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EVALUATING TECHNICAL INNOVATIONS UNDER LOW-RESOURCE FARMER CONDITIONS

By J. C. FLINN *and* J. LAGEMANN†

International Institute of Tropical Agriculture, Ibadan, Nigeria

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SUMMARY

Before an innovation can be judged as superior to existing technology, its relevance should be jointly evaluated by researchers and farmers by testing the proposed practice in a farm environment. Using a proposed maize technology as an example, it is demonstrated how site-related and management variables can be used to quantify the factors influencing actual yields on farmers' fields. Similarly, economic and management analysis of the practice provides an estimate of the probability of the farmer being better off by using the technology. The integrated analysis of the practice provide insights for the design of problem-oriented research projects.

There seems to be general agreement that problem-oriented agricultural research designed to develop technical innovations appropriate to the low-resource farmer should be focused on the farm rather than the experiment station (Dillon *et al.*, 1978). The on-farm experimental phase normally passes through a sequence from research-managed trials to the farmer evaluating the proposed technology in collaboration with the researchers (Zandstra, 1978). The concept of conducting problem-oriented research in the environment in which the results will be implemented also has the advantage of broadening the scientist's experience and understanding of the real problems and characteristics of the farming systems that the research is proposed to change.

The purpose of this paper is to report on an example of a proposed technical innovation that was evaluated at the point where the farmers were managing the practice. The procedure focused on three points.

(1) An analysis of factors influencing the yield of the recommended practice,
(2) An economic assessment of the proposed practice, and
(3) The farmers' impressions of the proposed technology.

The specific practice evaluated is a maize production package researched in south-eastern Nigeria.

The study area and approach

The farming systems of three villages in Imo State, varying from low to high population densities per hectare of cultivated land (but similar in other respects), were studied to evaluate the impact of increasing man/land ratios on the

† Present addresses: International Rice Research Institute, Los Baños, Philippines, and German Technical Aid Program, Yaounde, Cameroon respectively.

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productivity of bush-fallow based agriculture.† The result of the increasing pressure on land resource was an intensification of compound farming, reduced periods of fallow in outer fields, and an increase in the importance of tree crops and livestock as sources of cash income (Table 1). The impact of reduced periods of fallow was diminishing productivity of land and labour resources committed to food crop production (Lagemann *et al.*, 1976). Sixty-eight farmers collaborating in the farm management study agreed to grow a field of maize, using a set of recommended practices which included an improved maize variety (TZBc4, a white grained composite); land selection (freely-drained soils

Table 1. *Characteristics of farms in sample villages, 1975†*

	Village/population density		
	High	Medium	Low
Persons/km² (estimated)	500	350–500	350
Compound (home) farms	intensive	well developed	less well developed
Outer fields			
years of crop	1–2	1–2	1–2
years of fallow	1–2	3–4	5–6
Value of production per farm (₦)	246	324	484
Value of sales (₦)	77	175	309
of which arable crops (%)	10	21	47
tree crops (%)	77	71	49
livestock (%)	13	8	4
Sales as proportion of production (%)	31	54	64

† Source, field survey conducted by Farmings Systems Program, IITA

directly out of fallow); minimum tillage; planting patterns and population (40,000 plants/ha); application rates of fertilizer (100-50-50 NPK); weed control; and where necessary, plant protection.

The views of collaborating farmers were sought before details of the recommended practice were finalized to ensure that they regarded the practice as sensible and that only locally available inputs were recommended. Prior to planting time, and before each major activity on the maize crop, a field day was held in each of the three villages in collaboration with the local agricultural officer, to demonstrate the practices to the farmers. While the farmers were subsequently encouraged to follow the recommended practices, there was no pressure on them to do so, thus simulating a situation in which extension services and inputs were available to the farmers at an appropriate time.

† The mean annual rainfall in the area is in the order of 2300 mm with peaks in July and September and a trough in August. The cropping season normally lasts from mid-March to late November. Soils in the area are coarse-textured Ultisols derived from deeply weathered Plio-Pleistocene sedimentary rocks. Floyd (1969) provides a general overview of the study area, while Lagemann (1977) provides an in-depth analysis of farming systems in the three villages.

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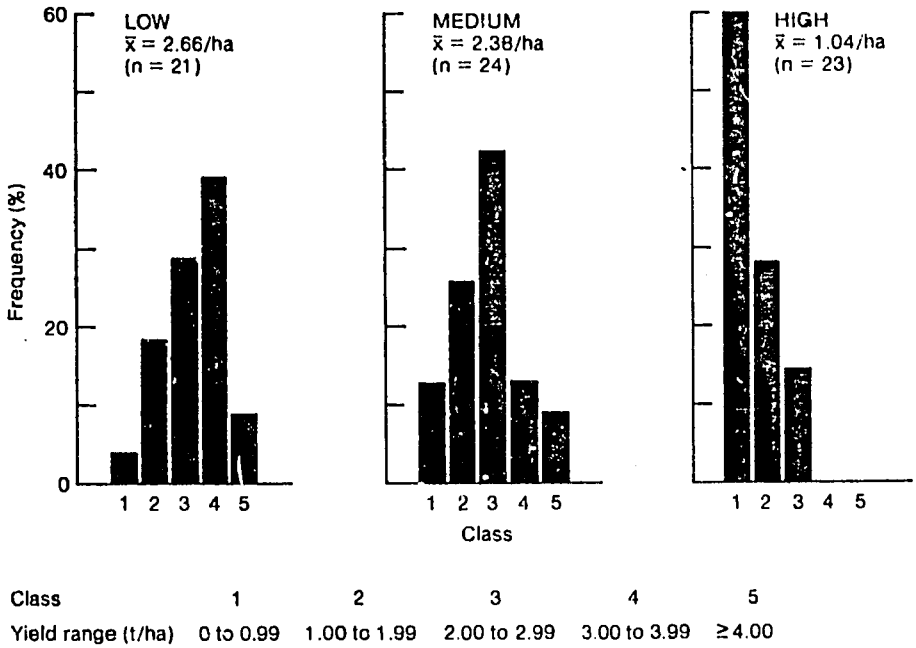

Fig. 1. Distributions of maize yields for low, medium and high population density villages, 1975.

MAIZE YIELDS AND FACTORS INFLUENCING YIELDS

Maize yields realized by participating farmers are shown in Figure 1. Both modal and average yields declined from the low to medium to high population density villages. Average values for some of the fertility parameters derived from composite soil samples from each field (Table 2) confirm other reports (Nye and Greenland, 1960) that increasing intensity of cultivation and shorter fallows on these coarse-textured Ultisols causes the pH, cation exchange capacity and soil phosphate to decline. The base saturation was also considerably lower in village H than in L or M, but there was no apparent decline

Table 2. *Analyses of surface soils of maize plots in the three survey villages, 1975*

	Village/population density					
	High		Medium		Low	
	x̄	SD	x̄	SD	x̄	SD
pH	4.85	0.39	5.14	0.40	5.18	0.49
Organic carbon (%)	2.77	0.27	3.15	0.24	2.74	0.37
Base saturation (%)	50.4	23.2	74.4	22.3	71.3	27.7
P (Bray P1) (ppm)	9.60	6.73	22.12	10.5	29.8	14.0
Exchangeable K (meq/100 g)	0.12	0.05	0.11	0.04	0.13	0.02
Effective CEC (meq/100 g)	2.86	0.32	3.91	0.73	4.10	1.63

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in organic carbon or potassium with fewer years of bush fallow, probably because the fields had only recently been cleared and burned.

The low base saturation of soils in village H probably contributed to its dismal maize yields, and low calcium and magnesium levels were presumably more important yield-limiting factors than aluminium toxicity on these acid soils (Juo and Uzu, 1976; Pearson, 1975). Mean potassium levels in all the soils were below the generally accepted minimum of 0.15 meq/100 g, but the addition of muriate of potash (50 kg K_2O/ha) overcame this deficiency. Thus it is not surprising that the maize in village H showed little response to N, P and K fertilizers, because Ca and Mg probably remained deficient. Liming (or burning of older bush) has been shown to ameliorate these problems (Forbes, 1975), but agricultural lime is not locally available and liming may also induce deficiencies in other nutrients, such as Zn (Greenland, 1975).

Maize yields, soil fertility and management

The soil parameters measured and the management inputs recorded during growth of the maize were included in regression models to explain the observed differences in yields and to assess the relative importance of each of these factors in determining yields. During the initial analysis, the level of labour inputs proved to be unstable in sign and not significant, so the timing of operations instead of hours of labour inputs per ha are included in the two final models (logarithmic or Cobb-Douglas functions) in Table 3. Model 1 includes base saturation as a variable and Model II, pH, using the variables separately due to their high collinearity ($r = 0.72$). Model 1 is statistically more robust and

Table 3. *Factors significantly influencing maize yields on farmers' fields*

Variable	Mean value	Range Min	Range Max	Model I† Bi	Model I† t-value	Model II† Bi	Model II† t-value
X_0 Constant	–	–	–	0.9636 × 10^{-5}	7.83	0.8343 × 10^{-4}	6.44
X_1 Planting date‡	25	5	48	−0.0135	0.45	−0.2322	2.16
X_2 Days to first weeding	23	7	65	0.3460	3.25	0.4212	3.28
X_3 Days to thinning	17	7	53	−0.4368	2.12	−0.6065	2.46
X_4 Dummy for second weeding	–	1	2	0.4450	2.80	0.4557	2.37
X_5 Density at harvest ('000)	184	106	346	0.7152	4.23	0.8093	3.93
X_6 Organic carbon (%)	2.90	2.00	3.71	1.2353	2.88	0.8347	1.62
X_7 Phosphorus (ppm)	20.7	1.36	49.9	0.1761	2.58	0.1144	1.36
X_8 Base saturation (%)	66.0	18.1	98.4	0.8300	7.44	not included	
X_9 pH	5.07	4.2	6.1	not included		3.1488	4.48
$\bar{R}^2$ (adjusted for degress of freedom)				0.729		0.603	
F ratio $n_1 = 8$, $n_2 = 56$				22.51		13.17	
Durbin Watson statistic				1.894		2.001	
s_{yx} (tons/ha)				0.375		0.454	

† $\hat{Y} = b_0 \Pi X_i^{bi}$ where $\hat{Y}$ is estimated yield in tons/ha

‡ Number of days after 15 March 1975 when the crop was sown

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superior biological underpinning, thus further discussion of factors influencing the observed yields is based on that model.

The partial regression coefficients provide a direct measure of how sensitive the yield of maize was to changes in levels of the various explanatory variables. For example a 1% increase in base saturation would be expected to increase maize yield by 0.83%, other input levels being held constant. In summary, the base saturation and organic matter levels of the maize plots appear to have been the most critical soil factors, while the density of the crop at harvest, not surprisingly, was the most important management factor.

PROFITABILITY OF THE PRODUCTION PRACTICES

Cash costs of the recommended practices

The cash costs of the recommended practice (excluding an opportunity cost on the farmer's labour and land) were the same for the three villages and consisted of the cost of seed, fertilizer (including transport), aldrin dust and interest on cash costs. When the research was being conducted, fertilizer prices were subsidized by over 70%. Farmers were charged ₦1.80† per 50 kg for both 15-15-15 and sulphate of ammonia though the unsubsidized prices were about ₦9.10 and ₦7.85 per 50 kg respectively (Wells *et al.*, 1975). Thus, two estimates of cash costs are given (Table 4) representing subsidized and unsubsidized prices. On the former basis the cash cost of paying for the technical inputs, was approximately ₦40/ha but about ₦137 if fertilizer had not been subsidized, which represents the social cost of the technology.

Table 4. *Direct cash costs (₦/ha) of the recommended maize technology*

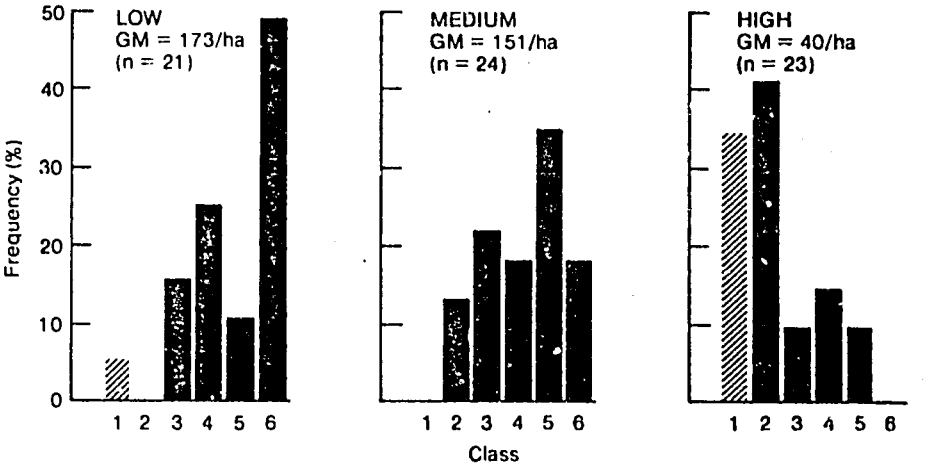
Input	Quantity	Subsidized	Unsubsidized
Seed	30 kg	3.00	3.00
15-15-15 fertilizer	7 X 50 kg bags	12.60	63.70
Nitrogen (sulphate of ammonia)	7 X 50 kg bags	12.60	54.95
Transport	14 bags	5.60	5.60
Aldrin	10 packets	4.00	4.00
Interest	5% for 6 months	1.89	6.56
Total cash costs/ha		₦39.59	₦137.81

Cost effectiveness of the technology

Discussions of production practices revealed that the farmers were more concerned with the potential loss of cash (required for purchasing the inputs) in the event of crop failure, than with losses due to extremely low returns from their labour and land.‡ Thus as would be anticipated from the yield data, the

† ₦, the Nigerian unit of currency, had an official exchange rate of ₦1.00 = $1.60 at the time of the investigation.

‡ These results are consistent with the findings of Williams *et al.* (1978) for the same locality.



Class	1	2	3	4	5	6
GM (N/ha)	negative	0-50	51-100	101-150	151-200	>200

Fig. 2. Frequency distributions of gross margins/ha from maize in three villages, Imo State, 1975. Prices used were maize ₦80/ton at harvest, subsidized fertilizer prices.

cost effectiveness of the technology within the three villages (gross receipts less cash costs) show that a larger proportion of the farmers covered their cash costs in the medium and low population villages than in the high population one (Fig. 2).

However, a more useful assessment is whether a farmer would be better off using the proposed method than with the traditional low cash-cost technology. Ideally the yields and value of production under the latter should be compared with the alternative for each farmer. In the absence of comparable information for each farmer on yields and inputs with his current practices in the same year, typical yield figures for the village were used as the expected output from distant fields under traditional systems for each village (Table 5). By following

Table 5. *Typical yields of maize and the more important associated crops (kg/ha) in outer fields of three survey villages, Imo State, 1975*†

Crop	Growing season (months)	Village/population density		
		Low	Medium	High
Maize (*Z. mays*)	3½-4	800	600	100
Cassava (*M. esculenta*)	14-18	10,000	4000	2000
Egusi melon (*C. vulgaris*)	3-4	300	–	160
Groundnut (*A. hypogea*)	4-5	–	440	–
Yam‡ (*Dioscorea spp.*)	8-10	–	–	1100
Grain equivalents§	16-18	9700	4480	2926

† Source: Farming Systems Program Survey, 1974-75

‡ Net yields of yams

§ Total grain equivalents (using maize as the base) from 1 ha over a 16-18 month cropping cycle

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the recommended sole-crop maize technology, the farmer is forgoing the revenue from his traditional maize, egusi melon or groundnut, and yams, though he could still plant cassava, as many did when the maize was about 10 weeks old; so it was assumed that cassava yields were unaffected by the new technology.

On the above basis, the revenue forgone by not growing traditional crops in a mixture was approximately ₦102, ₦74, and ₦70 per ha for the low, medium, and high population density villages. Given this assumption, at current input prices, approximately 20% of the farmers in villages L and M, and 74% in village H, would be 'worse off' by using the technology than if they had continued to follow their traditional practices (Table 6). If farmers had to pay for all the cash inputs used, it is likely that the technology would be too risky and not sufficiently superior to present practices – particularly on the poorer soils – to be generally attractive to typical local small farmers.

Table 6. *Percentage of farmers who were worse off using the 'improved' technology than if they had followed traditional practices*

Village	Level of fertilizer subsidy		
	Current	50%	Nil
L	19	43	52
M	17	38	67
H	74	83	91

FARMER'S REACTIONS TO THE PRODUCTION TECHNOLOGY

After harvest, farmers' reactions were sought to their maize yields, the method of growing the crop, and the performance of the variety compared to their traditional ones.

The package

Of the farmers, 76, 83 and 22% were satisfied with their maize yields in villages L, M and H, those dissatisfied tending ($P = 0.1$ by χ^2 test) to be those who were 'worse off' with the technology (see Table 6).

The reasons for the poor yields given by the sub-set of farmers who were dissatisfied with it are listed in Table 7. Those in the high and low population villages thought that 'poorness' of the soil was the most important factor whereas termites were regarded as the most critical factor in the medium population village. About half of the dissatisfied farmers felt that applying more fertilizer at planting time would overcome the soil fertility problem; others felt that growing the maize on ridges (as opposed to the flat) would have partly overcome this particular problem; all agreed that aldrin dust effectively controlled the termites.

Table 7. *Factors thought by farmers to account for their 'unsatisfactory' maize yields*

Factor/reason	Responses per village		
	H	M	L
Soil not suitable	12	1	3
Termites	0	3	2
Late planting	2	0	0
Other	4	0	0
Total 'unsatisfactory yields	18	4	5

The farmers were asked which practices they would modify in the following year, better to suit their particular circumstances (Table 8). A substantial number felt that they would want to plant their maize earlier and reduce stand density to enable cassava to be more easily intercropped. There was general agreement that they would weed their maize at least once, but some farmers felt that a second weeding would not be worthwhile.

Table 8. *Percentage of farmers who would modify various components of the maize technology in 1976*

Practice	H	M	L
Land preparation	0	0	0
Date of planting	36	12	71
Spacing of stands	36	25	100
Plants/stand	8	12	14
Sole crop maize	83	64	100
Fertilizer at planting	8	0	0
Fertilizer at 4–5 weeks	40	0	24
Early weeding	0	0	0
Late weeding	20	21	43
Insect control	0	17	0

Sole versus intercrop maize

The impressions of co-operating farmers on how much they thought the yield of their sole-crop maize would have been reduced if they had grown it with cassava and egusi or groundnuts are listed in Table 9. In the high-population village (where cassava is the dominant intercrop) 69% of the farmers felt that the addition of cassava would not have reduced the yield of their maize, but it is not suprising that these were also among the farmers with the lowest maize yields. In the medium and low-population villages, where the farmers got higher sole-crop maize yields, the majority felt that their maize yields would have been halved if it had been grown as an intercrop.

The factor which most influenced farmers to grow maize as an intercrop was to obtain a varied supply of foodstuffs, throughout the year, from a limited area of land (Table 10). Many farmers also considered that growing crops in mixtures was more profitable, increased the efficiency of their labour use, and

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Table 9. *Farmers' estimates of the amount by which their sole-crop maize yields would have been reduced if it had been grown as an intercrop*

Proportion reduction in maize yield	Responses/village					
	High		Medium		Low	
	No.	%	No.	%	No.	%
Not at all	16	70	0	0	8	38
By one-quarter	2	8	1	4	3	14
By one-half	5	22	18	75	10	48
By three-quarters	0	0	5	21	0	0

Table 10. *Reasons advanced by farmers for preferring intercropping to sole cropping*

Reasons	Responses/village †		
	H	M	L
Varied food supply over time	9	17	10
Limited land	15	13	11
Labour efficiency	9	8	5
Make more money	7	5	9
Guard against crop failure	3	6	4
Other‡	6	3	0

† Most farmers gave more than one reason for intercropping; hence the totals seem more than the sample size

‡ Conserves the soil, because of tradition, do not know

helped guard against total crop failure, which is consistent with preferences reported elsewhere (Norman, 1974).

The improved variety

The majority of farmers who grew the composite variety felt that it tasted as good as, or better than, the local variety (Table 11). Several also commented that TZBc4 had a higher starch content than the local maize when milled, and was thus superior for making processed products like *agidi* and *akamu*. However, several farmers said that the recommended variety was harder than the local variety when it was dry, which made it more difficult to eat roasted.

Table 11. *Farmers' comparisons of the taste of TZBc4 and the local variety of maize*

Taste of TZBc4 *versus* local variety	Responses/village		
	H	M	L
Better	5	21	13
About the same	16	3	5
Worse	6	0	3

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As a plant, the maize composite appeared to have several advantages and disadvantages compared with the local variety. Many farmers felt that it had better-filled and larger cobs and that the white colour of the grain was superior to their own, a preference that was reflected in the high demand for, and sale price of, the cobs when sold green in the local market compared with local varieties. In village H, where the maize did poorly, farmers felt that the improved and the local varieties tended to be similar in most characteristics, but those in the medium- and low-population villages felt that TZBc4 was higher-yielding and earlier-maturing. Characteristics in which farmers regarded the local maize as superior to the recommended one was in its resistance to termites and lodging, the greater number of cobs per plant, and its superior (or at least equal) productivity on poor soils. In total, the superior aspects of TZBc4 outweighed its inferior ones; all farmers retained seeds of the variety for their major maize plantings the following year.

IMPLICATIONS FOR TECHNOLOGY DESIGN AND EVALUATION

The proposed maize package was not judged successful in this high rainfall region of the humid tropics where, through intensive use, the soils are becoming too acid and infertile for intensive maize production. It is not certain what is missing from the package although it appears to be connected with crop nutrition (e.g. Ca, Mg, Zn). Soil chemistry- and fertility-related research at IITA is currently investigating nutritional aspects of crop production on these acid soils in the context that low-cost agricultural lime is not available as a short-term ameliorant, and organic levels and cation exchange capacities of the soils are low and will probably continue to diminish as fallow periods are reduced with increasing population pressures on the land. As a result, it is likely that long-term improvements in agricultural productivity should be based on the integration of fertilizer practices and developing more effective fallows and methods of managing organic residues from crop and fallow species.

Alternatives for increasing the productivity of these farming systems might include the partial substitution of fertilizers for the recycling of nutrient through bush fallow, introducing fallow species that have multiple uses and are efficient nutrient recyclers or producers of organic matter (e.g. *Leucaena spp.*, *Acioa spp.*), and the development of alternative crop combinations and sequences. The latter should probably have multi-layered canopies and include annual and perennial crops. Further, the advantages of other food crops (e.g. legumes, roots and tubers), if more thoroughly exploited in these agroclimatic zones, may well result in maize remaining of limited importance in these environments.

The procedure used for evaluating the proposed innovation included biologic and economic analyses of the technology in addition to soliciting farmers' opinions of the practice, to provide insights into the bio-technical and management factors that largely determine crop yields in farmers' fields. The approach also provides an impression of the technology as the farmer sees it.

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There are several potential payoffs from this approach to designing technology. First, a link is established in which farmers contribute to the specification of design parameters (bio-technical, managerial, economic) that should be considered when fabricating new technology. Second, providing the evaluation of technology is collaborative with extension workers, an environment is created for strengthenening the dialogue between researchers, extension officers and farmers. Third, the approach provides an empirical test - under farmer management - of a proposed technology before it becomes an extension recommendation.

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