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Ex-ante agricultural research evaluation with site specific technology generation: the case of sorghum in Kenya [1]

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Abstract

Agricultural commodity research has very site-specific productivity impacts. Crucial determinants of the magnitude and distribution of research benefits include agroecological conditions for technology generation and adoption, as well as commodity market-structure. This paper presents a process for ex-ante research evaluation which accounts for these factors with a dynamic, spatial multi-market model. Simulation results based on sorghum research in Kenya demonstrate that potential research benefits can vary dramatically across program research target zones. In Kenya, however, population-induced demand growth not technological development will have the greatest influence on future sorghum markets. © 1997 Elsevier Science B.V.

1. Introduction

The complex relationship between technology generation and other components of the agricultural economy limits effective forecasting of the benefits from alternative agricultural research investments. This limitation is particularly true is sub-Saharan Africa where agricultural production systems are characterized by tremendous diversity and rapid change. Most ex-ante research evaluation and priority setting efforts in the region, to date, have been based almost exclusively on the subjective assessment of senior research managers, often within a scoring model framework [2]. The lack of systematic incorporation of quantitative information on the current environment, as well as future trends, have often limited the credibility of these research-evaluation and priority-setting efforts. Furthermore, the results have provided little guidance for resource allocation by geographic area or major research theme within commodity groups. Many countries are now embarking on a second generation of priority-setting efforts with a recognition of the need to develop information bases,

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[1] This paper is based on the author's contribution to the Kenya Agricultural Research Institute Sorghum Program priority-setting exercise.

[2] Scoring models rank potential research impact based on standardized scores attached to several weighted research objectives. Nine out of ten national research institutes in the Association for Strengthening Agricultural Research in East and Central Africa have set cross-commodity research priorities with scoring models.

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processes, and methods for ex-ante research evaluation which address both the site-specific nature of technology generation and the dynamic environment within which technical change occurs.

This paper presents a program-level method for ex-ante research evaluation and priority setting developed by the Kenya Agricultural Research Institute (KARI) and the International Service for National Agricultural Research (ISNAR). The method has several unique features: 1) priorities are set spatially, as well as thematically, in recognition of the site-specific nature of much of the research conducted by the institute; 2) the uncertain nature of technology generation and the process of adoption over time is explicitly accounted for in the elicitation of research potential; and 3) important market factors such as changes in the demand for sorghum owing to population growth, as well as price wedges between different sorghum growing zones in Kenya, are included in a spatial, multi-market model of potential research impacts over a thirty-year time horizon. The KARI Sorghum Program application is presented, however, the process has now been implemented by more than half of the institute's national commodity programs.

The next section of the paper establishes the spatial framework for the analysis by using a geographic information system to identify sorghum-research zones within which the impact of research technologies is reasonably homogeneous. Section three presents a conceptual framework for the elicitation of the potential for technology generation and adoption within target zones. Section four analyses sorghum markets in Kenya, particularly net consumption surpluses and production balances by zone and the accompanying spatial distribution of prices, as well as expected demand increases owing to population growth. Section five presents the major elements of the spatial multi-market model for agricultural research evaluation as well as simulation results of sorghum-program research benefits over a thirty-year planning horizon. Finally, the paper concludes with a brief discussion of the process for using ex-ante research benefit estimates to guide medium-term resource allocation decisions.

2. Major program research themes and zones

The priority-setting process was guided by a Priority Setting Working Group composed of key program scientists and extension workers from different disciplines and regions throughout Kenya. [3] The working group identified four major research themes within the sorghum program, three of which are reviewed in this paper: varietal development; crop management, and processing; utilization; and storage. [4] In addition to these themes, the national mandate of the program was divided into broad research zones which demarcate areas within which the application of new technologies arising from the major research themes deemed to have a relatively homogeneous biophysical (e.g. yield) effect.

Four research zones were identified by the working group: Humid Coastal, Semi-Arid Lowland, Moist Mid-Altitude, and Cold Dry Highlands by interactively mapping alternative sets of agroclimatic criteria from a geographic information system. [5] The three agroclimatic determinants (elevation, rainfall, and temperature) and the final criteria used to define relevant sorghum-research zones are given in Table 1. A map of zone locations within Kenya is presented in Appendix A.

[3] The Working Group consisted of agronomists, entomologists, pathologists, plant breeders, processing specialists, socio-economists, and extension officers.

[4] The forth major research theme of the Sorghum Program is technology dissemination, which focuses on disseminating existing research results through improved linkages with farmers and extensions. The translation of research results into economic benefits under the theme is, arguably, different and benefit estimates are not presented in this paper.

[5] Further description of the final criteria used in the Sorghum Program target zones is found in KARI (1995).

Table 1
Sorghum target zones

Zone	Elevation (m)	Rainfall [a] (mm)	Temperature (°C)
Humid coastal	0–250	225–500 (March–June); 50 (March–April); 40 (June)	na
Semi-arid lowlands	250–1150	250–525 (March–July or October–December)	> 11° (average minimum for July)
Moist-mid. altitude	1150–1750	500–1250 (March–July)	na
Cold dry highlands	1750–2300	40 (March–April)	> 5° (average minimum for July)

na is ''not applicable''.
[a] For the Semi-arid lowlands, rainfall may occur either between March and July or October and December.

Table 2
Sorghum area, production, and yield by research zone

	Humid coastal	Semi-arid lowlands	Moist mid-alt.	Cold dry highlands	Total
Estimate of area currently under sorghum (100 ha)	0.06	71.56	142.51	10.88	225.01
Estimate of current production (1000 t)	0.02	13.85	61.20	3.53	78.60

Sorghum area and production estimates for each zone were then calculated based on district-level averages of 1990 to 1993 Central Bureau of Statistics, first rain (March–June) and second rain (October–December) estimates, Table 2. [6] When area and production statistics are allocated to zones, the Moist Mid-Altitude zone ranks first in terms of both area and production (accounting for 63% of the area sown to sorghum and 78% of total sorghum production). The Semi-Arid Lowlands zone ranks a distant second in terms of both area and production, while the Cold Dry Highlands and Humid Coastal zones have very low imputed area and production estimates.

3. Potential for generation and adoption of technologies

Since the outcome of research investments will not be realized for many years, ex-ante technology generation and adoption parameters must be based on the subjective opinion of informed sources. The most knowledgeable sources for this type of information are often program experts with vested interests in the outcomes of the priority-setting exercise. The KARI priority-setting process attempts to control for the bias inherent in these subjective estimates of interested parties by basing estimates on discussion and consensus from both the Priority-Setting Working Group and subsequently a larger group of program stakeholders know as the Program Research Advisory Committee (PRAC). [7] However, the reliability of estimates is also often compromised by a poorly developed conceptual framework for elicitation of technology generation and adoption parameters.

[6] District area and production statistics were allocated to research zones based on the proportion of the district classified to each zone. See Mills et al., 1994 for a discussion of district-level sorghum production data.

[7] Benchmark information on historical yield and production-growth trends in the target zones, along with available information on adoption of previously released technologies was also used as a reference point when examining the ex-ante potential for technology generation and adoption.

The conceptual framework for the structured elicitation process can be divided into technology generation and adoption profile parameters.

3.1. Technology generation

Technology generation, by the nature of the research process, is uncertain and best represented as a distribution of possible outcomes. For commodities, outcomes are most commonly conceptualized in terms of yield increases (or avoided yield losses). However, such yield increases often require additional inputs, which lower the effective value of yield gains. Therefore, the working group focused on potential net yield gains, taking both gross yield increases and required additional input costs into account.

Net yield gains were specified in terms of minimum, most likely, and maximum possible outcomes. As mentioned, benchmark historical growth trends were used to guide the estimation of these parameters. [8] A more rigorous definition of what is commonly referred to as the ''probability of research success'' was also incorporated into the elicitation process in order to properly account for research outcomes with no possibility for dissemination. [9] Farmers, particularly resource-poor farmers, will only adopt technologies if net yield increases are significantly greater than zero. This threshold level for adoption will depend on factors such as farmer perception of technology risk, additional labor investments associated with the technology, and additional capital investments associated with the technology. Technologies whose net yield gains do not exceed this threshold will not successfully pass through the on-farm testing and evaluation phase of the research cycle and will not be released for dissemination. For each major research theme and zone, the threshold net yield gain needed for technologies to be released for dissemination was defined accounting for these factors.

For simplicity, potential net yield increases were assumed to follow a triangular distribution. The expected net yield gain was then calculated as the product of two parameters derived from the triangular probability density function: 1) the probability of exceeding the net yield gain threshold for the technology to be released for dissemination; and 2) the expected net yield increase conditional on the dissemination threshold being exceeded. Formulas for these calculations are given in Appendix B. The working group assumptions on the potential for technology generation are given in Table 3 and the rationale behind the assumptions is available in the programs' priority-setting document (KARI, 1995).

3.2. Technology adoption

Research impact will also depend on the rate and extent of adoption of technologies. Thus, it is essential to include an assessment of the likely adoption pattern. The basic characteristics of the adoption profile are: a) the research development lag, ending with the release of the new technology; b) the initially increasing adoption rate as a growing number of farmers in the target area become exposed to the technology; c) the adoption plateau where most target farmers have been exposed to the technology and have decided whether or not to adopt it; and d) the declining adoption rate as the technology becomes obsolete. Combined, these components determine the speed and frequency with which research results are translated into farmer's fields. However, the profile parameters will also depend on the magnitude of the net yield gain embodied in the technology being

[8] Potential outcomes were also based on current program allocations of human and financial resources.

[9] In the standard framework, probability of success is multiplied by the expected net yield gains across the full distribution of possible outcomes. This practice erroneously includes research outcomes with no possibility of occurrence in farmers fields in the calculation of expected net yield gains. The present framework corrects for this problem, but still does not completely capture the complexity of the technology generation process. In particular, aggregate research themes often result in a package of technologies. Inter-related elements of the package are selectively adopted by farmers, which makes specification of a discrete threshold problematic.

Table 3
Estimated expected yield gains from research

Theme / zone	Net yield gains (%)				Probability of dissemination	Conditional expected net yield increase (%)
	Minimum	Most likely	Maximum	Adoption threshold		
Varietal development						
Humid coastal	6.75	40.50	54.00	15.00	0.96	34.71
Semi-arid lowlands	5.25	37.50	49.50	15.00	0.93	32.11
Moist-mid altitude	0.00	14.30	42.00	15.00	0.63	22.91
Cold dry highlands	0.00	10.00	22.00	15.00	0.19	17.05
Crop management						
Humid coastal	22.50	45.00	75.00	25.00	0.99	47.62
Semi-arid lowlands	15.00	37.50	45.00	30.00	0.67	36.25
Moist-mid altitude	17.50	37.50	125.00	50.00	0.60	71.97
Cold dry highlands	25.00	50.00	83.30	30.00	0.98	53.19
Processing, utilization, and storage						
Humid coastal	10.00	17.50	25.00	20.00	0.22	21.46
Semi-arid lowlands	3.50	7.50	20.00	15.00	0.12	16.46
Moist-mid altitude	10.00	20.00	50.00	12.50	0.98	27.09
Cold dry highlands	0.00	10.00	20.00	15.00	0.13	16.46

disseminated. Expected net yield gains, conditional on the dissemination threshold being exceeded, were used as the basis for estimating potential adoption profiles.

Like the technical potential of research, the ex-ante specification of adoption profiles was based on expert opinion from the working group and reviewed by the PRAC. The profile components are presented in Table 4 by theme and zone.

Table 4
Estimated adoption parameters

Zones	Research and development lag (years)	Maximum adoption (years)	Maximum adoption rate (%)	Start of disadoption (years)	Complete disadoption (years)
Varietal development					
Humid coastal	7	22	5	29	44
Semi-arid lowlands	6	16	20	22	32
Moist-mid altitude	6	16	20	22	32
Cold dry highlands	8	23	50	nd	nd
Crop management					
Humid coastal	4	19	20	nd	nd
Semi-arid lowlands	4	14	25	nd	nd
Moist-mid altitude	4	14	5	nd	nd
Cold dry highlands	4	14	40	nd	nd
Processing, utilization, and storage					
Humid coastal	3	8	40	nd	nd
Semi-arid lowlands	2	7	40	nd	nd
Moist-mid altitude	2	5	70	nd	nd
Cold dry highlands	3	8	12.5	nd	nd

nd: no significant disadoption of technologies is expected within the 30-year research planning horizon.

4. Characteristics of sorghum markets in Kenya

In this section, current net sorghum production, i.e. consumption balances, prices, and expected exogenous demand shifts owing to population growth are estimated for each research zone. Sorghum markets in Kenya can generally be characterized as closed to international trade. [10] Hence, the aggregate demand for sorghum within Kenya is assumed to equal aggregate supply. The distribution of sorghum consumption across districts is then calculated based on household sorghum/millet consumption estimates from the 1979 Kenya Rural Household Budget Survey and 1989 district-level household population figures (Central Bureau of Statistics, 1982, 1994). [11] Finally, the consumption of sorghum is allocated to target zones based on the area proportion of every district lying within each zone. The resulting figures are compared with the research zone production estimates to impute the current net sorghum surplus by zone, Table 5.

The results show the Moist Mid-Altitude zone is the major surplus producer of sorghum in Kenya, while the Semi-Arid Lowlands zone is roughly self-sufficient in an average year. The major net deficit zone is the Cold Dry Highlands which, along with the Humid Coastal zone, Nairobi and the non-urban rest of Kenya, must rely on surpluses from the Moist Mid-Altitude zone to meet consumption needs.

The spatial distribution of sorghum prices was empirically estimated from 1992 and 1993 Central Bureau of Statistics and Ministry of Agriculture monthly retail price data for 23 markets across Kenya. The markets were spatially referenced and Thiessen polygons were constructed in order to allocate all areas within Kenya to the nearest market (Eastman, 1992). Area-weighted monthly prices were then calculated for each research zone. In Table 6 the observed distribution of zone prices is expressed relative to January-through-April-1995 retail prices in the capital city of Nairobi. In the spatially linked production zone model, these wedges are held constant in absolute terms as prices rise and fall owing to research-induced supply shifts in specific zones.

While research can be expected to influence the supply of sorghum in Kenya, the most important factor influencing sorghum demand is population growth. Zone specific population-growth rates are calculated using 1979 and 1989 district census estimates, again assuming population is proportionally distributed by zone area in each district (Central Bureau of Statistics, 1994). Between 1979 and 1989 the Nairobi area had the highest rate of population growth, 4.7% per annum, while the non-urban rest of Kenya (primarily the Northern Province districts) showed the lowest rate of growth at 1.2% per annum, Table 6. The sorghum producing zones all showed very high rates of population growth, ranging from 3.1% per annum in the Moist Mid-Altitude zone to

Table 5
Benchmark sorghum supply and demand by research target zone

Zone	Production (1000 t)	Consumption (1000 t)	Net surplus (1000 t)
Humid coastal	0.02	3.51	−3.49
Semi-arid lowlands	13.85	12.08	1.77
Moist-mid altitude	61.20	31.53	29.67
Cold dry highlands	3.53	16.88	−13.35
Non-urban ROK [a]	0.00	8.58	−8.58
Nairobi	0.00	6.03	−6.03
Total	78.60	78.60	0.00

[a] These districts are in non-sorghum growing regions, primarily the arid Northern Province.

[10] FAO (1996) Trade Statistics indicate that between 1989 and 1992 Kenya imported only 15000 t of sorghum (all in 1992) and exported 16000 t. However, these figures do not include illicit cross-border trade, particularly with Uganda on the country's western border.

[11] No household-level millet/sorghum consumption figures existed for the urban centers of Nairobi and Mombassa, or the districts in the North Eastern Province. National household averages are used in these areas.

Table 6
Sorghum prices per metric ton by target zone

Zone	Price		Population growth	
	Kenyan shilling per metric ton	Wedge to Nairobi	1979–1989 growth rate (%)	Projected growth rate (−25%)
Humid coastal	10730	1795 [a,b,c,d]	4.12	3.09
Semi-arid lowlands	7671	−1264 [b,c,e]	3.44	2.58
Moist-mid altitude	6470	−2465 [a,d,e]	3.13	2.35
Cold dry highlands	6401	−2534 [a,d,c]	3.64	2.73
Nairobi	8935	0 [b,c]	1.24	0.93
Non-urban ROK	na	na	4.70	3.53

Sources: Central Bureau of Statistics and Ministry of Agriculture retail market prices surveys, Central Bureau of Statistics 1979 and 1989 censuses (Central Bureau of Statistics, 1994).
Note: Estimates in this table are expressed relative to January–April 1995 Nairobi retail prices in Kenyan shillings (1 US$ equals approximately 55 Kenyan shillings).
[a] Wedge significantly different (5% level) from the Semi-Arid Lowland zone in paired *t*-test.
[b] Wedge significantly different (5% level) from the Moist-Mid Altitude zone in paired *t*-test.
[c] Wedge significantly different (5% level) from the Cold Dry Highland zone in paired *t*-test.
[d] Wedge significantly different (5% level) from the Nairobi zone in paired *t*-test.
[e] Wedge significantly different (5% level) from the Humid Coastal zone in paired *t*-test.
na: Nairobi prices used in the analysis not available.

4.1% per annum in the Humid Tropics zone. These growth rates were discounted by 25% when modelling the impact of population growth on the demand for sorghum over the next thirty years in order to reflect projected decreased rates of population growth. In simulating supply side-shifts it was assumed there are no exogenous sources of growth other than the research-induced shifts of supply described in Section 3. This assumption is reasonable given that the overall area under sorghum production has remained fairly constant over the past twenty years and the focus of the study is on the potential benefits of research-induced supply shifts arising through yield-enhancing technologies.

Finally, the nature of shifts in the supply and demand curves will have an important impact on the magnitude, and particularly the distribution between producers and consumers, of research benefits. In the absence of contrary information, supply and demand curves are assumed to be linear and to shift in a parallel fashion. The actual slopes of the curves are determined by the supply and demand elasticities for sorghum. No supply elasticities have been estimated specifically for sorghum in Kenya. However, Rao (1989) reviews the empirical literature on supply response in developing countries and finds long-run supply responses to generally lie in the 0.3–1.2 range. In empirical studies of supply response, Bapna et al. (1984) estimate supply elasticities ranging from 0.38 to 0.77 for semi-arid sorghum zones of India, and Chidder and Hrabovszky (1983) estimate a supply elasticity of 0.16 for sorghum in the Sudan. In Kenya, a supply elasticity of 0.68 has been estimated for maize (Kiori and Gitu, 1992), a production substitute for sorghum in certain zones. Based on this range of estimates, a long-run supply elasticity of 0.5 is used in the current study. While the choice of supply elasticity will effect the absolute value of estimated research benefits, it will rarely effect the relative ranking of research themes and zones. Similarly, an own-price demand elasticity of −0.5 is used, in line with the estimate of Bezuneh et al. (1988) for sorghum and millet consumption in Kenya.

5. Research benefits in spatially linked production zones

The change in economic surpluses, (consumer surplus and producer surplus), is the most commonly used measure of the economic benefits generated from agricultural research. Changes in consumer and producer surplus are calculated for specific research themes within zones over a thirty-year time period with a multi-period, multiple (interlinked) market model. The model draws on Alston et al. (1995) and accounts for period specific research-induced supply shifts, increased demand for commodities owing to population growth, inter-zonal price wedges, and research-induced price spill-overs to other target zones.

5.1. Research-induced supply shifts

Successful research is assumed to induce a parallel downward shift in the commodity supply curve. The zone-specific expected unit cost reduction from research, K_{it}, is simply calculated for every period as the product of the probability of net yield gains exceeding the dissemination threshold ($\Pr(k_i > k_i^a)$), the expected net yield gain conditional upon the dissemination threshold being exceeded ($E[k_i|k_i > k_i^a]$), the expected adoption rate for the period ($A_i t$), and the initial unit price of the commodity (P_{i0}) divided by the supply elasticity for the zone (ϵ_i).

$$K_{it} = \Pr(k_i > k_i^a)\, E[k_i|k_i > k_i^a]\, A_{it} P_{i0}/\epsilon_i.$$

The initial zone-specific linear supply curve is specified as:

$$Q\mathrm{s}_{i0} = \alpha_{i0} + B_i P_{i0}$$

where $Q\mathrm{s}_{i0}$ is the initial quantity supplied in zone i, α_{io} is the initial supply intercept in zone i, and B_i is the fixed supply slope parameter in zone i. The initial supply intercept and fixed slope parameter are easily calculated from the initial quantity supply, price, and elasticity estimates for the zone.

The unit-cost reduction for a specific point in time t translates into a research induced change in the quantity supplied as follows:

$$Q^{\mathrm{r}}\mathrm{s}_{it} = \alpha_{it}^{\mathrm{R}} + B_i P_{it}$$

where $\alpha_{it}^{\mathrm{R}} = \alpha_{i0} + K_{it} B_i$ is the intercept of the "with research" supply curve in zone i for period t.

5.2. Demand curve shifts due to population growth

Exogenous shifts in the sorghum demand curve, owing to factors such as population growth, are included in the model. The linear demand curve for zone i in period t can be expressed as:

$$Q\mathrm{d}_{it} = \gamma_{it} + \delta_i P_{it}$$

where $Q\mathrm{d}_{it}$ is the quantity demanded in zone i at time t, γ_{it} is the demand intercept in zone i at time t, and δ_i is the fixed demand slope parameter for zone i.

Again, the zone-specific demand intercept and slope parameters are calculated from the initial demand, price, and elasticity. Population growth will prompt an increase in the intercept term of the demand function in period $t+1$ of:

$$\gamma_{it+1} = \gamma_{it} + \pi_i Q\mathrm{d}_{it}$$

where πi is the population growth rate for zone i.

5.3. Constant inter-zonal price wedges

Finally, prices in zone i for period t (P_{it}) are specified in terms of the Nairobi price (P_{nt}), net of a price wedge (T_i) which reflects the transactions costs of shipping surplus sorghum to (or from) Nairobi. T_i is held constant in real terms over time.

$$P_{it} = P_{\mathrm{nt}} - T_i.$$

5.4. Market clearing conditions

For each period, equilibrium quantities and prices are determined in the "with" and "without" research scenarios through the respective market clearing conditions:

$$\sum_i Q\mathrm{s}_{it} = \sum_i Q\mathrm{d}_{it} \text{ and } \sum_i Q^{\mathrm{R}}\mathrm{s}_{it} = \sum_i Q^{\mathrm{R}}\mathrm{d}_{it}.$$

If equilibrium quantities differ in the two scenarios, zonal prices will also differ in the without (P_{it},) and with (P_{it}^{R}) research scenarios.

5.5. Producer and consumer surplus measures

Research-induced changes in producer and consumer surplus (ΔPS and ΔCS) are easily calculated from equilibrium quantities and prices for the "with" and "without" research scenarios. The change in producer surplus in zone i at time t is calculated as:

$$\Delta \mathrm{PS}_{it} = \left(K_{it} + P_{it}^{\mathrm{R}} - P_{it}\right)\left[Q_{it} + 0.5\left(Q_{it}^{\mathrm{R}} - Q_{it}\right)\right].$$

The corresponding change in consumer surplus is:

$$\Delta \mathrm{CS}_{it} = \left(P_{it} - P_{it}^{\mathrm{R}}\right)\left[Q_{it} + 0.5\left(Q_{it}^{\mathrm{R}} - Q_{it}\right)\right].$$

The present values for the stream of producer and consumer surplus changes (VPS and VCS, respectively) over the thirty-year research planning horizon for each zone are:

$$V\mathrm{PS}_i = \sum_{t=0}^{30} \Delta \mathrm{PS}_{it}/(1+r)^t \text{ and } V\mathrm{CS}_i = \sum_{t=0}^{30} \Delta \mathrm{CS}_{it}/(1+r)^t.$$

Where r is the real discount rate for the use of public sector financial resources. In this study, the real discount rate is assumed to be 5%, based on the interest rate of Government of Kenya agricultural sector loans. Surplus changes can be added across zones to assess the total impact (within and across zones) of spatially targeted research.

Simulated changes in producer and consumer surplus, owing to research, are presented in Table 7. Changes in total surplus vary markedly across research themes and target zones. Based on the assumptions described in the previous sections and its current allocation of human resources, the sorghum program expects to generate total benefits of 294 million 1995 Kenyan shillings (K. Sh.) through varietal development research, 445 million K. Sh. through crop management research, and 2392 million K. Sh. through processing, utilization, and storage research.

Table 7
Potential economic surplus generated by sorghum research

Surplus type	Humid Coastal	Semi-Arid Lowlands	Moist-Mid Altitude	Cold Dry Highland	All Zones
	Million Kenyan shilling				
Varietal Development					
Producer surplus	0.03	55.91	88.54	2.46	145.89
Consumer surplus	0.02	46.20	98.84	2.77	148.17
Total surplus	0.05	102.10	187.39	5.23	294.06
Crop management					
Producer surplus	0.24	78.04	90.55	56.67	222.74
Consumer surplus	0.12	64.29	101.13	56.26	222.70
Total surplus	0.37	142.33	191.67	112.92	445.43
Processing, utilization, and storage					
Producer surplus	0.07	12.97	1134.43	0.78	1146.17
Consumer surplus	0.04	10.92	1233.78	0.89	1246.29
Total surplus	0.10	23.89	2368.21	1.67	2392.46
Per full-time equivalent researcher					
Varietal development					
Total surplus	0.17	102.10	187.39	5.23	89.11
Crop management					
Total surplus	0.53	118.61	95.84	112.92	90.90
Processing, utilization, and storage					
Total surplus	0.50	23.89	4736.42	0.84	646.61

Note: real discount rate is 5%; Nairobi price is 8935 K.Sh per metric ton.

The level of sorghum production shows a greater variance across zones than do expected yield gains, adoption rates, or prices. Therefore, for each theme, the ranking of benefits estimates corresponds to the ranking of the level of production across research zones. However, the potential for generation and adoption of technologies plays an important role in determining the relative level of research theme benefits within each zone. In the Moist Mid-Altitude zone, the processing, utilization, and storage research theme shows far greater potential benefits than the varietal development and crop management research themes owing to the dramatically higher expected rate of adoption of technologies generated under the theme. Similarly, for the Semi-Arid Lowlands zone, benefits are concentrated under the varietal development and crop management research themes. While in the Cold Dry Highlands, crop management shows higher benefits than the other themes. Finally, in the Humid Coastal zone, benefit estimates are extremely low for all themes owing to the small production base.

In all cases, producer surplus changes comprise a slightly higher proportion of total surplus changes than consumer surplus. Furthermore, consumer surplus benefits are widely distributed across Kenya owing to the equal distribution of price decreases through inter-linked markets. Producer surplus changes, by contrast, are concentrated within the targeted research zone, where the additional surplus generated from lower unit production costs outweighs the loss from a lower price. In zones not targeted by research, producer surplus is negative because the lower equilibrium price is not offset by unit-cost reductions in the zone.

Potential research benefits are also presented on a full-time equivalent (FTE) researcher basis in Table 7, based on the current allocation of sorghum program human resources across themes and zones. Zone-specific

Table 8
Sorghum market conditions in thirty years under closed and open markets

Economy type	% Change		Imports as percent of base production	Research benefits (Million K. Sh.)
	Quantity produced in Kenya	Equilibrium price		
Closed market				
Without research	46.8	69.7	0	0
With research	58.6	50.9	0	3090
Open market				
Without research	3.2	3.7	101.5	0
With research	26.9	3.7	78.5	2701

themes with large benefit to FTE ratios may be priority areas for further human resource investments. Research production functions, however, are rarely linear and the re-allocation of specific human and financial resources needs to be determined through a consensus-building process with the PRAC. [12]

Finally, an examination of equilibrium price and quantity trends over time highlights the challenge which population growth poses for agricultural technology development in Kenya. Without research, and explicitly assuming no other source of increased productivity, population-induced demand growth in a closed economy is projected to cause the equilibrium sorghum price to increase by 69.7% over the thirty-year planning horizon, Table 8. The accompanying increase in equilibrium quantity, induced by the price rise, is 46.8%. If the expected research impacts are achieved in all themes and zones, the equilibrium price of sorghum will still increase by 50.9%, while the equilibrium quantity will increase by 58.6% over the same thirty-year horizon. [13] The accompanying net present value of research benefits over the thirty-year time horizon is estimated at slightly over three billion Kenyan shillings.

Little external trade in sorghum currently occurs. The simulated price increases may be sufficient over thirty years, however, to stimulate expanded regional trade in sorghum. The sensitivity of sorghum research benefits to closed-market assumptions is explored by including a regional sorghum-market composed of bordering countries. Based on current production estimates, Kenya holds only a 4.8% share in this regional market. [14]

Without research, in an open sorghum-market the supply of Kenyan-produced sorghum increases by only 3%, and after thirty years, imports increase from zero to an equivalent of 102% of base domestic production. Under the "with research" scenario the growth in imports is ameliorated. Kenyan domestic supply increases 27% but imports still equal 79% of base domestic production after thirty years. Benefits attributable to research will also be slightly lower in the open-market scenario than in a closed market owing to lower base prices and production levels. The distribution of research benefits, however, shifts strongly in favor of producers since research-induced price-decreases are dampened by the wider regional market. [15] Overall price increases are

[12] Alternatively, non-linearities in the research production function can be modelled by eliciting expected changes in technology generation and adoption parameters for a given change in program resources.

[13] Technology generation and adoption parameters were aggregated across themes in each zone by adding expected net-yield parameters and averaging adoption profile parameters.

[14] Kenyan sorghum production is grouped with Ethiopian, Somalian, Sudanese, Tanzanian, and Ugandan.

[15] Consumers do gain substantial benefits from lower prices compared to the closed-market scenario. However these benefits are due to the assumed change in market structure, not to research.

contained at under 4% over the 30 year horizon. Most importantly, for the purposes of this analysis, the relative ranking of expected program benefits does not change across themes and zones. Thus, while market structure can dramatically change terminal market conditions and the distribution of research benefits between consumers and producers, the effect on total research benefits and their distribution across themes and zones is not significant.

Accounting for potential cross-commodity substitution effects over a thirty-year time horizon is more problematic, particularly with zone-specific consumption and production patterns. In the 1970s, Kenya saw a general substitution away from sorghum production and consumption to maize and wheat. The 1980s then showed relatively stable ratios within the sorghum, maize, wheat commodity-group. Outside of the commodity group, however, major shifts to high-value horticultural export crops occurred in some zones.

Cross-program priority-setting exercises may wish to focus more effort on clearly delineating potential future cross-commodity effects when comparing the potential impacts of alternative commodity-research programs. However, careful thought must be given to the trade-off between the increased accuracy of research benefits measurement from inclusion of these interactions, on the one hand, and the increased complexity and measurement errors associated with linking commodity supply and demand responses, on the other. Within program priority-setting exercises like the one presented in this paper, diminished focus on the internal elements of the research program driving research benefits more than outweighs potential gains from explicitly addressing cross-commodity affects.

6. Linking benefit estimates to resource allocation decisions

This paper has presented an efficient process for estimating the spatial and thematic distribution of potential research benefits within national commodity research programs. Such information is of little value, however, unless it is actually used by research managers to improve program formulation and resource allocation. The information must, therefore, be incorporated into the existing institutional process for making resource allocation decisions. In the sorghum program, this was done by presenting the results to PRAC for review, modification, and implementation.

The PRAC generally supported the assumptions of the working group and identified medium and high priority research areas based on the results. High priority was assigned to the technology dissemination research theme in the Moist Mid-Altitude and Semi-Arid Lowlands zones. Medium priority was assigned to the varietal development, crop management, and processing, utilization, and storage themes in the Moist Mid-Altitude and Semi-Arid Lowland zones, as well as to crop management and technology dissemination in the Cold Dry Highland zone. These priorities were then translated into a set of medium-term resource-allocation guidelines, particularly for human resource development, which are now being used by the PRAC during its annual program review. Finally, as part of the continuing process of research evaluation and priority setting, upon completion of all within-program priority-setting exercises, the results from all program exercises will also be used to update the 1991 institute-wide commodity program priority-setting exercise.

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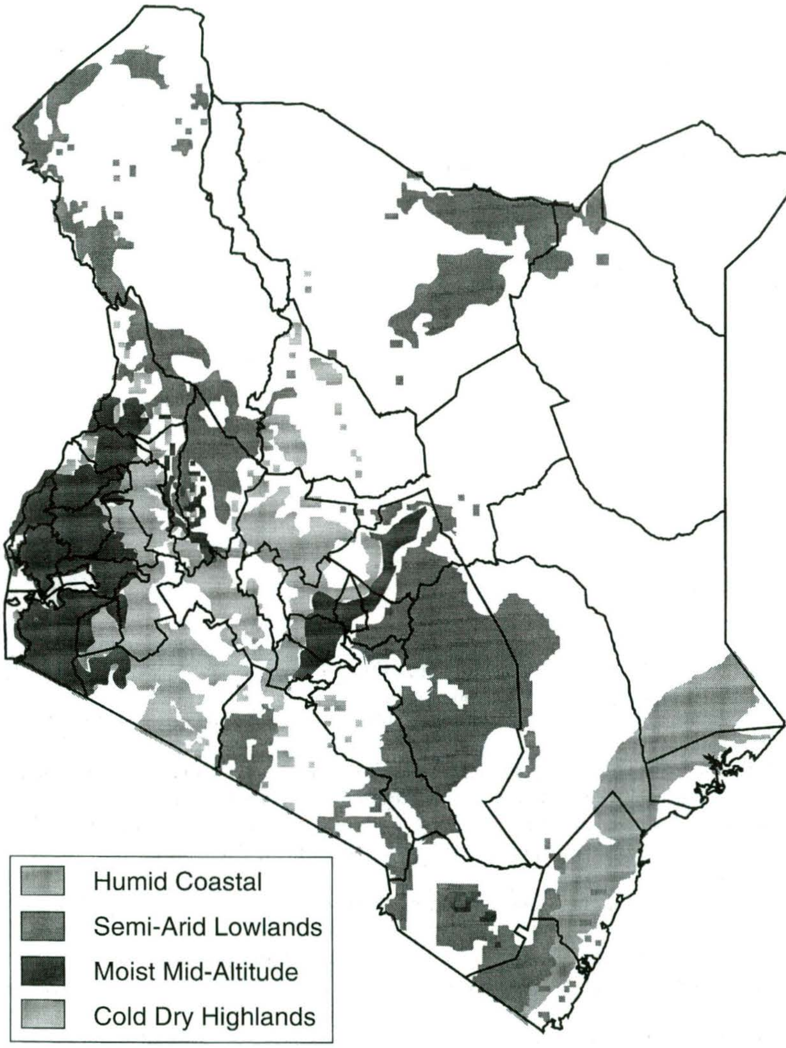
Appendix A. Sorghum research target zones



Appendix B. Formulas for calculating the "probability of dissemination" and conditional expected net yield gain

For a triangular probability density function, the cumulative probability of producing an innovation with a net yield gain above K^* is:

$$\Pr(K \geq K^*) = 1 - \frac{(K^* - K_1)^2}{(K_h - K_1)(K_m - K_1)} \text{ if } K_1 \leq K^* < K_m$$

and

$$\Pr(K \geq K^*) = \frac{(K_h - K^*)^2}{(K_h - K_l)(K_h - K_m)} \text{ if } K_m \leq K^* < K_h.$$

The expected net yield gain, $E[K]$, given that the threshold value for dissemination is reached, can be easily calculated on a computer spreadsheet with the following formulas:

$$E[K|K \geq K^*] = \frac{\left[_{K^*}^{K_m}\left(\frac{2}{(K_h - K_l)(K_m - K_l)}\right)(1/3K^3 - 1/2K^2K_l) + \left[_{K_m}^{K_h}\left(\frac{2}{(K_h - K_l)(K_h - K_m)}\right)(1/2K^2K_h - 1/3K^3)\right.\right.}{\left[_{K^*}^{K_h}\frac{2}{(K_h - K_l)(K_m - K_l)}(1/2K^2 - K_l) + \left[_{K_m}^{K_h}\frac{2}{(K_h - K_l)(K_h - K_m)}(K_h - 1/2K^2)\right.\right.}$$

for $K_l \leq K * < K_m$ and

$$E[K|K \geq K^*] = \frac{\left[_{K^*}^{K_h}\left(\frac{2}{(K_h - K_l)(K_h - K_m)}\right)(1/2K^2K_h - 1/3K^3)\right.}{\left[_{K^*}^{K_h}\frac{2}{(K_h - K_l)(K_h - K_m)}(K_h - 1/2K^2)\right.}$$

For $K_m \leq K^* < K_h$.

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