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Planting strategies of maize farmers in Kenya: a simultaneous equations analysis in the presence of discrete dependent variables

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Abstract

A fairly comprehensive range of planting choices made by maize farmers in Kenya (including discrete endogenous variables creating self-selectivity) is modelled and estimated as one system of interrelated decisions. Two-stage and three-stage probit procedures are used to handle the simultaneity and self-selectivity problems. Results showed that population pressure and agroclimatic diversity are important determinants of crop intensification and planting regimes among maize farmers and further supported the importance of focusing maize research in terms of agroclimate and socio-economic domains. Shorter maturity and efficient double and multiple cropping methods are needed to increase land productivity and intensity of labour use in areas of high population pressure and bimodal rainfall, i.e. mid-altitude zones. On the other hand, technologies that would lead to increased productivity of capital and higher response to external inputs are desired for the highlands of Kenya. Access to extension and machine services, distance to the maize plot, and time of onset of the rains were also found to significantly influence the planting strategies of maize farmers.

1. Introduction

Before placing seed into the soil, farmers make several decisions to select an optimal planting regime. These include the date of planting, seeding rate and arrangement, selection of a suitable cultivar (variety), and cropping intensity (single vs. multiple cropping) and pattern (mixed or monocropping). These choices are made by the farmer as a set of interdependent decisions. Different cropping systems are adapted by farmers to fit different agroecological and socio-economic circumstances. Farmers then decide what production methods and technologies are best suited for the prevailing environment and system of farming. For instance, the desired duration to maturity, and hence a suitable cultivar to be planted, depends on whether double or single cropping is followed. The same applies to the optimal time of planting. Also, certain cultivars, seeding rate and arrangement, and planting dates are preferred to others in mixed cropping (compared with monocropping) for various agronomic, labour availability, and conservation purposes. Therefore, careful analysis of the jointness and complex interactions between these choice variables and their independent determinants will reveal the optimal types and points of technological interventions for more efficient planting regimes. Understanding how farmers make their planting plans will help agricultural researchers decide on appropriate breeding and crop management strategies for increased productivity. That information will also help policy-makers better understand the institutional and policy factors that would promote the development and diffusion of relevant improved technologies.

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In spite of their joint nature, however, these decisions are commonly analysed separately or in partial combinations. For example, the importance of socio-economic factors is rarely considered in the design and evaluation of improved planting methods. Biological research concerned with determining the optimal date, method and sequence of planting is conducted with a subset of the relevant experimental variables and in isolation from non-experimental socio-economic factors, such as population density and land pressure, size of the farm and the farming family and their influence on labour supply and food demand, access to extension advice and means of cultivation, and the age and sex of the farmer. Such research mainly evaluates alternatives on the basis of yield advantage (Allan, 1971; Osiru and Willey, 1976; Fisher, 1979; Waddington et al., 1991). On the other hand, socio-economic investigation of the sources of variation in farmers' planting methods is often done independently of the agroecological circumstances determining farmers' planting strategies. In this study, information on agroclimatic attributes and socio-economic aggregates is combined with data from a geo-referenced survey of maize production practices to analyse the agroecological and socio-economic determinants of maize farmers' planting regimes and to explore their implications for maize research in Kenya.

It is also common that, although some elements of farmers' planting decisions are observed as qualitative endogenous choices, such as whether or not to double crop, they are usually treated as exogenous explanatory variables. (Few examples of simultaneous estimation of qualitative adoption decisions are found in the agricultural technology adoption literature; see Nerlove and Press (1973), Maddala and Trost (1980), Saha et al. (1994) and Smale et al. (1995)). This has important implications for the numerical specification of parameters. First, inclusion of a dummy endogenous variable on the right-hand side of the equation renders ordinary least-squares (OLS) estimates inconsistent (Heckman, 1979; Maddala, 1983). Second, estimation of model parameters using single-equation procedures does not correct for the simultaneity in farmers' planting decisions and hence leads to inconsistent and biased estimation (Amemiya, 1979; Lee et al., 1980). In this study, a fairly comprehensive range of planting choices (including discrete variables) made by maize farmers in Kenya is modelled and estimated as one system of interrelated decisions.

2. The data and diversity of maize production environments in Kenya

Two data sets are utilized in the present study. First, a maize-specific agroclimatic zonation scheme developed by the Kenya Maize Data Base Project (MDBP) is employed to capture the effects of variations in the physical environment. (The Kenya MDBP is a collaborative research project between the Kenya Agricultural Research Institute (KARI) and the International Maize and Wheat Improvement Center (CIMMYT).) The MDBP climatic classification is based on long-term monthly averages of climate data, i.e. air temperature and precipitation (Corbett, 1994). Moreover, the study used information on maize production practices compiled from a geo-referenced survey of 1400 maize farmers. Geographic Information Systems (GIS) techniques were employed to differentiate agroclimatic zones, design the farmer survey, and integrate the survey and spatial data into one digital data base (Hassan et al., 1994b).

Hassan et al. (1994a) showed that farmers' practices, system constraints, socio-economic characteristics of the farming population, and biotic and abiotic stress factors affecting maize vary significantly across six main agroclimatic zones (ACZ) in Kenya. The six zones, described in Table 1, are maintained as distinct maize production domains in this study. Farmers have developed a wide range of complex crop planting regimes to fit the diverse agroecological and socio-economic conditions under which maize is produced in Kenya. The length of the dry spell between rainy seasons and the intensity and reliability of the seasonal rainfall peaks vary significantly across the country, leading to substantial variations in the length of the growing season. Maize is also grown at almost all elevations, from sea-level on the coastal strip to more than 2400 m in the Kenyan highlands. This indicates the wide range of temperature and photoperiod regimes influencing maize growth and development, and hence the time to maturity.

Table 1
Maize-specific agroclimates, duration to maturity, and cropping pattern

Zone	Altitude (m ASL)	Average seasonal temperature (°C)		Total seasonal precipitation March–Aug. (mm)	Total seasonal precipitation Sept.–Feb. (mm)	Total between-seasons precipitation June–Aug. (mm)	Variability in seasonal precipitation (% CV) [a]	% Farmers where March rains are major season [b]	Average time to maturity in days [b,c]	Population density (person km^{-2}) [d]	% Farmers double cropping maize [b]	% Farmers intercropping maize [b]	
		Max.	Min.									Small (< 2 ha)	Large (> 2 ha)
Lowland tropics	< 800	29.4	20.0	300–1000	349	219	36	99	120 (33)	121	35	78	50
Dry mid-altitude (semi arid)	700–1300	27.9	16.1	< 600	414	13	52	48	114 (47)	210	60	88	77
Moist mid-altitude	1100–1500	28.3	15.9	> 500	585	293	32	96	163 (40)	310	60	77	50
Dry transitional	1100–1700	25.3	14.0	< 600	460	45	40	46	144 (20)	398	76	95	–
Moist transitional	1100–2000	23.3	13.4	> 500	545	338	27	98	181 (39)	331	40	89	16
High tropics	> 1600	23.0	10.0	> 400	384	326	32	89	213 (53)	238	22	90	39

[a] Coefficient of variation, calculated by author based on long-term rainfall data for Kenya.
[b] Survey data.
[c] Figures in parentheses are per cent CV.
[d] Average of population density in surveyed sites within the zone according to the 1989 population census (Hassan et al., 1994a).

Rainfall peaks twice each year in Kenya: in March–May and September–November. In most places, the March (long) rains support the major growing season. This is evident in the wetter segments of the mid-altitude (MAT) and transitional (TNZ) zones as well as in the highland (HT) and lowland tropics (LT), where the vast majority of farmers consider the March rains to be their major maize season (Table 1). On the other hand, both seasons are of at least equal importance to farmers in the drier environments (i.e. semi-arid and dry TNZ). Another factor distinguishing the moist and dry maize agroclimates in Kenya is the intensity of rainfall between seasons (June–August). Very little (less than 50 mm) rainfall is received between the two seasonal peaks in the semi-arid and dry TNZ zones, which is clearly indicative of a bimodal rainfall pattern. In contrast, the greater amount of rainfall between the two rain peaks in the relatively wetter zones (i.e. LT, moist MAT, moist TNZ, and HT) suggests a continuous single cropping season (Table 1). This is particularly so in the HT, where average total precipitation in the 3 months between the two rain peaks nearly equals the amount of rainfall during the 6 months of the short rains (September–February). Together with population density, rainfall pattern can therefore explain the spatial variation in the intensity of maize cultivation in Kenya. It is clear from Table 1 that the frequency of double cropping maize is higher in areas where rains follow a bimodal pattern and where population pressure is high. Moreover, temperature and moisture regimes influence maize development and hence determine average time to maturity, which is an important factor in farmers' planting decisions, especially in the selection of germplasm that fits the prevailing physical and socio-economic conditions.

The data also suggest that reliability of rainfall may be an important determinant of the optimal time to plant. For example, whereas the short rainy season in the semi-arid and dry TNZ zones calls for early planting, farmers are required to time their maize planting more efficiently with the onset of the rains, owing to the high rainfall variability, i.e. the high chance of rain failure in these regions (Table 1). The importance of all of these factors in explaining the planting strategies of maize farmers in Kenya is measured and formally tested in the following sections.

3. An empirical model of farmers' planting regimes

A formal model is developed to analyse the determinants of farmers' planting choices. Four decisions characterize the planting strategies of maize farmers in this model: choice of cropping intensity (number of plantings per year, y_1), cropping pattern (mono or mixed, y_2), suitable cultivar (variety, y_3), and time of first planting (y_4).

3.1. The decision problem and econometric procedures

The four choice variables are defined as:

Cropping system choices. Multiple cropping is considered the most common strategy for crop intensification among tropical farmers (Andrews and Kassam, 1976; Beets, 1990). Two major patterns of multiple cropping are defined: sequential, where crops succeed each other over time (double or triple cropping), and mixed or intercropping. Both patterns are followed by maize farmers in Kenya (Hassan et al., 1994a). In this model, cropping pattern choices are specified as binary decision variables: (1) intensity (y_1)—farmers may choose to grow two maize crops in sequence on the same piece of land during the same year (double cropping). In this system, however, there is no simultaneous competition for land and other resources. This variable takes the value of unity if maize is double cropped and zero otherwise. (2) Pattern (y_2)—farmers may grow more than one crop simultaneously on the same plot (intercropping), and hence there is competition for resources during part or all of the crops' growth cycle; if maize is intercropped, y_2 takes the value of unity and zero if not. Several advantages are thought to underlie the popularity and suitability of intercropping for smallholder farming in the tropics. Apart from its agronomic advantages, intercropping is practised (1) to meet demands for other farm products, whether for nutritional balance in household consumption or for sale (potatoes, beans, groundnuts); (2) to avoid the risks of environmental uncertainties, pests, and diseases associated with sole cropping; (3) to reduce demand for labour for weeding; (4) to provide continuous cover so as to minimize erosion (Norman, 1974; Oloo, 1977; Nadar and Rodewald, 1979; Beets, 1990).

Variety (y_3). Owing to the large number of maize cultivars used by farmers, choice of the most suitable germplasm represents a polychotomous variable of more than 15 categories, i.e. more than 15 individual varieties used during the survey year, 1992 (Hassan et al., 1994c). Although probabilistic choice models have been developed to handle polychotomous decision variables, the computational difficulty involved in deriving error statistics sheds doubt on the usefulness and efficiency of these procedures, especially when the number of choice variables exceeds four (Maddala, 1983). (The multinomial logit or probit models were used by many workers to deal with the case of categorical choice variables with more than two categories (see Maddala (1983) for a detailed review of such case studies).) Because this study does not attempt to explain farmers' varietal choice behaviour, coupled with the difficulty in estimation involved, an alternative definition of the most suitable maize germplasm is sought. Although farmers select individual varieties for several other traits (such as yield, taste, tolerance to biotic stress, etc.), time to maturity is the most important concern of maize farmers in making their planting decisions. Average time to maturity in the first season was therefore employed in this study as an alternative index of farmers' varietal selection. (Another option explored was to reduce the number of categories by grouping varieties according to duration to maturity into three groups: early-, medium- and late-maturing cultivars. This option, however, was not considered an improvement over the proposed index, because some measure of how long it takes a variety to mature is required before they are classified. Although this measure is not well established for the land races, breeders' classification of improved maize germplasm in terms of maturity is based on a measure similar to the proposed index, i.e. time to silking (Bonhomme et al., 1996).) Time to maturity is determined by the type of germplasm and the physical environment, particularly temperature. The same maize cultivar can have shorter duration to maturity in relatively warmer climates. Accordingly, farmers are assumed to choose the maize cultivar that gives the desired maturity, given the prevailing (exogenous to farmers' choice) temperature regime. Average time to maturity, in days between planting and harvesting, was used to approximate cultivar choice for the particular planting regime. (The use of thermal time (heat units) was shown to be a more stable method of measuring maize maturity across environments than real time, e.g. days. However, thermal time is relevant when similar materials or the same germplasm are compared across environments, i.e. altitudes or temperature and photoperiod regimes (Bonhomme et al., 1996). As maize farmers in Kenya use a mixture of various improved and local varieties that vary significantly across agroecological zones, the measure of average thermal time over all varieties in each zone does not compare the same thing.)

Time of planting (y_4). After deciding on the intended cropping intensity and the variety to plant during the first season, farmers decide on the optimal date for sowing their first season maize. This decision variable is measured in number of days from the onset of the first rains, defined as the date at which 80 mm of rainfall accumulate.

The choice of whether or not to intensify production over time (by double cropping) or over space (by intercropping) is determined by farmers' self-choice on the basis of several criteria. Accordingly, the discrete planting decisions y_1 and y_2 are specified as endogenous choice variables in the model. At the same time, interdependence between the four decision variables is very subtle, depending on the nature and complexity of the crop–environment–farming system interactions. For example, farmers' selection of the suitable cultivar (y_3), is influenced by the cropping pattern (y_2) and intensity (y_1). Depending on whether farmers plan to have a second planting of maize or not, they select the variety that gives the desired maturity during the first (or the only) season. Given the biophysical environment, maize cultivars vary significantly in terms of time to maturity. Therefore, certain maize germplasm, such as early- and medium-maturing varieties, will fit a double cropping system better than late-maturing germplasm. Similarly, certain varietal traits are more desired than others for intercropping. Competition from intercrops can also become a stress factor causing earlier maturity of maize.

On the other hand, the optimal date of planting (y_4) depends on all three other choice variables (y_1, y_2, and y_3). For every cultivar–cropping system combination, there is an optimal time for planting maize. For example, given the temperature and rainfall pattern at a particular location, the best date for planting maize under double cropping will depend on whether the selected variety is early- or medium-maturing. Early-maturing cultivars may be selected for their suitability for the temperature and moisture regimes of a short growing season, and hence the importance of optimal planting to ensure the highest efficiency in utilizing available moisture and photoperiod. Also, medium- to late-maturing cultivars are sometimes selected under double cropping, mainly owing to their yield advantage or for other qualities (e.g. taste and processing qualities). Such germplasm, however, requires different planting dates to fit the biophysical conditions in a two seasons system (to avoid the onset of second season rain and thus escape rotting and stalk lodging, for instance) (Hassan et al., 1994a).

Moreover, the date of planting maize depends on whether it is grown in pure stand or intercropped for various agronomic reasons, such as (1) efficiency in nutrients, moisture, and photoperiod utilization, (2) conservation and better cover, and (3) effective pest, weed, and disease control. The optimal time for maize planting depends on whether or not it is sown in combination with other crops and on the type of the intercrop. Time of planting maize is also influenced by the cropping pattern owing to socio-economic factors, such as optimal sequencing of operations to avoid peaks in demand for labour and other resources (i.e. the optimal labour profile), and to ensure continuous availability of food products.

However, the relationship between the crop intensification choices (y_1 and y_2) and selection of a suitable variety and date of planting decisions (y_3 and y_4), runs in one direction. This means that what farmers consider to be the suitable maturity range (y_3) and planting time (y_4) is the result and not the cause of the decision to plant one or two crops per year (y_1). Similarly, it is assumed that the choice of what (y_3) and when (y_4) to plant is influenced by, but does not determine, the cropping pattern (y_2). If one assumes no causal relation between cropping system variables (y_1 and y_2), the model becomes fully recursive, i.e. Eqs. (1)–(4) can be estimated sequentially (Fig. 1(a)). On the other hand, if a two-way relation exists between y_1 and y_2, the model becomes partially recursive with Eq. (1) and Eq. (2) forming a system of interdependent qualitative response variables that is independent of y_3 and y_4.

Nevertheless, the fact that y_1 and y_2 are arguments in y_3 and y_4, coupled with the across-equations error correlations, makes this model a system of simultaneous equations with mixed discrete and continuous dependent variables. Whereas the logit and probit maximum likelihood estimators (MLE) correct for heteroscedasticity and deviations from normality in the case of dichotomous dependent variables, they are consistent only in the single equation framework (Maddala, 1983). Alternative estimation procedures have been used to generate consistent and more efficient estimates of the structural parameters in simultaneous equation systems involving limited dependent variables. The logit and probit two-stage estimation procedures have been applied to a wide range of cases estimating simultaneous equation models with endogenous discrete variables such as the case of sample selection bias or self-selectivity (Nelson and Olson, 1978; Heckman, 1979; Lee et al., 1980). (In general, the two-stage procedure involves estimation of the reduced form equations of the system in Stage 1, i.e. the regression of endogenous variables (y_is) on all exogenous regressors (Xs). Reduced form estimates are then used to compute fitted values of the dependent variables (y_i), which are used as regressors (instruments) sub-

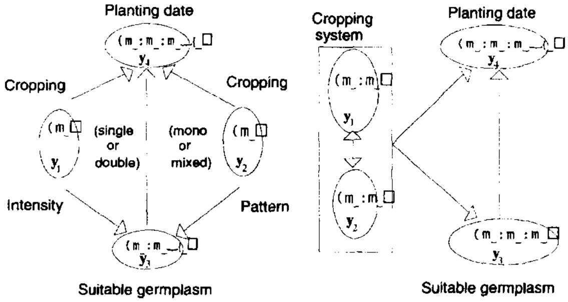

Fig. 1. Path diagram for farmers' planting decisions. (a) Fully recursive system; (b) partially recursive system.

stituting for actual y_is in the relevant structural equation to estimate the structural parameters of the model in Stage 2. In both stages, the ordinary least-squares method (OLS) is used for the estimation of continuous dependent variables equations, whereas limited dependent variables equations are estimated by the Tobit or probit MLE procedures (Maddala, 1983).) Another procedure, using generalized least-squares (GLS), was suggested by Amemiya (1979) as asymptotically more efficient than the two-stage method. (The GLS estimator of Amemiya (1979), on the other hand, requires transforming the data in the structural equations to be estimated before a GLS method is applied to estimate the structural parameters of the system). This procedure is analogous to the three-stage least-squares method of the general linear regression model. Application of GLS instead of OLS to the second-stage estimation generates more efficient estimators by utilizing information on the contemporaneous error correlation across equations to derive the correct covariance matrix. Amemiya (1979) showed that this estimator (which will be referred to as the probit three-stage least-squares, P3STG) is more efficient than the probit two-stage (P2STG) estimator, although the covariance matrix is more complex to compute.

This study adopted the fully recursive system as the most plausible specification of the model. Whereas a high correlation is observed between mixed and double cropping under smallholder farming in the tropics (Beets, 1990; Hassan et al., 1994a), there is no good reason to believe that they cause each other. In spite of the fact that the two systems are commonly used as a joint strategy for crop intensification, there is no evidence for any biological or socio-economic causality between double and mixed cropping. Accordingly, model equations for the fully recursive system can be specified as follows:

$$y_1 = f_1(x_1, \beta_1, \mu_1) \tag{1}$$

$$y_2 = f_2(x_2, \beta_2, \mu_2) \tag{2}$$

$$y_3 = f_3(x_3, y_1, y_2, \beta_3, \mu_3) \tag{3}$$

$$y_4 = f_4(x_4, y_1, y_2, y_3, \beta_4, \mu_4) \tag{4}$$

where x_i is the set of exogenous regressors, and β_i and μ_i, are respectively, vectors of model parameters and the random error term for Eq. (1). According to this specification, the single-equation probit estimator is consistent for Eq. (1) and Eq. (2). On the other hand Eq. (3) and Eq. (4) were estimated using both P2STG and P3STG procedures. In Stage 1, Eq. (1) and Eq. (2) were estimated by the probit MLE procedure. In Stage 2, fitted values of the endogenous variables ($\hat{y}_1$ and $\hat{y}_2$) were computed using the Stage 1 parameter estimates. These were then used as regressors in Eq. (3) to generate a consistent estimator of β_3, using OLS. Eq. (4) was then estimated using OLS after replacing the actual values of the endogenous variables on the right-hand side with their fitted estimates (i.e. $\hat{y}_1$, $\hat{y}_2$, and $\hat{y}_3$). This generates the typical P2STG estimator (Maddala, 1983). The iterative seemingly unrelated regression (SUR) procedure was used instead of OLS in the Stage 2 to generate the P3STG estimates of the structural parameters of Eq. (3) and Eq. (4).

3.2. Exogenous determinants of farmers' planting choices

Several factors were hypothesized to influence maize farmers' planting decisions. First, the physical environment in which maize is grown is the most important factor determining the possible number of maize plantings per year. To a large extent, climatic attributes such as rainfall pattern and temperature dictate the optimal cropping intensity. For example, double cropping is feasible with bimodal rainfall. At the same time, temperature levels influence the rate of maize development and hence the length of the growing season or production cycle. Second, human population density in a region is an important determinant of the total demand for food or scarcity of farmland, and consequently of the need for more than one maize harvest per year. Third, larger families require more food (maize) per year, though the ability to meet family demand for maize depends on the total farm area available to the household (i.e. farm size).

The influence of climatic variability, farm size, and population density on the pattern of maize cropping in Kenya is shown in Table 1. A higher frequency of intercropping is observed among small-scale farmers, and under high population pressure.

Proximity of the maize plot ('Shamba') to the homestead and its topography (i.e. steep slopes or flat land), are also assumed to influence farmers' decision to plant maize in a pure stand or with other crops. Planting maize in combination with other crops, especially food crops, is expected to be practised more on the home Shamba (maize plot near the homestead), as it is considered the major source of food for the farming family compared with 'away' fields (Beets, 1990; Hassan et al., 1994a). Farmers may choose to intensify maize production (i.e. use double and mixed cropping) on sloping plots to reduce erosion (by providing continuous crop cover). Access to extension (information), and the farmer's age, sex and level of education are expected to influence cropping pattern choices (y_1 and y_2) through their influence on availability of labour, division of work, experience or knowledge, and the ability to acquire and process information.

Ways in which cropping-system choices are expected to affect selection of the suitable cultivar are discussed above. At the same time, the most important exogenous elements determining cultivar suitability are moisture and temperature, as they define the length of the growing season. The physical climate also determines the spectrum of biotic and abiotic stress factors affecting maize production, and consequently tolerance or susceptibility of the selected germplasm. Moreover, certain cultivars may be preferred to others on the home Shamba compared with distant fields, for quick maturity, taste for roasting green, etc. The effect of population pressure on germplasm selection is expected to work indirectly through its influence on cropping intensity (y_1). Female farmers may have preferences for certain varietal traits, that may be different from those of male farmers. Again, experience and knowledge (age, education, and extension) of the farmer are expected to affect their varietal choices.

As hypothesized earlier, whether the farmer will have a second crop of maize or not (y_1), plant maize as a sole crop or in combination with other crops (y_2), and the type of germplasm planted (y_3), are all expected to influence farmers' decision of when to plant (y_4). Moreover, the date of planting the first (or only) maize crop is expected to vary with variations in the time of the onset of the rains, availability of labour (family size, holding size), access to machinery services, method of sowing, distance between the homestead and the maize field, experience, and information. Agroclimate affects the date of planting choice indirectly, through its effect on the other choice variables ($\hat{y}_1$, $\hat{y}_2$, and $\hat{y}_3$). Average time of onset of the rains is also expected to be highly correlated with agroclimatic classification. Accordingly, agroclimatic zones were dropped as regressors from Eq. (4) to avoid multi-collinearity. Population pressure is also expected to work indirectly on the date of planting through cropping system choices.

The elements of the x_is (exogenous regressors) in Eqs. (1)–(4) are defined as follows:

1. the six agroclimatic zones (Table 1), which reflect the range of climatic conditions (rainfall and temperature variability) under which maize is produced.
2. Population density, measured as number of people per square kilometre. The 1989 census data for the survey sites are used. (This study surveyed maize farmers at 75 sites across 30 districts in Kenya (see Hassan et al., 1994b).)
3. The ratio of family size to farm size (number of family members per hectare of farm land). This variable measures the combined effect of family size and available farm land.
4. The sex, education, and age of the farmer. Whereas the age variable is measured on a continuous scale, dichotomous indices are used to code sex (male, female) and education (none, some) variables.
5. Extension advice (scored as one for those who received some extension advice and zero for those who received none).
6. Distance between the maize field (Shamba) and homestead. This variable was measured as a binary index of values (one for 'away' Shamba and zero for the home Shamba).
7. Slope of the maize farm, defined as flat (value of one) or sloping to very steep (value of zero).
8. Method of sowing (one or zero). Whether maize is sown mechanically (by machine or oxen) or manually may influence time of planting.
9. Average time of the onset of the first-season rains, indicating the start of the season. This variable is measured as number of days from the beginning of the year.

10. Access to machinery services (one or zero). This variable controls for the effect of ownership of a tractor or oxen on the timeliness of planting maize.

The elements of x_1 and x_2 consist of Factors 1–8 of the above list (i.e. $x_1 = x_2$). x_3 contains all factors up to regressor Factor 8 except population density. As discussed above, population density and agroclimatic factors were excluded from x_4 and regressor Factors 9 and 10 were added.

4. Results and discussion

Goodness of fit and error statistics (Table 2) indicate that the explanatory power and statistical performance of the fitted model are good. Parameter estimates from the P2SLS were not significantly different from the P3SLS-SUR estimates reported in Table 2, owing to the low cross-model correlation ($\sigma = 0.016$). The marginal effects of regressors on the probability of double cropping and intercropping were calculated as follows:

$$\partial P_i / \partial X_i = \varnothing(X'\beta)\beta_i \tag{5}$$

where P_i is the probability (or likelihood) of event i (i.e. a second maize crop), $\varnothing$ is the normal density function, and X and β are vectors of regressors and model parameters, respectively. These derivatives were evaluated at the mean values of the elements of X and parameter estimates β reported in Table 2.

The results show that the probability of planting two maize crops per year is higher in areas with bimodal rain, such as the mid-altitude zones, than in high potential areas (i.e. the moist TNZ and HT), where rainfall is predominantly unimodal. Intercropping is more likely in drier than wetter zones. This confirms results obtained elsewhere indicating that intercropping is used as a risk-management and food-security strategy in marginal environments (Norman, 1974; Nadar and Rodewald, 1979). On the other hand, greater land pressure (higher population density and higher family-to-farm ratio) increases the odds of both intensification strategies, double cropping as well as intercropping. By double cropping, more maize (the basic food staple) is produced per year from the same piece of land (land intensification) and intercropping contributes to increased food supply for the farming family, as the major intercrops are mainly food products, such as beans, potatoes, peas, and cassava. However, intercrop species tend to change from beans and potatoes in high rainfall areas to pigeon peas, sorghum, millet, and cassava in areas of unreliable rainfall (Hassan et al., 1994a).

Whereas education did not seem to be an important determinant of cropping intensity, the negative influence of extension contact on the probability of double cropping and intercropping was statistically significant. This reveals a very important relationship between access to information through extension and intensity of maize cultivation, and suggests that extension advice tends to promote single-season mono-cropping of maize. These results also imply that extension contact may be a substitute for formal education among the farming communities in developing countries, where education levels are very low. Older age reduces the probability of intensive cultivation. This could be because older farmers, through experience or more contact with extension, are more aware of the negative long-term consequences of intensive farming on soil fertility and pest control under poor management conditions. It may also be due to the lower demand for food and labour availability from families headed by older farmers, as adult members of the household begin to tend the land of their own newly established independent families.

Maize fields nearer to the homestead and relatively sloping fields are more likely to be intercropped than more distant Shambas and flat fields. Female farmers are also more likely to intercrop maize. Whereas intercropping may be used to reduce erosion (thick cover), double cropping is avoided on sloping plots. The high frequency of double cropping and intercropping on plots nearer to the homestead indicates that the home Shamba is the major source of food for the farming family, especially families headed by females. Intensive farming in maize is less likely on farms that are sown mechanically. This is mainly because mechanical cultivation is more common among large commercial maize farmers who mostly sow maize in pure stands and who concentrate in high-potential zones.

Table 2 also shows that cropping-system choices significantly influence germplasm selection in terms of desired duration to maturity. On average, relatively early maturing cultivars are selected when maize is planted in combination with other crops or when double cropped. Although it is expected that early maturity is preferred when two maize crops are harvested every year, this result also suggests that late-maturing cultivars are less adapted to the stress caused by the competition from intercrops. Shorter maturity time was associated with dryer and warmer zones, high population pressure, and home Shambas. This confirms the earlier findings that the home Shamba is more intensively cultivated and hence early maturing maize materials are needed, especially if land pressure is high. On the other hand, the

Table 2
The probit and probit three-stage (SUR) estimates of model parameters [a]

	y_1 (double cropping)		y_2 (intercropping)		Probit three-stage (SUR) estimates	
	Parameter estimate	Marginal effect	Parameter estimates	Marginal effect	Maturity y_3 (days)	y_4 (planting date) (days)
Double cropping (two crops = 1)	–	–	–	–	– 16.84 (6.7) ***	– 4.02 (– 1.87) *
Intercropping	–	–	–	–	– 11.7 (– 4.22) ***	7.11 (3.08) ***
Maturity in days (y_3)	–	–	–	–	–	0.16 (5.23) ***
Time of planting in days (y_4)	–	–	–	–	–	–
Zones:						
Dry mid-altitude	0.34 (11.7) ***	0.59	0.284 (7.4) ***	0.38	– 42.3 (– 14.1) ***	–
Moist mid-altitude	0.26 (6.4) ***	0.41	– 0.343 (12.7) ***	– 0.16	10.9 (3.6) ***	–
Dry transitional	0.62 (18.9) ***	0.77	0.363 (5.2) ***	0.52	– 10.2 (– 2.5) ***	–
Moist transitional	– 3 (14.1) ***	– 0.09	– 0.023 (0.08)	– 0.003	24.3 (10.4) ***	–
High tropics	– 0.8 (107.5) ***	– 0.27	0.074 (0.9)	0.016	53.6 (23.4) ***	–
Population density (persons km^2)	0.003 (158.9) ***	0.004	0.003 (1.9) *	– 0.0004	–	–
Ratio (members ha^{-1})	0.005 (.62)	0.001	0.0003 (0.003)	– 0.002	– 0.75 (– 3.41) ***	– 0.41 (– 2.39) ***
No education	0.12 (1.5)	0.008	0.008 (0.01)	0.01	4.32 (1.6)	1.07 (0.48)
Received extension advice	– 0.15 (13.6) ***	– 0.02	– 0.09 (5.4) ***	– 0.001	4.74 (3.8) ***	– 4.18 (– 4.21) ***
Age of farmer (years)	– 0.002 (.41)	0.02	– 0.008 (9.4) ***	– 0.003	0.148 (2.0) *	0.025 (0.42)
Male farmers	0.06 (2.1) *	0.012	– 0.04(0.81)	– 0.001	–	–
Distance (home shamba)	– 0.015 (0.04)	– 0.001	– 0.19 (6.7) ***	– 0.004	– 0.64 (– 0.27)	– 1.39 (– 0.74)
Flat field	0.0002 (1.0)	0.07	– 0.016 (0.2)	0.07	–	–
Mechanical sowing	– 0.28 (30.1) ***	– 0.04	– 0.4 (74.6) ***	– 0.12	–	– 2.97 (– 2.11) **
Used own planter or oxen	–	–		–	–	– 4.4 (– 2.8) ***
Onset of rains	–	–		–	–	0.59 (11.45) ***
Constant	– 0.93 (26.9) ***	– 0.496	0.74(16.6) ***	– 0.395	142.5 (26.2) ***	– 4.54 (– 0.58)
Log likelihood	– 738.2		– 698.2		–	
F ratio	–		–		80.3 ***	16.9 ***
R^2	–		–		0.43	0.24
n	1407		1407		1406	1406

Figures in parentheses are the χ^2 for y_1 and y_2 (and the t ratios for y_3 and y_4). *, **, and *** denote a 10%, 5%, and 1% significance level, respectively.

magnitude and high statistical significance of the extension factor indicate the important correlation between extension advice and maize maturity or germplasm selection (Table 2). This may be due to mere statistical correlation, indicating that extension services concentrate more on areas where late-maturing maize germplasm dominates.

The cropping pattern (y_1 and y_2), type of germplasm selected (y_3), land pressure (or availability of labour, i.e. high ratio), and access to extension advice and mechanical means of sowing are the most important determinants of the date of planting first-season maize, both in terms of magnitude as well as statistical significance (Table 2). Double cropped maize is planted about a week earlier on average than single-season maize. (To avoid singularity of the $x'x$ matrix, one dummy is dropped using the rule $\Sigma_i d_i = 1$, where d_i is the derivation of the mean of category i form the overall mean. Accordingly, the coefficient for one season crop is the negative of the coefficient of the included dummy (double cropping), i.e. 4 days later than average, whereas double cropped maize is planted 4 days earlier (Table 2).) On the other hand, monocropped maize (in pure stand) is planted 2 weeks earlier than intercropped maize. This may be due to the fact that intercropping is more common in drier environments (i.e. semi-arid and dry TNZ), where the rainy season starts later than in the moist zones. Availability of labour or access to mechanical means of cultivation appear to allow early planting. For instance, the larger the number of family members on the same farm land (high ratio) the earlier maize is planted. Also, farmers who use their own tractors or oxen plant earlier than those who hire machinery services (use but do not own). The time of onset of the rains is also a very important factor explaining variability in the time of planting. On average, for every day of delay in the onset of the rains, there is about one-half a day delay in planting. This indicates that, although farmers adjust their planting calendar according to the rains, they do not shift dates proportionally. As the date by which 80 mm of rainfall is accumulated was considered an indication of the beginning of the season (date of onset), most farmers did not seem to want to wait too long for accumulation of the full amount. This could imply that farmers consider the season to begin at a rainfall level lower than 80 mm (e.g. 60 mm). The age, sex, and level of education of the household head were not important in determining the time of planting.

5. Conclusions and implications for research and policy

Maize production in Kenya is practised under diverse agroecological and socio-economic conditions. As a result, a wide range of planting dates and cropping intensities, and significant variations in the length of the growing season (and hence choice of the suitable cultivar) are observed. The determinants of maize planting regimes were analysed in this paper. Better understanding of how farmers make their planting decisions is necessary for the design and dissemination of technologies suited to farmers' circumstances. This information should assist maize researchers and policy-makers to develop more relevant technologies and design appropriate policy and institutional intervention strategies to promote adoption of improved planting methods for increased productivity. Four interdependent decisions characterized farmers' planting strategies: choice of cropping intensity (double or single cropping) and pattern (mixed or monocropping), the suitable cultivar, and time of planting. These choices were modelled as one system of simultaneous equations. The model also contained endogenous categorical choice variables that appear in other structural equations (cropping system choices). The simultaneity and endogeneity problems were handled by using the probit two-stage and probit three-stage procedures to estimate the structural parameters of the model.

Choice of the cropping system proved to be an important determinant of farmers' decisions as to what variety to plant and when to plant their maize crop. Farmers attempting two maize crops per year or planting maize in combination with other crops used maize cultivars that matured earlier, on average, than under less intensive farming situations (i.e. single season or monocropping). On the other hand, population pressure and agroclimatic diversity explain a significant proportion of the variability in the intensity of maize cultivation and planting regimes. Land pressure tends to increase the likelihood of both intensification strategies (double and multiple cropping). This is mainly due to the high demand for food and labour availability at relatively higher man-to-land ratios. In drier and warmer zones shorter duration maize varieties were selected and planting started relatively early. These results further support the importance of focusing maize research and technology development in terms of agroecological zone and socio-economic conditions. Crop breeding and management technologies and planting regimes that would contribute to increased land productivity and intensity of labour use (land saving and labour using), such as shorter maturity and efficient double and multiple cropping methods, are required in areas of high population pressure, bimodal rainfall and more marginal environments. On the other hand, maize technologies that would lead to increased productivity of capital, e.g. higher response to modern external inputs (fertilizer, hybrid seed, pesticides, mechanization, etc.) and increased efficiency of their use (levels and timing) are needed in areas of high biological potential and population pressure, such as in the HT of Kenya.

These research strategies must be supported with appropriate policy and institutional arrangements. For instance, improved access to cheaper modern inputs is crucial for promoting adoption, especially in high potential zones where the payoff to the use of external inputs is high. Examples include investments in rural roads and marketing infrastructure (storage, credit to private dealers, etc.), which will lower transportation and transaction costs and, consequently, lead to lower input prices to farmers. Marketing margins will also improve, attracting private input traders, and this will lead to more competitive and efficient input supply systems and in turn lower prices. Lower transportation costs will also contribute to increased labour mobility and establish an inter-region wage differential that reflects scarcity (opportunity cost) and productivity of labour. Access to machinery, distance to the maize plot, and time of onset of the rains were also found to significantly influence planting regimes. Farmers who use their own mechanical means of planting (oxen or tractor) were able to plant earlier. Mechanical planting, however, was associated with monocropping and higher frequency of single cropping, which concentrate in the large commercial maize sector in the highlands of Kenya. Improved access to mechanical means is therefore critical for optimal planting, particularly in more marginal areas where the rainy season is shorter and less certain.

Regression results also showed that better access to extension advice tended to reduce the probability of intensive maize cultivation and was associated with a longer growing season and cultivar maturity period. Although this could be dismissed as a chance correlation, it could also suggest a systematic bias in focusing such advice on high-potential regions where large commercial farming, longer cropping seasons, and monocropping are the dominant mode of maize production. If the latter is true, extension services need to be redirected towards areas of relatively lower production potential, such as the MAT and semi-arid zones.

Maize plots nearer to the homestead were planted earlier and double cropped with relatively earlier maturing maize cultivars that are planted in mixtures with other crops. This indicates the high intensity of farming practised on such plots. Given the dominance of home fields in smallholder agriculture in Africa, it is critical to the welfare of farming families and agricultural development to develop and introduce technological, policy, and institutional innovations that would enhance the sustainability of such intensive cropping systems. Of special importance are policies and methods that contribute to more efficient fertility management, nutrient recycling, and soil conservation on such small family plots. Unlike population and technical factors, farmer characteristics such as the sex, age, and level of education of the farmer did not prove to be important determinants of the planting regimes of maize farmers.

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