Agricultural Systems 51 (1996) 85–95

0308-521X/96/$15.00+0.00

ELSEVIER

0308-521X(95)00017-8

Comparing Productivity of Millet-Based Cropping Systems in Unstable Environments of the Sahel: Possibilities and Challenges

J. Baidu-Forson

ICRISAT Sahelian Center, BP 12404, Niamey, Niger

&

C. Renard

ICRISAT Asia Center, Patancheru, AP 502324, India

(Received 4 November 1994; accepted 5 May 1995)

ABSTRACT

Falling per capita food production, increasing population pressure on arable land and soil nutrient mining that occurs under traditional cropping systems in West Africa have generated a strong demand for more productive yet sustainable cropping systems. Total factor productivity methodology was used to analyze millet-based cropping systems developed for the Sahel. Interspatial total factor productivity comparisons indicate that the new cropping systems were more profitable than the traditional cropping system. However, the determination of the sustainability of the tested systems was constrained by lack of appropriate time series data to cope with environmental instability in the Sahel and changes in resource stocks. In designing new cropping system technologies for areas prone to degradation, a multidisciplinary research strategy is needed to identify and measure resource stock changes that affect productivity. It is also imperative to use crops and systems models, particularly in unstable climatic environments, to generate adequate time series data for the measurement of sustainability. Finally, cropping systems evaluated should include both packages and components. This will permit the formulation of recommendations that fit resources or preferences of different farmers.

INTRODUCTION

Pearl millet (*Pennisetum glaucum* L. Br.) interspersed with cowpea (*Vigna unguiculata* [L] Walp.) predominate the traditional cropping system of the Sahel. Both crops are sown at very low densities. The soils are inherently poor in fertility — low in phosphorus (P) (Bationo *et al.*, 1989), organic matter (OM) and total nitrogen (N) (Spencer & Sivakumar, 1987). Traditional crop management is extensive with few yield-increasing inputs (Fussell *et al.*, 1987). Farmers rely on long fallow periods to restore soil fertility. However, increasing demographic pressure has necessitated drastic reduction of fallow period. In the absence of remedial interventions to restore soil fertility, reductions in fallow period increase soil nutrient mining and reduce productive capacity. Modest applications of inorganic fertilizer could restore some of the depleted soil nutrients.

Low surface porosity, weak structure, susceptibility to crust formation and low water-holding capacity are some of the limiting properties of soils in the Sahel (Fussell *et al.*, 1987). Tillage reduces soil bulk density, and enhances root penetration (Nicou, 1974; Chopart & Nicou, 1976; Chopart, 1983; Nicou & Charreau, 1985) and extensive rooting, which improves access to applied fertilizer (Charreau & Nicou, 1971). The use of animal traction permits deeper tillage and saves on labor typically used in the highly labor-intensive traditional manual tillage operations.

Management practices which improve soil fertility, soil physical properties and reduce labor demands promote greater economic viability. Millet-based cropping systems, that combine the management practices, were evaluated on typical sandy soils of the Sahel at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Center at Sadoré in Niger to test the hypothesis. The cropping systems combined P application, high plant densities, a new pearl millet variety with or without animal traction. The specific objective of this paper is to use total factor productivity (TFP) comparisons over space (interspatial TFP) to test the hypothesis of improved economic viability. The challenges of using intertemporal TFP to assess the sustainability of the cropping systems were also examined.

DATA AND ANALYTICAL METHOD

Sources of data used in analysis

Crop yield data were obtained from experiments conducted from 1986 to 1993 at the Sahelian research station of ICRISAT at Sadoré in Niger.

TABLE 1
Description of Traditional and New Cropping Systems Tested at Sadoré in Niger, 1986–1993

Treatment components		*Yearly cropping Pattern 1986–1993*
T1	Traditional (no P + low M and C densities + manual tillage)	Continuous M/C intercrop
T2	P + animal traction[a]	Continuous M/C intercrop
T3	P + manual tillage	Continuous M/C intercrop
T4	P + animal traction	Continuous sole millet
T5	P + manual tillage	Continuous sole millet

[a]Animal traction was used for ridging and weeding.
Note: M/C = millet/cowpea intercrop. Sadoré local millet and cowpea were sown at low densities in the traditional treatment (T1). Millet variety (cv ITMV 8001) and cowpea variety (cv Sadoré local) were sown at high densities in the non-traditional treatments (T2, T3, T4 and T5).

The cropping systems and management packages tested are presented in Table 1.

Plant hill spacing in the traditional millet-based system (T1) was 1·5 m × 1·0 m for millet (cv Sadoré local) and 1·0 m × 2·0 m for the local spreading cowpea (cv Sadoré local). In the new intercropping systems (T2 and T3), pearl millet (cv ITMV 8001) was spaced at 1·5 m × 0·7 m and was intercropped with local cowpea (cv Sadoré local) spaced at 1·5 m × 1·32 m. The sole millet systems (T4 and T5), included the same millet variety and spacing as in the intercropped systems. Millet was thinned to three plants per hill while cowpea was thinned to two plants per hill. Phosphorus fertilizer was broadcast on plots marked for the new cropping systems before sowing. The annual P fertilizer applications were 60 kg of triple superphosphate (TSP) ha^{-1} in 1986, and 65 kg TSP ha^{-1} in 1987 and 1988. Single superphosphate (SSP) was applied at the rate of 167 kg SSP ha^{-1} from 1989 to 1993. The replacement of TSP applications by SSP was to correct for sulphur (S) deficiency. Plot size per cropping system was 500 m^2 and each system was replicated eight times.

The cycle of each cropping system is a season. Therefore, seasonal data on the quantities of seed, P and hours of animal traction services and human labor collected from the experiment are used in the analysis. Seeds were valued at pre-sowing market prices. The unit costs of TSP and SSP were obtained from 'Centrale D'Approvisionnement' of Niger. The hourly labour wage of FCFA 75, obtained from surveys of hired labor cost in Niger (Krause *et al.*, 1990), was assumed. The hourly cost of renting traction services was estimated at FCFA 800 from surveys conducted in western Niger villages. Immediate post-harvest prices of cowpea and millet were collected from the Statistics Division of Niger's Ministry of Agriculture and used to value outputs.

Analytical method

Productivities of cropping systems are frequently analyzed partially in terms of the ratio of total output to a single input which may be most limiting. However, partial productivity is inferior to total factor productivity (TFP) (Trueblood & Ruttan, 1992). Total factor productivity measures the total value of all output produced by a system over one cycle divided by the total value of all inputs used by the system over the same cycle. Advances in production economics have provided a theoretically sound and simple measure of the total factor productivity. In particular, the use of a growth accounting method and economic index numbers to calculate TFP eliminates the need for econometric estimations (Ehui & Spencer, 1993). The economic index numbers method requires the aggregation of detailed inputs and outputs into indices which are used to calculate a TFP index (Antle & Capalbo, 1988). In this axiomatic approach, TFP is calculated as the difference between the weighted sum of output indices minus the weighted sum of input indices (Trueblood & Ruttan, 1992).

The Tornqvist–Theil indexing procedure used to obtain TFP index is a discrete approximation to the continuous Divisa index. Therefore, the axiomatic approach is theoretically consistent with properties of flexible production function (Trueblood & Ruttan, 1992). Since the Tornqvist–Theil indices are based on cost and revenue shares, and Shephard's lemma is used in derivation, the exact index number approach implicitly assumes competitive behavior (Antle & Capalbo, 1988).

Generally, the TFP index, the ratio of productivity for two consecutive time periods or cropping systems B and A, is formulated as:

$$\ln(I_{BA}) = \ln \frac{TFP_B}{TFP_A} = [\frac{1}{2}\Sigma (V_B + V_A)^* \ln(\frac{Q_i^B}{Q_i^A})] - [\frac{1}{2}\Sigma (S_B + S_A)^*\ln(\frac{Q_j^B}{Q_j^A})]$$

where V_i and S_j represent revenue and cost shares, for $1...i$ outputs and $1...j$ inputs:

$$V_i = \frac{P_i^B Q_i^B}{\Sigma_i P_i^B Q_i^B}$$

$$S_j = \frac{P_j^B Q_j^B}{\Sigma_j P_j^B Q_j^B}$$

I_{BA} is the index of productivity in period B relative to period A; Q_i is the ith output; Q_j is the jth input; P_i and P_j are the prices of ith output and jth input.

The bilateral TFP index can be expanded multilaterally, to permit comparisons of the performance of a cropping system over time (intertemporal TFP) or multiple cropping systems at a single point in time (interspatial TFP). However, comparisons of productivity across systems at a single point in time could be misleading where degradation occurs. Research in the Sudano–Sahelian zone shows that OM content and crop yields decline on continuously cultivated arable when crop residues are not recycled, even if inorganic fertilizer is applied (Pichot *et al.*, 1981). Since crop residues were not recycled in the cropping systems analyzed in this paper, degradation is likely to occur. Hence the multilateral index is extended, following Caves *et al.* (1982), to a comparison across time and space using panel data. The formula for calculating this type of multilateral index is (Whitaker & Lalitha, 1993):

$$\ln(I_{BA(C)}) = [\frac{1}{2}\Sigma_i ((\frac{P_i^{BC} Q_i^{BC}}{R^{BC}} + \frac{P_i^T Q_i^T}{R^T})(\ln Q_i^{BC} - \ln Q_i^T))$$

$$- \frac{1}{2}\Sigma_j ((\frac{P_j^{BC} Q_j^{BC}}{W^{BC}} + \frac{P_j^T Q_j^T}{W^T})(\ln Q_j^{BC} - \ln Q_j^T))]$$

$$- [\frac{1}{2}\Sigma_j ((\frac{P_i^{AC} Q_i^{AC}}{R^{AC}} + \frac{P_i^T Q_i^T}{W^T})(\ln Q_i^{AC} - \ln Q_i^T))$$

$$- \frac{1}{2}\Sigma_j ((\frac{P_j^{AC} Q_j^{AC}}{W^{AC}} + \frac{P_j^T Q_j^T}{W^T})(\ln Q_j^{AC} - \ln Q_j^T))]$$

$$R^T = \frac{\sum_1^n \sum_1^m \Sigma_i P_i^B Q_i^B}{n^* m}$$

$$R^{BC} = \Sigma_i P_i^{BC} Q_i^{BC}$$

$$W^{BC} = \Sigma_j P_j^{BC} Q_j^{BC}$$

where A and B represent two time periods (or cropping systems) compared; C is the common cropping system (or time period); m and n represent the number of cropping systems and time periods respectively; and T denotes the mean across both time and space.

TABLE 2
Average Millet and Cowpea Yields obtained from Cropping Systems Tested at Sadoré, Niger, 1986–1993

Cropping system[a]	*Annual average yields (kg ha⁻¹)*							
	1986	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*
Millet grain								
T1	300	299	268	125	102	120	248	285
T2	750	368	557	485	615	368	313	734
T3	616	404	482	240	341	80	288	565
T4	886	510	696	483	454	320	402	580
T5	715	383	498	345	336	118	272	463
SE ±	98	34	69	70	84	59	27	74
Cowpea grain								
T1	261	15	45	80	98	15	54	23
T2	308	84	57	125	139	5	16	30
T3	185	32	53	80	142	5	32	12
SE ±	65	16	13	25	32	3	10	6
Cowpea hay								
T1	273	195	332	240	327	188	260	240
T2	412	325	464	515	220	400	53	333
T3	537	268	477	335	247	218	87	343
SE ±	108	68	107	99	67	75	48	77

[a]See Table 1 for description of cropping systems.

DISCUSSION

Millet and cowpea yields

Millet yields were generally lower than typical on-station yields by at least 50%. This was because of the adoption of minimal crop protection practices, particularly insect pest control, practised on farmers' fields. The highest millet grain yields were produced by systems T2 or T4 where crops were sown on ridges made with animal traction (Table 2). This confirms earlier research findings which showed that a combination of P, ridging and the use of genetic materials selected for better crop establishment significantly improve yields (Fussell *et al.*, 1987). Cowpea grain yields were also very low, particularly in 1991, possibly as a result of competition from millet. The largest cowpea grain yields were obtained from cropping

TABLE 3
Interspatial TFP Indices and Regression Results

Year	*Interspatial TFP indices*			
	T2 versus T1	*T3 versus T1*	*T4 versus T1*	*T5 versus T1*
1986	2·2	1·4	2·7	1·7
1987	2·5	1·8	2·4	2·3
1988	1·9	1·7	2·3	2·1
1989	2·6	1·1	2·0	1·6
1990	2·3	1·3	2·1	1·5
1991	2·0	0·7	2·6	1·1
1992	0·5	0·7	1·2	1·2
1993	2·0	1·5	2·1	1·7
Regression[a]				
intercept	2·63	1·69	2·65	2·13
SE	0·46	0·31	0·34	0·27
slope	−0·14	−0·09	−0·10	−0·11
SE	0·09	0·06	0·07	0·05
R^2	0·2778	0·2664	0·2864	0·4013

[a]Regression results are based on data points of up to two decimal places. All the estimated slopes are not significant at 5%.

system T2 (Table 2), the exceptions being 1990 to 1992. No cropping system produced the highest yields of cowpea hay in most years.

Interspatial total factor productivity comparisons

Interspatial TFP indices that measure the economic viability of the new systems, compared with the traditional system, were greater than 1 in most cases (Table 3). Since economic viability shows the efficiency with which resources are used in a production process at a given period (Ehui & Spencer, 1993), the new cropping systems tested appear to be comparatively more efficient in the use of resources. Table 3 shows that continuous sole millet systems (T4 and T5) are more viable than the intercropped systems. This is possibly due to good millet yield response to P application (Table 2), observed in earlier research (IRAT, 1975; Bationo *et al.*, 1985). However, definitive attribution of the source of economic viability can only be made where components are examined separately. In addition, some farmers may want to adopt components if they do not have the resources to adopt the most desirable technology package. Therefore, future research on technology packages should also evaluate individual components of each package.

The slopes of interspatial productivity comparison trends are negative but not statistically significant. Therefore, economic viability of the new systems, as compared to the traditional system, seemed to have been maintained at a relatively constant level.

Crop yields and relative sizes of the interspatial TFPs suggest that it is best to plant sole millet on ridges (system T4). The relevance of this recommendation is limited to a labor to traction services cost ratio of at least 0.094. In cases where owned traction equipment is underutilized, annualized costs of using animal traction for ridging would be higher and therefore the ratio of labor cost to traction cost could be lowered.

Intertemporal total factor productivity comparisons

It is not possible to make definitive sustainability judgements about the tested cropping systems for a number of reasons. The slopes of productivity time trends for the traditional and the new cropping systems are not significant and the R^2 values are low (Table 4). The poor fit of intertemporal TFP data to trend lines shows the need for longer time series data considering the large annual variations in crop performance induced by erratic rainfall that characterizes the Sahelian environment. Literature indicates that where rainfall is erratic, 15 to 25 years of data would be needed to determine a trend within stipulated limits with 68% probability

TABLE 4
Summary of Intertemporal TFP Regression Results

Cropping system	*Estimated regression of TFP indices*		
	Intercept	*Slope*	R^2
T1	0·787	0·07	0·0950
	(0·430)	(0·096)	
T2	0·109	0·287	0·2528
	(0·987)	(0·221)	
T3	0·430	0·198	0·3140
	(0·584)	(0·131)	
T4	0·603	0·112	0·1975
	(0·451)	(0·101)	
T5	0·599	0·126	0·2142
	(0·484)	(0·108)	

Note: Numbers in parentheses represent the standard errors associated with the estimated coefficients.

(Monteith, 1990). However, field experiments are costly to run over long periods of time. There is, therefore, a need for crops and systems models that provide the framework for generating enough data from a few years of experimentation.

Time trends of TFP based solely on applied inputs and outputs show only the maintenance of year-to-year benefits that do not necessarily guarantee the sustainability of the systems. This is because sustainability requires reconciliation of two imperatives, namely maintenance of the year-to-year benefits and non-deterioration of a system (Monteith, 1990). Consistent with these requirements, Ehui and Spencer (1993) intuitively modified TFP measures and showed the need to accommodate changes in resource stocks and flows. In the Sahelian and Sudanian zones, reductions in the level of OM occur (Bationo & Mokwunye, 1991), resulting in increased soil acidity and reduced crop yields (ICRISAT Sahelian Center, 1992, p. 81). In cropping systems where crop residues are not recycled, data on changes in soil pH, build-up of Al toxicity and the cost of lime required to restore soils to the initial state of nature would be needed for more complete sustainability analysis. It is therefore essential that in the planning of future long-term trials, multidisciplinary effort is made to identify and collect data on sustainability indicators. This will permit the incorporation of the costs of restoring original environmental state in TFP analysis.

CONCLUSIONS

Farming remains the main source of livelihood to the majority of the population in sub-Saharan Africa. Traditional crop production systems have shown great resilience in providing the food and fibre needs of the population in the past. However, they cannot cope with food demands to feed a population increasing at high growth rates. Pressure on arable land resources has generated demand for more productive yet sustainable systems of production. International agricultural research institutes with crop productivity improvement mandates and their partners in the national research institutes are searching for more viable and sustainable cropping system technologies.

The lengths and types of data series needed to make sound sustainability judgements in environments that have erratic rainfalls, high costs of long-term experimentation and declining research resource envelopes require changes in traditional cropping systems research strategy of narrowly focused long-term experimentation. There is a need for increased reliance on multidisciplinary studies and crops and systems models to generate appropriate data on the basis of fewer years of experimentation. Crops and systems models would also be useful in measuring changes in resource stocks that affect crop productivity. It is also important that experiments on technology packages do not omit the separate testing of components of technology packages. This is necessary to permit the formulation of appropriate recommendations for different types of farmers.

ACKNOWLEDGMENTS

The authors acknowledge the statistical assistance of Roger Stern. David Rohrbach, Meri Whitaker, Merle Anders, Sivakumar, Ramadjita Tabo, Andre Bationo, Bonny Ntare and Timothy Williams provided useful comments and suggestions on earlier versions of the paper. Data analyzed were from a collaborative experiment supervised by C. Renard and S. V. R. Shetty. Data processing assistance of J. Adeyemi, M. Manzo and H. Bonkoula are gratefully acknowledged. The authors are solely responsible for any error or omission.

Submitted as JA 1676 by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

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