		10		-0.57***		10		-1.01***		10	
Mean population density locally (hab/km ²)	NS		NS		3.27***		100		0.90**		100	
Tarmac road distance to two the nearest urban centres	0.27**		1 unit		-0.30**		1 km		NS		NS	
All-weather earth road distance to two the nearest urban centres	-0.90***		1 unit		-0.76***		1 km		-0.60***		1 unit	
Seasonal road distance to two the nearest urban centres (unit)	1.17***		1 unit		NS		NS		NS		NS	
District dummies (Kiambu = base district)												
Number of district dummies significant at minimum of 0.10 level			12				12				10	
Number of observations	2214		2178		1908		1843		908		1787	
Log of likelihood function	-1253		-1130		-1154		-1019		-797		-751	
Overall percent correct prediction (%)	72.13		74.98		69.21		73.09		81.71		80.19	
Percent correct prediction: adopters	74.74		75.37		70.25		74.04		68.91		66.04	
Percent correct prediction: non-adopters	65.85		73.85		67.84		71.76		84.21		83.29	

Market access							
Distance to the nearest market centre (km)			5.00*	10		NS	NS
Distance to the nearest formal milk collection centre on tarmac (unit)	-0.63***	1			NS		-0.26*** 1
Total distance by road to Nairobi in km	-0.74***	10			-0.57*** 10		-1.01*** 10
Mean population density locally (hab/km ²)	NS				3.27*** 100		0.90** 100
Tarmac road distance to two the nearest urban centres	0.27**	1 unit			-0.30** 1 km		NS
All-weather earth road distance to two the nearest urban centres	-0.90***	1 unit			-0.76*** 1 km		-0.60*** 1 unit
Seasonal road distance to two the nearest urban centres	1.17***	1 unit			NS		NS
District dummies (Kiambu = base district)							
Number of district dummies significant at minimum of 0.10 level			12			12	10
Number of observations	2214		2178		1908	1843	1908 1787
Log of likelihood function	-1253		-1130		-1154	-1019	-797 -751
Overall percent correct prediction (%)	72.13		74.98		69.21	73.09	81.71 80.19
Percent correct prediction: adopters	74.74		75.37		70.25	74.04	68.91 66.04
Percent correct prediction: non-adopters	65.85		73.85		67.84	71.76	84.21 83.29

^a Regression with GIS-derived variables compared with regression using survey based distances and district dummies.

* Significant at 0.10 probability level.

** Significant at 0.05 level.

*** Significant at 0.01 level.

related to farmer ability to better control this risk. Years of education have very significant and positive association with all three technologies. An additional year of education raises the probability of adoption in each case by more than 1%. This is likely to be related to increased ability to manage the technologies and to use information. Sex of household head, however, is not significant in any case. This suggests that female-headed households are not differentially constrained from adoption of these technologies, in spite of the capital implications of cattle acquisition. This is a positive result for the promotion of dairy production in smallholder systems, at least in similar cultural settings.

The labour resource and constraint variables show mixed results. The number of adults in the household is not significant in any case. If some of these adults are not active in farming but instead are engaged in other occupations, then this variable may not be useful measure of labour availability. A higher proportion of women among the household adults is slightly significant and positive for the uptake of dairy cattle keeping, and is significantly negative for use of concentrate feeds. The former result is in keeping with the general view that women provide most of the labour for cattle keeping (Maarse, 1995). The latter result is not easily explained, but may be related to the fact that women tend to be the main gatherers of fodder from common land, which in this case may be substituted for concentrate feed. The dependency ratio is significant and negative in each case, suggesting that the constraints imposed on the household by having more dependents materially affect the labour availability. This affects apparently outweighs the increased demand for milk consumption that increased dependents implies.

Land resource effects are also mixed. Acreage under maize is only significant in the case of concentrate uptake. If higher acreage of maize is associated with lower acreage of Napier grass and pasture, then concentrates are possibly being used to substitute for the lower availability of fodder. The land size variable results are clearly reflective of the multiple sources of feed, and of farmer multiple objectives in keeping dairy cattle. Land size is significant only in the case of cattle keeping and is positive. The marginal effect of land size, however, is very small, with an additional acre only contributing about 0.5% to the probability of keeping dairy cattle, even though mean total

acreage among the farms surveyed is only 4.5 acres (Table 2). Land is not apparently the constraint to dairy production that dairy development planners assume it to be, who often operate using the notion of recommended stocking rates. Feed and fodder can be purchased rather than grown, and importantly, demand for manure is likely to increase as land sizes decrease and food cultivation for subsistence becomes more intensive. By consuming feed imported from off-farm, with the manure applied on farm, the cattle become conduits for positive nutrient flow into the farm, critical for maintaining nutrient balances under heavy cultivation (Lekasi et al., 1998). Again, the low association with land size has significant positive implication for the promotion of smallholding dairying, as it appears to be an enterprise open for even those with very small landholdings, if market conditions are favourable. Even Napier cultivation is not associated with land holding size, again underlining the substitutability of purchased and farm-grown fodder.

The GIS-derived measure of rainfall and temperature (PPE) is highly significant and strongly positive in each case. An increase in PPE of 0.1, holding temperature constant, is approximately equivalent to an increase in rainfall of 143 mm annually. That level of increase is associated with an increase in the uptake of dairy cattle of nearly 9%, and of Napier grass of over 7%. This simply demonstrates the importance of underlying land productivity to dairying, including increased availability of fodder from common property. While significant, the effects of PPE on concentrate uptake are much smaller as expected, and may be a result of higher concentrate use generally with more market-oriented dairy production found in the higher potential areas.

Many of the neighbourhood measures of access to services and formal market are very significantly associated with uptake. Animal health service access is linked to the uptake of improved dairy cattle, and with the uptake of concentrates that are particularly associated with the highest grade of cattle, those at most threat from disease. Access to extension, however, is not significant with either dairy cattle or Napier uptake. Given the severe reductions in government support for extension services since the early 1990s, this result is not surprising. There is no apparent explanation, however, for the negative association of extension with concentrate use. Local formal milk market

access, reflecting the density of formal market intermediary activity in the neighbourhood, is significant and positive for the uptake of all three technologies. Farmers report that while formal milk markets offer lower prices, they offer more reliable collection and payment (Ngigi, 2002). These results underline the importance of formal milk markets for the long-term success of smallholder dairy production.

The market access measures are significant and informative. Increased distance to the nearest formal milk collection centre by main road reduces the uptake of both dairy cattle and concentrate feed. An additional kilometre of road between farm and collection centre reduces probability of cattle uptake by 0.6%, so that the tens of additional kilometres that separate some farms from the centres can be expected to reduce uptake dramatically. This is likely to be an effect of both farm-gate prices received, and of market availability, since these routes are served by private intermediaries who charge farmers directly for transport costs. Concentrate use, associated with market-oriented dairy production, is also negatively affected. Similar effects are seen for total road distance to the largest formal market, Nairobi, for all three technologies. Again, the factors are likely to be price and availability, this time through differential milk prices paid by processors themselves to rural milk bulking agents, depending on distance to their plants, mostly located near Nairobi. The effects of distances to local urban markets, differentiated by road type and designed to proxy informal market access, are less consistent. Seasonal and main road distances to these centres are associated with an increase in the probability of dairy cattle uptake, which is not expected if these measures reflect market access. However, as seen in Table 2, these distances are relatively small, since there are some 16 urban centres of at least 50,000 inhabitants in the survey area. These measures may thus reflect some degree of urban and rural interface, so that locations quite close to local urban centres may offer greater opportunities for other enterprises such as horticulture, or non-agricultural enterprises, thus lowering the competitiveness of dairy production and reducing its uptake. The distance to nearest urban centres along all-weather earth roads produces the expected negative effect for all three technologies. The measure of local population density does not exhibit the characteristics of a market access measure. There is no associated affect on dairy

cattle uptake with this variable. However, uptake of the improved feeding strategies, Napier and concentrates, is positively associated with local population density. This measure may thus be more reflective of the reduced availability of feed from common property expected with higher population densities. As a set of measures, these GIS-derived distances and densities can be seen when combined to reflect different facets of milk market access, rural versus urban location, and competition for local resources. Further, the demonstrated effects of even short distances of road underlines the need for high resolution measures of market access, particularly when the economic agents under study have limited means of transportation.

9.2. Comparisons with estimations using only survey data

In order to better assess the potential gains from integrating GIS-derived variables into such household models, estimations were made using only survey data for comparison. Instead of the GIS-derived measures of agro-climate, demographics and market access, variables were introduced that mirror those typically used in such studies. Market access was partially represented by farmer-reported distance to the nearest local market centre, obtained from the surveys. Market access and other locational factors were further represented by district dummy variables, with Kiambu, the district with the largest sample, as the base. The results are also shown in Table 3, in columns adjacent to those showing the integrated household-GIS model estimates. While the log likelihood results cannot be compared directly because of differing sample sizes, they along with the percent correct predictions suggest that the survey-only estimates have about the same or better explanatory power. However, much of that power seems to now lie in the 15 district dummy variables, 12 of which are significant at least at 0.10 probability level in the cases of dairy cattle and Napier, and 10 in the case of concentrate feeding. The farmer-reported distance to local market is significant only in the case of dairy cattle.

While overall explanatory power is not reduced by using only survey data, the ability to interpret and use the locational results is significantly impaired. Interpretation of the district dummy variables now requires detailed understanding of the differences between

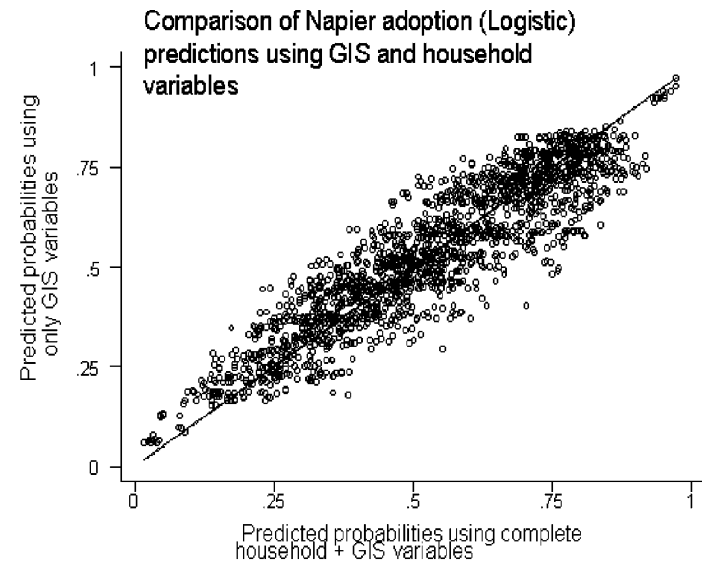
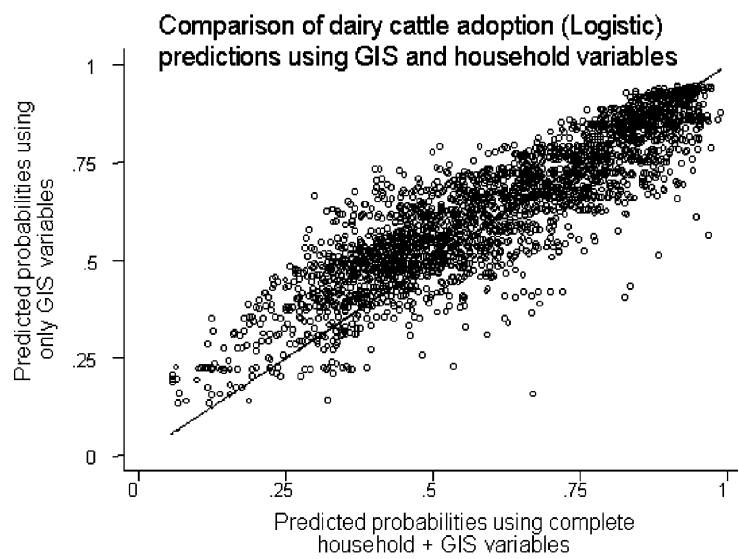


Fig. 2. Comparison of predicted values for uptake using full set of explanatory variables against using only GIS-derived variables.

districts, and speculation as to which of the factors associated with them, agro-climate, demographics or market, are associated with the observed outcomes. Further, these location proxies cannot easily be used to make useful spatial predictions.

9.3. Spatial predictions of technology uptake

The percent of correct predictions for the logit models, shown in Table 3, suggest satisfactory prediction levels of between 69 and 81%, with similar results for predictions of both adopters and non-adopters. However, to make spatial predictions, only the variables for which GIS surfaces are available can be used. We thus compared the levels of prediction when using the full set of variables, and those obtained when using only the GIS-derived variables. These are illustrated for two technology choices in the distribution graphs in Fig. 2.

Given the relatively good comparisons, spatial predictions of probability of uptake of the three technologies were made using only the significant GIS-derived

variables, including PPE, population density and the distance measures, with all other variables held constant at their mean. The resulting probability of uptake maps are shown in Figs. 3–5, for dairy cattle, Napier, and concentrate uptake respectively. The spatial patterns of dairy cattle uptake show close correspondence with agro-climate potential, due to the strong effect of the PPE variable. Napier adoption demonstrates the combined effect of agro-climate and markets, with the highest probabilities in areas where both are favourable. Concentrate use, on the other hand, shows strong links to markets, with highest probability near large urban areas, particularly Nairobi, and very low probabilities elsewhere.

9.4. Spatial predictions of simulated infrastructure policy scenario

To further demonstrate the potential usefulness of the estimates of GIS-derived variables, a policy of upgrading some parts of the road infrastructure is

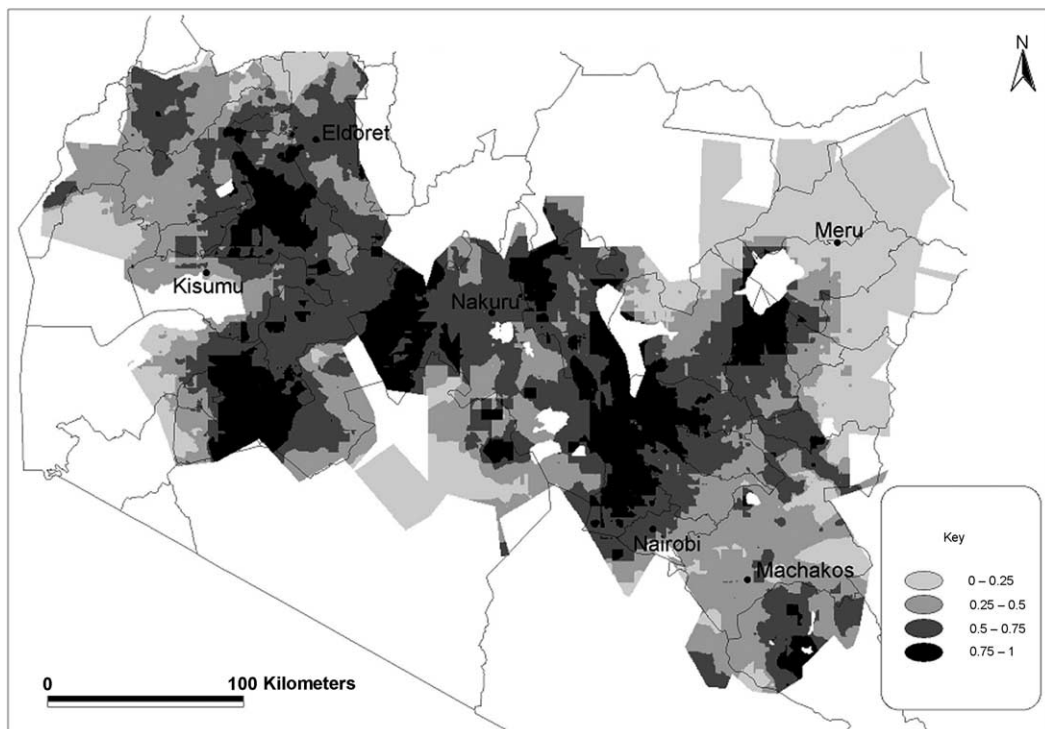


Fig. 3. Map of spatial prediction of probability of dairy cattle adoption, based on parameter estimates of GIS-derived variables.

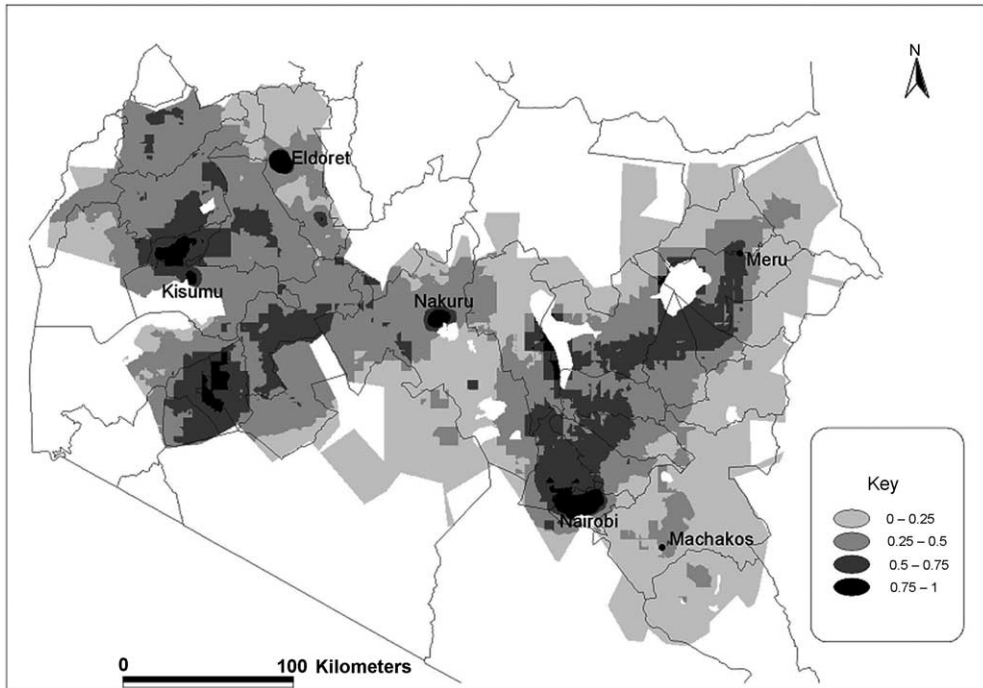


Fig. 4. Map of spatial prediction of probability of Napier adoption, based on parameter estimates of GIS-derived variables.

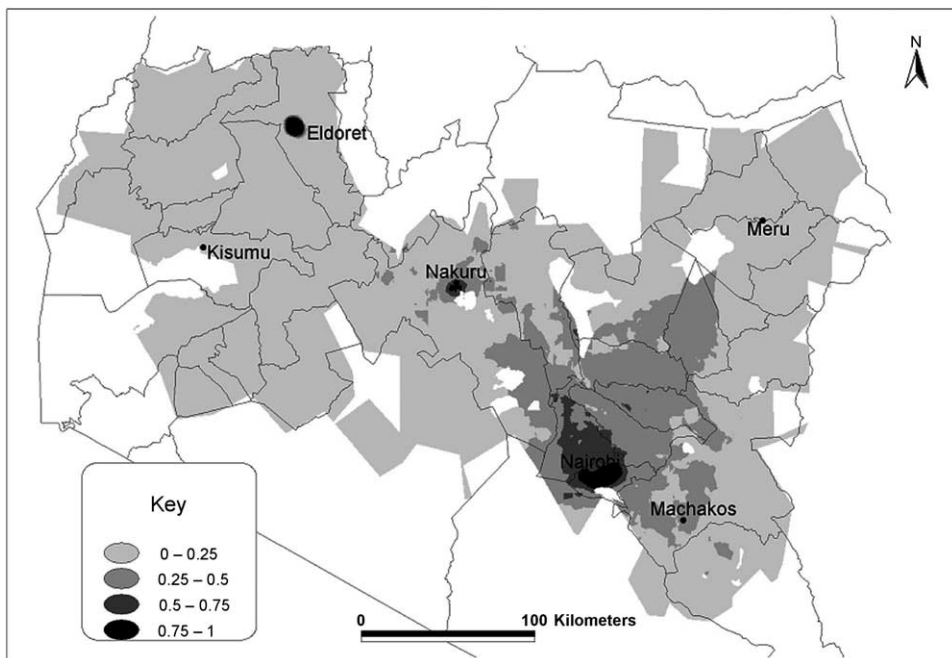


Fig. 5. Map of spatial prediction of probability of concentrate adoption, based on parameter estimates of GIS-derived variables.

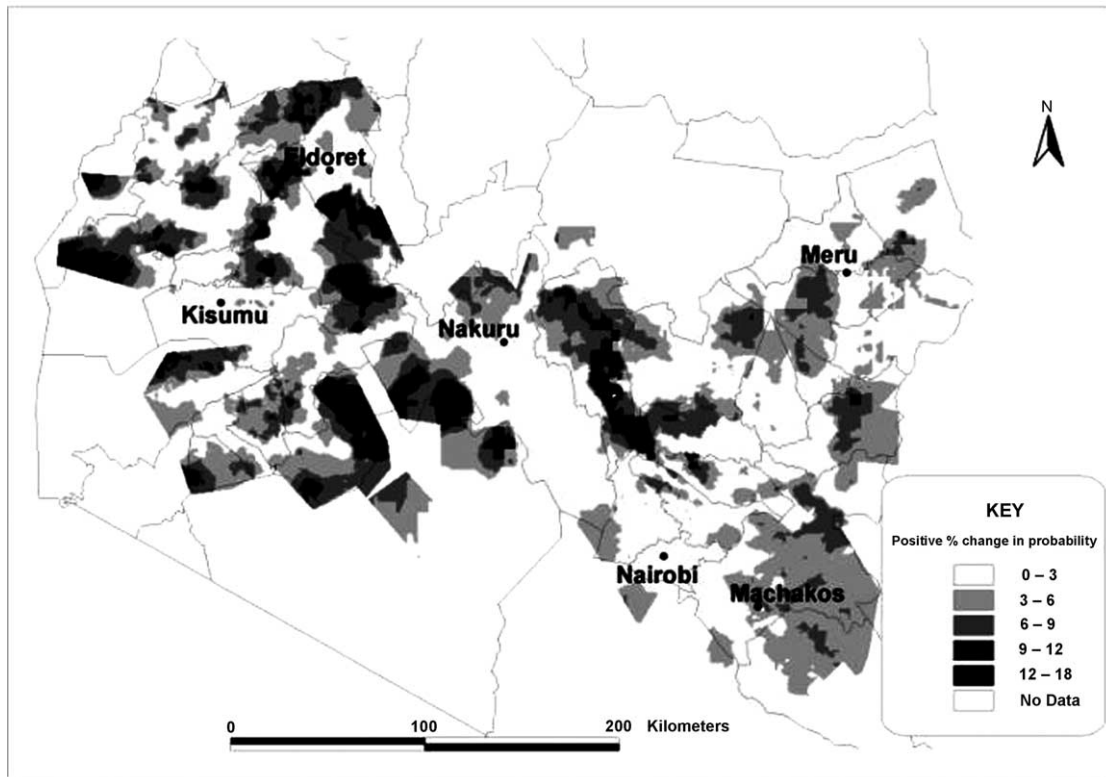


Fig. 6. Map of predicted positive change in probability of adoption of Napier cultivation with simulated upgrading of all-weather roads to tarmac roads, based on parameter estimates of GIS-derived variables.

simulated. The potential effect is examined, on the probability of uptake of Napier cultivation, of upgrading all sections of the “all-weather earth roads” to hard surface tarmac. To do this, the spatial predictions are adjusted to reflect the change in reduced probability of 1 km of all-weather road (-0.76) to that of 1 km of tarmac road (-0.30), measured along the routes to the two nearest urban centres. Such upgrading is thus expected to raise probability of uptake by 0.46 per km, the difference between the parameter estimates for the two roads type effects. Fig. 6 shows the change in probability of uptake that could potentially result from this upgrading of the infrastructure. The analysis highlights those areas that could potentially be most positively impacted by infrastructure development if smallholder dairy production is seen to be a strategic development strategy.

Generally, when the GIS-derived variables are significant, predictions could be made for a wide variety of policy scenarios, including location of collection centres, or location of livestock or extension services, and investment and impacts could be compared with cost-benefit analyses, etc. This could be used to target planning and investment to those areas where desired impacts would be greatest. Conversely, if changes in rainfall due to global climate change can be predicted, for example such an integrated model could predict potential changes in technology use. These spatial predictions demonstrate the ability of the integrated household model to provide better understanding of potential recommendation domains for sets of technologies. Since the spatial parameters are estimated in a household model and individual household characteristics are controlled for, the spatial estimates better reflect the locational effects themselves.

10. Conclusions

The well-established integration of spatial variables into models of land use and ecology is a tool equally available to economic analyses of technology uptake. As seen in these results, GIS-derived variables offer the potential to better differentiate the components of location, and to generate measures in units that can easily be used in spatial prediction and policy analysis. These results also illustrate the continued difficulty of creating close proxy variables for the types of access being targeted, as some variables aimed at market access instead appear to reflect other differences in rural and urban settings. More experience in application of GIS-derived variables in household models will no doubt improve the refinement of this technique, and our ability to select spatial proxies, including the use of both simple and composite access measures. The use in this case of relatively simple distance measures allowed per kilometre impacts to be assessed, which would not be possible if composite market access measures were employed. Bockstael notes that Von Thünen's model (Von Thünen, 1966) is of a system in which the landscape is a featureless plain. GIS-derived spatial measures help us to identify and differentiate the features that do exist, and integrating them into household models of economic behaviour may allow us to better understand how they affect farmer choices.

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