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African Journal of Agricultural Research

Table of Contents: Volume 9 Number 42 1 6 October, 2014

ARTICLES

African Journal of Agricultural Research

Table of Contents: Volume 9 Number 42 1 6 October, 2014

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African Journal of Agricultural Research

Full Length Research Paper

Optimization of furrow irrigation systems with continuous flow using the software applied to surface irrigation simulations - SASI

Valéria Ingrith Almeida Lima[1], Roberto Vieira Pordeus[1]*, Carlos Alberto Vieira de Azevedo[2], Joaquim Odilon Pereira[1], Vera Lúcia Antunes de Lima[2] and Márcia Rejane de Queiroz Almeida Azevedo[3]

[1]Department of Environmental Sciences, Federal Rural University of the Semi-arid, Av. Francisco Mota, 572, Mossoró-RN - CEP: 59.625-900, Brazil.
[2]Department of Agricultural Engineering, Federal University of Campina Grande, Av. Aprígio Veloso, 882, Bodocongó, CEP 58109970, Campina Grande -PB, Brazil.
[3]Center of Agrarian and Environmental Sciences, Paraíba State University, Lagoa Seca – PB, Brazil.

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Surface irrigation systems still remain the most used irrigation system worldwide mainly due to its energy savings capacity and ease of operation. However, they show low performance level as a consequence to the general design and inadequate management. Therefore, the aim of this study was to develop a tool capable of optimizing the performance level of furrow irrigation systems with the continuous flow from successive simulations of the advance phase and predictions of performance parameters in irrigation systems. The proposed model, written in DELPHI 5.0 programming language and called Software Applied to Surface Irrigation Simulations (SASIS) had its validation tested for different field conditions. The results showed that the applied flow rate plays a decisive role on the performance parameters of irrigation systems with the best performances flow rates close to the minimum allowable levels. The field parameter that most impairs the optimization of the irrigation performance is infiltration, while the length and slope did not decisively interfere in optimization, which can be achieved for a wide range of values for these parameters, and also in soils with high infiltration rates. The great difficulty in optimization is to minimize percolation losses, but in soils with low infiltration rates, both percolation and runoff losses can be easily minimized. The SASIS model has been an effective mechanism in performing numerous simulations within a flow range between minimum and maximum, aiming to determine the relationship between flow rate and water application efficiency, percolation and runoff rates and hence optimize the performance of furrow irrigation systems with continuous flow.

Key words: Furrow irrigation, flow rate, performance.

INTRODUCTION

Although, surface irrigation is the most widely used it is considered as low water application efficiency, particularly in furrow irrigation systems, in which the furrow is responsible for lower efficiency levels. Surface irrigation is an irrigation method where water drains by gravity, using the agricultural soil surface as part of the water distribution system. The flow rate decreases as the water advances towards the irrigated portion due to infiltration. For the infiltrated water to be distributed as uniformly as possible along the area, irrigation should be designed and managed so that there is a balance between advance and water infiltration processes (López, 2006). Furrow irrigation is one of the most widely used irrigation system due to its low cost in materials and energy. The low efficiency of surface irrigation systems is due to the large part of the absence of careful designing and improper irrigation practices. According to Rezende et al. (1988), reduced levels of performance in furrow irrigation systems can be attributed to incorrect dimensioning. The use of assessment tests would be recommended, despite the high cost and time required for the performance of field works and analysis of results. Furthermore, it is virtually impossible to assess the combined results of numerous parameters involved in the designing and operation of systems.

To improve the efficiency of water application and distribution, some designs have used the maximum non-erosive flow rate, reducing the flow when the advance front reaches the end of the furrow. The efficiency of furrow irrigation systems can often be improved by reducing the inflow rate after water has advanced to the end of the field, a common practice is to cut back to 50% of the inflow (Clemmens, 2007). Another alternative is the use of intermittent flow to distribute water in the furrows. Both methods, despite showing improvement in the performance of furrow irrigation systems, have the disadvantage of requiring more labor and more investment in equipment. In practice, it is observed that the use of constant flow is predominant in furrow irrigation designs, which is probably due to the farmer's tradition of using only one flow in the water application during irrigation and to ease operation in the distribution of water in the furrows.

Rodríguez et al. (2004), comparing surge irrigation and conventional furrow irrigation for covered black tobacco cultivation in a Ferralsol soil, found that surge flow furrow irrigation with variable time cycles increased the application efficiency by more than six fold, and the water volume was reduced by more than 80% compared to continuous irrigation. The largest rises in distribution uniformity and reductions in percolation losses were obtained with a furrow length of 200 m and a discharge of 1 L s^{-1}, respectively.

Valipour (2012), researching the management strategies to increase the efficiency of furrow irrigation obtained from simulations using the software SIRMOD, found that the cutback and surge irrigation methods were able to increase irrigation efficiency in 11.66 and 28.37%, respectively. According to farmers the choice of limiting regime inflow can identify the best input flow to achieve maximum irrigation efficiency. The furrow irrigation system presents different variables with regard to operating system and with respect to field data, which influence its performance. The operating system variables are flow rate and time of application of water, while the field variables are slope, size, roughness of the surface, the furrow geometry and characteristic of water infiltration into the soil. Infiltration depends primarily on physical, chemical and biological soil properties, affecting the advance and recession processes, and it is important to estimate the optimal flow rate derived in an irrigated soil (Walker et al., 2006). For a good furrow irrigation design, one should consider these variables and their interactions (Wu and Liang, 1970; Reddy and Clyma, 1981).

Valipour and Montazar (2012b), studying the optimization of all effective infiltration parameters in furrow irrigation, worked to achieve full irrigation status. They used Genetic Algorithm Programming and MS Visual Basic (VB) programming. The best equation of distribution of curve water in the soil was determined by using the MS Visual Basic (VB) programming. While for the Genetic Algorithm (GA) coding in MATLAB software environment, all effective infiltration parameters in furrow irrigation were obtained for the best equation of distribution curve of water in the soil. The found results showed that by using VB and GA programming, water delivery and farm size could be optimized.

The SWDC and WinSRFR models were evaluated by Valipour and Montazar (2012a) to optimize the parameters of furrow irrigation. They found that because of the differences between the two models it was not possible to say which one is better. However, in SWDC model, input discharge becomes optimized, other infiltration parameters could be optimized in furrow irrigation using WinSRFR model and combining it with SWDC model.

The mathematical simulation of surface irrigation is a complex process of hydraulics and surface flow. These processes have been simulated by computer models with a large degree of complexity and accuracy (Strelkoff and Katopodes, 1977; Elliott et al., 1982; Walker and Humpherys, 1983; Strelkoff and Souza, 1984; Rayej and Wallender, 1985), and such models simulate the advance and recession of water over the soil surface and the volume of infiltrated and percolated water.

The different models that simulate surface irrigation have been developed to simulate an isolated irrigation event, assuming that there is no spatial variation in field parameters (infiltration, roughness, slope and cross section). In practice, the validity of this hypothesis has been found, considering that simulations have been very

*Corresponding author. E-mail: rvpordeus@gmail.com, Tel: 55 84 3317 8322.
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close to measurement made in field along the crop season. The objective of this study was to develop a freely accessible mathematical computer model to simulate and optimize furrow irrigation with continuous flow in both languages Portuguese and English. The model predicts through simulations of the advance phase, the performance of an irrigation event and selects the optimal flow rate in furrow irrigation systems with continuous flow, that is, one that maximizes the water application efficiency, balancing runoff and percolation losses.

MATERIALS AND METHODS

This study uses the kinematic wave model which represents a simplified form for the Hydrodynamic model. It assumes that there is no height variation of flux with distance, the force due to the weight component in the direction of flow is in balance with friction forces, that is, $\partial y/\partial x = 0$, completely neglecting the momentum equation, leaving the continuity equation (Equation 1) undetermined in term $\partial A/\partial t$. To solve this problem, assuming that there is a unique relationship that describes flow as a function of the flow area, then the momentum equation is replaced by the Manning equation (Equation 2). Therefore, the equations that constitute the kinematic wave model become continuity equation:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} + \frac{\partial Z}{\partial \tau} = 0 \quad (1)$$

Manning Equation:

$$A = \sqrt{\frac{Q^2 n^2}{S_o\, R^{4/3}}} \quad (2)$$

Where A = flow cross-sectional area (m^2), t = time (s), x = distance of water advance in the field (m), τ = infiltration opportunity time (s), Z = infiltrated volume per furrow length unit ($m^3\ m^{-1}$), Q = discharge rate ($m^3\ s^{-1}$), n = Manning roughness coefficient ($m^{-1/3}$ s), S_o = field slope ($m\ m^{-1}$), R = hydraulic radius (m), cross-sectional area divided by the wetted perimeter.

The Manning equation was used in this analysis to generate unique relationship between flow and hydraulic section. Elliott et al. (1982), proposed an empirical relationship for the hydraulic section, given by:

$$y = \sigma_1\ A^{\sigma_2} \quad (3)$$

and

$$A^2 R^{1,33} = \rho_1 A^{\rho_2} \quad (4)$$

Where y = flow height in the furrow (m), σ_1, σ_2, ρ_1 and ρ_2 = empirical parameters that depend on the furrow shape.

The hypothesis described ensures that the potential functions adequately describe relationships between flow height, cross-sectional area, width of the free-water surface, hydraulic radius etc. Through the Manning equation and according to Equation 4:

$$S_0 = \frac{Q^2 n^2}{A^2 R^{4/3}} = \frac{Q^2 n^2}{\rho_1 A^{\rho_2}} \quad (5)$$

Thus, obtaining Q, whose derivative, together with the infiltration equation is used in equation 1, to yield a continuity equation of one unknown dependent parameter, A. It is assumed that the spatial and temporal dependence of Z are defined (Walker and Humpherys, 1983).

According to Equations 2 and 5, this type of model does not apply to furrows when the slope is very small or tends to zero. According to FAO (1989), the maximum and minimal recommended furrow slopes are 0.5 and 0.05%, respectively. In fact, their accuracy will decrease when S_0 approaches zero. Strelkoff and Katopodes. (1977), found that the higher the longitudinal slope, model simulates the flow conditions. Walker and Skogerboe (1987), do not recommend this type of model to simulate the recession phase.

Using Equation 4, the Manning equation becomes:

$$Q = \alpha A^m \quad (6)$$

where:

$$\alpha = \frac{\sqrt{\rho_1 S_0}}{n} \quad (7)$$

$$m = \frac{\rho_2}{2} \quad (8)$$

Where α and m = empirical constants.

Depletion and recession phases

Generally, it is said that when the flow is suspended, the cross-section area at the head end of the furrow immediately drops to zero, favoring the statement that the depletion and recession phases could be neglected; this is a reasonable assumption for slope furrows, since the volume of water stored into the furrow is very small at the flow cutoff time making the duration of the depletion and recession phases very short, and therefore has a small effect on the water infiltration profile. The behavior of the recession phase is similar to the advance phase, but in the opposite direction. In this work, the depletion and recession phases were neglected, considering that the irrigation ends when water flow is stopped, that is, it was assumed that the recession time is equal to the flow cutoff time (Bernardo et al., 2009).

Over the years, infiltration has received much theoretical attention. Today, there are many equations that describe infiltration such as Kostiakov, Kostiakov-Lewis, Horton, Philip and Green-Ampt. In this study, the Kostiakov-Lewis equation was used (Equation 9), as one of the most widely used empirical expressions for furrow irrigation modeling.

$$Z = k\tau^a + f_o\tau \quad (9)$$

where τ = infiltration opportunity time (s), k = empirical coefficient of Kostiakov-Lewis infiltration equation ($m^2\ s^{-a}$), a = empirical exponent of the Kostiakov-Lewis infiltration equation, dimensionless, f_o = infiltration rate ($m^3\ m^{-1}\ s^{-1}$).

To calculate the maximum non-erosive flow rate, the SASIS software was based on the method recommended by Walker and Skogerboe (1987). The authors studied the maximum non-erosive flow rate as a function of parameters obtained from the furrow dimensions and proposed the following equation:

$$Q_{máx} = \left[\left(\frac{V_{máx}{}^{\rho_2}\ n^2}{3600\ S_0\ \rho_1}\right)\right]^{\frac{1}{\rho_2-2}} \quad (10)$$

Where Q_{max} = maximum non-erosive flow ($m^3\ min^{-1}$), V_{max} = maximum non-erosive speed ($m\ min^{-1}$), estimated by Walker and Skogerboe (1987) 8-10 $m\ min^{-1}$ in erosive soils and 13-15 in less erosive soils.

Optimal flow

In the determination of the relationship between flow rate and water application efficiency, percolation and runoff losses, numerous simulations were performed by the SASIS model. The simulations occurred in a flow rate ranging between the minimum and maximum allowable, initiating at the minimum flow rate and increasing in the rate of 2% until it gets to the maximum allowable flow rate. The minimum flow rate is the one that guarantee the water will get to the end of the field. The optimal flow rate considered by the SASIS model through the successive simulations is the one that provides the best irrigation performance and balance between runoff and percolation losses.

Procedure for assessing the surface irrigation system

Assessing a surface irrigation system will identify various management practices that can be implemented to improve the efficiency of the irrigation system. These practices can be a reduction in the flow rate and its time of application, changes in the field length or maybe a combination of various strategies is required. The main goal of the SASIS software is to help search for surface irrigation management strategies, resulting in satisfactory efficiency levels.

The assessment procedure of furrow irrigation proposed by Walker and Skogerboe (1987) used in this analysis initially involves the trapezoidal rule to integrate the subsurface flow profile, thus determining the total infiltrated volume:

$$V_z = \frac{L}{2n}\left[Z_o + \left(2Z_1 + 2Z_2 + \ldots + 2Z_{n-1}\right) + Z_n\right] \quad (11)$$

Where V_z = infiltrated volume (m^3), L = furrow length (m), Z_i = accumulated infiltration for point I ($m^3\ m^{-1}$), n = number of segments in which the furrow is subdivided.

The infiltration accumulated in each furrow segment is given by:

$$Z_i = k\left[t_r - (t_a)_i\right]^a + f_o\left[t_r - (t_a)_i\right] \quad (12a)$$

Where k, a and f_o = as defined previously, t_r = recession time (min), $(t_a)_i$ = advance time for the i-th station (min).

For the purpose of project the flow cutoff time, t_{cutoff}, replaces t_r in Equation 12a, according to Equation 12b.

$$Z_i = k\left[t_{cutoff} - (t_a)_i\right]^a + f_o\left[t_{cutoff} - (t_a)_i\right] \quad (12b)$$

Measures to evaluate performance

Among the factors considered in evaluating the performance of an irrigation system or its management, the most common are efficiency and uniformity. The evaluation parameters are defined in various ways. There is no single parameter that adequately defines irrigation performance. Conceptually, achieving adequate irrigation depends on the amount of water stored in the crop root zone, percolation losses (below the root zone), runoff losses, uniformity of the water applied and on the remaining deficit in the root zone. After all, performance means knowing whether irrigation optimizes or not.

When a field has uniform slope, the soil receives uniform flow at its upper end and a wetting front will slowly advance at a decreasing rate until it reaches the end of the field. If not blocked, runoff will occur up to the end of recession. Figure 1 shows the water distribution along the furrow length, arising from the assumptions given above. The differences along the area in the infiltration opportunity time produce water depths that are not uniformly distributed - with a characteristic inclination to the end of the field.

The water that can be stored in the root zone can be found by the expression $V_{rz} = (L * Z_{req}) - V_{di}$, where Z_{req} is the required root zone depth calculated on the project. But as shown, some region of the root zone may not receive enough water due to the spatial variation in infiltration distribution. The water depth that would supply the root zone is Z_{req}, and the water that percolates below this zone is lost[1] to drainage or groundwater system. Calculating each of these components requires numerical integration of water infiltrated along the field length, and according to the aim of this discussion, it is convenient to define the components as follows:

V_{rz} = Water volume per width unit (1 m), which is actually stored in the root zone;
V_{di} = Water volume per width unit (1 m), corresponding to the portion of the root zone that is not irrigated;
V_{dp} = Water volume per width unit or furrow spacing that percolates under the root zone;
V_{ro} = Water volume per width unit or furrow spacing that flows out of the irrigated area;
Z_{min} = Minimum infiltrated water depth that generally occurs at the end of the furrow; and
Z_{lq} = Average water depth infiltrated in the 25% of the least irrigated area.

Distribution uniformity refers to the water distribution in the soil profile. Merriam and Keller (1978) proposed that the distribution uniformity is defined as the average water depth infiltrated in the 25% of the least irrigated area (Z_{lq}) divided by the average water depth infiltrated in the entire area ($\overline{Z}$). This term can be represented by the symbol *DU*. The same authors also suggest an absolute uniform distribution *DU*a, which is the minimum water depth (Z_{min}) divided by the average water depth of the entire area.

The water application efficiency was accessed (E_a). For the no deficit irrigation condition, the following equations were used:

$$E_a = \frac{Z_{req}\ L}{Q.\ t_{cutoff}}100\% \quad (13)$$

$$PL = \frac{V_z - Z_{req}\ L}{Q.\ t_{ccutoff}}100\% \quad (14)$$

[1] Generally, these flows return to the reservoir and can be reused in another place or in the same area. Thus, they are lost in terms of the irrigated area in question, but perhaps not for the regional condition or basin. The negative connotations of loss should be maintained to the area being irrigated, although this water can be recovered and reused. The quality of these flows is almost always not good and the reuse time should not be computed (Walker, 2001).

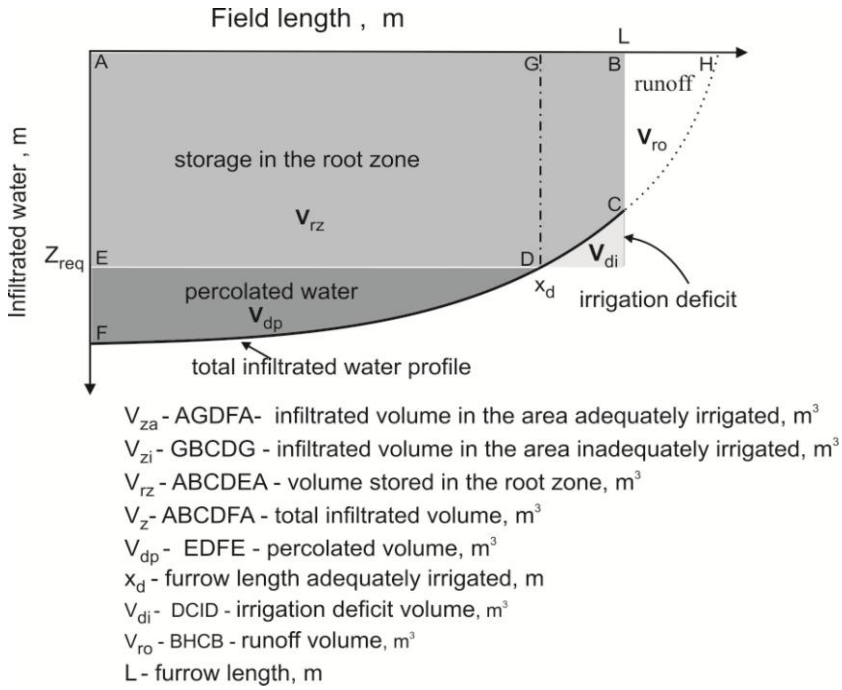

Figure 1. Components of the infiltration water profile in surface irrigation.

$$RL = 100 - E_a - PL \quad (15)$$

Where: E_a = water application efficiency, PL = percolation loss, RL = runoff loss.

For the no deficit irrigation condition it was assumed on the project that the efficiency of water requirement (E_r), also called storage efficiency, was 100%, with no deficit in the root zone. In the case of deficit irrigation, the following equations were used:

$$E_a = \frac{Z_{req}\, x_d + V_{zi}}{Q.\, t_{cutoff}} 100 \quad (16)$$

$$PL = \frac{V_{za} - Z_{req}\, x_d}{Q.\, t_{cutoff}} 100\% \quad (17)$$

$$RL = 100 - E_a - PL \quad (18)$$

$$E_r = \frac{Z_{req}\, x_d + V_{zi}}{Z_{req}\, L} 100 \quad (19)$$

$$DU = \left(\frac{Z_{lq}}{\overline{\overline{Z}}}\right) 100 \quad \text{or} \quad DU = \left(\frac{L.Z_{lq}}{V_{rz} + V_{dp}}\right) 100 \quad (20)$$

$$DU_a = \left(\frac{Z_{\min}}{\overline{\overline{Z}}}\right) 100 \quad \text{or} \quad DU_a = \left(\frac{L.Z_{\min}}{V_{rz} + V_{dp}}\right) 100 \quad (21)$$

The definition of water application efficiency E_a, was standardized as:

$$E_a = \frac{V_{rz}}{Q * t_{cutoff}} 100\% \quad (22)$$

The water requirement efficiency, E_r, which is also called storage efficiency, was defined as:

$$E_r = \frac{V_{rz}}{Z_{req} * L} * 100\% \quad (23)$$

If the furrow shows infiltrated water depth smaller than required, the infiltrated volume should be evaluated separately for the areas of excessive and deficient irrigation. After identifying the furrow section, x_d, from which the infiltrated water depth is less than required, the infiltrated volume will be calculated for the appropriately irrigated area V_{za}, by equation 11 and for the inadequately irrigated area, V_{zi}, as follows:

$$V_{zi} = V_z - V_{za} \quad (24)$$

The volume of runoff loss per unit width is given by:

$$V_{ro} = Q\, t_{cutoff} - V_z \quad (25)$$

The runoff loss (RL) is determined by equation:

$$RL = \left(\frac{V_{ro}}{Q\, t_{cutoff}}\right) 100\% \quad (26)$$

Table 1. Field data used in the validation of the SASIS model.

Field data	PISG1	PISG2	PISG3	PISG4	KWF	AMALGACQ	GUFCQ
Parameter	Soil type						
	Clay-sandy loam	Clay-sandy loam	Sandy loam	Clay-sandy loam	Silty-clay loam	Silty-clay	Silty-sandy
Flow (L s^{-1})	1.33[1]	1.47[1]	1.54[1]	1.13[1]	1.50[2]	1.80[2]	1.30[2]
Furrow length (m)	67	100	70	115	360	403	217
Slope (m m^{-1})	0.0030	0.0016	0.0043	0.0024	0.0104	0.0066	0.0173
Cutoff time (min)	90	115	41.7	86	450	500	300
Manning Coefficient, n ($m^{-1/3}s$)	0.020	0.020	0.025	0.020	0.013	0.013	0.013
Parameter of section, ρ_1	0.291	0.185	0.532	0.339	0.730	0.730	0.730
Parameter of section, ρ_2	2.847	2.766	2.840	2.806	2.980	2.980	2.980
k (m^3 m^{-a} m^{-1})	0.03781	0.02931	0.01024	0.0054	0.0088	0.00182	0.00896
a	0.165	0.302	0.326	0.412	0.533	0.234	0.0
f_o (m^3 min^{-1} m^{-1})	0.000186	0.000186	0.000264	0.000186	0.00017	0.00019	0.000022
Z_{req} (m)	0.090	0.060	0.020	0.020	0.090	0.090	0.050

[1] Flow rate adopted by the farmer in the field; [2] Flow determined in the design, used by the authors in the demonstration of the SIRMOD and SIRTOM models.

Table 2. Water advance data measured in the field and used in the validation of the SASIS model.

PISG1		PISG2		PISG3		PISG4		KWF		AMALGACQ		GUFCQ	
XA[1]	TA[2]	XA	TA	XA	TA	XA	TA	XA	TA	XA	TA	XA	TA
0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.70	2	9.09	1.05	7	1	11.50	3	40	5	31	12	31	4
13.40	4	18.18	2.35	14	2	23.00	5	80	14	62	22	62	8
20.10	6	27.27	3.60	21	3	34.50	7	100	20	93	30	93	12
26.80	9	36.36	5.00	28	5	46.00	10	120	30	124	46	124	16
33.50	13	45.45	6.50	35	7	57.50	14	140	37	155	53	155	20
40.20	16	54.54	8.50	42	10	69.00	17	160	48	186	68	186	24
46.90	20	63.64	9.65	49	13	80.50	27	200	75	217	85	217	28
53.60	23	72.73	11.55	56	16	92.00	40	220	89	248	98		
60.30	27	81.82	13.60	63	19	103.50	48	240	102	279	120		
67.00	32	90.91	15.65	70	24	115.00	66	275	130	310	140		
		100.00	17.95					300	150	341	155		
								320	170	372	191		
								350	200	403	232		
								360	208				

[1] XA = advance distance (m); [2] TA = advance time (min).

The SASIS model simulates the infiltrated water and the runoff conditions in the field. Regarding the water that infiltrates the field surface, the software determines depth of infiltrated water in the root zone and how much percolates below this zone. Considering that this information is determined for each point simulated in the field, the data can be used for the calculation of various efficiencies and uniformities.

The field data used in the validation of the SASIS model corresponded to four data sets (PISG1, PISG2, PISG3 and PISG4) collected in this research, relating to field assessments of furrow irrigation events in the irrigated region of São Gonçalo, Brazil, two data sets (AMALGACQ, private property and GUFCQ, Utah State University farm in Logan, USA) published by Azevedo (1992) used in the demonstration of the SIRTOM model, and one data set (KWF-Kimberly Wheel Furrow) published by Walker and Skogerboe (1987). The data for advance time measured in field, which was used to validate the SASIS model is shown in the Table 2. The SASIS model validation used both the measured flow practiced by the farmers and that suggested by the authors Walker (1989) and Azevedo (1992) in the demonstration of the SIRMOD and SIRTOM models.

RESULTS AND DISCUSSION

The curves generated by the model proposed for the irrigation performance as a function of the flow rate are shown in Figure 2. It was observed that in all studied cases, when the flow rate increases, the water application efficiency decreases, showing that this parameter is much more affected by runoff losses than by percolation losses. For the maximum non-erosive flow rate runoff losses are maximal and percolation losses minimal, whereas for minimum flow, that is, the one that ensures that the water will get to the end of the area, the opposite occurs. In addition, runoff losses are much more sensitive to flow variations in relation to percolation losses, a fact observed by the slopes of the curves. For the studied cases, there were dominance runoff losses over percolation losses, which occurred in the largest flow range. This leads to a greater effect of runoff losses in the water application efficiency value, making the water application efficiency curve to present almost the same behavior as the curve of percolation losses.

Figure 2a to f show the curves representing the runoff and percolation losses intersect for a given flow, indicating a change in the higher or lower effect of these losses on the water application efficiency from this value, as described in Table 3. It appears that, when there is a balance between runoff and percolation losses, that is, when they are balanced to the point that there is no predominance of one over the other. High levels of water application efficiency in furrow irrigation are achieved, according to field data PISG1 (Figure 2a), KWF (Figure 2b) and GUFCQ (Figure 2c). However, for field data PISG2 (Figure 2d), PISG3 (Figure 2e) and PISG4 (Figure 2f), runoff and percolation losses were high, consequently, low maximum water application efficiencies were obtained, respectively, 50.57, 34.28 and 48.51%.

Based on the maximum water application efficiency simulated for all studied field conditions, the optimal flow rate was found, as described in Table 3. In general, for all the field conditions the optimal flow rate corresponded to a value close to the minimum flow rate that was better accepted by the SASIS model, starting from 0.6 L s^{-1}. This tendency can be explained by the direct relation existent between the water application efficiency and water losses. The selection of the highest balance among the water application efficiency and water losses leads to values different from the highest flow rate, when the water losses are maximum.

For PISG1 (Figure 2a), the optimum flow rate was predicted by the SASIS model to be 1.05 L s^{-1}, which is close to the minimum (0.9 L s^{-1}). Values of runoff and percolation losses presented minimal discrepancy between them for the optimal flow, only 2.88%, and large discrepancy for maximum flow rate of 47.27%. This resulted in a predicted water application efficiency of 82.42% using the optimal flow rate and 43.7% using the maximum flow rate. It appears that the runoff loss was largely affected by the flow, which does not occur with percolation loss, a fact that can be justified by the type of soil for this data, which was clay-sandy loam, characterized by low infiltration rate (k = 0.03781 and f_o = 0.000186). For the flow rate adopted by the farmer in the field, the values for water application efficiency and for runoff and percolation losses were, respectively, 77.74, 16.20 and 6.06%, showing that percolation and runoff losses presented values well balanced, with difference of 10.14% between them. The results demonstrate that the smaller the difference between these losses, the better the performance of the irrigation system. For the optimal flow rate, the difference between percolation and runoff losses was 2.88%, resulting in a water application efficiency of 82.42%. The flow rate adopted by the farmer approached the optimal value predicted by the SASIS model.

For example KWF (Figure 2b), appears that for optimal flow rate, the values of runoff and percolation losses showed variation of only 9.91% between them, thus reaching high performance level in this irrigation system. Certainly, the low water infiltration rate (k = 0.0088 and f_o = 0.00017) in this clay-sandy loam soil greatly contributes in obtaining small values for these losses. For the flow rate adopted by the farmer, the values predicted for water application efficiency, for runoff and percolation losses were, respectively, 75.14, 14.47 and 10.39%, indicating values close to those predicted for the optimal flow rate, showing that this flow rate was a good option.

For field data GUFCQ (Figure 2c), it appears that the curve that refers to the runoff losses presents high slope, showing a large variation of the performance with the flow rate, since the curve that indicates the percolation losses has small slope, demonstrating that under these field conditions, it was slightly affected by the flow rate. The curve related to the water application efficiency shows the same slope as that of the runoff losses, but in the opposite direction. In this example, the difference between these losses for the optimal flow rate was only 1.78%, showing that the smaller these losses and the smaller the difference between them, the greater the water application efficiency in furrow irrigation. Furthermore, when optimal flow rate was applied, both runoff and percolation losses were low, resulting in high water application efficiency and when maximum flow rate was applied, the percolation losses remained low, while the runoff losses were very high, reaching 53.04%. It could be concluded that the low percolation losses, either for maximum or optimal flow rate, and the high runoff losses for maximum flow rate, can be explained by the low water infiltration rate in this type of soil (k = 0.00896 and f_o = 0.00022) and also by the presence of steep slopes in this area (0.0173 m m^{-1}). For the design flow rate (1.30 L s^{-1}), the values predicted for the water application efficiency, runoff and percolation losses were 44.65, 34.12 and 21.23% respectively, indicating that the flow rate selected by the SASIS model was absolutely inadequate.

For PISG2 (Figure 2d), the curves representing the water application efficiency and the percolation losses

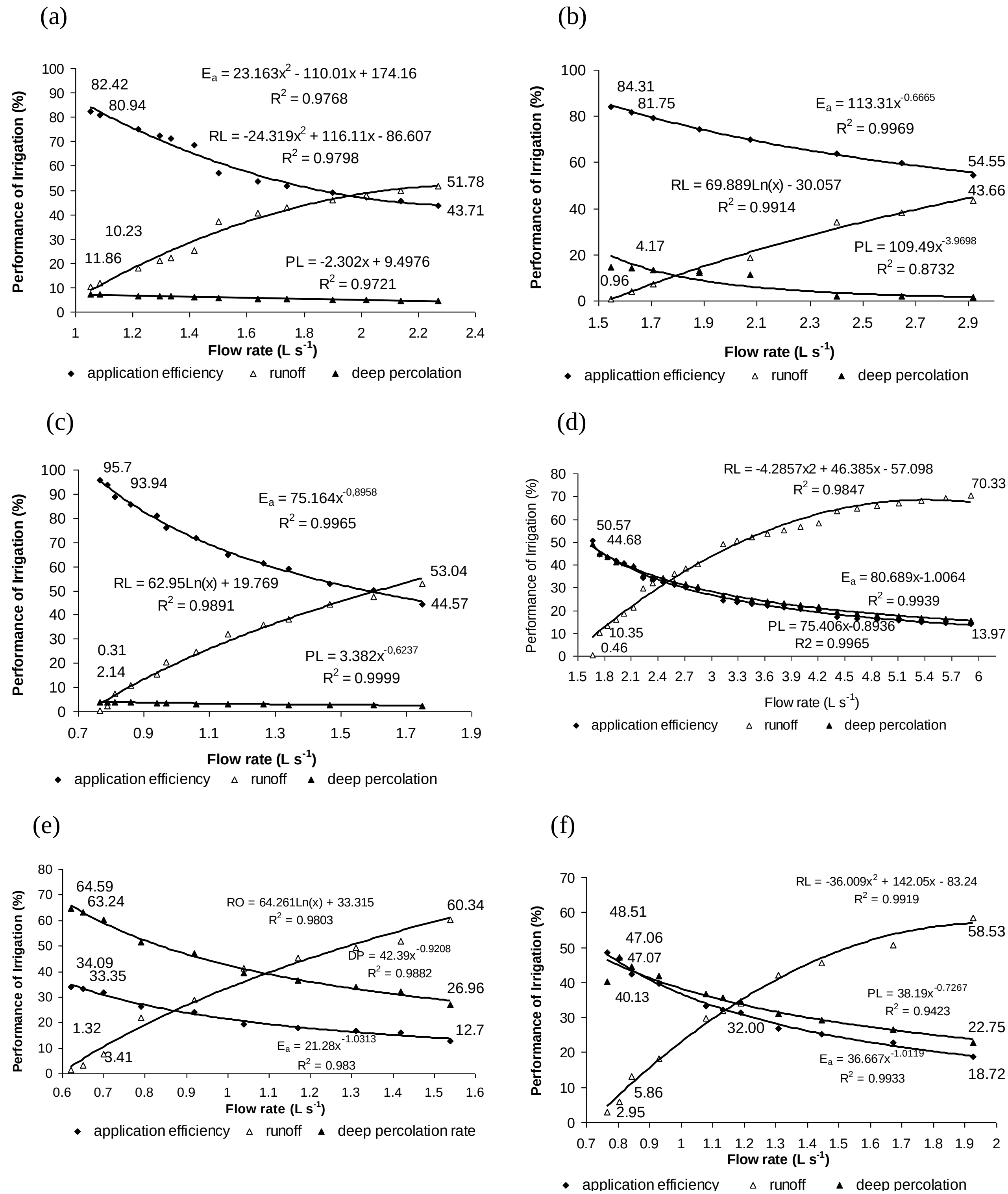

Figure 2. Irrigation performance as a function of flow rate and optimal flow rate: (a) PISG1 data and 1.05 L s^{-1}; (b) KWF data and 1.62 L s^{-1}; (c) GUFCQ data and 0.79 L s^{-1}; (d) PISG2 data and 1.66 L s^{-1}; (e) PISG3 data and 0.64 L s^{-1}; (f) PISG4 data and 0.77 L s^{-1}. E_a – water application efficiency, RL - runoff loss and PL - percolation values.

Table 3. Simulated data for minimum, maximum and optimal flow rate and performance parameters based on field data.

Field data	Minimum flow rate (L s^{-1})	Maximum flow rate (L s^{-1})	Optimal flow rate (L s^{-1})	Flow rate practiced by the farmer (L s^{-1})	Minimum [1]E_a (%)	Optimal [1]E_a (%)	Runoff (%)		Percolation (%)	
							MFR[2]	OFR[3]	MFR	OFR
PISG1	0.90	2.33	1.05	1.33	43.71	82.42	51.78	10.23	4.51	7.35
KWF	1.60	3.01	1.62	1.50	54.55	81.75	43.66	4.17	14.08	1.79
GUFCQ	0.60	1.79	0.79	1.30	44.57	93.94	53.04	2.14	2.38	3.92
PISG2	1.50	5.92	1.66	1.47	13.97	50.37	70.33	0.46	15.70	48.96
PISG3	0.76	1.56	0.64	1.54	12.66	34.28	60.45	0.78	26.88	64.94
PISG4	0.81	2.02	0.77	1.13	18.72	48.51	53.53	2.95	22.75	48.54

[1]E_a – water application efficiency; [2] Maximum flow rate; [3] Optimal flow rate.

is very similar to the point of practically overlap, with values very close to the same input flow. This example shows a large difference between runoff and percolation losses, since the difference between them was 48.5% for optimum flow rate and 54.63% for maximum flow rate, resulting in low water application efficiency. The flow rate also showed greater effect on runoff losses, with difference of 69.88% between values predicted for optimal and maximum flow rates, compared to percolation losses, for which the difference was 33.26%. For the design flow rate (1.47 L s^{-1}), the values predicted for the water application efficiency and for runoff and percolation losses were 47.62, 0 and 53.16%, respectively. Thus, showing values close to those predicted for the optimal flow rate, demonstrating that the farmer made the right choice for these field conditions.

For field data PISG3 (Figure 2e), the value predicted by the SASIS model for the optimal flow rate was 0.64 L s^{-1}, close to the minimum flow rate and for the maximum flow rate, it was 1.56 L s^{-1}, whose runoff losses were 0.78 and 60.45%, respectively, while percolation losses were 64.94 and 26.88%, resulting in water application efficiencies of 34.28 and 12.66%. That is also a critical field condition for the irrigation system management, whose percolation and runoff losses show large difference for both optimal flow rates as for the maximum flow rate. The difference between them for the optimal flow rate is 64.16%, and for the maximum flow rate is 37.57%. It was observed in this example that the curve for the percolation losses has basically the same behavior as the water application efficiency curve that is, similar slopes in certain flow rates, however, always with different values. For the design flow rate (1.54 L s^{-1}), the values predicted for the water application efficiency, runoff and percolation losses were 12.7, 60.3 and 27%, respectively, showing quite different predicted losses, demonstrating that the flow choice will cause large runoff losses, which indicates the need for flow management to reduce difference between these losses.

In the example of PSG4 (Figure 2f), the optimal flow rate predicted by the SASIS model, the difference between runoff and percolation losses was 45.59%, and for the maximum flow rate the difference was 35.78%. However, the results demonstrated that the flow rate has a much greater potential to affect the irrigation performance by runoff losses than the infiltration rate by percolation losses, considering that for the same water infiltration conditions the water application efficiency was 48.51% for the optimal flow rate, while for the maximum flow rate, it was 18.72%. Figure 2f shows that the curves that represent the water application efficiency and the percolation losses presented the same tendency, that is, the same slope with values quite close, while the curve related to the runoff losses shows high slope and values distinct from runoff losses predicted for optimal and maximum flow rates. When the flow rate practiced by the farmer (1.13 L s^{-1}) was used as input data to calculate water application efficiency and runoff and percolation losses, they were 38.25, 30.40 and 31.35%, respectively. Both runoff and percolation losses show very high values, which makes the water application efficiency low, even below the value for the optimal flow rate. Thus, in this example, the choice of the flow rate was not adequate. The fact that the values for water application efficiency, runoff and percolation losses were very close to each other is because the flow rate selected by the SASIS model is close to the intersection points of these curves.

The results of this research show the need for optimization in furrow irrigation systems with continuous flow and also identify that in some field conditions, one can achieve high performance levels. According to the studied examples, it was found that the best furrow irrigation performances with continuous flow are achieved for flow rates near the minimum allowable. When runoff and percolation losses are minimal, with little difference between them, that is, with no predominance of one over the other (total maximum losses around 20%), the best water application efficiency is achieved. In some field conditions, such losses cannot be controlled, that is water application efficiency cannot be optimized, and another flow rate which results in improved irrigation performance must be selected. The analyses of the obtained results show that high water application efficiencies were achieved for the low infiltration soils: PISG1, KWF and GUFCQ. While lower performances were achieved for high infiltration soils: PISG2, PISG3 and PISG4.

In field conditions in which runoff and percolation losses were controlled, soils have low infiltration rates; for these infiltration conditions, it was possible to obtain greater control of these losses for a furrow length range from 67 to 360 m and slope from 0.030 to 0.0173 m m^{-1}, showing that the optimization of the furrow irrigation system can be obtained in a wide range of length and steepness. In field conditions in which this control is not achieved, soils have high infiltration rates and the length and slope ranges were 70 to 115 m and 0.0016 to 0.0043 m m^{-1} respectively, showing once again that length and slope do not interfere in optimization.

Valipour (2012a), used the SIRMOD software to compare the hydrodynamic models, zero inertia and kinematic wave in surface irrigation. It was found that the hydrodynamic models and zero inertia were very accurate in the simulation process. However, when the gradient field was increased up to 0.01, the zero inertia and hydrodynamic models showed no difference, but for values greater than 0.01, due to the water velocity increasing, the zero inertia model failed. According to the author, for the Manning roughness coefficient up to 0.15 the error increases, after this value the error remains constant, and n = 0.15 is determined as critical flow. For the author, the accuracy of the kinematic wave model is reduced for heavy clay soils, high flow rates, elevated Manning roughness coefficient and basin irrigation.

Runoff losses affect the performance of furrow irrigation systems with continuous flow, since the low performance levels of furrow irrigation systems used in this study occurred due to the use of flow rates near maximum allowable values, and it is believed that this fact occurs in most areas where furrow irrigation with continuous flow is practiced, explaining the low performance levels recorded in literature.

According to Eldeiry et al. (2004), the high efficiency in furrows with length from 25 to 50 m can be achieved with small discharge. The authors affirm that furrows with a length of 100 m had an efficiency of 80% with discharge ranging from 0.05 to 0.10 m^3 min^{-1}. For small furrows, the efficiency is high for low flow rates with minor variations, while for long furrows, greater efficiency is obtained with less dependence on the flow rate, being the most widely used.

Thus, this study demonstrated well the importance of the SASIS model in forecasting the performance of furrow irrigation systems with continuous flow, selecting input flow in open furrow at the end of the area, allowing better water application efficiency and avoiding waste of water during irrigation.

Conclusions

The results showed that the flow rate plays a decisive role on the performance parameters of irrigation systems, with the best performances on flow rates. The analyses of the obtained results show that high water application efficiencies were achieved for the low infiltration soils, while lower performances were achieved for high infiltration soils. In soils with high infiltration rates, the immense difficulty in optimization is to minimize percolation losses, but in soils with low infiltration rates, both percolation and runoff losses can be easily minimized.

The SASIS model has effective mechanisms in performing numerous simulations within a flow rate range between minimum and maximum, aiming to determine the relationship between flow rate and water application efficiency, percolation and runoff losses and hence optimize the performance of furrow irrigation systems with continuous flow.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Influence of physical protectors with different filters on the initial development of *Peltophorum dubium* (Spreng.) Taub seedlings

Jeferson Klein[1]*, João Domingos Rodrigues[2], Vandeir Francisco Guimarães[3], Leandro Rampim[3], Débora Kestring[3], Daniel Schwantes[3], Rubens Fey[4], Valdemir Aleixo[1], Alfredo Richart[1], Michelli Carline Ferronato[1] and Augustinho Borsoi[3]

[1]Pontifical Catholic University, PUC, City of Toledo, Parana state, Brazil.
[2]São Paulo State University, UNESP, Biological Sciences, City of Botucatu, São Paulo State, Brazil.
[3]State University of West Parana, Unioeste, CCA/PPGA, Pernambuco Street No. 1777, P.O. Box 9, Zip Code 85960-000, city of Marechal Candido Rondon, Parana State, Brazil.
[4]Federal University of South Border - UFFS, city of Laranjeiras do Sul, Parana State, Brazil.

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The use of physical protectors has been considered as an efficient technique for tillage farming of different species, mainly native ones. Based on the importance of the species, *Peltophorum dubium* for revegetation of degraded areas, this study evaluated the emergence, survival and initial development of *P. dubium* seedlings under the influence of physical protectors with different filters. Thus, the following treatments were adopted: absence of physical protector (APP), transparent physical protector (TPP), transparent physical protector + blue cellophane (BPP) and transparent physical protector + red cellophane (RPP). The evaluated characteristics were: emergence velocity index (EVI), seedling survival and emergence percentage, plant height, leaf area and root collar diameter. All of these physical protectors increased the mean values of EVI and survival. In conclusion, the emergence speed and initial development of *P. dubium* (Spreng.) seedlings grown in the interior of physical protectors, independent on the filters, presented positive results. The reduction on the light intensity interferes positively in the initial growth of these plants.

Key words: Native species, reforestation, seedlings.

INTRODUCTION

Since the beginning of the millennium, the reduction of forest resources and the increase of the consumption of wood products were widely discussed because of the increasing need of reforested areas, mainly because, few existent native areas are restricted to preservation, parks and reserves (Mattei et al., 2001). The production of native seedlings species with quality and good characteristics are important for the success of *P. dubium*

*Corresponding author. E-mail: jefersonklein@yahoo.com.br.
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seedlings populations. This production must be performed using appropriate techniques which may provide an efficient and secure quality control (Souza et al., 2005), ensuring a production in quality and quantity (Neves et al., 2005) being that the seedlings are resistant to the adverse conditions. Thus, the direct seedling is a versatile technique in the reforestation process (Barnett and Baker, 1991). According to Ferreira et al. (2007), native seedlings species consist of the dispersion of seeds of the forest species being the seeds sown directly in the reforestation area. This technique have the advantage of reducing the implantation cost for forest stands, in order to eliminate the nursery stage and labor costs, while increasing its importance in areas that lack these resources or with difficult access (Soares and Rodrigues, 2008).

Derr and Mann (1971), studies with direct seedlings observed that only one technique is not enough for the protection of seedlings against adverse conditions. In this way, the use of physical protectors allowed with direct seedling become relevant, once it can cause the reduction seeds and seedlings predation. Besides, the advantage of its interference in germination and establishment of species created a favorable microenvironment (Ferreira, 2002; Mattei and Rosenthal, 2002).

In this way, the *P. dubium* (Spreng.) Taub. popularly known in Brazil as “canafistula” or “faveiro” is a native species found in all domain of the semi-deciduous forest, as well as in the Brazilian cerrado, being that these species are also profuse in secondary formations (Donadio and Demattê, 2000). These species are classified as an opportunist pioneer, tolerant to high taxes of light and temperature, and also considered as a great potential for the use of mix crops destined to the recomposition of degraded areas and areas of permanent protection (Lorenzi, 2000).

Overall, these species is prejudiced, because the production of seedlings have restrictions on the germination and initial development, which are related to tegumentary characteristics and seeds dormancy overcome with the use of physical and chemical scarifying (Salerno et al., 1996; Mattei, 1999; Perez et al., 2001; Teles et al., 2000; Oliveira et al., 2003; Paulino et al., 2004; Viecelli et al., 2011), decreasing the efficiency of seedlings obtaining.

However, other studies which quantify the increment in the initial development of native forest species in function of the light quality provided in the sowing point at the reforestation area. A pilot study conducted at a laboratory show that species as *P. dubium* present potential of susceptibility to light quality variation (Klein et al., 2012). Nonetheless, the real behavior or *P. dubium* in reforestation areas with physical protectors at field level was never evaluated. This procedure is crucial, mainly during the critical period for the establishment of one seedling comprehend in the first 30 days (Meneghello and Mattei, 2004). It is during this period of time, the protection of the seeds is essential, mainly because they can be exposed to dryness, soil compaction caused by strong rainfalls, vulnerability to be attack by birds and ants and also by the breaking in the loading and transportation of the seedlings. In this way, the use of physical protectors in the sowing of forest species is important; it is also favorable to the formation of an adequate micro clime to the germination and survival of the seedlings (Lahde, 1974).

Different materials with different sizes, shapes and colors had been used as physical protectors by many researches (Barnett and Baker, 1991; Serpa and Mattei, 1999; Mattei et al., 2001; Klein, 2005; Klein et al., 2005; Ferreira et al., 2007). According to Carneiro (1995), those protectors must be light, non-toxic, hygroscopic and must recover all soil surface. It is observed in the literature that some benefits of the use of physical protectors when used in the sowing points, contributes to the higher emergence and survival rates in the first months for plants of *Pinus elliotti* (Mattei, 1998; Mattei et al., 2001), *Pinus taeda* (D’Arco, 1999) and in plants of *Enterolobium contortisiliqum* and *P. dubium* (Malavasi et al., 2010). However, there are no reports of physical protectors associated with colored polymers. With all these aspects mentioned above, this study aim to evaluate the influence of physical protectors of different filters in the initial development of *P. dubium* (Spreng.) Taub. seedlings.

MATERIALS AND METHODS

The experiment was performed between April to December, 2007, in open area of the Botanic department (48º 26’ W, 22º 52’ S), Institute of Biosciences, State University “Julio de Mesquita Filho” (UNESP), Botucatu – Sao Paulo State, Brazil. The fruits were collected from matrix trees located in the city of Botucatu – SP. After collection, the seeds were removed from the fruits and clean with the help of a sieve, and after that, they were mixed and selected, thereafter, disposing the damaged ones.

The determination of the physical characteristics of the seeds, was determined with the percentage of germination, level of seed moisture, drying them at 103ºC for 24 h, weight of one thousand seeds and number of seeds per kilogram. The calculations were performed according to the recommendation of the Rules for Seeds Analysis (Brasil, 2009). The seeds of canafistula were submitted to manual mechanical scarification, by the use of a sandpaper number P 80 (Piroli et al., 2005), for the overcome of dormancy (Viecelli et al., 2011). After that, the seeds were submerse in water to room temperature for 8 h and seeds which showed numbness and signs of the imbibition were selected for the sowing. These seeds, were taken to the experimental area for the sowing in vases of 12 liters containing a Rhodic Hapludox, characteristic from the region, was corrected and fertilizer 60 days before the sowing.

The test of germination was performed with five subsamples of 20 seeds, in a acclimatized room, with light exposure from fluorescent lamps (20 W), internally fixed, with temperature between 20 to 30°C and photoperiod of 8 h of light. The experimental design was completely randomized, with four treatments and ten replications. The physical protector used, was constituted from P.E.T. bottles (polyethylene terephthalate), with a volume of 2,500 ml without bottom and with cover. Different length waves were obtained engaging the P.E.T. bottles with two layers of cellophane paper with different colors (transparent, blue and red).

Table 1. Evaluation of the physical characteristics and initial viability of *Peltophorum dubium* (Spreng.) Taub. seeds, performed after 8 months of storage.

Weight of one thousand seeds (g)	Number of seeds per kg
34.93	28,629
Seed moisture content	**Germination**
7.23	90%

Table 2. Speed Index of emergence *Peltophorum dubium* (Spreng.) Taub, subjected to treatment with the presence or absence of colored protectors at 8, 11, 16, 24 and 48 days after sowing (DAS).

Treatment	Days after sowing (DAS)				
	8	11	16	24	48
Absence of physical protector	0.0^{C}	20.0^{C}	55.0^{C}	65.0^{C}	65.0^{C}
Transparent physical protector	5.0^{B}	37.5^{B}	80.0^{A}	80.0^{A}	80.0^{A}
Blue physical protector	7.5^{AB}	62.5^{A}	82.5^{A}	82.5^{A}	82.5^{A}
Red physical protector	10.0^{A}	60.0^{A}	72.5^{B}	75.0^{B}	75.0^{B}
CV (%)			6.23		
F			14.82*		
LSD			4.81		

Means followed by same letter in column do not differ significantly by Tukey test at 5% probability. CV, Coefficient of variation; LSD, least significant difference.

This way, the following treatments were obtained: T1: no physical protector; T2: transparent physical protector; T3: transparent physical protector + blue cellophane and T4: transparent physical protector + red cellophane. Daily, the following evaluations was performed: emergence speed index (ESI): The seedlings emergence evaluations were performed daily for 48 days after sowing, seedlings which present cotyledonary leaves were completely expanded and emerged; percentage of survival and seedlings emergence: This was initiated after the first emerged plant and it was concluded in 48 days after sowing, when the protectors were removed to avoid the effect of the environment pollution; height of plants: This was determined measuring the distance from the root collar to the terminal bud of the plant; diameter of the root collar: Measure performed with a digital caliper and expressed in millimeters; and leaf area: This was defined as the surface of the blade leaf measure performed with the use of an instrument called area meter, model LI-3100 (cm^2).

The obtained results were tested with the suppositions of normality and homoscedasticity for parametric tests, by Shapiro-Wilk and Levene. After that, the analysis of variance (ANOVA) was performed and regression analysis was used also with the program SIGMA PLOT, which described the interactions between the evaluated characteristics. The treatments means were compared by the Tukey test at 5% of probability. For the evaluations of emergence percentage and survival the means were transformed in arccosine of the square root of x/100.

RESULTS AND DISCUSSION

The canafistula seedlings presented a percentage of moisture around 7%. In relation to the number of seeds per kilogram and the weight of one thousand seeds (Table 1), the obtained results reveals that the seeds of canafistula presented a common behavior just like the most pioneer species, as described by Wanli et al. (2001). In general, the canafistula present itself as a great option for reforestation projects, due to its great viability even with low content of water, high quantity of seeds per kilogram and the presence of a dormancy mechanism.

The first emergence of canafistula seedlings in the presence of the physical protector, independent of the color, initiate at 8 days after sowing and the maximum of seedlings emergence was observed 16 days after sowing (Table 2). In the other hand, the first emergences occur in the absence of the physical protector detected, only at 11 days after sowing, being the maximum of seedlings emergence observed only at 20 days after sowing. This increase in the emergence speed is probably due to the function of high taxes of temperature and moisture inside physical protectors (Table 3).

This results, confirm what was observed by Klein et al. (2005), the temperature inside the physical protectors, P.E.T. bottles in three different heights. The same authors observed the increase of nearly 2°C in the interior of the physical protectors in relation to the environmental temperature, no matter how high the protector height.

The use of protectors was also responsible for the increase of the soil moisture and the increase of the the germination and survival study with different forest

Table 3. Temperature and air relative moisture in the seeding points from *Peltophorum dubium* (Spreng.) Taub. 48 days after sowing.

Treatment	Temperature	Air moisture
Absence of physical protector	21.00^{A}	47.90^{B}
Transparent physical protector	22.20^{A}	68.90^{A}
Blue physical protector	21.70^{A}	69.20^{A}
Red physical protector	22.50^{A}	69.80^{A}
CV (%)	5.31	12.50
F	1.02^{ns}	10.93*
LSD	1.67	11.37

Means followed by same letter in column do not differ significantly by Tukey test at 5% probability. CV, Coefficient of variation; LSD, least significant difference.

species in the no tillage system (Santos-Junior et al., 2004). The same type of physical protector was also responsible for the increase in the internal temperature of this environment independently of the year station evaluated (Klein, 2005).

In relation to the emergence speed index (ESI) inside each treatment, those without cover and also with colors presented quadratic behavior (Table 2). In this way, the ESI of the seedlings presented higher values of emergence between 20 and 30 days after sowing. In the other side, for the decomposition of the response in each evaluation (Table 2) significant difference was verified between the treatments in all perform evaluations, where higher ESI was also detected in the seedlings which were inside the physical protectors, independently of the color of the filter.

The emergence percentage of canafistula seedlings presented an increase in all treatments between 16 and 24 days after emergence. But, the largest significant difference was verify between 11 and 16 days after emergence, where all the treatments with physical protector, independently of the filter, originate superior values when compared to the one observed in the absence of the physical protector, being equal at 115, 107 and 100% for the blue protector (BLUE), transparent protector (TRANSP), and red protector (RED), respectively. This way, the higher seedlings emergence may have occur because of the increase of the temperature and phytochrome influence, probably because, the physical protectors may have allowed the canafistula seeds a higher period of time in the optimal temperature for germination, that would explain the maximal germination percentage in a very short time (Silva et al., 2004).

In a study with *Cedrela fissilis*, Mattei. (1995) reports that the used physical protector, a plastic cup of 250 ml, without bottom and with the largest circumference of the circle to the face down, promoted an increase in the tax of germination. Mattei and Rosenthal (2002), notice that protectors as plastic cups and paper cups, without bottom, contributed in the initial emergence and in the establishment of the canafistula seedlings evaluated at 18 months after sowing. Conflicting results were observed by Ferreira et al. (2007), in a study with *Senna multijuga,* observed significant effect for the physical protector, which correspond to transparent plastic pots of 500 ml without bottom, putted above the sowing points. The mean values of canafistula seedlings survival emerged 48 days after sowing, independently of the treatment, were 85% superiors (Table 4), which means that the survival of the emerged seedlings was influenced by the physical protectors independently of the color of the filter. The weakness of seedlings in function to the soil compression resulted because of the less moisture observed as the principal factor of the cause of seedlings death.

Serpa and Mattei (1999), observed a larger percentage of survival in plants of *Pinus taeda,* used for timber and cellulose originated in the interior the physical protectors. Besides, Santos-Junior et al. (2004) observed an increment in the survival percentage of *Tabebuia serratifolia*, used for landscape and reforestation*,* while physical protector used for transparent plastic cups of 500 ml without bottom and buried 2 cm under the hole, was in relation to the absence of physical protector. The increase, promoted by the physical protector in the survival of seedlings can be directly related to the ecological group which the vegetal species is classified (Perez et al., 2001). In this way, the protector initiates great benefits to slow development species (Ferreira et al., 2007).

The mean values obtained at 48 DAS of plant height, observe that the blue and red physical protectors provided significant growth of stem in comparison to the other treatments (Table 5). The transparent physical protector promoted the third higher increment of this variable, without significant difference in the height provided by the absence of the physical protector. The use of the physical protectors associated with color filters in the points of sowing can interfere in the quality of light in seeds and seedlings, stimulating or causing inhibition in different physiological processes. According to

Table 4. Mean values of seedling survival *Peltophorum dubium* (Spreng.) Taub., submitted to treatment with the presence or absence of colorful protectors 48 days after sowing.

Treatment	Survival (%)
Absence of physical protector	878^{B}
Transparent physical protector	932^{A}
Blue physical protector	966^{A}
Red physical protector	954^{A}
CV (%)	732
F	706*
LSD	452

Means followed by same letter in column do not differ significantly by Tukey test ta t 5% probability. CV, Coefficient of variation; LSD, least significant difference.

Table 5. Mean values of height, leaf area and root collar diameter of seedlings were *Peltophorum dubium* (Spreng.) Taub., submitted to treatment with the presence or absence of colorful protectors 48 days after sowing.

Treatment	Height (cm)	Leaf area (dm^2)	Root collar diameter (mm)
Absence of physical protector	5.3^{B}	9.9^{B}	1.4^{A}
Transparent physical protector	5.6^{B}	11.0^{B}	1.5^{A}
Blue physical protector	9.3^{A}	15.3^{B}	1.8^{A}
Red physical protector	7.6^{A}	21.3^{A}	1.1^{A}
CV (%)	9.9	21.29	18.29
F	1.17*	3.91*	0.45^{ns}
LSD	1.86	8.63	0.84

Means followed by same letter in column do not differ significantly by Tukey test ta t 5% probability. CV, Coefficient of variation; LSD, least significant difference.

Almeida and Mundstock (2001), many signaling when presented in the different plant tissues can be responsible for acting in the vegetal growth in function of quality and quantity of the received light. For Taiz and Zeiger (2004), the increment in the stem stretching reveals the response to light intensity reduction on the seedlings, which indicate the involvement of the phytochrome in this perception.

The same behavior was found in *Cattleya loddigessi*, where Braga et al. (2007) verified that the shoot system and the root system grown were promoted by the red mesh. The influence of the blue, black and red mesh in the plant height was also verified in *Aralia* sp., *Monstera deliciosa, Aspidistra elatior* and *Asparagus* sp. (Shahak et al., 2002). The no tillage system in the presence of the red physical protector provided higher mean values for the leaf blade area when compared to the other treatments (Table 5). The plants which was grown in the interior of the red physical protector presented mean values for leaf area around 21.30 dm^2, and the other treatments without physical protector, transparent physical protector and blue physical protector presented 9.90, 11.00 and 15.30 dm^2, respectively. Those values suggested a positive correlation between the reduction in the light quantity received, photosynthetically active radiation (PAR) and the values of shoot system area. In this context, Larcher (2004), reports about the heliophytic plants during the evolution and how this species develop efficient strategies in order to maximize the electron transportation to the chloroplast, even in low radiation intensities. However, presenting high percentages of leaf area can be one important alternative in reforestation projects (Coelho Filho et al., 2005), mainly in relation to the initial development of seedlings.

In the present study, the mean value of the root collar in canafistula seedlings was not influenced by the different treatments after 48 DAS (Table 5). It is important to affirm that those treatments did not prejudice in the initial development of canafistula in the evaluated period. When the obtained mean values with the use of red physical protector was analyzed it was observed that they were 25, 31 and 40% respectively, lower to the ones obtained in the absence of physical protector, transparent physical protector and blue physical protector, respectively.

Guariz et al. (2006), evaluated the diameter and height growth of *Posoqueira acutifólia* seedlings in different solar radiation levels and it was observed that as the shading level was increased, the root collar diameter decreased. The same result was obtained by Aguiar et al. (2005), analyzing the influence of different levels of shading in the initial development of *Caesalpinia echinata* seedlings which presented higher mean values in the root collar diameter in relation to the plants maintained in full sunlight.

Conclusion

All types of physical protectors increased the mean values of EVI and survival. In the conditions of this study, emergence speed and the initial development of *P. dubium* (Spreng.) seedlings grown in the interior of physical protectors, independently on the filters, presented positive result. The reductions on the light intensity interfere positively in the initial growth of plants.

Conflict of Interest

The authors have not declared any conflict of interest.

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Review

Overview of soil subsurface flow in hydrological perspectives

Yinghu Zhang, Jie Yang*, Haijin Zheng and Jialin Jing

Jiangxi Provincial Institute of Soil and Water Conservation, Jiangxi Provincial Key Laboratory for the Control of Soil Erosion, Nanchang, China.

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With respect to chemical and biological perspectives, runoff generation mainly includes surface flow, subsurface flow and groundwater flow. Subsurface flow as a pivotal phenomenon has been studied for many years. Research on subsurface flow is a long-term challenge due to its complicated water flow at the soil profile scales. In general, subsurface flow has two typical patterns: preferential flow (vertical flow) and matrix flow (horizontal flow). In this paper, overview on subsurface flow including definition, characteristics, mathematical models, trends and needs have been implied. Understanding the mechanisms of subsurface flow is a huge future challenge from hydrological perspectives because soils are gradually regarded as the most complex component on earth. Finally, research gaps, trends and needs are listed in detail.

Key words: Subsurface flow, models, soil, surface flow.

INTRODUCTION

Soil particles are particularly important parts of the typical soil-plant-atmosphere continuum (Philip, 1966). At the soil profile scales, water movement and solute transport is a common phenomenon when they move through the total soil layers even groundwater reservoir.

Soil subsurface flow influenced by rainfall events, soil depth, slope gradient, vegetation, cultivation, irrigation, tillage systems and soil physical and chemical properties is a typical flow pattern compared with surface flow.

Some hydrologists confirmed the relation of loss of nitrogen (N) and phosphorus (P) components to soil subsurface flow with respect to contaminants pollution. Meanwhile, they illustrated the vital effects of soil preferential flow (vertical flow as one kinds of soil subsurface flow in soil layers) on pollutants preferential transport. And the effect of soil matrix flow (horizontal flow as one kinds of soil subsurface flow in soil layers) was also significant to understand the comprehensive effects of soil subsurface flow. From the year 1990, people began to pay more attentions to the studies of soil subsurface flow (Figure 1).

To prompt learning more about mechanisms of soil subsurface flow whether at the profile scales or in the landscape or global scales, maybe it is critical to understand structure, rate, characteristics, controlling factors, mathematical models, and methodology of soil subsurface flow. In general, mathematical model simulation, indoor and field experiments, theoretical

*Corresponding author. E-mail: zljyj@126.com.
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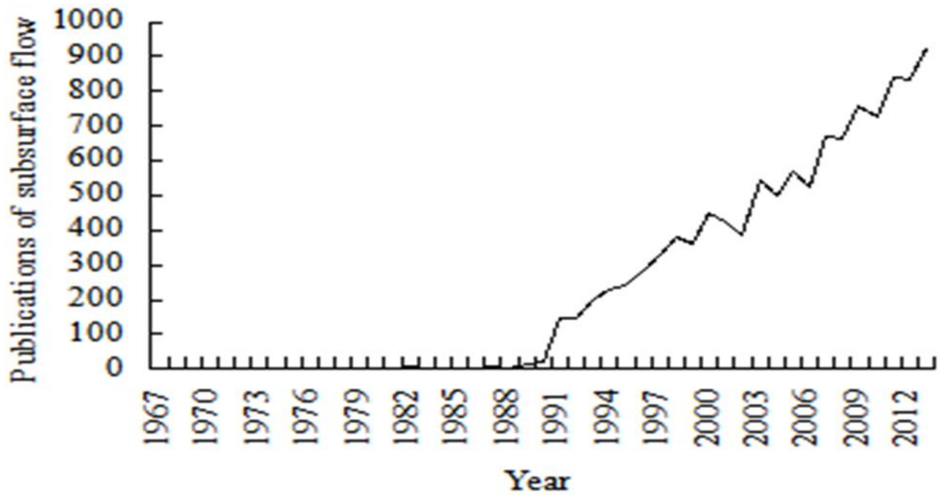

Figure 1. Publications of subsurface flow from 1967 to 2013 (source from web of science).

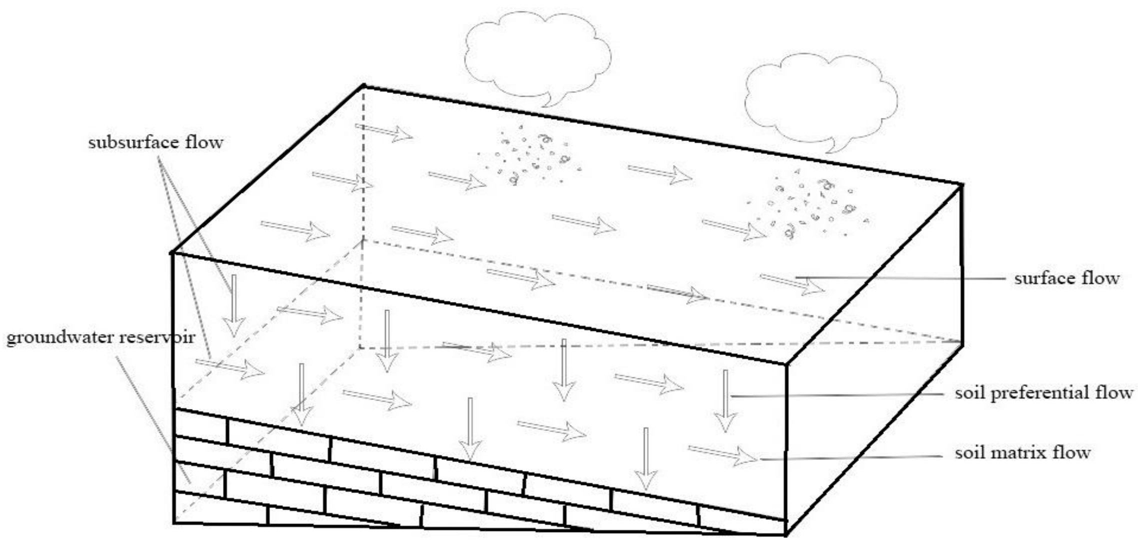

Figure 2. Subsurface flow process including soil preferential flow and soil matrix flow in the hillslope.

analyses are carried out to imply the characteristics of soil subsurface flow in detail. During field experiments process, it is difficult to observe subsurface flow processes.

DESCRIPTION OF SOIL SUBSURFACE FLOW

As for subsurface flow, a small portion or the total portion of rainfall could move through the upper soil layers, and get to the groundwater level finally. Generally speaking, subsurface flow phenomenon is obvious in humid regions because soil infiltration rate is high there. As a pivotal component of runoff generation, studies upon soil subsurface flow which belongs to hydrological processes are promising increasingly in the watershed. It is of great importance to simulate runoff generation process.

In the last few years, more attentions had been paid to soil subsurface flow studies by means of indoor simulating events, and also excellent results were showed.

However, researchers still disputed of soil subsurface flow way patterns and resident time at the soil profile scales. Currently, few attentions have been paid to soil subsurface flow simulations, especially those controlling factors which exert significant influences on subsurface flow processes. Subsurface flow described by the runoff generation process is showed in Figure 2.

Characteristics of soil subsurface flow

Soil subsurface flow mainly occurs in the unsaturated zone where soil permeability is different from surroundings. External controlling factors, such as soil properties, rainfall, initial soil moisture and so on, exert significant influences on soil subsurface flow.

In general, the effluent of soil subsurface flow takes accounts for only 10 to 50% of the total runoff generation in the watershed, while some hydrologists also stated that the effluent of soil subsurface flow was larger than that of surface or overland flow in some areas.

Though surface flow, subsurface flow and base flow are usually correlated in hydrological perspectives, they tend to be regarded as individual systems due to the complexity among them when hydrologists concentrated on their relationships.

WHICH CONTROLLING FACTORS COULD AFFECT SOIL SUBSURFACE FLOW?

Soil texture and structure

From pedological perspectives, rock fragments or gravels are used to characterize the forms of soil texture. In usual, three different kinds of soil textures, such as low sandy soil, intermediate sandy soil and high sandy soil, are described in terms of rock fragments content. Soil texture has a vital influence on soil moisture content and soil pores, especially soil macropores and preferential flow pathways. Generally speaking, preferential flow and matrix flow are two aspects of soil subsurface flow. For example, soil macropore flow usually occurs in the place where silty sand is abundant. Meanwhile, finger flow usually occurs in the place where coarse sandy soil is abundant. Soil structure usually has a high spatial heterogeneity because of soil macropore connectivity and tortuosity, soil pore diameter and density and so on. Changes of soil structure will lead to a complicated heterogeneity with regard to large soil profile scales.

Rainfall and irrigation events

Rainfall intensity exerts on significant influences on the effluent of soil subsurface flow directly, especially surface flow. In general, two processes are involved during the total rainfall events. On the one hand, soil water and solute tends to move through the deep soils even groundwater levels. On the other hand, soil water and solute usually move along with surface flow as rainfall intensity is larger than infiltration rate. Most studies confirm that preferential flow pathways could not disappear with the increase of rainfall intensity. Meanwhile, water movement by means of matrix flow is promising increasingly, while it is contrary for preferential flow. The effects of irrigation are the same as rainfall events.

Vegetation

Vegetation plays a critical role in runoff generation, especially soil water flow components, because vegetation tends to bring about lag effects. Meanwhile, three kinds of flows including low flows, intermediate flows and high flows are characterized on the basis of the conditions of vegetation.

Cultivation and tillage systems

With regard to farmlands, human activities have significant influences on soil porosity, soil structure, soil physical and chemical properties (Oostwoud and Poesen, 1999; Follain et al., 2012). Cultivation patterns including tillage and no tillage systems could exert effects on the proportion of soil aggregates during the liquid and gaseous phases in the total soil ecosystem. Cultivation tends to enlarge the infiltration time of soil water by means of altering soil structure, finally increasing the effluent of soil subsurface flow.

Soil physical and chemical properties

For soil physical properties, it mainly contains soil porosity, soil structure, soil moisture, soil gaseous, soil energies, soil evaporation and so on. While for soil chemical properties, soil colloid and ion exchange, soil PH, soil buffer action, soil redox properties are listed.

Plant roots and microorganism activity

Plant roots are able to form well-connected macropores or channels and also normally grow into rigid pores broader than their own diameters. Channels created by plant roots may contribute to water and solute transport, especially macropore flow. Li and Ghodrati (1994) recorded that the saturated hydraulic conductivity (K_{sm}) in soil columns with root channels was six time higher than in control columns without root channels. Devitt and Smith (2002) realized that there were likely to be fewer pores with a lower root density as it was generally accepted that roots generated macropores.

Rock fragments in the soil

Rock fragments containing all materials whose horizontal dimensions are smaller than a pedon are stones and soil mineral particles 2 mm or larger in diameter. Rock fragments distributed in the topsoil (at the soil surface, well embedded in the topsoil and completely incorporated in the topsoil) and subsoil gradually become emphasis, especially soil surface rock fragments. Katra et al. (2008) confirmed the influence of rock fragments on water movement and reported that water content was high as the soil surface containing rock fragments. Zhou et al. (2011) demonstrated that there was a complex relationship between rock fragments and water movement and solute transport in undisturbed soil columns.

Hillslope gradient and slope length

Generally speaking, hillslope gradient may depend on the effluent rate of surface flow and subsurface flow to some extent. Compared with gentle slope, steep slope has the higher effluent rate of surface flow. Especially, it is easy to form surface flow under steep slope conditions. While for subsurface flow, it is complicated during the forming process, because people could not change the boundary conditions in the subsoil. With respect to steep slope, only few portions of water will infiltrate into soil layers under high rainfall intensity conditions. Water tends to move along with the slope to form surface flow. Meanwhile, slope length also has significant influences on runoff generation. Some covering mulch distributed in the soil surface may prevent soil water and solute from being eroded when the slope is long. That is, soil water will be obstructed along with the long slope. Consequently, the effluent and flow rate decrease increasingly as water get to the outlet sections.

Hillslope geometry

Hillslope geometry has a significant influence on subsurface flow. Especially, hillslope length exerts pivotal effects on hillslope travel time in the subsurface flow. Meanwhile, lots of studies have paid more attentions to the stable effluent rate of subsurface flow in the hillslope considering the hillslope geometry.

Surface coverage

Surface coverage is a pivotal index when considering runoff generation. Especially for the forest ecosystems, surface flow or subsurface flow will be postponed because of the interception from forest canopy, branch and litter layers compared with bare land. With respect to farmland, crops may also have the same effects. The nutrition and fertilizer in soils will not be eroded with high surface coverage.

Freezing/thawing, wet/dry seasonal recycling

With the changes inherent to freezing/thawing cycles and wet/dry seasonal recycling, soil moisture content correspondingly increases and decreases (Weiler and Naef, 2003). As soil moisture content increases, soil aggregates expand at the soil profile scale under wet or freezing conditions, resulting in a decrease in macropore density and in the area of flow water. However, macropore tortuosity will be implied fully (Zhou et al., 2009, 2011). On the contrary, soil aggregates are expected to shrink because of low soil moisture content under wet or thawing conditions, forming a series of large pores that can facilitate flow rate or effluent movement.

MATHEMATICAL MODEL OF SUBSURFACE FLOW

On the basis of field experiments and events, simulated models are be used to characterize the runoff generation, such as surface flow, subsurface flow and base flow. But, lots of simulated models are not suitable for runoff generation process because of the complicated controlling factors. Therefore, more and more comprehensive indexes must be adjusted so as to improve the accuracy. With regard to those models, Richards' equation, Kinematic wave model, Storage discharge model, Tsinghua hillslope runoff model, Instantaneous unit hydrograph model, and HYDRUS models are widely used.

Richards' equation

Richards' equation was described by Richards (1931) who took advantage of soil water movement continuity principle and Darcy laws on the basis of micro perspectives. The equation is described as follows:

$$\nabla\left(K_s K_r \nabla h\right) = c\frac{\partial \psi}{\partial t} - Q \qquad (1)$$

∇ represents Hamiltonian, K_s represents saturated permeability coefficient, K_r represents relative permeability coefficient, h represents total head, Ψ represents pressure head, t represents time, Q represents source term of any flow.

In general, it is impossible to solve the Richards equation. Researchers only obtain some results by means of data materials. According to the characterizing analysis of this equation, three kinds of models are described, such as one-dimensional Richards' equation, two-dimensional Richards' equation and three-dimensional Richards' equation.

Kinematic wave model

Kinematic wave model was described by Beven (1982) who considered that the flow line in impermeable layers distributed in the saturated zones was parallel to the bedrock, meanwhile, hydraulic gradient was equal to the bedrock gradient. This model is listed as follows:

$$\begin{cases} q = K_s H_x \sin\alpha \\ c\dfrac{\partial H_x}{\partial t} = -K_s \sin\alpha \dfrac{\partial H_x}{\partial x} + i \end{cases} \tag{2}$$

q represents discharge per unit width, H_x represents the thickness of saturated zones in the impermeable boundary, i represents water flow rate from the unsaturated zones to saturated zones per unit, c represents the water holding capacity.

Storage discharge model

Storage discharge model was described by Sloan and Moore (1984) who assumed that there was an impermeable boundary in the hillslope. On the basis of water balance theories, subsurface flow was studied from macro aspects. Meanwhile, researchers supposed that the gradient was α, slope length was L, and soil depth was D. Relative index is described as follows:

$$\frac{V_2 - V_1}{t_2 - t_1} = iL - \frac{q_2 + q_1}{2} \tag{3}$$

V represents discharged water volume in saturated zones per width, t represents time, q represents discharge per unit width, i represents water flow rate from the unsaturated zones to saturated zones per unit, 1 and 2 represent start and end time.

PERSPECTIVES

Soil subsurface flow as a typical phenomenon in hydrological perspectives has been treated as a considerable index when hydrologists carry out studies to imply the relation of hydrogeology to subsurface flow. To date, people have concentrated on studying subsurface flow increasingly. However, the complicated processes among surface flow, subsurface flow and base flow interactions confuse people to some extent. And researchers could not characterize the mechanisms of subsurface flow accurately. Some research needs are listed as follows:

Conventional models should be adjusted to characterize subsurface flow process in detail.

Subsurface flow mainly includes preferential flow and matrix flow. During the rainfall events, what is the proportion of water movement by preferential flow? And what is the proportion by matrix flow? It is difficult to quantify and simulate.

Most researchers simulate the loss of N and P even other contaminants by observing the changes of concentrations during the rainfall events. However, they neglect that the concentration of compounds change anytime. They do not consider each phase during the experiments.

Water exchange between preferential flow pathways and soil matrix is a complicated process. How many is the transfer extent between preferential flow pathways and soil matrix? Such should be measured accurately.

CONCLUSIONS

Overviews on subsurface flow studies including subsurface flow definition, mathematical models, and characteristics have been implied. Studies upon subsurface flow are confronted with many difficulties which could not be solved accurately. Conspicuously, people should pay more attentions to preferential flow and matrix flow if they would like to know more about subsurface flow. As it is well known from the researches, subsurface flow mainly includes preferential flow and matrix flow. Therefore, understanding soil subsurface flow is a huge future challenge from hydrological perspectives because soils are gradually treated as the most complicated component on earth.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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Efficiency impact of the agricultural sector on economic growth in Togo

Kamel HELALI*, Koffi TSAGLI and Maha KALAI

Department of Applied Quantitative Methods, Faculty of Economics and Management of Sfax. University of Sfax, Airfield Road Km 4, BP 1088, Sfax. 3018, Tunisia.

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The fundamental idea of this article is to study the efficiency of the Togolese agriculture and its relationship with economic growth on the basis of economies of scale. We tackled efficiency, in its input and output orientations, using parametric and non-parametric methods in which an annual product analysis is carried out. In this context, agriculture is modelled by the usual Translog and Cobb-Douglas functions and efficiency estimating techniques, such as the stochastic frontier analysis (SFA) and data envelopment analysis (DEA). Agricultural production was analyzed on a product basis depending on the cultivated area and the number of workers in the agricultural field. The study sample consists of 15 agricultural products for the period running from 1990 to 2009. The Togolese agriculture is generally inefficient according to the DEA and SFA methods.

Key words: Togolese Agricultural Sector, efficiency, stochastic frontier, data envelopment analysis (DEA).

INTRODUCTION

The agricultural sector in the developing countries is the focal point of the policy makers and international organizations that laid the foundation in the fight against poverty. Agriculture, beyond its economic dimension, remains a prerequisite for survival for the poor countries threatened by famine. The major global organizations that struggle for the welfare of the whole humanity put agriculture at the heart of their preoccupations. Financial assistance that developed economies grant to third world economies is based on the idea that agriculture is a key sector that should be promoted to back any idea of development.

The main question that we try to answer in this work is simple: Can we say that agriculture in the developing countries is efficient? This question leads to another more important one: What impact does the agriculture efficiency have on the economic growth of these countries? Or, more specifically, what role does an efficient or inefficient agriculture have on the GDP of a developing country? More clearly, our work raises the question of the agriculture impact on economic growth regarding efficiency.

An African country, particularly Togo, is going to be the subject of our investigation since this country has (Danklou, 2006; Thierry, 2010). In addition, more than 70% of the active workforce is engaged in agriculture; more than 60% of its arable land, while only 11% of these lands are being value according to official figures

*Corresponding author. E-mail: helali.kamel@gmail.com, Tel: 00216 74 27 87 77. Fax: 0021674279139.
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nevertheless, no signs of food self-sufficiency were observed in Togo. For this reason, we really wonder if the use of agricultural resources in Togo is optimal.

The issue here is to know whether economic growth is caused by agriculture or vice versa. In other words, is causality between agriculture and economic growth simple or double? Obviously, it is very logical and justified to say that it is agriculture that causes economic growth because its importance in economic growth has long been noticed by eminent economists, such as Lewis (1956). Economic growth, by the savings made, promotes the funding of research necessary for technical progress that sustains agriculture. Technical progress may reduce or complicate the appropriation of natural resources by humans over other species. However, some authors emphasize that economic growth measured by the GDP tends to destroy the natural capital. One of the criticisms of the market economy is that the environment is poorly reflected in the current economic models. When technical progress ignores the environmental constraints, growth and productivity can have negative effects on the environment. In short, agriculture contributes to economic growth which has both beneficial and devastating effects on it.

LITERATURE REVIEW

Obviously, it is very logical and fair to say that it is agriculture that generates economic growth because its importance has long been noticed by eminent economists. Johnston and Mellor (1961) identified two important relationships that distinguish the agricultural sector in economic growth. Yorgason (1974) believes that in almost all countries, agriculture is actually an important sector. There is a temporal growth in the agricultural sector whenever we notice a process of growth or development. Besides, Johnston and Mellor (1961) indicated that the importance of the transformation and the size of the labor requirements and the capital needed to develop a modern industrial sector, represent a large burden for agriculture. These authors identified five categories of agricultural contributions to the economic development. These categories are the agricultural production for domestic consumption, the exports of agricultural products and substantial gains on external trade, the transfer of labor in the industrial sector, the flow of money for the capital development and the high incomes in agriculture as a market for industrial products. However, Kuznets (1968) identified only three categories of contributions: product contributions, market contributions and factor contributions.

Although Kuznets and Johnston-Mellor's classifications are artificially important, they did not reach the heart of the problem. Naturally, the contributions of agriculture to economic growth can take several forms. However, we may wonder under which conditions these transfers actually will take place. These classifications indicate what might have happened without giving any real idea of why the process starts or what must be done to maintain or strengthen it. There have been attempts by some economists to produce a theoretical basis for the development of the transfer process. In general, they used the model approach. Although they originally tackled the problem using the transfer of goods and factors, some market transfers were taken into consideration.

Given that the GDP is a perfect measure of economic growth, the debate will be formulated rather around the causality direction between agriculture and economic growth. It should be underlined that these two processes (agriculture and economic growth) are the essential part of our work. Nobody shall hold such a debate without resorting to the concept of efficiency since the concepts of efficiency and profitability cannot conclude this debate in a convincing way. Efficiency will be the centre of inertia of the triangle formed by the agriculture, economy of scale and growth. The concept of efficiency borrowed from the Life Sciences is a fundamental concept which is of a great importance today due to the extent of its field of application. In the managerial, social, and industrial sciences, the concept of efficiency is omnipresent. Today, even the health sector closely examined efficiency. Our study of agriculture is entirely based on the concept of efficiency. For this reason, agriculture will be modelled as a company which uses the capital and labor factors to achieve production.

The study of efficiency refers to the use of resources available in production. The theoretical framework of the efficiency measurement was originally developed by Farrell (1957) in measuring the efficiency of firms or production units within a production process. Efficiency is the best use of resources in production. The decision units, which manage to produce a maximum output from a given level of inputs, or equivalently, a given output from a minimum level of inputs can be considered efficient. The approach is particularly interesting because it uses a concept of relative efficiency, which helps avoids setting a standard characterizing of the efficient situations. A producer will then be considered to be relatively inefficient if another producer uses a lower or equal amount of inputs to produce as many or more outputs. The production function estimation, which is the relationship between the inputs and outputs of the production process in the considered sample, enables then to define the "best practices" located on the production frontier (Djokoto, 2012). This frontier represents the technological limits of what an organization can produce with a given level of inputs. The inefficiency of a decision unit is then measured according to the distance from the frontier.

In what follows, we will go back, in a second section, to a literature review that shows the causal relationship between economic growth and agriculture. The data and

Table 1. Descriptive analysis of the variables.

Products	Production		Capital		Labor	
	Mean	S-D	Mean	Mean	S-D	Mean
Sorghum	572.0	82.9	512.2	191.1	127.2	63.9
Millet	562.3	101.6	143.0	20.7	109.3	54.9
Maize	418.4	96.7	58.7	7.8	77.4	38.9
Fonio	146.9	19.6	56.2	10.2	68.1	34.2
(paddy) Rice	142.7	35.4	51.8	12.2	59.1	29.7
Yam	61.7	18.8	51.5	14.0	56.7	28.5
Sweet potato	53.2	14.6	39.0	1.4	28.0	14.1
Taro	36.0	9.8	36.0	1.3	18.8	9.4
Bean and Niébé	31.1	7.3	35.9	1.3	14.6	7.3
Voandzou and beans	15.9	5.5	33.9	1.2	14.4	7.2
Groundnut in Hull	14.8	4.7	29.2	1.0	8.2	4.1
Manioc	8.8	8.3	10.1	6.7	5.9	2.9
Cotton Granulates	6.3	1.2	8.4	8.3	4.0	2.0
Cocoa raw Coffee	6.0	4.0	4.5	1.6	1.8	0.9
Broad beans	6.0	5.7	1.7	1.6	0.3	0.2
Total	**2082.1**	**286.0**	**1072.1**	**224.7**	**593.9**	**298.4**

S-D, Standard deviation.

models will be presented in the third section. The parametric and non- parametric estimates of the efficiency scores will be the subject of the fourth section. Finally, the main conclusions will be presented in the last section.

METHODOLOGY

Data and variables

Efficiency seen from the angles of its input and output will be measured in a technical and allocative way through non-parametric and parametric methods. In fact, we focus on a third world economy, Togo, about which the data are obtained mainly from the Statistics Centre of Togo. Each variable is characterized by panel data with 15 agricultural products over a period of 20 years, which gives us 300 observations for each variable. The Translog and Cobb-Douglass functions will serve as working tools whereas the ordinary least squares methods help us estimate the coefficients of the models. The efficiency estimate will be ensured using the SFA and DEA methods. Finally, a special attention will be paid to the interpretation of the results.

Agricultural data about Togo are very scarce today. The available ones stopped to exist in 1999 or 2001 at the General Directorate of Statistics and National Accounts of Togo (DGSCN). Although these data were of great help for us, we had to complete them in the field through surveys conducted over three months in some Togolese leading agricultural towns, such as, Tsévié, Kpalime Togoville Atakpamé, Sodoké, Dapaong and Sinkassé. In total, we could collect the information required to fill out the gaps left by the DGSCN to reach a 20-year period (1990 to 2009).

We selected a sample of 15 agricultural products to model the total agricultural production. These outputs include: Millet, maize, sorghum, fonio, rice, yam, sweet potato, taro, cassava, beans, cowpeas, bambara groundnuts, inshell peanuts, cotton seeds, cocoa beans and green coffee. The reader should have the right to wonder about the choice of these products. The answer is simple: They are the products selected by the DGSCN to collect national statistics which are more representative of the agricultural production in Togo since these products represent more than 80% of the Togolese agricultural production. The purpose of this choice is to make the Togolese authorities understand this work easily so that they will eventually use it for their future agricultural policies. The food products are at the forefront in terms of volume since they represent more than 75% of the production of this sample. The prevalence of food crops is due to the period chosen for the research. In total, worked work with three variables, namely production (Y), capital stock (K) and labor (L) over a period from 1990 to 2009.

Our major factor is the overall area of the cultivated area in Togo which is estimated at 1072100 ha per year (Table 1), that is to say, approximately 30% of the arable land in Togo. This area is increasing at a rate of 2.72% per year. The labor factor is the number of inhabitants in the agricultural sector in general. On average, 593900 inhabitants work in the agricultural sector each year whose number can vary more or less by 298400 inhabitants per year (Thierry, 2010). The overall production is measured in volume because we do not have the prices of the various products over the studied period. The average production in Togo is of 2082100 tons with an increase of 1.71% per year.

Models

Using two production factors, namely, capital and labor, as well as a trend component to measure evolution over time (t), we limit our work to the use of the Cobb-Douglas and Translog functions (Eric et al., 2004).

The Cobb-Douglas production function is then defined by:

$$LnY_{it} = \beta_0 + \beta_L \, LnL_{it} + \beta_K LnK_{it} + \beta_t \, t + \varepsilon_{it} \quad (1)$$

Similarly, the Translog production function takes the form:

Table 2. Unit root test of (Levin et al., 2002).

Variables	Model 1		Model 2		Model 3	
	T_B^*	T_C^*	T_B^*	T_C^*	T_B^*	T_C^*
LY	1.55(0.939)	1.54(0.939)	3.3(0.990)	18.02(1.000)	10.35(1.000)	32.17(1.000)
LK	5.70(1.000)	5.70(1.000)	-0.94(0.17)	2.03(0.97)	-12.55(0.000)	-10.03(0.000)
LL	5.1(1.000)	5.1(1.000)	-6.132(0.000)	-3.45(0.000)	-48.61(0.000)	-48.7(0.000)
LK2	5.55(1.000)	5.55(1.000)	4.12(0.939)	8.27(0.939)	-2.60(0.004)	-0.42(0.33)
LL2	4.86(1.000)	4.86(1.000)	-1.71(0.156)	2.58(0.990)	-30.71(0.000)	-27.46(0.000)
LKL	5.65(1.000)	5.65(1.000)	5.47(1.000)	10.02(1.000)	-13.026(0.000)	-3.91(0.000)

LY = Ln(Y); LK = Ln(K); LL = Ln(L); LK2 = 0.5*(Ln(K))^2; LL2 = 0.5*(Ln(L))^2; LKL= Ln(K)*Ln(L). P-values are put between brackets.

Table 3. Co-integration tests of the various variables.

Tests	Statistics	Cobb-Douglas	Translog
Pedroni (1999)	Panel v−statistic	-3.37 (0.00)	0.14 (0.00)
	Panel ρ−statistic	-56.38 (0.03)	-41.79 (0.00)
	Panel PP−statistic	-16.59 (0.00)	-12.38 (0.06)
	Panel ADF−statistic	-2431.4 (0.00)	-2460.8 (0.00)
	Group ρ−statistic	-56.02 (0.37)	-54.29 (0.37)
	Group PP −statistic	-15.31 (0.00)	-14.18 (0.37)
	Group ADF −statistic	-19.52 (0.00)	-16.64 (0.00)
Mc Coskey and Kao (1998)	LM	20.5208 (0.00)	138.4012 (0.00)

$$LnY_{it} = \beta_0 + \beta_L LnL_{it} + \beta_K LnK_{it} + \beta_t t + \frac{1}{2}\gamma_{LL}(LnL_{it})^2 + \frac{1}{2}\gamma_{KK}(LnK_{it})^2 + \frac{1}{2}\gamma_{tt}tt^2 + \rho_{LK} LnL_{it} LnK_{it} + \rho_{tL} tLnL_{it} + \rho_{tK} tLnK_{it} + \varepsilon_{it} \quad (2)$$

To know if the Cobb-Douglas production function advantageously substitutes the Translog specification, we used the likelihood ratio test (LR) to see whether the general Translog functional form, as specified, dominates the Cobb-Douglas functional form. Therefore, we marked by M1 the Cobb-Douglas model and M2 the Translog specification.

Integration analysis

As previously specified, the efficiency estimation is made through two types of methods: the parametric (SFA) and the non-parametric (DEA). However, before we get there, it would be interesting to study the correlations between the study variables.

The used transformed variables are spread over a 20-year period. We therefore need to justify the long-run relationship between them. The tests proposed by Levin et al. (2002) show that none of the variables is stationary in level (Table 2).

Since the variables are not stationary (I[1]), it is necessary to check the existence of a co-integration relationship between the long-term variables of the model (Table 3). Actually, the tests of Pedroni (1999) and McCoskey and Kao (1998) show that the variables are co-integrated and, therefore, the long-term equilibrium relationship is justified.

EMPIRICAL ANALYSIS

Estimation models

Concerning the parametric analysis, the efficiency of the agricultural sector in Togo was estimated using four models: A Cobb-Douglas model with and without technical progress (M1) and (M3) and a Translog model (M2) and (M4) with and without technical progress (Table 4).

In most models (M1, M3 and M4), the results show that the capital and labor, the factors production as well as the trend and the constant are all significant. Moreover, for M2, which represents the Translog function with a non-neutral technical progress model, the results show that the capital output factor is significant whereas the labor and trend are insignificant. This means that agricultural production in Togo depends on the area of the cultivated land and the number of workers in the plantations.

Actually, this production induces an upward trend for M1 of 2.4% per year. Hence, if the cultivated area increases by 1%, production rises by 0.94%, and if the number of workers goes up by 1%, production rises by 0.18%.

The minimum log production in Togo is 1.673, which gives a real production of 5328 tons per year. However, at the level of the M4 model, production induces an upward trend of 3.3% per year. Thus, if the cultivated area increases by 1%, production rises by 0.9%, and if the number of workers increases by 1%, production goes up by 0.27%, that is a minimum production of 5640 tons per year.

The LR tests of maximum likelihood help choose the model that best describes the Togolese agricultural production. Indeed, comparing M1 and M3 models gives

Table 4. Estimates of the models through the SFA.

Variables	Cobb-Douglas		Translog	
	M1	***M3***	***M2***	***M4***
β_0	1.673(0.000)***	1.631(0.000)***	1.862(0.000)***	1.730***(0.000)
β_K	0.943(0.000)***	0.905(0.000)***	0.968 (0.000)***	0.924***(0.000)
β_L	0.187(0.003)***	0.229(0.000)***	0.158(0.291)	0.266***(0.000)
β_t	0.024(0.002)***	0.021(0.001)***	0.021(0.228)	0.033***(0.001)
γ_{KK}	-	-	-0.034(0.01)***	-0.418***(0.01)
γ_{LL}	-	-	0.017(0.67)	-0.020*(0.09)
γ_{tt}	-	-	-0.000(0.59)	0.001*(0.07)
ρ_{LK}	-	-	0.005*(0.70)	0.008(0.468)
ρ_{tK}	0.005(0.000)***	-	-0.003(0.147)	-
ρ_{tL}	0.005(0.002)***	-	0.005(0.240)	-
μ	1.648(0.000)***	1.661(0.000)***	1.684***(0.000)	1.659***(0.000)
θ	0.002(0.000)***	0.001(0.614)	0.003*(0.097)	0.002(0.178)
σ^2	1.069	1.133	1.010	1.060
γ	0.972	0.973	0.971	0.973
Log-Likelihood	55.02	48.10	58.28	57.12

*, **, *** Significance at 10, 5 and 1%.

a value of the likelihood ratio equal to 13.84 above the critical value of the chi-square table at 5% (7.11), which makes us reject the null hypothesis. In other words, M1 model is preferred to M3, and the Cobb-Douglas model for non-neutral technical progress is preferable in this case.

Furthermore, the comparison of M2 and M4 models gives a value of the likelihood ratio equal to 2.32 but inferior to the critical value of the chi-square table at 5% (7.11), which makes us accept the null hypothesis. Consequently, the M4 model is preferred to M2. For the Translog specification, we accept the model with a neutral technical progress.

Finally, the comparison of the M1 and M4 models gives a value of the likelihood ratio equal to 4.2 but inferior to the critical value of the chi-square table at 5% (7.11). Therefore, the null hypothesis where the M4 model is preferred to M1 is accepted. In the end, the Translog specification with a neutral technical progress is better than the Cobb-Douglas one.

Estimation of technical efficiencies in the agricultural sector of Togo

From the above estimates, we will discuss the estimation of the efficiency scores of the Togolese agriculture. Actually, the SFA method shows the following efficiency scores related to the various specifications selected above: 75.3, 75.6, 75.8 and 76.3% (Figure 1). These scores show that the rate of the input use is generally acceptable (Somayeh et al., 2012). More precisely, the Togolese farmers can use at least 25% of the agricultural resources to achieve the same level of production.

Rice, maize, bambara groundnut, peanut, coffee bean, cocoa are products that have efficiency scores above the found average scores (Figure 2). These five products are all grown in highlands where agriculture is flourishing. This area receives annually a large amount of rainfall and farmers there are very laborious. Cocoa takes the top spot with 97.6% while the yam is around 7%. Products that have high efficiency scores are either for exportation or food products mainly for consumption.

Using the SFA approach, we could see that the Togolese agriculture has a minimum efficiency of 75%, which means that is very efficient in using these resources. Besides, we can observe a uniformity of efficiencies along the 20-year study period. The consistency of this efficiency shows that farmers are steady in the management of the agricultural resources. We noticed that the labor force shrinks through time whereas efficiency remains stable. Furthermore,

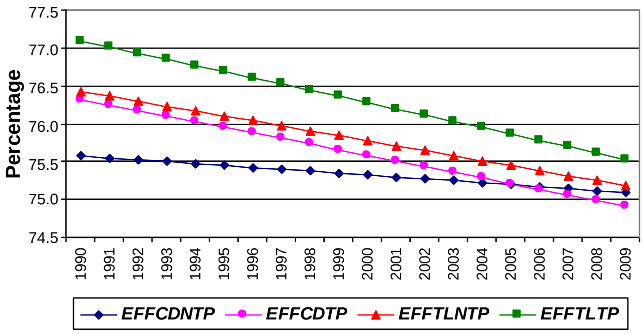

Figure 1. Yearly average efficiency with SFA. EFF: Efficiency, CD: Cobb-Douglas, TL: Translog, NTP: Neutral Technical Progress, TP: Technical Progress.

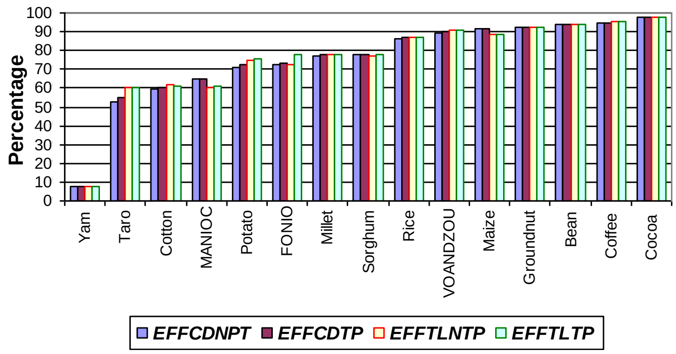

Figure 2. By product average efficiency with SFA

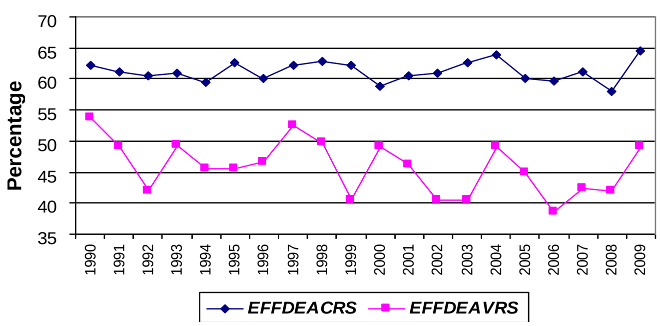

Figure 3. Yearly average efficiency with DEA. *EFF*, Efficiency; *DEA*, DEA method; *CRS*, constant returns to scale; *VRS*, variable returns to scale.

production remains constant or tends to decline slightly. We can see from this that agriculture is being specialized and modernized because the minimum number of farmers who keep domestic production constant owe it to an efficient work organization.

On the basis of the non-parametric DEA approach, overall efficiency is estimated at 61.2% for constant returns to scale and 45.8% for variable returns to scale

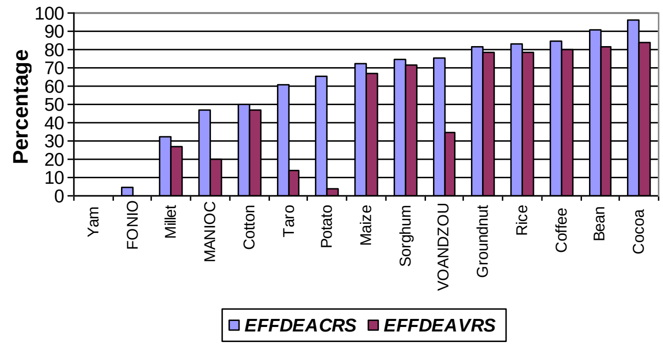

Figure 4. By product average efficiency with DEA.

(Figure 3). The highest efficiency is that of the cocoa, with 83.6%. Beside cocoa, the other products that have efficiency above 80% are coffee and beans (Figure 4). We can wonder why coffee and cocoa are export products; is it because they are the most favorable cultivated products? We do not think so because cotton, the Togolese main export product, is efficient only at 49% whereas the bean, which is a food product for local consumption, reached an efficiency score of more than 80%. The most frightening case is that of the yam which has an efficiency of 0%, in fact, it is the most inefficient product maybe due to the archaic way it is grown. Yam is predominantly grown in highland areas where the other products have very high efficiency scores. Would farmers have preferred some kinds of products to others?

The DEA method gives efficiency scores that do not exceed 65%. Taking into account the constant returns to scale, we can see that efficiency scores are around 60%, whereas those of the variable returns to scale do not exceed 50%. This second consideration shows a totally inefficient agriculture throughout the reporting period of this research. This vision of the Togolese agriculture can be explained by the youth's widespread lack of interest in agriculture, which means that the resources (labor and land) are available but poorly used. However, the opposite view, which considers constant returns to scale, goes with the SFA vision of the Togolese agriculture.

COMPARISON AND DISCUSSION OF RESULTS

The efficiency estimate of the Togolese agriculture using the SFA and DEA methods identified different and sometimes contradictory results. However, the SFA method showed that the Togolese agriculture, with or without technical progress, is efficient regarding the Cobb-Douglas and Translog functions (Table 5). However, the DEA method revealed conflicting results depending on whether we put ourselves in a context of constant or variable returns to scale. With the constant returns to scale, the efficiency score is 0.612 because there is no huge wastage. This means that the Togolese agricultural resource management is acceptable. With non-constant returns to scale, the efficiency score is 0.458. This clearly means that the management of the Togolese agricultural wealth has failed. The differences between the SFA and DEA are based on the concept that these approaches have some distance from the efficiency frontier.

The DEA method ignores the measurement errors. Therefore, the whole distance from the frontier is considered inefficiency. On the other, the SFA method, which considers measurement errors, seems to be more realistic. It is noteworthy that the SFA method is more efficient for theoretical studies, whereas the DEA is very useful for practical or empirical studies. Therefore, the conclusion drawn is that, in general, the Togolese agriculture is inefficient like the finding of Agossou (2009).

The general findings show that the agricultural labor in Togo is shrinking the cultivated is increasing nonchalantly and production tends to stagnate. Instead of announcing the death of the Togolese agriculture, these indices are rather encouraging because it is easily seen that the increase of agricultural labor in Togo will necessarily propel agricultural production. We should not either declare victory because the results via the DEA analysis are inconsistent with the idea of a promising Togolese agriculture. All we can keep from this analysis is that agriculture in Togo is promising and all the efforts made to increase awareness, investment and innovation in this area will pay off.

Conclusion

The empirical study of the Togolese agriculture efficiency gave results that defy the prejudices about agriculture. Beyond the pessimistic views that discourage investors, this study revealed a reality quite opposite to the widespread ideas about the Togolese agriculture and Africa in general. The stochastic frontier analysis method shows that the Togolese agriculture is weakly efficient. This observation was affirmed by the results of the DEA method. However, we prefer the SFA which shows that the Togolese agriculture is generally better efficient. By referring to the DEA, which is more empirical than the SFA, we will find ourselves forced to consider that the Togolese agriculture is globally inefficient.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

One and one half bound dichotomous choice contingent valuation of consumers' willingness-to-pay for pearl millet products: Evidence from Eastern Kenya

Okech, S.O.[1]*, Ngigi, M.[1], Kimurto, P. K.[2], Obare, G.[1], Kibet, N.[3] and Mutai B. K.[1]

[1]Department of Agricultural Economics and Agribusiness Management, Egerton University, Kenya.
[2]Department of Crops, Horticulture and Soil Sciences, Egerton University, Kenya.
[3]Department of Agricultural Sciences, Kisii University, Kenya.

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Pearl millet is the fourth most important cereal after maize, rice and sorghum in terms of cultivation and production in the tropics, yet the least traded of all cereals in Kenya. New pearl millet varieties (KAT/PM1, KAT/PM2 and KAT/PM3) were introduced in response to low yield and birds' menace that was wiping out the traditional pearl millet varieties in Kenya. Despite this, limited information exists on consumers' willingness to pay and the determinants of willingness to pay estimates for these newly introduced varieties products. This study was undertaken to analyze consumers' willingness to pay and the determinants of willingness to pay estimates for these pearl millet products. Results showed that most consumers (70%) were willing to pay a premium price with the mean willingess to pay off 42% over finger millet market price. Age, number of children below 12 years in a household, gender of household head, income and awareness levels were the important factors that positively influenced consumers' willingness to pay premium prices.

Key words: Pearl millet, new varieties, willingness- to-pay, consumer, Kenya.

INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is the fourth most important cereal after rice, maize and sorghum in terms of cultivation and production in the tropics. It is estimated that over 11.36 million tons of pearl millet grains are produced in 17.4 ha globally (FAO, 2003). In Kenya, for instance, the areas under pearl millet have reduced from 100,143.9 ha (2011) to 93,310 ha in 2013. Areas that have experienced this drastic fall in hectares under pearl millet include: Eastern province (Tharaka, Mbeere, Mwingi, Kitui, Makueni districts) and Rift Valley province (Baringo, Elgeyo-Marakwet and West Pokot districts) (GoK, 2007; KARI, 2008; MoA, 2008). Pearl millet yields also have been declining since 1980 from 1,610 kg ha^{-1} to an estimated 200-800 kg ha^{-1} in 2008. The current yields per ha is low against the estimated global potential of 1,500 to 3,000 kg ha^{-1} (KARI, 2007; GoK, 2007; KARI, 2008; MoA, 2008).

In terms of consumption, pearl millet has several merits in the rural household food baskets. It contains high level of protein (up to 12%), energy (3600 K cal kg^{-1}) and a

*Corresponding author. E-mail: silasokech@gmail.com, Tel: +254724855300. Fax: +25451 61576.
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balanced amino acid profile making it a cheaper source of grain iron (Fe) and zinc (Zn) (Parthasarathy et al., 2006; ICRISAT, 1996). In addition, it is a staple diet for over 500 million households who are mainly small scale farmers living in arid and semi-arid lands. However, in the past three decades, its consumption pattern has been declining partly due to the changing consumers taste and preference, diseases (leaf blight and rust) and birds' damage. Moreover, pearl millet industry has been facing numerous constraints which include: poorly developed and fragmented marketing channels with weak value chains, high assembly and processing costs, uncompetitive grain prices which collapse during harvesting season, lack of market information, limited processing facilities, in-adequate grain supply all year round and high cleaning costs among other several factors (FAO, 1996; Rohrbach, 2004). According to Gulia et al. (2007), in the USA market, pearl millet has no minimal set price; Eastern Kenya is not an exception to such marketing risks. These challenges have not only limited farmers' interest but have also threatened to wipe pearl millet out of farmer's fields despite local communities' interest. In fact, it is reported that most processing companies in Kenya (Kirinyaga Millers Limited, Kabansora Millers Limited, Proctor and Allan Limited) have lost contact with local farmers because of unreliable supply and poor quality grains. Data showed annual imports from Tanzania and Uganda for industrial processing as 1,560 metric tons (United States Agency for International Development, 2010). It is possible that pearl millet might be lost completely from farmers fields unless serious intervention is put in place.

As part of the intervention, the government of Kenya has put more emphasis on promoting pearl millet value addition to improve its competitiveness, acceptability and food security (GoK, 2003). In addition, from 1994 to 2007, the government of Kenya and International Fund for Agricultural Development (IFAD) initiated a US $ 15.5 million Eastern Province Horticulture and Traditional Food Crops Project to improve incomes and food security for small scale farmers' (Karanja et al., 2009). To further promote pearl millet, International Crops Research Institute for Semi-Arid and Tropics (ICRISAT), International Sorghum and Millets (INTSORMIL) and Bill and Melinda Gates Harnessing Opportunities for Productivity Enhancement (HOPE) project have developed interventions such as breeding, distribution of improved varieties and promotion of resource conservation and management to address productivity, profitability and marketing challenges of dry land cereals (Karanja et al., 2009). HOPE project is currently promoting high yielding, low soil fertility resistant and disease tolerant pearl millet varieties (KAT/PM 1, KAT/PM 2 and KAT/PM 3) in the market. It is expected that the small scale farmers will adopt these new varieties in order to improve their food security situation and income levels through sale of surplus. These efforts are in line with Kenya's vision 2030 of promoting economic development and food security amongst households residing in arid and semi arid lands. However, a keen look at these past efforts in addition to a review of earlier research work reveals a strong focus on pearl millet production and value addition.

Therefore, studies on pearl millet products demand and consumption have received a slight or no research consideration which have resulted in inadequate knowledge on consumer attributes and willingness-to-pay (WTP); that may hamper production optimization and marketing of pearl millet products in Kenya. Therefore, knowledge of consumers' attributes and willingness to pay for products made out of these introduced pearl millet varieties are necessary for researchers to improve on the already produced pearl millet hybrids. Moreover, information on pearl millet products consumption may lead to the development of pearl millet products meeting specific demands of consumers. The objective of this study was to find out if consumers were willing to pay premium prices for these pearl millet products and which factors would influence their willingness to pay for the pearl millet products made out of these varieties. Understanding of consumers' willingness to pay is important to farmers as they will benefit from having a better understanding of the value of their products and are thus be in a position to determine how to maximize their profits. Companies, on the other hand, may benefit by being able to determine the economic gain or loss associated with investment they make in value addition.

MATERIALS AND METHODS

Study area

This study was undertaken in Mbeere district, Kenya due to its favourable climatic conditions (LM3 and LM4) necessary for pearl millet production, presence of numerous small scale pearl millet processing units and the long history of pearl millet production. The district covers a total area of 2,097 KM^2 and lies between latitude 0°45′ N and 0°52′ N; longitude 37°35′ E and 37°40′ E with an altitude range of 500 to 1200 m above sea level on Tana River basin with a slope moderated by Kiambere, Kiang'ombe and Kianjiru Hills (Government of Kenya (GoK), 2005). The district experiences bimodal and unreliable rainfall averaging between 640 to 1110 mm with most parts receiving less than 750 mm annually. However, this unreliability of rainfall increases major crop failures especially for maize.

It has two main growing periods: long rains of April - June and short rains occurring between October-December with a growing length of between 90 to 119 days. The economic activity of the area is mixed farming with livestock production mainly composed of indigenous species of cattle, goats and chickens while crop production is limited to rain fed agriculture (GoK, 2005). The average temperature ranges between 20 to 30°C and sometimes rises above 30°C in March- the hottest month. The soils range from chromic Cambisols to rhodic Ferralsols and Luvisols with varying degree of stoniness, rockiness and soil depth (GoK, 2005). These soils are infertile and are highly sensitive to erosion as a result of surface sealing and hard pan setting.

Data description

This study was undertaken between August and September, 2012 – harvesting period to minimize variation in the consumption patterns. A two stage sampling technique was used to select 100 consumers for the study. In the first stage, purposive sampling technique was used to select Mbeere district due to its pearl millet history, presence of numerous small scale pearl millet processing units and the agro-ecological zones (LM3-LM4) necessary for pearl millet growing. In the second stage, a random sampling technique was used to select 100 consumers within the peri-urban areas of Siakago, Ishiara and Kiritire towns. To improve on questionnaire validity and content in tangent with study objectives, pretesting was done. Important data to the study included: the level of consumer awareness, socio-economic characteristics of pearl millet consumers, and the willingness to pay for new pearl millet products. Specifically, socio-economic factors considered important for the study included: income level of household head, number of children below 12 years, educational level of the household head, gender of household head/decision maker, employment status of household head, age of household head, level of awareness of household head of pearl millet and if a household have heard of the new pearl millet products before the study.

The model specification

In estimating consumers' willingness to pay for novel goods in the absence of a real purchasing power, and in situations where primary data sources are available like in this study, contingent valuation methodologies are commonly applied (Stevens et al., 2000; McCluskey et al., 2001; Lusk and Hudson, 2004; Lin et al., 2005).

In that regard, a Contingent Valuation (C.V.) methodology following a closed ended survey format was applied in this research. This survey will only provide meaningful results if it is grounded on consumer maximization theory. This theory holds that consumers maximize utility subject to budget constraints. It was assumed that the consumers would choose a bundle of pearl millet products giving him high satisfaction levels. The choice of C.V. methodology was also based on the assumption that it exactly mirrors the value of non market goods in the absence of a real purchasing power. This is because it constructs a hypothetical market which is not only structured but also realistic by ensuring respondents' are faced with a well defined situation contingent on the event occurrence. Although, opponents of C.V. have punched holes on its reliability, the selection of an appropriate survey and elicitation methodology is capable of reducing or minimizing these preconceptions. In this study, a modified dichotomous elicitation technique - an extension of discrete choice with follow up approach was applied (McCluskey et al., 2001; Lin et al., 2005; Cooper et al., 2002).

In this technique, percentage bids were pegged on price differentials and the first bid (B_1) was assumed to be equivalent to KES 100 to indicate price equality between pearl millet products and finger millet products to reduce starting point bias. The second bid (B_2) or the premium bid was contingent to the first bid and was assigned to a consumer only if he was willing to buy at a price higher than initial bid amount. The second bid (B_2) and the initial bid (B_1) allows for setting of the lower and upper bounds on the unobservable consumers true willingness to pay for products. If the consumer responded to the first question with a 'yes', then he was willing to purchase pearl millet product at a premium price. From this, a follow up question with varying bid levels was given. From these iterations, three possible outcomes of a semi-double-bounded model was obtained: 'yes' 'yes'; 'yes' 'no' and 'no'. A 'yes' 'yes' indicated a consumers willing to purchase pearl millet product at a premium; 'yes' 'no' indicated a consumer as having intermediate willingness to pay while a 'no' indicated customers non willingness to purchase pearl millet products at a premium. Therefore, discrete outcomes (Dg) of the above bidding processes can be written as (Rodríguez et al., 2008; Lin et al., 2005; McCluskey et al., 2001):

$$Dg = \begin{bmatrix} group\ 1\ WTP \leq B_1 \\ group\ 2\ B_1 < WTP \leq B_2 \\ group\ 3\ B_2 < WTP \end{bmatrix} \quad (1)$$

From the discrete outcomes above, group 1 represented individuals not willing to purchase at any discount and are considered to have the lowest WTP; group 2 represent intermediate willingness to pay and finally, group 3 represented those who did not require any discount but accepted to pay the highest premium. Therefore, assuming a linear function of an individual *i* WTP for new pearl millet products can be summarized as:

$$WTP_i = \alpha - p\beta_i + \lambda z_i + \varepsilon_i \text{ for i= 1, …n} \quad (2)$$

Where βi is the ultimate bid an individual *i* faces; z_i is a column vector of observable socio- demographic characteristics of an individual (age, income, employment status, gender of household head, and the number of children below 12 years in a household); α, p and λ are the parameters to be estimated; z_i and ε_i are assumed to be linear in parameters for all individuals, with the error term being independent and identically distributed with a mean zero and a variance σ^2. Under the above assumptions, the individual choice probability may be stated as in McCluskey et al. (2001):

$$\text{Prob. (D=J)} = \begin{bmatrix} G(\propto -\rho\beta_1 + \lambda Z)\ for\ 1 \\ G(\alpha - \rho\beta_2 + \lambda Z) - G(\alpha - \rho\beta_1 + \lambda Z)\ for\ 2 \\ 1 - G(\alpha - \rho\beta_2 + \lambda Z) for\ 3 \end{bmatrix} \quad (3)$$

The likelihood function can therefore be stated as below:

$$L = \Sigma_i \begin{bmatrix} I_{D_{i1}} = InG(\alpha - \rho\beta_{D_i} + \lambda z_i) + \\ I_{D_{i2}} = InG(\alpha - \rho\beta_{D_i} + \lambda z_i) - G(\alpha - \rho\beta_{D_i} + \lambda z_i) \\ + \\ I_{D_i 3} = In(G(1 - G(\alpha - \rho\beta_{D_i} + \lambda z_i) \end{bmatrix} \quad (4)$$

Where I_k is the indicator function for even k and $I_k = j$ denoting the j^{th} alternative occurrence. In the empirical implementation, G $(.)$ may be defined as a standard logistic distribution function with a mean of zero and standard deviation $\sigma = \pi/\sqrt{3}$. The parameters of the function to be estimated using maximum likelihood function are α and ρ. The value of (*rho*) ranges between 0and 1 and should be positive to form downward sloping *S*-curve as a negative value would contradict economic theory. Finally, the mean WTP is derived as a ratio of α / p through restricting variables coefficients to zero in parameter estimation with the exception of the random bid (Rodríguez et al., 2008; Lin et al., 2005; McCluskey et al., 2001). The final mean WTP is written as:

$$E\ (WTP, \alpha, p, \beta, z) = \alpha + \lambda z_i)/ p \quad (5)$$

REGRESSION MODEL

In understanding the factors affecting consumer's willingness to pay premium price, a logit model was adopted. The choice of this model was guided by the discrete structure of WTP questions used in this study. A logit model is initially set up in the form of a latent regression with Equation (6) as its starting point;

$$y^* = x'\beta + \varepsilon_i \quad (6)$$

In the Equation (6), y^* represent unobserved portion while the observed section is represented as (Green, 2006):

$$y_i = \begin{pmatrix} 0 \; if \; y \leq \mu_1 \\ 1 \; if \; \mu_1 \leq y \leq \mu_2 \\ 2 \; if \; \mu_2 \leq y \leq \mu_3 \\ \dots \\ J \; if \; \mu_{j-1} \leq y \end{pmatrix} \quad (7)$$

In the Equation (7) above, μ_i's are known parameters under estimation in conjunction with parameter β with an error term normally distributed across all observations. Therefore, restricting mean and the variance of the error term to 0 and 1, the below probabilities are attained (Pishbahar et al., 2013);

$$\left.\begin{aligned} &\text{Prob}\,(y = 0|X) = F(-X'\beta); \\ &\text{Prob}\,(y = 1|X) = F(\mu_1 - X'\beta) - F(-X'\beta); \\ &\text{Prob}\,(y = 2|X) = F(\mu_2 - X'\beta) - F(\mu_2 - X'\beta) \dots \\ &\text{Prob}\,(y = j|X) = 1 - F(\mu_{j-1} - X'\beta) \end{aligned}\right\} \quad (8)$$

For the above probabilities Equation (8) to be positive, the following conditions needs to be met;

$$0 < \mu_1 < \mu_2 < \cdots < \mu_{j-1}$$

In a logit model, coefficients and marginal effects of explanatory variables on the probabilities are usually different. By undertaking first order differentiation of Equation (8), the marginal effects of changes in the explanatory variables can be obtained as shown in Equation (9) (Pishbahar et al., 2013;

$$\frac{\partial \text{prob}(y=0|X)}{\partial X_i} = -F(-X'\beta)\beta; \quad (9)$$

$$\frac{\partial \text{prob}(y = 1|X)}{\partial X_i} = \frac{F(-X'\beta) - F(\mu_1 - X'\beta)}{\beta}; \dots$$

$$\frac{\partial \text{prob}(y = j|X)}{\partial X_i} = F(\mu_{j-1} - X'\beta)$$

The empirical specification of the final model for estimating factors of WTP is shown below.

$$\begin{aligned} &\mathbf{WTP_i} = \\ &\alpha - \rho\mathbf{HHhead} + \lambda_1\mathbf{Income} + \lambda_2\mathbf{Nochildren} + \lambda_3\mathbf{EducLevel} + \lambda_4\mathbf{Employstatus} + \\ &\lambda_5\mathbf{Gender} + \lambda_6\mathbf{AgeofHH} + \lambda_7\mathbf{Awareness} + \lambda_8\mathbf{Heardproduct} + \varepsilon_i \end{aligned} \quad (10)$$

In estimating factors affecting consumers WTP, LimDep version 7.0 software was used. The model significance was verified through Chi-square statistics computation by calculating the restricted and unrestricted log likelihood functions.

DESCRIPTION OF LOGIT MODEL VARIABLES

The explanatory variables influencing consumers' WTP premium prices and therefore included in the above logit model were obtained from review of relevant past researches. Although demand for a product is usually affected by its price, in this study, only socio-demographic factors (age, household head, employment status, income, gender of household head, education and presence of children below 12 years in a family), awareness and whether a consumer has ever heard of the pearl millet product or not were included. These socio-demographic characteristics were assumed to be similar to those affecting consumer expenditure and analysis for local products. The inclusion of awareness and whether a person has ever heard of pearl millet products were based on an assumption that not all consumers perceive quality in a uniform manner despite their objectivity in the measurement of utility. In fact, there exist possibilities that some product quality may yield negative or positive utility to consumers.

The presence of children below 12 years in a household was found a direct influence between consumers' WTP and beef products (Loureiro and Umberger, 2003). Gao et al. (2011) also observed a positive linkage between WTP and presence of children below 12 years in a family for fresh citrus consumers. And because these products were considered high quality goods, we also hypothesized pearl millet to be in this group. Therefore, a positive relationship was expected (Table 1). Kimenju and De Groote (2005) observed a positive connection between WTP and maize consumers' income levels. Also, Loureiro and Umberger (2003) found a positive link between income levels and WTP amongst beef consumers. In this study, a positive association was also expected.

Govindasammy et al. (2006) acknowledged a positive relationship between consumer level of awareness and WTP. In addition, Bate et al. (2007) observed a negative association amongst organic foods consumers and their WTP. These results offer divisive empirical evidence and as a result, we hypothesized that it could take either a positive or negative sign. Owusu and Onfori (2012) observed a direct relationship between level of education and WTP for organic product consumers. Budak et al. (2010) also observed a positive relationship between the level of education and Turkish livestock producers WTP. In this study, we believe that highly educated consumers consider pearl millet products as a poor man's food and therefore would not associate with it. And as a result, a negative relationship between educational level and WTP was eminent.

Carpio and Isengildina-Massa (2009) found out that female headed households were more willing to pay premium prices than male counterparts to obtain animal products. Haghiri and McNamara (2007) noted that male headed households as willing to pay premium than female headed households for pesticide free products. Because of the inconclusiveness of discussion in this variable, a positive or negative relationship was hypothesized. Employment is a source of income and exposure to current information. Therefore, consumers who were in employment were expected to be well exposed and would buy pearl millet products due to its health benefits and so a positive relationship was anticipated.

The age of a household head affects his/her purchase decision making. We hypothesized that older household heads as less willing to pay premium prices due to their low income levels. Consumers are rational people and would want more out of less. In that sense, we hypothesized that whether a household have ever heard of pearl millet or not was positively related to his willingness

Table 1. Nature and a priori expected signs of Logit analysis of the factors determining consumers' WTP.

Dependent variable	Definition of variables	Expected sign
WTP (Willingness to Pay)	If respondent is WTP a price premium for pearl millet products	1-Yes; 0- Otherwise
Independent variables		
Income (Income)	The monthly income level of the household head	+
Children (Nochildren)	The number of children below 12 years in the household	+
Education (EducLevel)	Highest educational level of the respondent	-
Gender (Gender)	Gender of the household head	+/-
Employment (Employstatus)	Is the household head employed	+
Age (AgeofHH)	Age of the decision maker (years)	-
Household head (HHhead)	If the buyer is the head household	+
Awareness (Awareness)	The household head level of awareness of pearl millet product	+/_
Heard (HeardProduct)	If the Household have heard of a pearl millet product	+

to purchase it at higher prices. Finally, we believed that whether a consumer was a household head or not was positively related to his/her WTP premium prices. This was because if purchaser was a household, he was responsible for decision making exercise and therefore he would be more willing to pay a premium than if otherwise.

RESULTS AND DISCUSSION

Socio-economic characterization of pearl millet consumers

A socio-economic characterization of pearl millet consumers are shown in Table 2. Results showed that in terms of education, majority of the consumers (52%) were in primary school; 31% were with secondary education; only 3% had university education while 5% were of illiterate category. On average, therefore, there was low level of literacy amongst the consumers and this implies that consumers may not be in a position to capture the benefits associated with pearl millet marketing as they may be disadvantaged during bargaining process (Table 2).

The number of years a person takes in performing any marketing function directly influences his/her marketing experience and thus his profit levels. Therefore, the more experience a marketer is, the higher his understanding of a marketing system, conditions and prices trends. From the study, the average mean age of consumers was 45.42 years (Table 2) and this implies that majority of pearl millet consumers were dynamic youths within the economically active age bracket of 21 to 50 years and thus they were able to take risks associated with marketing. Therefore, these actors could make a meaningful impact in the consumption of new pearl millet products. Result further revealed that, 61% of pearl millet consumers were males or male headed households (Table 2). This might partly be attributed to the high prevalence of HIV/AIDS menace in the area. Moreover, statistics confirmed that 55% of pearl millet consumers were not in formal employment, 21% were employed on part time basis while 18% were on full time employment.

Consumers' willingness to pay for pearl millet products

Contingent valuation methodology is normally criticized due to starting point bias and complication of the relevant estimates of willingness to pay. Therefore, to reduce these biases while simplifying consumer tasks in decision making, a starting point price of KES 100 (US $1.18)[1] was proposed. This price (KES 100) was the operating market price for substitute products (finger millet) commonly available in the Eastern Kenya markets during the study period. Moreover, the choice of this substitute product was also informed by our baseline survey undertaken in 2011 in which producers reported that they had replaced pearl millet with finger millet in their farms. Indeed, this price was similar to a true Kenyan market situation where consumers are usually faced with a fixed price for a product and then required to make decision in its purchase. With this background, consumers were asked if they were willing to purchase pearl millet products at KES 100 for a two kilogram tin.

Those respondents who gave a positive response to the first question were further given the option of selecting a bid[2] amongst the 5 point bids of 10, 20, 25, 50 and 75% and the result is presented in Table 3. Although all consumers were assumed to be rational in their purchase decisions, they exhibit varying WTP for given products. And as a result, 5 point bids (Table 3) were randomly chosen to bracket their expected maximum willingness to pay. These bids were assigned to a

[1] Exchange rate – US $1 = KES 85
[2] Bid – This the maximum amount of money a consumer would be willing to pay to get a pearl millet product in the market

Table 2. A summary of pearl millet consumers' socio-demographic characteristics.

Specific variables	Description	Consumers
Mean age	years	45.4 (11.7)[1]
Educational level (%)	Illiterate	5
	Primary	52
	Secondary	31
	Tertiary	9
	University	3
Total (%)		**100**
Gender (%)	Male	61
	Female	39
Total (%)		**100**
Employment status (%)	Full time	18
	Part time	21
	Unemployed	55
	Housekeeper	4
	Retired	2
Total (%)		**100**

[1]Standard deviation.

Table 3. Distribution of willingness-to-pay (WTP) responses.

WTP category (%)	Frequency	Percentage
10	23	32.86
20	19	27.14
25	14	20.00
50	10	14.29
75	4	5.71
Total	**70**	**100.00**

respondent, and they were only given one second chance to bid for these percentages. The random selection and distribution of WTP percentage bids was assumed to offer excellent market information for pearl millet market actors.

Distribution of willingness-to-pay responses

The percentage of the respondents who indicated positive WTP decreased with increase in premium offered implying that an increase in price decreases demand levels (Table 3). Out of the 70 positive respondents, 32.9% were willing to pay 10% while only 5.7% were willing to pay 75% price premium for the new pearl millet products. This implied that most consumers did not believe that these new pearl millet products could attract higher prices or be used as a raw material in making products described by the study instrument. Similar studies by Shukri and Awang-Noor (2012) in Malaysia reported 53.4% of their respondents as WTP RM 500 in comparison to 90.3% of respondents who were WTP RM 100 to acquire certified timber products. In addition, Kimenju and De Groote (2005) in Kenya found out that 50.3% of the respondents were willing to pay 5% while 39% were willing to pay a premium of 50% above the normal maize prices. Gunduz and Bayramoglu (2011), on the other hand, observed 81% of Turkish organic chicken consumers' were willing to pay price premiums. Out of these, 28, 29 and 10% were WTP less than 5%, 6 to 10% and more than 10% price premium respectively above the regular chicken prices.

Estimate of consumers mean willingness-to-pay

Based on the result from contingent valuation method, the mean WTP was estimated and presented in Table 4. The result indicated that respondents were on average willing to pay Kshs.142 representing a premium of 42% over the normal price of Kshs 100 for similar finger millet product. In general, consumers showed a positive willingness to pay for new pearl millet products. These findings are similar to those of Padilla et al. (2007) who estimated a mean WTP for Chilean consumers at 39% for officially certified labels on traditional food products. On the other hand, Nepal consumers were willing to pay between 40 to 60% for labeled tomatoes (Bhatta et al., 2010). Loureiro and Umberger (2003) also observed that USA consumers were willing to pay 38 and 58% for certified steak and Hamburger above the initial given prices respectively. It is important to note that the true

Table 4. Parameter estimates of mean WTP model.

Variable	Coefficient estimate	Standard error	P- value
Constant (α)	9.235	1.662	0.000
Bid (ρ)	0.065	0.013	0.000
Mean WTP (α/ ρ)	142.077		

Number of observations = 100; Log likelihood = -63.862.

Table 5. Empirical result from Logit model and their marginal effects.

WTP	Coefficients	Standard error	z	P>|z|	Marginal effects
HHhead	-0.555	0.716	-0.78	0.438	-0.056
AgeofHH	0.080	0.029	2.76	0.006*	0.008
Gender	1.252	0.728	1.72	0.086***	0.127
EducLevel	-0.102	0.348	-0.29	0.769	-0.010
NoChildren	0.558	0.244	2.29	0.022**	0.057
Employstatus	0.238	0.277	0.86	0.390	0.024
Income	1.029	0.388	2.65	0.008*	0.105
Awareness	1.351	0.420	3.22	0.001*	0.138
HeardProduct	0.229	0.455	0.50	0.615	0.023
Constant	-10.540	3.136	-3.36	0.001	-

Statistics: Number of observations = 100; Prob.> chi square = 0.0000; Log likelihood = -33.660; Pseudo R-squared = 0.4014; Likelihood ratio test of zero slope coefficients= 45.15; * significant at 1%; ** significant at 5%; *** significant at 10%.

position of the mean WTP might be lower than our mean WTP estimate partly due to the hypothetical nature of survey data used in the contingent valuation methodology. Such low levels of WTP (6-10 percent of regular price for equivalent products) have been observed by Boccaletti and Moro (2000) amongst Italian genetically modified consumers. Therefore, these results should be interpreted with caution.

Factors affecting consumer's willingness-to-pay

A total of 100 respondents from Mbeere district were interviewed to support the analysis of the factors affecting consumers WTP. The main variables hypothesized to influence consumers WTP and used in logistic regression analysis included: a household head monthly income levels in Kshs (Income), level of respondents awareness of new pearl millet product (Awareness), if the respondents have ever heard of new pearl millet products (HeardProduct), total number of children below 12 years in a given household (No Children); Age of the buyer or household head (AgeofHH), the highest number of years a buyer/ household head have been in school (EducLevel) and the employment status of a household head/buyer (employment status). In addition, dummy variables like if the respondent was a household head or otherwise (HHhead) and whether the household head was male or female (Gender) were also included in the study (Table 5).

The findings of the maximum likelihood estimate for WTP a premium price is presented in Table 5. The model revealed a McFadden's R^2 statistic of 0.40 which is a reasonable value considering the cross sectional nature of data and therefore correctly predicted the actual choice of WTP premium by consumers (Kennedy, 1994; Govindasamy and Italia, 1999). Moreover, the calculated Chi square statistic of 0.000 was statistically significant indicating the statistical significant of the model in explaining the result. In general, five out of nine hypothesized factors were significant at 1, 5 and 10%.

From empirical result, the coefficient of households with children below 12 years old is positive sign and significant at 5% level (Table 5). This means that households with children below 12 years old were 5.6% more WTP premium prices than those without these children. This is because, households with children are more concerned with the nutritional values of food they give to children and pearl millet is perceived as one such category of food. This empirical result mirror those of Gao et al. (2011) on USA fresh citrus consumers where he observed that households with children below 12 years tended to be in a pro quality cluster than perfectionist clusters. Because parents were more focused on fruit quality, they were willing to pay premium prices for quality fresh citrus fruits compared to those without children. In Turkey, Budak et al. (2010) observed those producers with larger herd sizes as more willing to pay premium prices than those with limited herd sizes to receive extension services due to their contribution to household income. In USA, Loureiro and Umberger (2003) observed a contradicting result as households with children portrayed a negative correlation with willingness to pay for beef products. Bhatta et al. (2010) also noted a negative relationship between family size and willingness to pay for inorganic vegetables like tomatoes. This they attributed to the fact that a larger family size means more expenditure on foods and to cut down on these expenditures, they need to opt for cheaper food types.

Educational level attained by a given household directly affects a consumer’s willingness to pay levels. Access to better education enhances understanding of nutritional information; therefore, respondents with education should possess higher WTP. However, from empirical result (Table 5), the coefficient of the variable representing educational level was negative and had no significant role in influencing consumers’ willingness to pay premiums. Those with higher education were 1.0% less likely to pay premium prices compared to those with low education. This result is consistent with the priori assumption that as a person stays more in school; its willingness to pay for a premium price reduces. This is true because educated consumers can think and judge between good and healthy food and which is not. Secondly, they might expect that it is government duty to provide these products free of charge and thus their unwillingness to pay premium prices. In addition, educated consumers are more likely to be in off farm employments and therefore might over emphasize the need for produce safety standards. These findings are similar to Budak et al. (2010) who observed that highly learned Turkish producers’ unwillingness to pay premium prices for extension services. Bhatta et al. (2010) also observed a positive and significant result with Nepal inorganic vegetable consumers. However, they negate those of Owusu and Onfori (2012) findings that well educated Ghanaian organic food consumers’ willingness to pay higher premiums compared to less educated consumers. In addition, they contrast studies of Loureiro and Umberger (2003) findings that a unit increases in the level of education increases the level of US consumers WTP premium for certified Hamburger.

According to economic theory, as household income increases, the probability of household willingness to pay also increases. From our empirical result (Table 5), a household’s monthly income levels had a positive sign which was significant at 5% level with willingness to pay for new pearl millet products. A unit increase in a household monthly income increases its willingness to pay premium for new pearl millet products by 10.5%. This is consistent with our earlier expectation that an increase in a household income levels had a direct and a positive effect on premium payment. These results are consistent with Kimenju and De Groote (2005) observation that Kenyan maize consumers with higher income levels (greater than Kshs. 50,000) were willing to pay premium prices than those with low incomes levels. Similarly, Owusu and Onfori (2012) recorded that Ghanaian organic food consumers were willing to pay premium prices as monthly income levels increases. In addition, Govindasammy and Italia (2009) pointed out that USA households with earnings less than USA $ 30,000 were 16% less likely to pay premium compared to those earning over USA $ 70,000. Loureiro and Umberger (2003) on the other hand observed that as income levels of US households increases, their WTP premium prices decreases. They attributed this to the fact that, wealthy consumers in the USA considered their meat supply as safe and therefore no labeling was necessary. Boccaletti and Moro (2000) also observed a positive relationship between an individual’s income level and his willingness to pay. For instance, individuals with high income levels translated greater benefits accruing from genetically modified (GM) foods to money equivalent.

In terms of gender, our empirical results showed that the coefficient was positive and statistically significant at 10% level with consumers’ willingness to pay premium prices (Table 5). This indicates that male consumers were 12.7% more likely to pay premium prices for new pearl millet products compared to female consumers. Similar finding was also reported by Haghiri and McNamara (2007) pointed out in Canada that male consumers’ were more willing to pay premium prices than female counterpart for pesticide free produce. In addition, In China’s urban cities, Lin et al. (2005) found out that male Chinese consumers were more willing to purchase Soybean compared to female consumers. However, in USA, Govindasamy and Italia (1999) observed that male consumers were 12% less likely to pay 10% premium to acquire an organic produce. In South Carolina- USA, Carpio and Isengildina-Massa (2009) observed female consumers’ as 44% more willing to pay an additional price to obtain animal products compared to male consumers. Loureiro and Umberger (2003) also observed female USA households as more willing to pay a premium for mandatory country of origin labeling programs.

Household heads are decision makers in a family, and therefore their age levels are important in making a purchase decision. From the a priori assumption, it was hypothesized that older household heads might not be willing to pay premium prices as they are in their retirement ages with little income. However, from the empirical results (Table 5), the coefficient for the age of household head has a positive and significant sign at 1% level. This indicates that if a respondent was old, they were 0.8% more likely to pay higher price for the new pearl millet products compared to when the respondent was young. This implies that older consumers were more motivated in purchasing new pearl millet products than younger consumers. This might be attributed to the long history of pearl millet in Mbeere district and so they had excellent knowledge in its benefits and uses.

Access to information increases the level of consumers’ awareness by eliminating consumer suspicion. According to economic theory as level of consumer awareness increases, the higher their willingness to pay premium prices. From Table 5, the coefficient of consumer level of awareness was positive and significant at 1% level with willingness to pay. Therefore, consumers who were aware of the benefits of consuming pearl millet products were 13.7% more likely to pay a premium than those with limited information about it. This implies that consumers aware of healthy foods are motivated in purchasing of the safe and healthy food items from the market. Bate et al. (2007) on USA consumers' willingness to pay for multi ingredient processed organic foods observed no significant difference between aware and not aware consumers about national organic products seal. Pokou et al. (2010) on Ivory Coast farmers' willingness to contribute to Tsetse fly control observed that farmers with better information on Tsetse fly symptoms and control increased their labour participation in its control mechanisms. Boccaletti and Moro (2000) also noted individuals with proper information had confident concerning genetically modified foods which therefore increases their willingness to pay.

In addition, Govindasamy et al. (2006) on Northeastern USA organic produce consumers concluded that higher price premium paid by consumers are a direct relationship with the level of awareness of the product's usefulness. Bhatta et al. *(*2010) also observed a positive and significant result with Nepal inorganic vegetable consumption. However, other variables like household head (HHhead), employment status (Employstatus) and if consumers have ever heard of new pearl millet products produced a statistically insignificant results (Table 5).

CONCLUSIONS AND POLICY RECOMMENDATIONS

Due to the importance pearl millet plays in rural households food baskets, this study examined whether consumers are willing-to-pay any additional amount if products of new pearl millet varieties were availed to them. Our results do recognize that 70% of Kenyan consumers were willing to show their appreciation for a pearl millet product through premium payment of 42%. Further analysis of data using a Logit model gave a consistent result with regard to signs and significance of coefficients. In terms of factors affecting consumers' WTP, results showed that households with a monthly income and children below 12 years and those with prior knowledge of pearl millet were most likely to pay price premium. Therefore, to boost profits from this potential niche and lucrative market sector, these households should be the prime target of marketers if they want to retrieve maximum returns.

In order to harness the existing opportunities in pearl millet market value chain, this study recommends the following. First, fast food marketers should be familiar with this price premium and adjust their marketing strategies to benefit from this niche market. Finally, empirical results also indicated that not all consumers were willing to pay equal price premium for pearl millet product. As empirical results showed that not all consumers were willing to pay equal price premiums for pearl millet products, marketers should classify consumers according to their willingness to pay percentage estimates and adopt matching marketing strategies to derive maximum benefit from these consumers.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Nitrogen application and inoculation with *Rhizobium tropici* on common bean in the fall/winter

Antonio Carlos Rebeschini[1], Rita de Cássia Lima Mazzuchelli[1], Ademir Sergio Ferreira de Araujo[2] and Fabio Fernando de Araujo[1*]

[1]UNOESTE, Agricultural Science Faculty , 19067-175, Presidente Prudente, SP, Brazil.
[2]Federal University of Piauí, Agricultural Science Center, Teresina, PI, Brazil.

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The objective of this study was to evaluate doses of nitrogen in the cultivation of bean under field conditions, associated with seed inoculation. The study was conducted under field conditions in two traditional bean cultivation in Paraná northern (Cafeara and Florestopolis).The experiment consisted of plots with or without seed inoculation with *Rhizobium tropici* and use of five doses of nitrogen coverage(0, 20, 40, 60 and 80 kg ha^{-1}). Evaluations were made about the nodulation, N content in leaves, shoot dry matter, N uptake, number of pods per plant and grain yield. The experimental design was randomized blocks with ten treatments and four replicates. It was factorially arranged in five levels of nitrogen with and without inoculation. In this study there was no response to inoculation in the evaluation of the yield of bean in Cafeara and Florestopolis with different soil management. The nodulation of bean with *Rhizobium* is reduced by fertilization with mineral nitrogen. The system with tillage cultivation favored the development of bean during autumn-winter.

Key words: N_2 fixation, *Rhizobium* spp., *Phaseolus vulgaris.*

INTRODUCTION

With an average yield of 951 kg ha^{-1} in 2011 Brazil produced approximately 3.5 million tons of beans (IBGE, 2012). The cultivation of this legume is accomplished in three seasons, the first being called "rainy season", the second "the dry season" and the third "season of fall / winter." The small bean producers have invested frequently in the rainy season, due to the dependence on weather conditions, while large producers invest in other crops by the increased availability of irrigation (Person, 2012).

For production of protein-rich grain bean requires an adequate supply of nitrogen (N), to care for their growth as well as for the formation of pods and grains (Fancelli and Dourado, 2007). The availability of mineral nitrogen for plants is directly dependent on the continuous decomposition of organic matter (N mineralization), fertilization (Binotti et al., 2010) or biological N_2 fixation (BNF) made by symbiotic association with rhizobia roots (Araújo et al., 2007). The need to improve productivity of legumes as a global source of dietary protein, however, has made it vital to understand the factors that influence nitrogen fixation (Schulze, 2004).

The efficiency of BNF in bean is very variable and under favorable environmental conditions can provide up

*Corresponding author. E-mail: fabio@unoeste.br
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Table 1. Analysis of soil composition of the experimental area of Cafeara and Florestopolis.

Parameter	Units	Cafeara	Florestopolis
pH $CaCl_2$		4.9	5.0
pH in SMP		6.4	6.8
Al	mmolc.dm^{-3}	0	0
Organic matter	g.dm^{-3}	16.0	11.0
Ca	mmolc.dm^{-3}	10.0	7.0
Mg	mmolc.dm^{-3}	4.0	3.0
K	mmolc.dm^{-3}	1.0	0.9
P	mg.dm^{-3}	2.0	11
SO_4	mg.dm^{-3}	8.9	6.2
Mn	mg.dm^{-3}	80.5	15.8
Fe	mg.dm^{-3}	31.9	15.1
Cu	mg.dm^{-3}	3.7	2.5
Zn	mg.dm^{-3}	6.9	1.2
B	mg.dm^{-3}	0.32	0.29

to 80 kg ha-1 of N fixed (Melo and Zilli, 2009). The application of 20 kg ha^{-1} of nitrogen at seeding associated with rhizobia inoculation can provide input of 160 kg ha^{-1} nitrogen (Pelegrin et al., 2009). It is necessary to care for the dose of N at sowing as studies have documented the negative impact of high nitrate concentration in soil on nodulation and nodule weight (Muller and Pereira, 1995).

The species of Rhizobium with higher prevalence in symbiosis with bean show frequencies of 17,1% at *Rhizobium tropici*, 35.9% *Rhizobium etli*, 32.5% *Rhizobium leguminosarum*, 1.7% *Rhizobium giardinii* and 12.8% with distinct profiles of described species of bean rhizobia, emphasizing the high genetic diversity of rhizobia, including the appointment of new species (Stocco et al., 2008).

The lack of response to inoculation of bean is usually due to the inability of strains inoculated to compete with native species for soil infection sites in roots (Ferreira et al., 2011). The bean can respond similarly with and without inoculation, indicating soils with high native communities of rhizobia in the soil (Pelegrin et al., 2009). There is a variability in responses to both bean rhizobial inoculation and to nitrogen fertilization, mainly influenced by the levels of soil fertility and other techniques used in production systems, especially the use of irrigated systems (Pelegrin et al., 2009). The efficiency of nitrogen absorption is enhanced in these cultivation systems, with this reducing production costs (Sant'ana et al., 2011).

In many regions of the world where common beans are grown, nitrogen fixation is limited by unfavorable soil conditions and temperature and water stress (Kabahuma, 2013). The tilling season and soil management contribute decisively to obtain high yields in dry beans. Bean plants grown in no-tillage has provided better conditions for nitrogen use, possibly because of increased soil water retention which may buffer temperature (Romanini Junior et al., 2007). In this context the hypothesis of this study is that the climatic conditions and soil water availability, found in the growing season of the third season (autumn-winter), are crucial for the evaluation of BNF. This work aimed at the effect of rhizobia inoculation and application of nitrogen in cover on bean cultivation in two distinct areas, the autumn-winter season.

MATERIALS AND METHODS

Experimental site

The study was conducted in two areas of traditional cultivation of bean in northern Paraná, Brazil in 2010. One area is located at Cafeara (22° 46'22"S; 51° 43'18"W) altitude of 377 m. The other at Florestopolis (22° 52'25"S; 51° 22'55"W) altitude 400 m. The soil in both areas is classified as ultisol, emphasizing that the soil Cafeara is under no-tillage (NT). The soil fertility analysis are presented in Table 1. The experiment was conducted in the fall / winter season, from April to August 2010.

Biological material

In the experiment was used bean genotype Carioca (IPR 139), indeterminate growth. The inoculum used in the study was commercial inoculant in peat formulation (Turfal, Curitiba, PR) containing *R. tropici*, strain SEMIA 4088, the concentration of 1.0 x 10^9 viable cells per gram of product. The dosage used was that recommended by the manufacturer of 100 g per 50 kg of seed. The product was added to seeds with use of sugar adhesive solution plus 10% (weight) immediately prior to sowing.

Experimental design

The experiment consisted of plots with or without inoculation of *R. tropici* seeds and use of five N rates (0, 20, 40, 60 and 80 kg ha^{-1}) in cover effected at 20 and 40 days after plant emergency. A completely randomized block with ten treatments arranged factorially with four replications was used. The experimental unit consisted of plots with six bean lines (5 m) spaced at 0.45 m

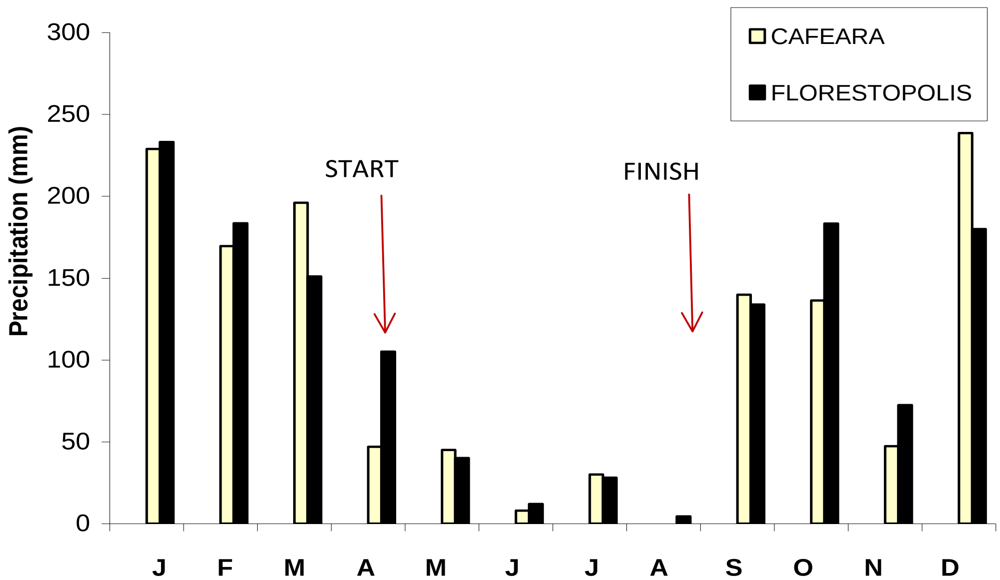

Figure 1. Rainfall accumulation in 2010 in the experimental areas in Cafeara and Florestopolis.

between rows and a total area of 13.5 m² per plot.

Cultivation

The plants was conducted in the field under natural conditions of climate and soil. Based on the analysis of soil fertility was effective at sowing fertilization with 250 kg ha^{-1} of NPK fertilizer (00-20-20), and afterwards we made fertilization coverage with urea (45% N) according to pre-established treatments. The seeds were sown in April. The production system and plant management such as control of pests, diseases and weeds were conducted in accordance with the detected events and technical recommendations for culture in the region.

Number and weight of nodules, foliar N and biomass

For evaluation of nodulation and dry matter of the plant were collected 10 plants per plot at the stage of full flowering (R6). To determine concentration of nitrogen leaves were collected from the middle third of 30 plants per plot. To count the number of pods per plant were collected ten plants per plot at maturity stage (R9). The analysis and quantification of shoot dry weight and dry weight of nodules were performed in the laboratory after drying the material on forced ventilation oven (60-70°C) to constant weight. The analysis of leaf total N were performed according to methodology (Malavolta et al., 1997).

Evaluation of yield

For the determination of final yield, the plants were collected from two central rows of each plot, ignoring 0.5 m of each line at the beginning and end, that after threshing and grain moisture correction to 13% was calculated grain yield per hectare.

Statistical analysis

The data were subjected to analysis of variance (ANOVA) by F test ($P \leq 0.05$ and $P \leq 0.01$) and when found statistical differences were applied to regression analysis doses nitrogen using the statistical software SISVAR (Ferreira, 2000).

RESULTS AND DISCUSSION

Climatic conditions, monitored here as water availability during the experiment period (Figure 1), showed in Cafeara precipitation total of 140 mm, below the crop necessity because there are reports that at 75 days cycle development bean has one evapotranspiration 220 mm (Silveira and Stone, 1979). In Florestopolis, there was total precipitation of 108 mm. With respect to temperature variation in both locations, there were minimum temperature of 12°C and maximum 25°C, during the period of the experiment.

With respect to use of inoculant only in the number of pods in Cafeara experiment showed positive effect with $P<0.01$ (Table 2), no significant response was obtained in the experiment Florestopolis (Table 3). Souza et al. (2011) also found that seed inoculation only increased the number of pods per plant in the absence of N. Was found significative F values in most parameters in the analysis of the effect of N rates. The bean yield ranged from 1883 to 2037 kg.ha^{-1} in Cafeara and 525 to 705 kg.ha^{-1} Florestopolis. The values obtained in Cafeara were well above the average of 951 kg.ha^{-1} in Brazil and 705 kg.ha^{-1} in the Paraná State (Conab, 2011).

There was a decrease in nodulation on the roots of bean, with regression adjusted a linear ($P <0.05$), when increase the dose of mineral nitrogen in Cafeara (Figure 2A). In Florestopolis no significant adjustment for nodulation between treatments with doses of N, in the absence and presence of inoculation (Figure 2B). In

Table 2. Mean values of nodulation, pod number, plant dry matter, leaf N and yield of beans in doses of inoculant and nitrogen. Cafeara – PR.

Treatments	Nodulation (number plant^{-1})	Nodules weigth (mg.plant^{-1})	N^o of pods per plant	N foliar (g.kg^{-1})	Yield (kg.ha^{-1})
Inoculation					
Yes	20.6	43.4	9.32	37.5	1996.9
No	24.4	53.1	8.38	36.9	1983.8
F	3.09	3.64	7.59**	0.65	0.073
N doses (Kg.ha^{-1})					
0	33.7 ^{a}	57.6 ^{ab}	7.46 ^{c}	34.9 ^{b}	1932
20	25.5 ^{ab}	63.2 ^{a}	8.45 ^{bc}	36.7 ^{ab}	2001
40	19.6 ^{b}	46.2 ^{ab}	8.91 ^{abc}	37.0 ^{ab}	1949
60	16.2 ^{b}	35.3 ^{b}	9.03 ^{ab}	38.1 ^{ab}	2046
80	17.4 ^{b}	38.9 ^{b}	10.4 ^{a}	39.2 ^{a}	2021
F	9.13**	4.43**	7.86**	3.61*	0.79
CV	30.6	33.1	8.85	6.42	7.66

* and ** significant at the 5% and 1% probability according to the F test.

Table 3. Mean values of nodulation, pod number, plant dry matter, leaf N and yield of beans in doses of inoculant and nitrogen. Florestopolis – PR.

Treatments	Nodulation (number plant^{-1})	Nodules weigth (mg.plant^{-1})	N^o of pods per plant	N foliar (g.Kg^{-1})	Yield (Kg.ha^{-1})
Inoculation					
Yes	36.9	45.8	3.50	37.1	612
No	30.3	44.7	3.78	37.6	624
F	2.24	0.011	1.05	1.53	0.185
N doses(Kg.ha^{-1})					
0	46.3	79.4 ^{a}	3.21	37.2 ^{ab}	509 ^{b}
20	26.6	43.2 ^{b}	3.68	36.5 ^{b}	642 ^{a}
40	34.3	34.9 ^{b}	3.58	36.5 ^{b}	658 ^{a}
60	33.9	38.4 ^{b}	4.01	38.1 ^{a}	656 ^{a}
80	26.9	29.2 ^{b}	3.71	38.6 ^{a}	624 ^{ab}
F	2.54	7.34**	0.85	3.75*	
CV	42.1	46.4	24.3	3.65	14.1

* and ** significant at the 5% and 1% probability according to the F test.

general, there was good nodulation of bean plants in the absence of inoculation, in two locations measured.

Pelegrin et al. (2009) observed that nodulation in bean plants that were not inoculated was similar to inoculated, mainly due to population of native rhizobia in the soil. Similarly, Hungria et al. (2003) observed no significant differences in the number of nodules of bean plants inoculated with rhizobia and that received N fertilization (30 kg ha^{-1} at sowing + 30 kg ha^{-1} in coverage) when comparing nodulation provided by the native population soil. The inhibitory effect of N on nodulation is probably plant mediated; however, differences in tolerance to nitrate and ammonium have also been found between rhizobial isolates when investigated in nodulated systems (Nelsen, 1987).

There was significant adjustment (P <0.05) for increasing the number of pods when increased doses of N and inoculated with Rhizobium in Cafeara (Figure 3A). In Florestopolis the adjustment quadratic was significant (P <0.05) for doses of N without inoculation (Figure 3B). In the analysis of the dry mass of the shoot, there was a significant adjustment quadratic (P <0.05) with increased dry matter at the highest levels of mineral N in uninoculated treatments in Cafeara experiment (Figure 4). In Florestopolis the regression analysis was significant (P <0.01), showing maximum production at the dose of 40 kg N per hectare, when using inoculation. Responses of bean to nitrogen fertilization have been variable in dry

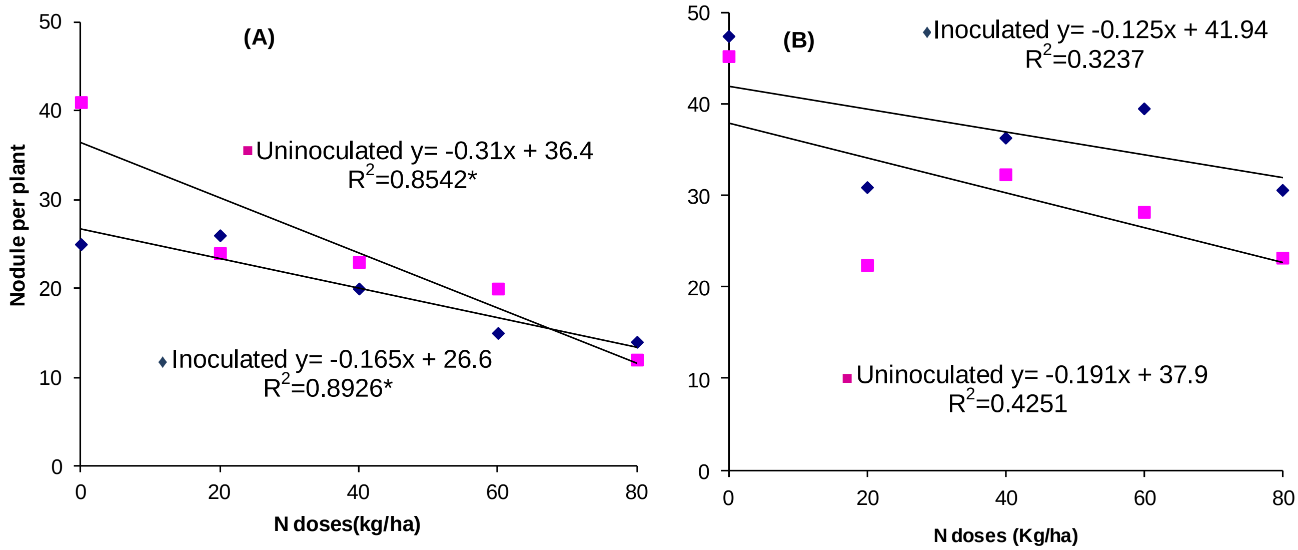

Figure 2. Nodulation after inoculation of bean seeds and applied dosages of nitrogen in (A) Cafeara and (B) Florestopolis. * significant differences (P<0.05).

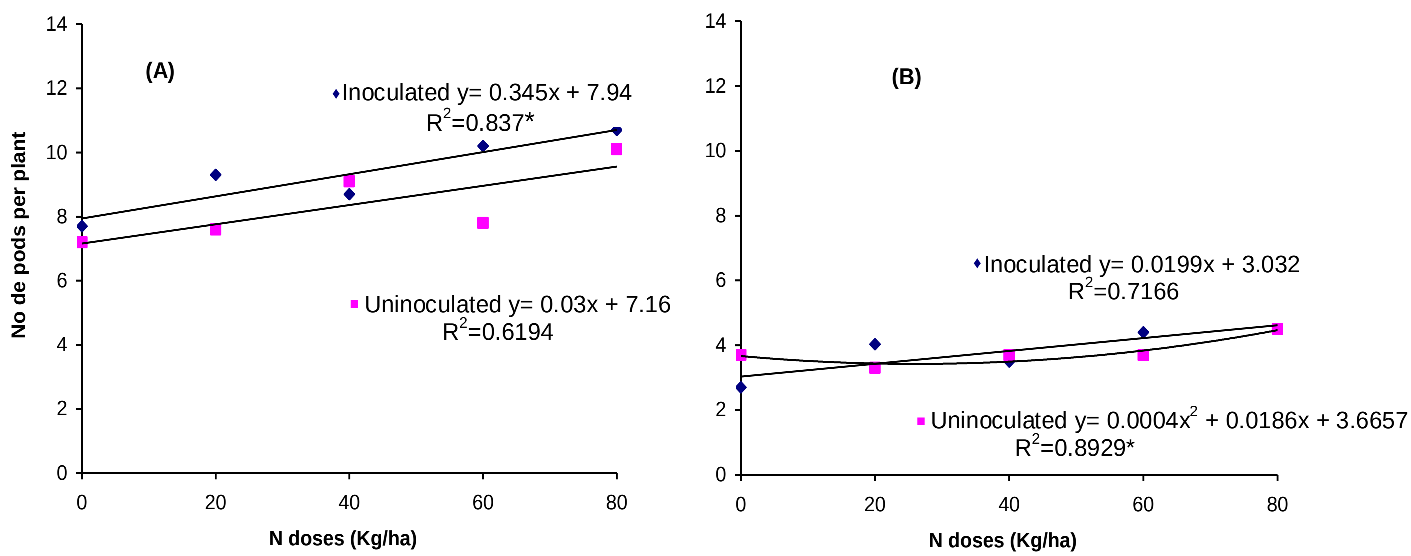

Figure 3. Number of pods after inoculation in bean seed and applied dosages of nitrogen in(A) Cafeara (B) Florestopolis. * significant differences (P<0.05).

matter production, observed positive effects (Carvalho et al., 2001) or no significant effects (Soratto et al., 2006). In Cafeara there was increase in the leaf N content, with significant linear adjustment for both the inoculated treatments (P<0.01) and for those without inoculation (P<0.05) (Figure 5A). Quadratic adujstment was found to be significant (P <0.05) for doses of mineral N without inoculation in Florestopolis (Figure 5B).

In all the treatments the foliar N content was observed to be below critical level for the plants, 30 g de N kg^{-1}, in accord with Ambrosano et al. (1997), or 30 to 50 g de N kg^{-1} (Malavolta et al., 1997). These levels are found in beans under conditions of fertility soil or native communities of rhizobia with high efficiency (Soratto et al., 2006; Farinelli et al., 2006). In conditions of poor soils in N (with low organic matter) and low populations of rhizobia symbiotically efficient the application of mineral nitrogen has provided higher foliar N than those in plants without fertilization (Carvalho et al., 2001).

Maximum values of nitrogen accumulation were found around 100 and 30 kg of N per ha, in Cafeara and Florestopolis respectively. In Brazil the average rates of BNF contribution to the beans are of the order of 60 kg N per hectare and represent 30 to 50% of total N

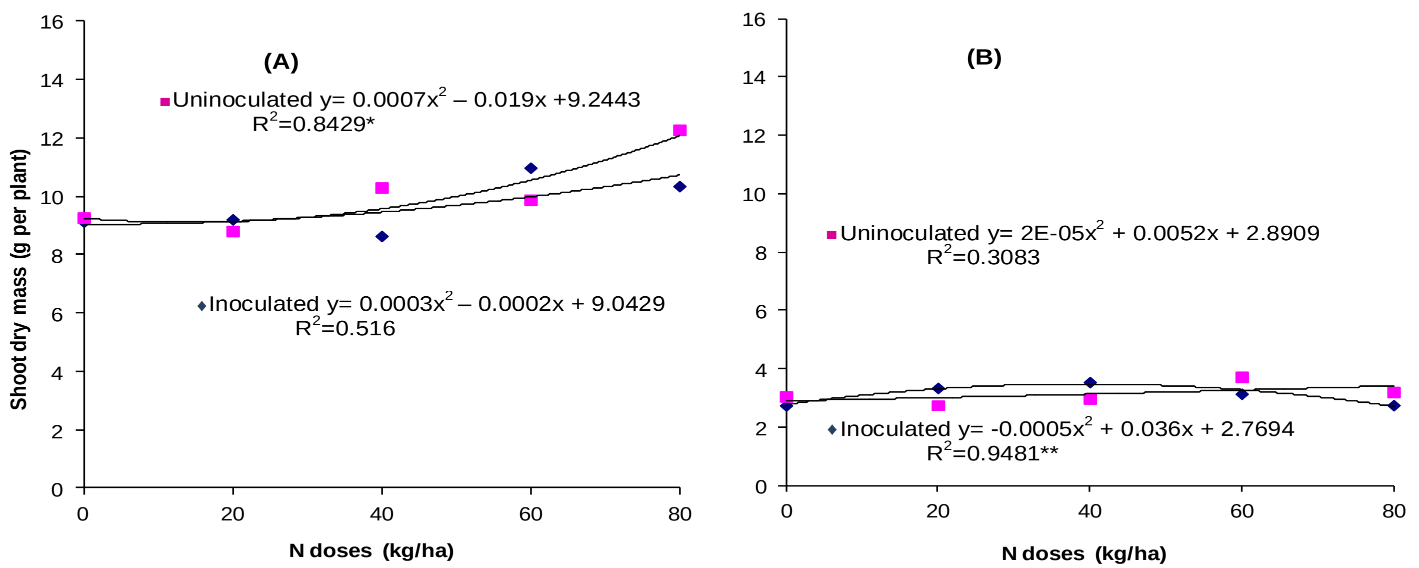

Figure 4. Dry mass of shoots in bean seed inoculation and after applied dosages of nitrogen in (A) Cafeara and (B) Florestopolis. * and **significant differences (P<0.05) and (P<0.01).

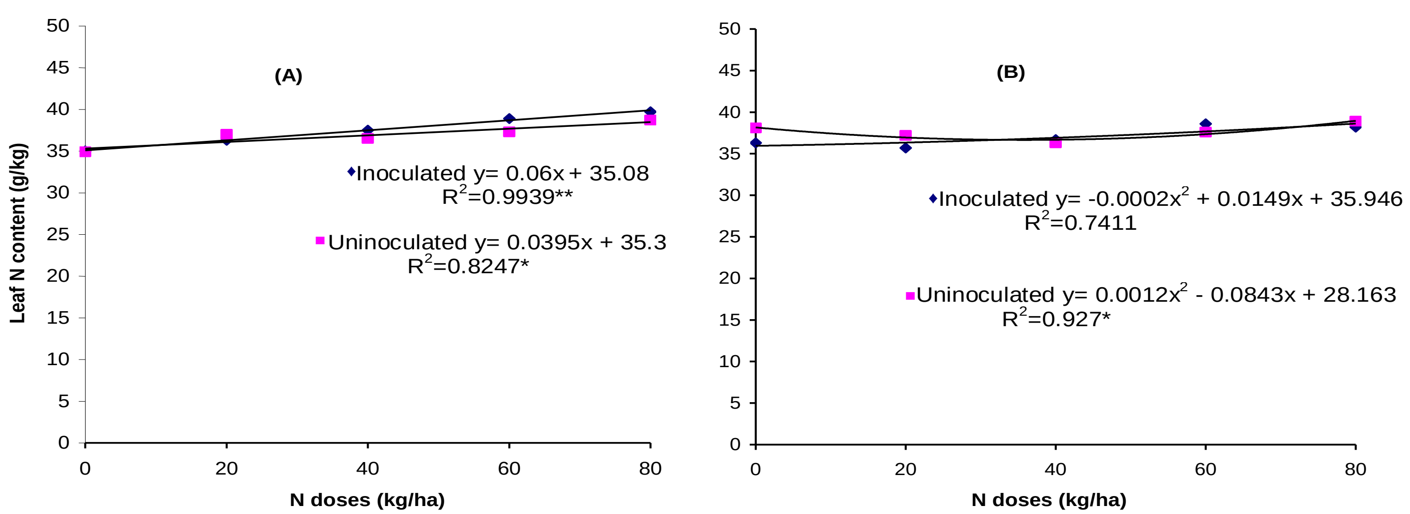

Figure 5. Leaf N content in bean seed inoculation and after applied dosages of nitrogen in (A) Cafeara and (B) Florestopolis. * and **significant differences (P<0.05) and (P<0.01).

accumulated by the plant (Pelegrin et al., 2009). Moura et al. (2009) concluded that the species of native soil rhizobia are as efficient as the inoculation of *R. tropici* in supplying N to the bean. The responses to nitrogen fertilization in grain production also has generated much controversy, about that Souza et al. (2011) found that yield of bean is little influenced by nitrogen fertilization. Soratto et al. (2006), in studies conducted in Brazilian Midwest, found significant responses for yield of bean, with the estimated dose for maximum response of bean in 140 kg ha^{-1} N. Farinelli et al. (2006), in Brazilian southeast, evaluated the application of N in bean crops under no tillage and conventional tillage and found the maximum yield with the application of 185 kg N per hectare. There has been variability in responses in productivity to levels of mineral N, mainly influenced by the levels of soil fertility and other techniques used in production systems, especially the use of irrigation systems (Pelegrin et al., 2009).

Concerning the performance of bean production in both locations, it was observed that the experiment of Cafeara had a good grain yield, indicating that this area is two years in no tillage. Soratto et al. (2006) also found increased yield of common bean in no-tillage, with inoculation and application of N in coverage. In Florestopolis showed low organic matter content in the soil (Table 1) and conventional soil management may have contributed to reduction in crop development especially in conditions of water stress, which may have been decisive for the low yield of bean.

The bean yield is affected by soil water availability. A deficiency of water in soil can reduce productivity in different proportions according to the different phases of the cycle, especially during flowering and early pod formation (Fancelli and Dourado, 2007).

Under the conditions of this study it was found adequate nodulation of bean and no response to inoculation of bean and supply of mineral N in two different situations, differentiated mainly by soil management. It was observed that the condition of the experiment Cafeara where good crop yield, factors N dose or inoculation was found was not used in determining this result. In this condition it can be suggested that the N mineralization of organic matter and FBN due to the presence of rhizobia provided greater supply of N to the bean. A favorable environment in the rhizosphere is vital to interaction legume-rhizobium; however, the magnitude of the stress effects and rate of inhibition of the symbiosis usually depend on the phase of growth and development, as well as the severity of the stress. For example, mild water stress reduces only the number of nodules formed on roots of soybean, while moderate and severe water stress reduces both the number and size of nodules (Williams and De Mallorca, 1984). Other factors are also related to the failure of inoculations as the competitiveness and efficiency of strains of *Rhizobium* inoculant and also by the response of bean genotype used.

Conclusions

In this study there was no response to inoculation in the evaluation of the yield of bean in Cafeara and Florestopolis with different soil management. The nodulation of bean with *Rhizobium* is reduced by fertilization with mineral nitrogen. The system with tillage cultivation favored the development of bean during autumn-winter.

Conflict of Interest

The authors have not declared any conflict of interest.

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Review

Gender mainstreaming in smallholder agriculture development: A global and African overview with emerging issues from Swaziland

Robert Mabundza[1], Cliff S. Dlamini[2]* and Banele Nkambule[3]

[1]Faculty of Natural and Agriculture Sciences, Centre for Sustainable Agriculture, at the University of the Free State, South Africa.
[2]WWF South Africa, C/O Table Mountain Fund, Centre for Biodiversity Conservation, Kirstenbosch National Botanical Gardens, PO Box 23273, Claremont, 7735, South Africa.
[3]World Vision Swaziland, P. O. Box 2870 Mbabane Swaziland.

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The paper presents a review of literature in gender mainstreaming in agricultural development. It begins by defining key terms related to gender mainstreaming, and then followed by the discussion of the historical background of gender mainstreaming. This is then followed by review of literature concerning the gender mainstreaming and agricultural development, and African perspective of gender mainstreaming and the current status of gender mainstreaming in Swaziland. The review ends by discussing the potential benefits that can be harnessed from mainstreaming gender in the country's agriculture sector and development programmes.

Key words: Gender, mainstreaming, smallholder farming, sustainable agriculture, development.

INTRODUCTION

The concept of gender mainstreaming

Engendering

Engendering is a term that is used to refer to ways in which gender based roles have been demystified to ensure participation of males and females, especially in the community development process. Engendering development means engaging men and women equally in the production process. This is geared towards enhancing equality in sustainable agricultural development. On the other hand, gendering is the dynamic way that makes female roles adapt, established or confirmed, clearly demonstrated in the historicity of gender relations in both private and public spheres. Due to the changing nature of economy and human needs, there is a need to engender development process and streamline the stereotypes that have characterized the

*Corresponding author. E-mail: cliffsdlamini@ymail.com; csdlamini@wwf.org.za. Tel: +27 (0)21 762 8525;
Fax: 086 775 15568.
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arena of development (Maseno and Kilonzo, 2010: 48).

Gender

Gender is defined as the set of characteristics, roles and behavior patterns that socially and culturally distinguish women from men in the society. Gender characteristics change overtime and differ from one culture to another and concept of gender refers to the roles and characteristics of women and men into the relations of power between them (GoS, 2010). Indeed, the term gender is often misunderstood and used indiscriminately as a synonym for sex. As mentioned earlier, “gender” refers to socially constructed differences between sexes, while sex refers to relatively fixed biological differences between men and women (Sanga, 2008: 107).

Gender equality

Gender equality refers to equal opportunities and outcomes for women and men in the community. According to AfDB (2010), gender equality involves the removal of discrimination and structural inequalities in access to resources, opportunities and services, and the promotion of equal rights. Equality does not mean that women should be the same as men. However, promoting equality recognises that men and women have different roles and needs, and takes these into account in development planning and programming.

Gender mainstreaming

Gender mainstreaming is defined as the process of assessing the implications for women and men of any planned action, including legislation, policies or programmes, in all areas and at all levels. It is a strategy for making women’s as well as men’s concerns and experiences, an integral dimension of the design, implementation, monitoring and evaluation of policies and programmes in all political, economic and societal spheres so that women and men benefit equally and inequality is not perpetuated (Dayanandan, 2011: 510). Gender mainstreaming means the process of identifying gender gaps and making the concerns and experiences of women, men, girls and boys integral to the design, implementation, monitoring and evaluation of policies and programmes in all spheres so that the benefits are equitably distributed (GoS, 2010).

Gender and development (GAD)

GAD is an approach based on the premise that development cooperation programs cannot succeed or the impact be sustained if the people affected do not support them. It examines the ways in how men’s and women’s differing roles, responsibilities, resources and priorities may affect project implementation.

HISTORICAL BACKGROUND OF GENDER MAINSTREAMING

Around the world, gender mainstreaming has emerged as a key gender equality strategy following the 1995 Beijing women’s conference (Alston, 2006: 123). Rural communities, where some 70% of the world’s rural poor are concentrated, generally rely on agriculture, forestry, fisheries and livestock for their livelihoods. Within those communities, the poorest of the poor are often women and young girls; and FAO (2010) stated that 6 out of 10 of the world’s poorest people are women who lack regular and decent employment and income. The reports further states that these women face hunger and/or malnutrition, poor access to health, education and productive assets, time poverty caused by disproportionate paid and unpaid work burdens and child labour. This is in contrast to the fact that women tend to be the main producers of food, while men manage most of the commercial crops (FAO, 2010).

Since the mid 1980s, there has been a growing consensus that sustainable development requires an understanding of both women’s and men’s roles and responsibilities within the community and their relations to each other. This has come to be known as the GAD approach. Improving the status of women is no longer seen as just women’s issue, but as a goal that requires the active participation of both men and women. For instance in Columbia, Nilsson et al. (2009) reported that due to the armed conflict, both women and men face problems accessing their land. Women, however, are discriminated against in a disproportionate manner; although legally they are entitled to land ownership, in practice they struggle to exercise this right.

As a consequence, when demining activities take place and land is released, women often lose access to their land as a result of gender-based discrimination. Moreover, profits made from these land areas seldom benefit women. Statistics reveal that women own less than 5% of the world’s titled land, a critical perspective of gender mainstreaming in African countries (Nilsson et al., 2009).

GENDER AND AGRICULTURAL DEVELOPMENT

The section identifies gender gaps and potential benefits that can be observed from mainstreaming gender in the design, implementation, monitoring and evaluation of agricultural programmes and projects to achieve sustainable development.

Improved socio-economic status of smallholder farmers

Women are crucial in the translation of the products of a vibrant agriculture sector into food and nutritional security for their households. They are often the farmers who cultivate food crops and produce commercial crops alongside the men in their households as a source of income (World Bank, 2009). Gender equality is fundamental for achieving agricultural development supported by economic empowerment so that more women receive secondary and tertiary educations to enhance their chances of finding jobs. According to World Bank (2009), gender equality and women's empowerment are far from being achieved, although women play a significant role in agriculture.

Access and control of productive resources

Despite women prominent role in food production, market and processing, women have limited access to land, agricultural extension services, credit, infrastructure, technology and markets that are crucial for enhancing their productivity (Mthuli et al., 2011). In North Africa 32.6% of women and 32.9% of men are employed in the agriculture sector, while the figures are much higher in sub-Saharan Africa where 67.9% of women and 62.4% of men are employed in the sector in 2007 (AfDB, 2010). Studies that were conducted in Kenya have shown that where women farmers have equal access to inputs, education and technology their productivity increases by 20%. African agricultural and rural development efforts cannot afford not to invest in initiatives that increase the productivity of women engaged in agriculture (Mthuli et al., 2011).

World Bank (2007) cited in AfDB (2010) stated that gender inequalities in access to productive resources, opportunities and services limit agricultural productivity and undermine sustainable and inclusive development in the sector. For example, in Kenya women contribute 80% labor to food production, account for 70% of the agriculture workers and manage 40% of the smallholder farms and yet they receive less than 10% of the credit allocated to small holders, hold less than 10% of the registered land titles and receive less than 5% agricultural credit.

Agriculture projects financed by AfDB indicate that considerations related to gender issues and women's participation influence the success and sustainability of a project. Women are major contributors to the economy, both through their remunerative work on farms and through the unpaid work they traditionally render at home and in the community. Yet in many societies they are systematically excluded from access to resources, essential services, and decision making. The predominance of patriarchy in law, policy, and practice ensures that the land has owners but that they are not women (Mbote, 2005).

Improved and meaningful participation of women in agriculture

Women contribute tremendously to agricultural output but unfortunately they hardly benefit from agricultural incentives and innovation because of economic suppression and traditional practices which undermine the constitutional provisions on the equality of men and women. Gender discrimination, rather than ignorance, is the reason for the lack of women participation in agricultural programmes and projects (Ogunlela and Mukhtar, 2009: 21). The loss of biodiversity in agriculture is the key threat to food security and sustainability in relation to diversity in food, feed, fish, and animal stocks which has narrowed down alarmingly. For example, in rural India, it is women who conserve biodiversity on farm as well as *ex situ* through various rituals. The role of women as custodians of agriculture and livestock still cannot be ruled out (Satyavathi et al., 2010: 44). They depend greatly on the environment for their basic needs such as fuel, water, food and medicine. According to a study that was conducted in the Philippines, it was noted that while women play important economic roles in fishing, particularly in processing and marketing, their roles are often neglected in programmes and projects in the sector. Women are particularly concerned about overfishing, which is reducing the viability of fishing communities, and are keen to participate in protection and sustainable management efforts (ADB, 2006). In addition, women, whose carbon footprint is smaller than that of men, should play a larger role in confronting climate change since they make the majority of consumption decisions for households (OECD, 2008).

Increased agricultural productivity

Ogunlela and Mukhtar (2009: 20) mentioned that women are known to be more involved in agricultural activities than men in sub-Saharan African countries, Nigeria inclusive. As much as 73% were involved in cash crops, arable and vegetable gardening, while postharvest activities had 16% and agroforestry, 15%. It is estimated that women's contribution to the production of food crops range from 30% in the Sudan to 80% in the Congo contributing substantially to national agricultural production and food security, while being primarily responsible for the food crops. Samuel and Dasmani (2010: 441) noted farm level efficiency can improved particularly when tradition, culture and other socio-economic constraints that hinder women participation are removed. Therefore, it is critical to amplify women's participation in agricultural development to increase their economic roles in rural development particularly in food production.

Policy development

Mbote (2005) stated that under all systems of law in many African countries, land ownership is anchored in patriarchy. Law can be used to reinforce or make permanent social injustices in the realm of women's rights, legal rules may give rise to or exacerbate gender inequality. Legal systems can also become obstacles when change is required: often the de jure position, which may provide for gender neutrality, cannot be achieved in practice due to numerous obstacles (Mbote, 2005).

According to Mbote (2005), the predominance of patriarchy in law, policy, and practice ensures that the land has owners but that they are not women. For law and policy to influence gender relations to land tenure, there is need to deconstruct, reconstruct, and reconceptualise customary law notions around the issues of access, control, and ownership. The view should be to intervene at points that make the most difference for women. There is need for innovative and even radical approaches. In determining tenure to land, rights should be earned or deduced from an entity's relationship to the land. Rights should be anchored on use and subjected to greater public good resident in the trusteeship over land for posterity.

PERSPECTIVE OF GENDER MAINSTREAMING IN AFRICAN COUNTRIES

Sanga (2008: 102) stated that during the closing decades of the last millennium, the African continent witnessed the emergence of a number of initiatives aimed at improving the social, economic, and political condition of its citizens that included a number of national, regional, and international development plans such as the Poverty Reduction Strategies, the New Partnership for Africa's Development and the Millennium Development Goals (MDGs). In the pursuit of this agenda, it has been widely recognized that women and men face different socio-economic realities especially in the development of sustainable agricultural activities.

According to Ogunlela and Mukhtar (2009: 19), the bedrock of agriculture and agricultural development in developing countries of sub-Saharan Africa is rural development, without which all efforts in agricultural development will be futile. A large majority of the farmers operate at the subsistence, smallholder level, with intensive agriculture being uncommon and women's and men's roles and responsibilities in a society or culture are dynamic and change overtime. Social, cultural, religious, economic, political and legal factors and trends all have a complex and profound influence on gender roles and responsibilities and tend to impede sustainable agricultural development. Many of these factors can constrain women's participation in development activities. Women have limited access to agricultural services and inputs, are more likely to lack assets, and grow more subsistence crops. Consequently, women farmers are more likely to be asset-poor subsistence farmers. In sub-Saharan Africa, it has been calculated that agricultural productivity could increase by up to 20% if women's access to such resources as land, seed, and fertilizer were equal to men's, yet women still face serious constraints in obtaining essential support for most productive resources, such as land, fertilizer, knowledge, infrastructure, and market organization (World Bank, 2009).

Ogunlela and Mukhtar (2009: 28) noted that in sub-Saharan Africa, agriculture accounts for approximately 21% of the continent's gross domestic product (GDP) and women contribute 60 to 80% of the labour used to produce food. Estimate of women's contribution to the production of food crops range from 30% in the Sudan to 80% in the Congo, while their proportion of the economically active labour force in agriculture ranges from 48% in Burkina Faso to 73% in the Congo and 80% in the traditional sector in Sudan. On another note, the World Bank (2009) stated that in sub-Saharan Africa, women are largely responsible for selling and marketing traditional crops such as maize, sorghum, cassava, and leafy vegetables in local markets. However, in countries where urban markets for these traditional crops are expanding rapidly, such as Cameroon and Kenya, the challenge is to ensure that women retain control over their production, processing, and marketing. In Uganda the strong demand for leafy vegetables (traditionally a woman's crop) in Kampala markets caused men to take over their cultivation. Maseno and Kilonzo (2010: 48) explain that considerable gender disparities exist in the Kenyan labour market. Although women constitute about 50% of Kenya's total population, they account for only about 30% of the total formal-sector wage employment and earn less than men, even after making adjustments for the type of employment, occupation, and hours of work. The scholars argue that women's participation rates are higher (compared to men's) in rural areas, where they are actively involved in subsistence activities and agricultural production in addition to unpaid domestic work.

This is further evidenced by Maseno and Kilonzo (2010: 48) that they spend more than 8 h in a day working in the fields in order to provide for their families with basic needs. Studies have documented that women work 12 to 13 h a week more than men, as the prevalent economic and environmental crises have increased the working hours of the poorest women. Women work hard to cope with their household chores like collecting firewood and fetching water from wells or rivers that may be far away from home, besides other activities. Most of these activities are recognized as 'minor' household jobs that are meant for women and are hardly shared with the spouses or the sons. Ara (2012: 8) noted that in the developing world, gender difference in the labour market is a common issue and it needs to be studied in relation to the social customs in those countries.

According to IFAD (2011), women's empowerment benefits not only women themselves but also their families and communities. Moreover, farm productivity increases when women have access to agricultural inputs and relevant knowledge. The report further states that in Gambia, although many development interventions actively promote the equitable control of and access to productive lands, in practice it has been found that the land rights of women and other disadvantaged groups may fare better under a local bargaining process than where redistribution is pushed by external interventions. Concerning the contribution of gender in economic growth, Mthuli et al. (2011) reported that in the sub-Saharan Africa, women contribute 60 to 80% of the labour used to produce food both for household consumption and for sale. Therefore, promoting gender equality in employment is an important cornerstone to advance women's economic empowerment in Africa.

Gender mainstreaming in Swaziland

The government of Swaziland has made some progress in promoting gender in alignment with regional and international commitments in providing equitable opportunities for women and men, boys and girls at all levels, women empowerment and social justice. This has been achieved through the enactment and the implementation of the nation gender policy. Through the policy the government of Swaziland conducts capacity building for gender mainstreaming in all national and sectoral policies, plans, programmes and budgets. It also focuses on strengthening the capacity and capability of the gender unit. The unit is responsible for the coordination of the implementation, monitoring and evaluation of the gender policy; advocate for the allocation of resources and public expenditure so that they are equally beneficial to men and women; strengthening partnerships with development partners, Non-Governmental Organizations (NGOs) and community leaderships for gender equity and the empowerment of women and girls. Lastly, mobilizing at all levels for social transformation on gender issues and for the implementation of the gender policy. The section discusses the potential benefits that can be harnessed from mainstreaming gender in the country's agriculture sector and development programmes.

Socio-economic improvement of smallholder sugarcane farmers

In Swaziland, the sugar sector is central to the economy of Swaziland accounting for 59% of agricultural output, 35% of agricultural wage employment and about 18% to the country output (SSA, 2012). The Government of Swaziland has noted that the sector can make a meaningful vehicle in the fight against high levels of poverty and unemployment. Small-scale sugarcane farming is now practiced by many households, particularly those in the poverty stricken areas of the Lowveld. SSA (2012) observed that sugar industry presents a good opportunity for small-scale farmers to get employment, raise incomes and move out of poverty. This is also supported by Mnisi and Dlamini (2012: 4337) when they observed that in India, the sugar industry is the focal point for socio-economic development in the rural areas by mobilizing rural resources, generating employment and higher income, and developing transport and communication facilities. In addition, the GoS (2005) stated that women are the major labour force in food production in Swaziland and also are responsible for food preparation, household hygiene, and childcare that are linked to household nutritional status. Therefore, women's rights, participation, needs, education and training, need to be recognized in all aspects of agricultural production.

Access and control of productive resources

Access and control over resources is also gendered as only males access Swazi Nation Land (SNL) through paying allegiance to the chief. Women on the other hand do not access resources in their own right and may only access land through males, as husband, father or son and other male relatives (LUSIP, 2011). Presently, women in Swaziland are particularly vulnerable to poverty, with about twenty percent (20%) of households are headed by women (GoS, 2006). Women are mainly disadvantaged by the Swaziland law and custom which deprives women from the right to own land and access to finances. The customary law of the country states that widowed women traditionally do not inherit land, but are allowed to remain on the matrimonial land and home until death or remarriage. Women also have less access to education in rural areas. It is estimated that over 70% of women in rural Swaziland are illiterate, compared to the national average of 21% (McKnight, 2009). According to GoS (2006), about 63% of female-headed households are poor and lack productive assets compared to 52% male counterparts. Therefore, agricultural production can be used as a source of income through crop production forestry, fisheries and animal production.

Equal and meaningful participation

The Government of Swaziland has recognized the need to ensure equitable and full participation of women and men at all levels of development. Deliberate efforts have been employed to ensure that the barriers that prevent full and effective participation of women and men in all sectors are removed (GoS, 2010). The government of Swaziland developed a gender policy that aims to address the inequities between women and men. It provides a vision to improve the living conditions of women and men including practical and forward looking guidelines and strategies for the implementation, monitoring and evaluation of the related constitutional provisions. Ogunlela and Mukhtar (2009: 22) examined the level of participation of rural women in the decision-making in different areas of agriculture and studied factors influencing their participation in the decision-making process in farm management. They found that women's participation in decision making was quite minimal. In each of the farm operations, less than 20% of the women were consulted, except in the sourcing of farm credit, where about 28% were consulted; about 13% or less of the women had their opinion considered in each of the farm operations. However, only between 1.0 and 2.5% took the final decision in all of the farm operations.

The role that women play and their position in meeting the challenges of agricultural production and development are quite dominant and prominent. Findings from a study financed by the United Nations Development Programme (UNDP) revealed that women make up some 60 to 80% of agricultural labour force in Nigeria (Ogunlela and Mukhtar, 2009: 20), depending on the region and they produce two-thirds of the food crops. In contrast, widespread assumption that men and not women make the key farm management decisions has prevailed.

Policy development

In most African countries female farmers are among the voiceless, especially with respect to influencing agricultural policies (Ogunlela and Mukhtar, 2009: 19). Policies which are aimed at increasing food security and food production tend to either underestimate or totally ignore women's role in both production and the general decision-making process within the household.

The promotion of gender equity and the empowerment of women have been recognized as a key millennium development goal and to meet this goal, the Kingdom of Swaziland has developed a gender policy to provide guidelines for attaining gender equity in the country. The development of appropriate policies and strengthening of national gender machineries to fully undertake the challenging mandates are crucial actions particularly in addressing structural relationships of inequality between men and women. The national gender policy provides guidelines, indicators and a framework to assist stakeholders to achieve gender equity as provided for in the country and other relevant international instruments that the country has ratified (GoS, 2010). On another note, the Government of Swaziland has undertaken numerous initiatives to ensure full and coherent participation of women and men in achieving the national objectives of economic growth, self-reliance, social justice and stability through involving women and men in the mainstream of the country's development (GoS 2010).

Conclusion

The research reviewed gave understanding of gender mainstreaming in agricultural development with reference to small-scale farmers involved in crop production. It also highlighted the critical issues that hinder participation of women in agriculture in African countries including Swaziland with regards to access and control of productive resources, participation of men and women in agricultural development and the potential benefits of gender mainstreaming in policy development and its positive contribution into the improvement socio-economic status of farmers and poverty reduction. Furthermore, it highlights the progress of the government of Swaziland in creating a suitable environment for implementing gender mainstreaming in community development activities.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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Effect of tillage system and nitrogen fertilization on organic matter content of Nitisols in Western Ethiopia

D. Tolessa[1], C. C. Du Preez * and G. M. Ceronio[2]

[1]Ethiopian Institute of Agricultural Research, P. O. Box 2003, Addis Ababa, Ethiopia.
[2]Department of Soil, Crop and Climate Sciences, University of the Free State, P. O. Box 339, Bloemfontein 9300, South Africa.

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Ethiopian soils, formed from old weathered rocks, are naturally low in fertility. Moreover, crop production is constrained by non-sustainable cropping practices, particularly repeated plowing and hoeing, which enhances loss of soil organic matter. Field trials were therefore conducted to determine the integrated effects of tillage system and nitrogen fertilization on organic matter content of Nitisols at five sites using maize as test crop during 2000 to 2004 in Western Ethiopia. Three tillage systems [minimum tillage with residue retention (MTRR), minimum tillage with residue removal (MTRV) and conventional tillage (CT)] and three N levels (the recommended rate and 25% less and 25% more than this rate) were combined in factorial arrangement with three replications. After 5 years, the two measured indices of organic matter, viz. the organic carbon (C) and total nitrogen (N) content were both significantly higher in the MTRR soil compared to the CT and MTRV soils. However, the influence of tillage systems on organic C and total N was confined to the upper 0 to 7.5 cm soil layer. On average, organic C and total N in this layer were 17 and 25%, and 20 and 29% higher with MTRR than with CT and MTRV, respectively. Application of N fertilization for 5 consecutive years showed profound effects on organic C and total N. Increasing levels of N application led to higher organic C and total N irrespective of tillage system. Both organic C and total N showed however a steady (115 kg ha^{-1} N level) to declining (69 and 92 kg ha^{-1} N levels) trend over time. Based on these results, replacement of CT with MTRR should be beneficial and sustainable to soil quality in the study area. However, MTRV is not an option at all to replace CT from a soil quality point of view. This study's findings may be applicable to other highland regions in Africa where cropping on Nitisols is common.

Key words: Conventional tillage (CT), crop residues, minimum tillage, organic carbon, total nitrogen.

INTRODUCTION

Western Ethiopia has a high potential for maize production due to favourable environmental conditions. This potential is seldom realized if at all because of non-sustainable cropping systems. Practices often mentioned contributing to the phenomenon are plough-based tillage resulting in soil and water loss through erosion

*Corresponding author. E-mail: dpreezcc@ufs.ac.za. Tel: +27-51-4012212; Fax: +27-51-4012212.
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(Bezuayehu et al., 2002) and insufficient fertilization resulting in poor growth and development of crops (Tolessa et al., 2002). Farmers will probably proceed with these practices for many years to come because of their financial limitations. Investigations into cropping systems comprising of alternative tillage practices are therefore justified.

Tillage plays an important role in the dynamic processes governing soil fertility (Triplett and Van Doren, 1977; Phillips et al., 1980; Mahboubi et al., 1993; Duiker and Beegle, 2006; Govaerts et al., 2009). Properly designed tillage practices usually alleviate soil-related constraints in achieving potential productivity and utility. However, improperly designed tillage practices can set in motion a wide range of degradative soil processes like organic matter depletion, aggregate deterioration, accelerated erosion, and disruption of water, carbon, nitrogen and other major nutrient cycles (Baeumer and Bakermans, 1973; Phillips et al., 1980; Lal, 1993; Bolliger et al., 2006; Du Preez et al., 2011).

Several studies indicated that minimum tillage increased organic matter on or near the soil surface mainly due to crop residues that are not mechanically mixed into the soil and hence decompose slower compared to conventional tillage (CT) (Lal, 1976; Barber, 1979; Blevins et al., 1983; White, 1990; Rasmussen and Collins, 1991; Unger, 1991; Ismail et al., 1994; Loke et al., 2012). This increase of organic matter has on account of its nature long-term beneficial effects on a number of soil properties and processes. In the broadest context, organic matter may be referred to as the total complement of organic substances in soil, including living organisms of different sizes, organic residues in various stages of decomposition and dark-coloured humus consisting of non-humic and humic substances (Stevenson and Cole, 1999; Powlsen et al., 2013). Claims are therefore that organic matter is a major source of nutrients and microbial energy, holds water and nutrients in available forms, promotes soil aggregation and root development, and improves water infiltration and water-use efficiency (Allison, 1973; Brady and Weil, 2008). Cropping usually benefits from the mentioned properties and processes influenced by organic matter.

Another benefit often attributed to minimum tillage is the sequestration of carbon (C) in the soil through higher organic matter contents (Kern and Johnson, 1993). This sequestrated C results in less CO_2 in the atmosphere and therefore reducing the rate of global warming. CT in comparison with minimum tillage releases more CO_2 to the atmosphere on account of enhanced biological oxidation of soil organic matter (Reicosky et al., 1995; Govaerts et al., 2009). However, Baker et al. (2007) cautioned against the widespread belief that minimum tillage favours C sequestration since it may simply be an artifact of sampling depth. In line with this view, Chaplot et al. (2012) mentioned that the impact of minimum tillage on CO_2 emissions is still a matter of debate because research results are often not complementary.

Nevertheless, minimum tillage is widely recognized for its role in conservation of the natural resources soil, water and air. Minimum tillage however often necessitates higher nitrogen (N) fertilization to maintain crop yields during its initiation phase until a gradual build-up of the organic N pool could compensate for sustainable production (Larson et al., 1972; Phillips et al., 1980; Rice et al., 1986; Smith and Elliot, 1990; Bakht et al., 2009). This additional N will be unaffordable for most Ethiopian farmers if not subsidized in one way or another.

Experiments were therefore conducted on Nitisols in Western Ethiopia to examine the integrated effects of tillage system and N fertilization on the performance of the maize crop and the change in soil properties.

The ultimate aim with this research was to obtain substantiated information on whether minimum tillage can be introduced successfully into the current cropping systems practiced in the region. Some of the results are already reported, viz. the effects on yield and yield components (Tolessa et al., 2007) and efficacy of applied nitrogen (Tolessa et al., 2009). In this paper, the response of soil organic matter is presented.

MATERIALS AND METHODS

Experimental sites

The field trials for this study were conducted under rainfed conditions at Bako Agricultural Research Center, and on farmers' fields at Shoboka, Tibe, Ijaji and Gudar. These five sites were selected to be representative of the major maize producing areas of Western Ethiopia in terms of climate and soil. Bako is located at 09° 01'N and 37° 02'E, Shoboka at 09°06' N and 37°21'E, Tibe at 09°29'N and 37°32'E, Ijaji at 09°43'N and 37°47'E, and Gudar at 08°09'N and 38°08'E latitude and longitude, respectively.

The altitudes for Bako, Shoboka, Tibe, Ijaji and Gudar are 1650, 1695, 1730, 1820 and 2000 m above sea level, respectively. Only climatic data of the Bako site with the lowest altitude and the Gudar site with the highest altitude as obtained from nearby weather stations is given in Table 1 since there are no weather stations close to the other three sites. Based on these data the mean annual rainfall over a 15-year period (1990 to 2004) ranged from 1042.2 mm at the higher lying Gudar site to 1239.6 mm at the lower lying Bako site, viz. a difference of 197.4 mm. For the cropping season (May to October) the average minimum temperature was 3.5°C lower and maximum temperature 0.9°C higher at the Bako site compared to that of the Gudar site.

At all five sites the soil was classified as a Nitisol (FAO, 1998). Some physical and chemical topsoil characteristics of these Nitisols before commencement of the trials are summarized in Table 2. The textural class of the Nitisols differed from loam at the Ijaji site to clay at the Shoboka site. Similar differences of 0.61 units in pH, 1.08% in organic C, 0.04% in total N, 3.9 mg kg^{-1} in extractable P and 85 mg kg^{-1} in exchangeable K were recorded between the five sites.

The aforementioned differences in climate and soil justified therefore the selection of the five sites for this investigation.

Field trial layout

At each of the sites a field trial was laid out in a randomized

Table 1. Climatic data for the Bako and Gudar sites as obtained from nearby weather stations.

Bako	May	June	July	August	September	October	*CS	Annual
				Rainfall (mm)				
1990 - 1999	146.1	214.1	254.1	231.7	141.4	70.8	1058.2	1243.7
2000	135.1	278.2	236.9	289.6	162.0	103.4	1205.2	1345.5
2001	161.3	219.3	328.9	264.3	96.7	92.7	1163.2	1354.2
2002	68.3	236.0	239.2	205.9	42.1	0.0	791.5	1040.9
2003	5.7	265.1	420.6	434.4	39.9	11.5	1177.2	1355.1
2004	14.1	268.6	225.5	257.8	85.2	43.5	894.7	1061.3
2000 - 2004	76.9	253.4	290.2	290.4	85.2	50.2	1046.3	1231.4
				Temperature (°C)				
Minimum	15.0	14.7	14.6	14.5	14.0	12.6		
Maximum	28.6	25.9	23.9	24.1	25.1	27.2		
Mean	21.8	20.3	19.3	19.3	19.6	19.9		
Gudar	**May**	**June**	**July**	**August**	**September**	**October**	***CS**	**Annual**
				Rainfall (mm)				
1990 - 1999	111.4	150.4	258.5	163.3	100.7	74.6	858.9	1069.0
2000	109.9	123.8	207.5	237.5	166.6	19.4	864.7	994.4
2001	194.0	166.6	301.5	209.7	61.0	17.8	950.6	1139.4
2002	29.5	216.2	211.6	131.0	30.2	17.8	636.3	881.8
2003	2.0	185.9	167.3	153.2	55.9	7.5	571.8	975.9
2004	37.4	110.0	293.5	172.1	147	28.9	788.9	951.5
2000 - 2004	74.6	160.5	236.3	180.7	92.1	18.3	762.5	988.6
				Temperature (°C)				
Minimum	11.6	11.1	11.1	11.2	10.3	9.6		
Maximum	28.4	25.3	23.1	22.6	24.5	25.7		
Mean	20.0	18.2	17.1	16.9	17.4	17.7		

*CS = Cropping season.

Table 2. Some physical and chemical topsoil characteristics of the Nitisols at the study sites before commencement of the trials.

Sites	Sand	Silt	Clay	pH (H_2O)	Organic C	Total N	P	K
	------------- % ---------------				----------------%------------		------ mg kg^{-1}-------	
Bako	35.1	31.6	33.3	5.59	1.77	0.15	12.6	192
Shoboka	34.7	23.3	42.0	5.52	1.65	0.14	11.5	155
Tibe	26.7	35.2	38.1	5.41	1.46	0.12	8.7	146
Ijaji	44.7	32.3	23.0	5.69	1.93	0.16	10.3	231
Gudar	18.8	42.5	38.7	6.02	1.69	0.14	9.6	159

complete block design. The layout consisted of two factors namely, three tillage systems: minimum tillage with residue retention (MTRR), minimum tillage with residue removal (MTRV) and CT and three N fertilization levels (69, 92 and 115 kg ha^{-1}) replicated three times in a complete factorial combination. Every field trial had therefore 27 plots. An application of 92 kg N ha^{-1} is the recommended fertilization rate for conventional maize production at the study sites, implicating the two other rates are 25% less and 25% more than this recommended rate. These experiments were conducted from 2000 until 2004. The experimental plots were kept permanent to observe the carry-over effects of the treatments for the five cropping seasons.

Agronomic practices

Before the initiation of the trials the fields at all sites had been under conventional maize production for many years. During the entire trial period immediately after harvesting, the plants were cut at ground level and uniformly spread on the CT and MTRR plots, and removed from the MTRV plots. For the MTRR and MTRV treatments, soil disturbance was restricted to the absolute minimum, viz. the soil was disturbed only to place the seed in the soil at the time of sowing. In contrast, the soil was ploughed three times with the local oxen-plough ‘maresha’ prior to sowing to obtain a suitable seedbed for the CT treatments.

Urea and triple super phosphate were used as the sources of N and P, respectively. The application of urea was split, and therefore half of the urea and all of the triple super phosphate were band placed 5 cm below the seed at sowing. At 35 days after sowing when maize was at knee-height the other half of the urea was band placed next to the row at 5 cm depth. The fertilizer in the small furrows was covered with soil soon after application. All treatments received the recommended phosphorus rate of 20 kg ha^{-1} annually.

Weed control in the MTRR and MTRV treatments was done by applying Round-up (glyphosate-isopropylamine 360 g a.i. L^{-1}) at a rate of 3 L ha^{-1} prior to planting and Lasso/Atrazine (alachlor/atrazine 336/144 g a.i. L^{-1}) at a rate of 5 L ha^{-1} as a pre-emergence application. The recommended weed control practice for CT in Ethiopia is hand weeding at 30 and 55 days after sowing followed by slashing at milk stage.

The standard cultural practices as commonly recommended to the farmers were adopted for the study. Therefore, from 2000 to 2004 the planting dates varied from 5 May to 5 June at all the sites. A late maturing commercial maize hybrid, BH-660 was planted. The plant density aimed for was 50 000 plants ha^{-1} as the 5.0 × 4.8 m plots consisted of six rows, 5.0 m in length and the inter- and intra-row spacing was 0.8 and 0.25 m, respectively.

Data collection

Soil samples were collected, just before the trials commenced, from the 0 to 30 cm layer of all five sites for their characterization. A 5 cm auger was used to sample 20 randomly selected spots per site. These subsamples were thoroughly mixed, dried at room temperature, sieved through a 2 mm screen and stored until analysis.

Since the trials started soil samples were collected annually after harvesting from the 0 to 30 cm layer of all plots at each site. At the end of the trial period, the 0 to 7.5 cm, 7.5 to 15 cm, 15 to 22.5 cm and 22.5 to 30 cm layers were sampled additionally. In both instances an auger with a 2 cm diameter was used to sample five randomly selected spots per plot. These sub-samples were prepared for analysis as described earlier.

Standard procedures (The Non-affiliated Soil Analysis Work Committee, 1990) were used to determine particle size distribution (Hydrometer), organic C (Walkley-Black), total N (Kjeldahl), extractable P (Bray 2) and exchangeable K (NH_4OAc) of the relevant composite soil samples.

Statistical analysis

Experimental data were analyzed through analyses of variance using the MSTATC statistical package (Michigan State University, 1989). Means for each parameter were compared by the least significant difference (LSD) test at P = 0.05.

RESULTS AND DISCUSSION

Organic carbon

The effect of tillage system on organic C in the 0 to 30 cm soil layer is displayed in Figure 1 for the year 2000 to 2004. Clear differences in the organic C development on account of the three tillage systems as the experiments progressed from 2000 to 2004 were observed. This phenomenon is attributed to the fact that organic C increased with MTRR and decreased with MTRV. In the case of CT the organic C at Tibe and Gudar remained almost constant, and at Bako, Shoboka and Ijaji it declined but to a lesser degree as compared to MTRV.

The change of organic C in the 0 to 30 cm layer resulting from the application of N fertilization at different levels is illustrated in Figure 2. Organic C increased with higher levels of N application though not significant in many instances. These differences in organic C become more apparent as the experimental period progressed from 2000 to 2004. Over this period it appears that there is a decreasing trend in organic C, especially with the lowest and intermediate rates of N application. This is a cause of concern for the long-term organic matter content.

The organic C differences evolved in the upper 30 cm of the Nitisols from tillage system and N fertilization had their origin mainly in the upper 0 to 7.5 cm layer as shown in Figures 3 and 4. In general the highest organic C in this layer was recorded with MTRR, followed by CT and then MTRV. Organic C also increased significantly with higher levels of N application at three of the five sites, viz. Bako, Ijaji and Gudar.

The application of the particular three tillage systems on the Nitisols for 5 consecutive years caused tremendous changes of organic C in the upper 7.5 cm layer. Organic C in this layer was on average for all sites with MTRR 17 and 25% more than with CT and MTRV, respectively. This finding is consistent with results reported by several other researchers (Baeumer and Bakermans, 1973; Hamblin and Tennant, 1979; Griffith et al., 1986; Mahboubi et al., 1993; Franzluebbers, 2004; Baker et al., 2007; Luo et al., 2010; Loke et al., 2012). They attributed the difference in organic C between MTRR and CT to the fact that crop residues and the organic matter originated from it are oxidized faster in CT than MTRR soils due to a higher microbial activity. The significance of retaining crop residues was emphasized by the difference of organic C between the MTRR and MTRV soils. Sufficient crop residues for retention to ensure organic C maintenance or increase can only be realized with proper N fertilization as was the case in this study.

Total nitrogen

As could be expected the effect of tillage system on total N in the 0 to 30 cm soil layer (Figure 5) was almost similar to that of organic C (Figure 1). The total N increased with MTRR and decreased with MTRV resulting in large differences after 5 years. In the case of CT, the total N also decreased but to a lesser degree

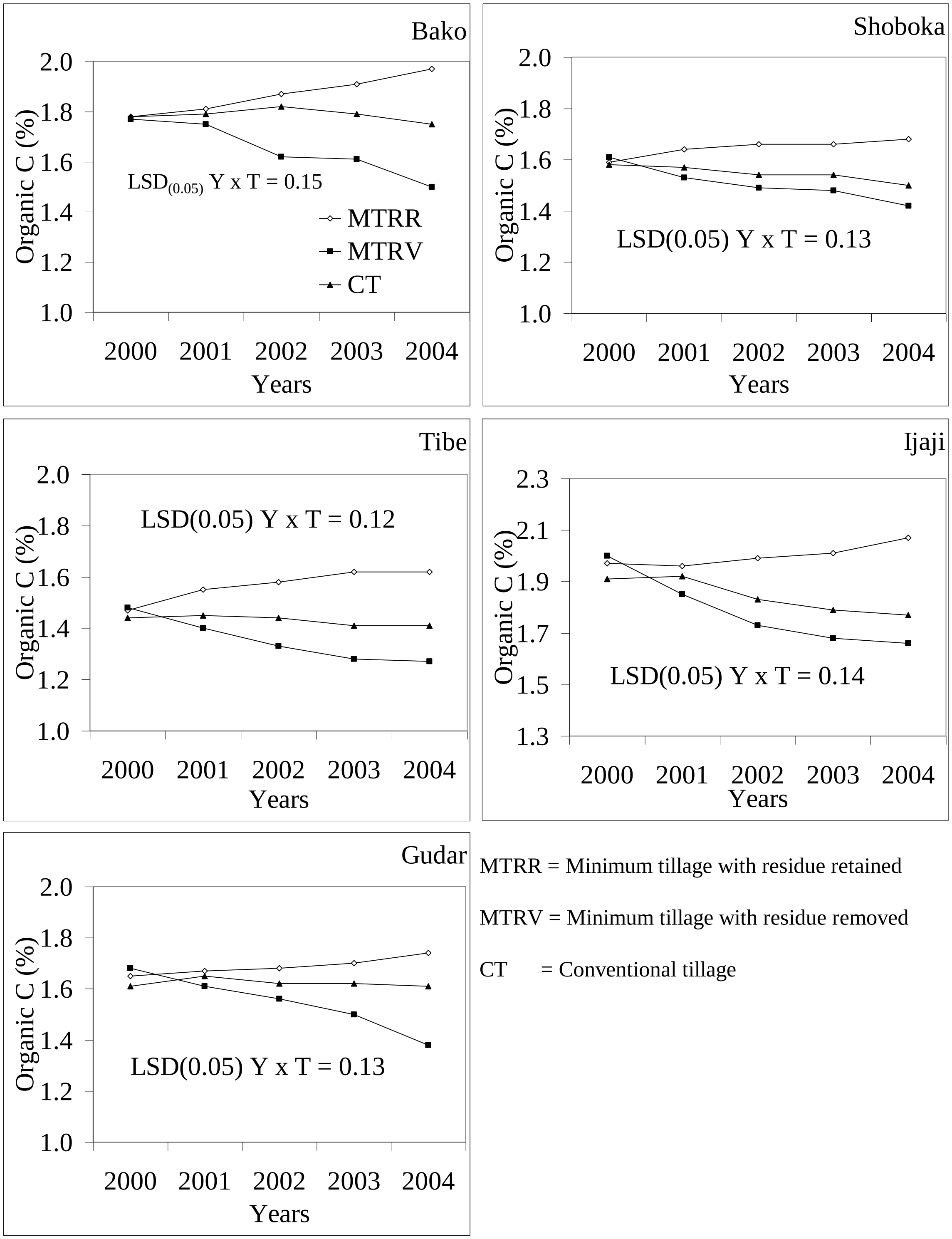

Figure 1. Effect of tillage system on organic C measured after harvesting in the 0-30 cm layer of Nitisols at the five experimental sites in 2000 to 2004. Y = year and T = tillage system.

than with MTRV. The change of total N in the 0 to 30 cm soil layer resulted from the application of N fertilizer at different rates is shown in Figure 6. Total N increased with higher rates of N application though not always significant. It seems however when the recommended rate of N or less is applied that total N like organic C

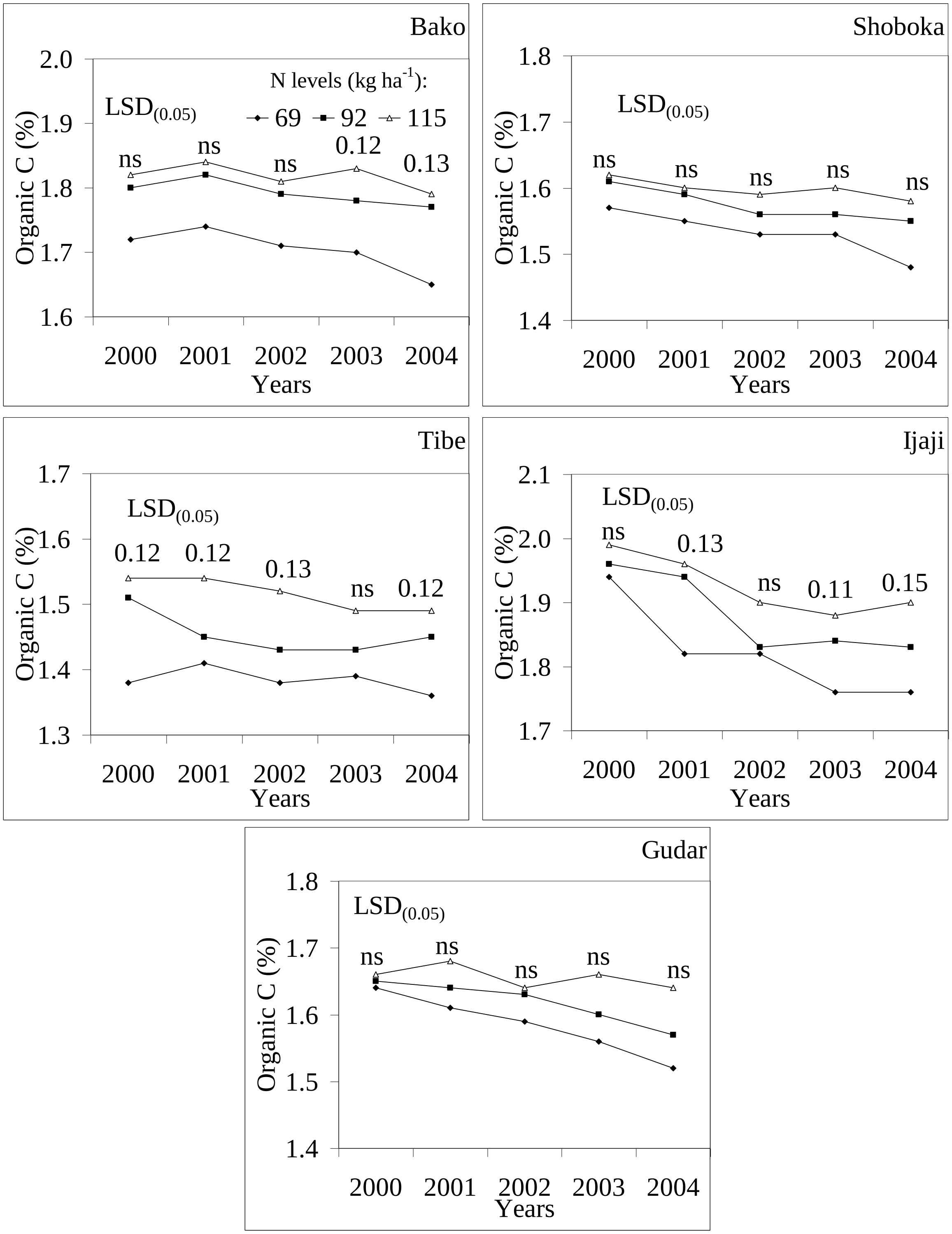

Figure 2. Effect of nitrogen fertilization on organic C measured after harvesting in the 0-30 cm layer of Nitisols at the five experimental sites in 2000 to 2004.

shows a declining trend from 2000 to 2004. Thus, maintenance of organic matter content could be in question over the long-term.

Inspection of Figures 7 and 8 show that the differences of total N in the 0 to 30 cm layer which resulted from tillage system and N fertilization are mainly attributable to

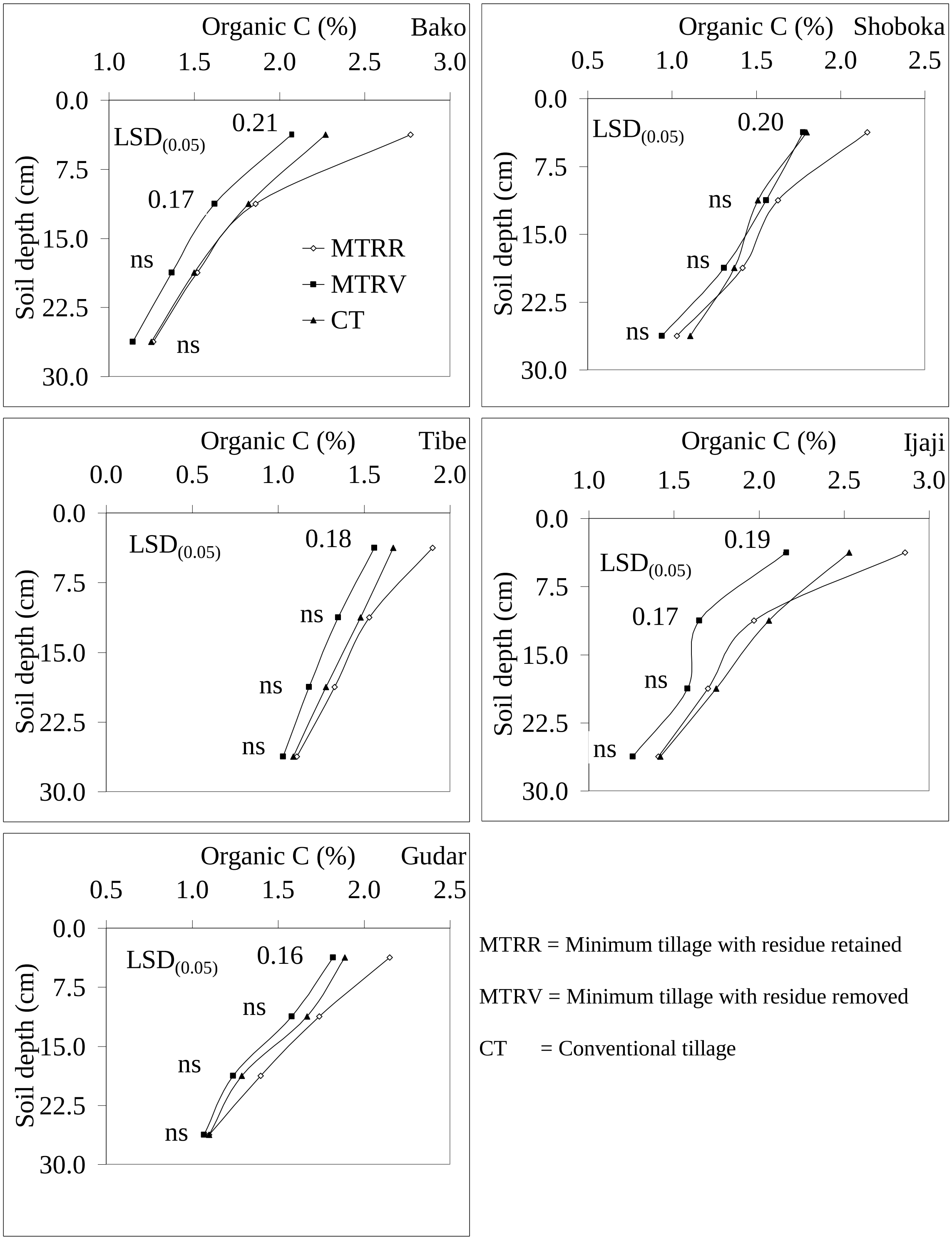

Figure 3. Effect of tillage system on organic C measured after harvesting in the 0-7.5 cm, 7.5-15 cm, 15-22.5 cm and 22.5-30 cm layers of Nitisols at the five experimental sites in 2004.

changes in the 0 to 7.5 cm layer. At all sites the lowest total N recorded in this layer was observed in MTRV, followed by CT and then MTRR. Total N increased also with higher rates of N application though only significant at Bako and Ijaji.

After 5 consecutive years of application, the three

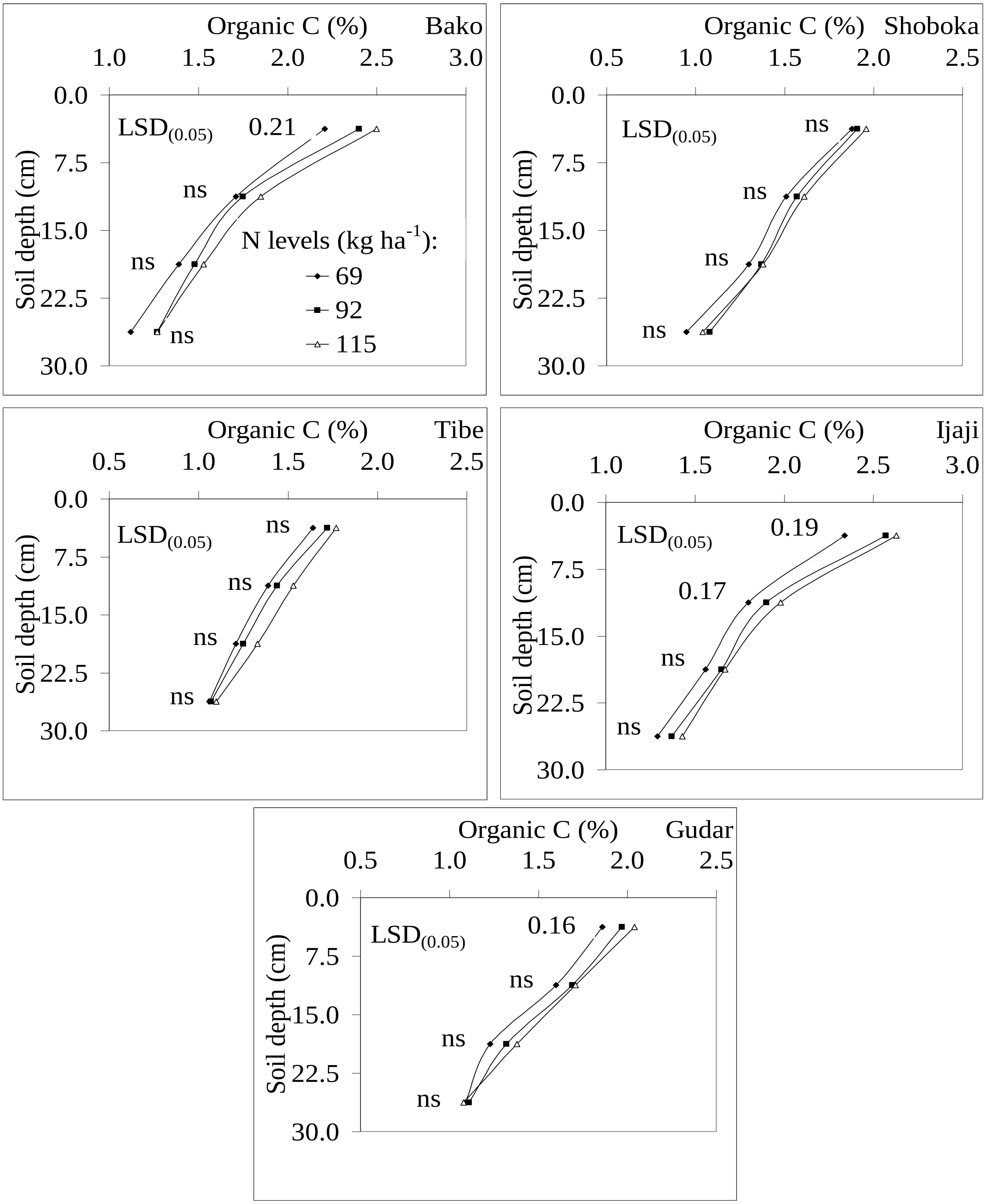

Figure 4. Effect of nitrogen fertilization on organic C measured after harvesting in the 0-7.5 cm, 7.5-15 cm, 15-22.5 cm and 22.5-30 cm layers of Nitisols at the five experimental sites in 2004.

tillage systems resulted in large changes of total N in the upper 7.5 cm layer of the Nitisols. The average total N in this layer for all sites was 20 and 29% higher with MTRR than with CT and MTRV, respectively. Similar results were reported by various other researchers (Tripplet and Van Doren, 1969; Phillips and Young, 1973; Lal, 1976; Blevins et al., 1983; White, 1990; Bakht et al., 2009). The fate of total N was therefore almost similar to that of organic C for the same reasons given earlier. This phenomenon is supported by the C/N ratios (Data not

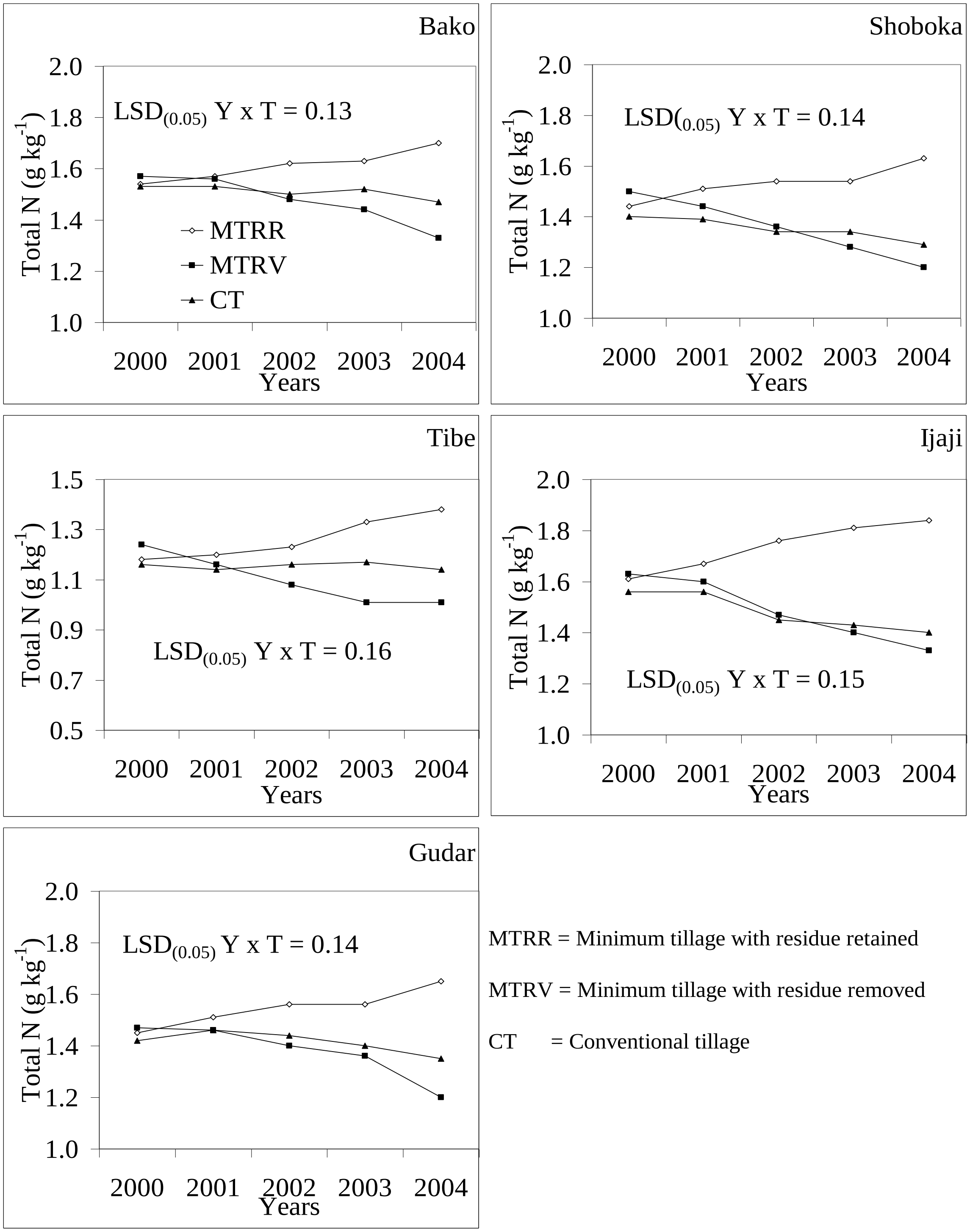

Figure 5. Effect of tillage system on total N measured after harvesting in the 0-30 cm layer of Nitisols at the five experimental sites in 2000 to 2004. Y = year and T = tillage system.

shown) that indicated no significant differences between the treatments. Thus, either organic C or total N can be used as an index to monitor the change of organic matter content in the Nitisols.

The replacement of CT with MTRR could be considered therefore to increase the organic matter content of degraded Nitisols in Western Ethiopia on the condition that the change in tillage system coincide with at least the

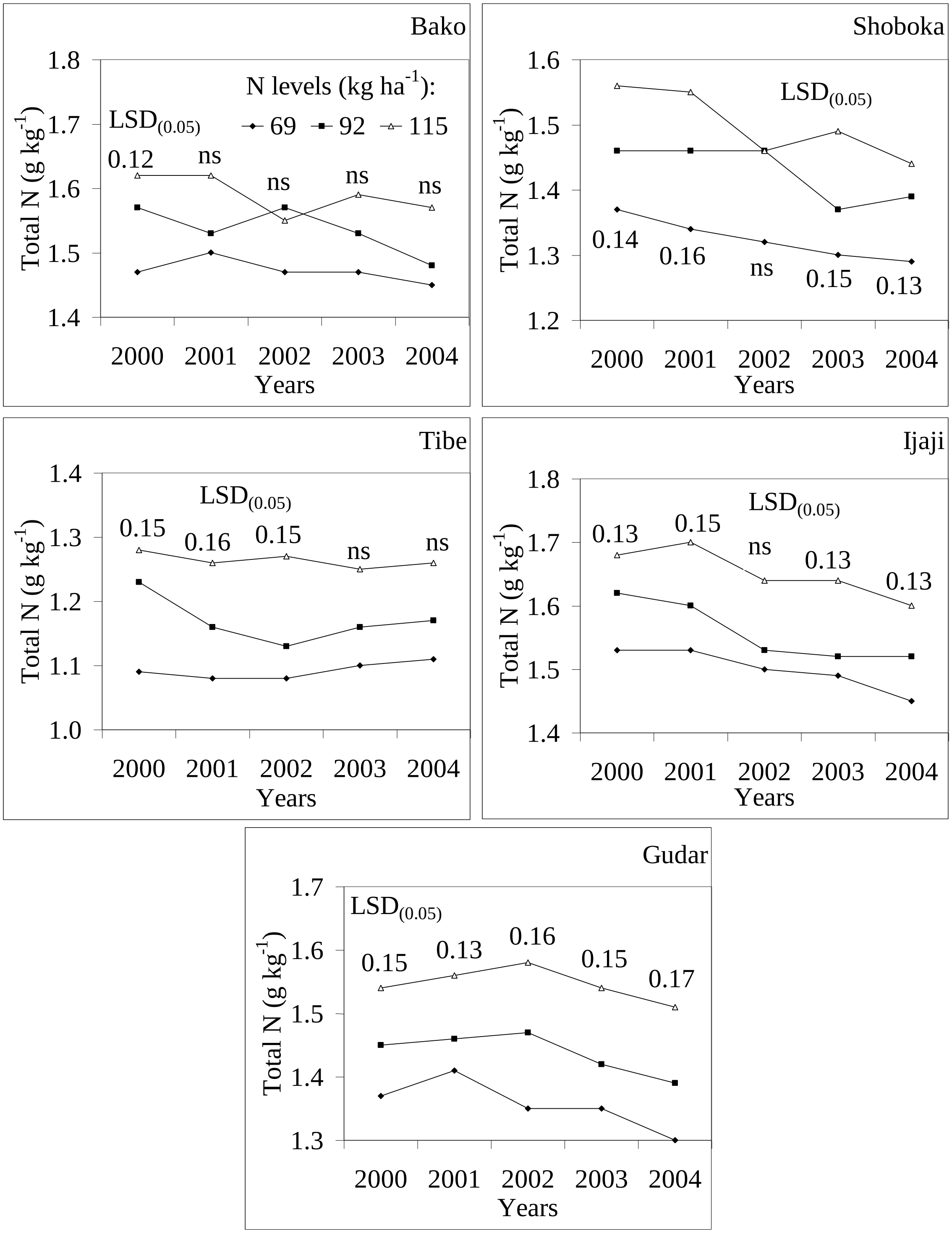

Figure 6. Effect of nitrogen fertilization on total N measured after harvesting in the 0-30 cm layer of Nitisols at the five experimental sites in 2000 to 2004.

recommended N fertilization rate of 92 kg ha^{-1}. An increase of organic matter in these degraded soils should improve their quality tremendously because Weil and Magdoff (2004) stated that organic matter influences the properties of mineral soils disproportionately to the quantity of organic matter present. Soil of good quality has according to Doran and Parkin (1994) the capacity to sustain biological productivity, maintain environmental

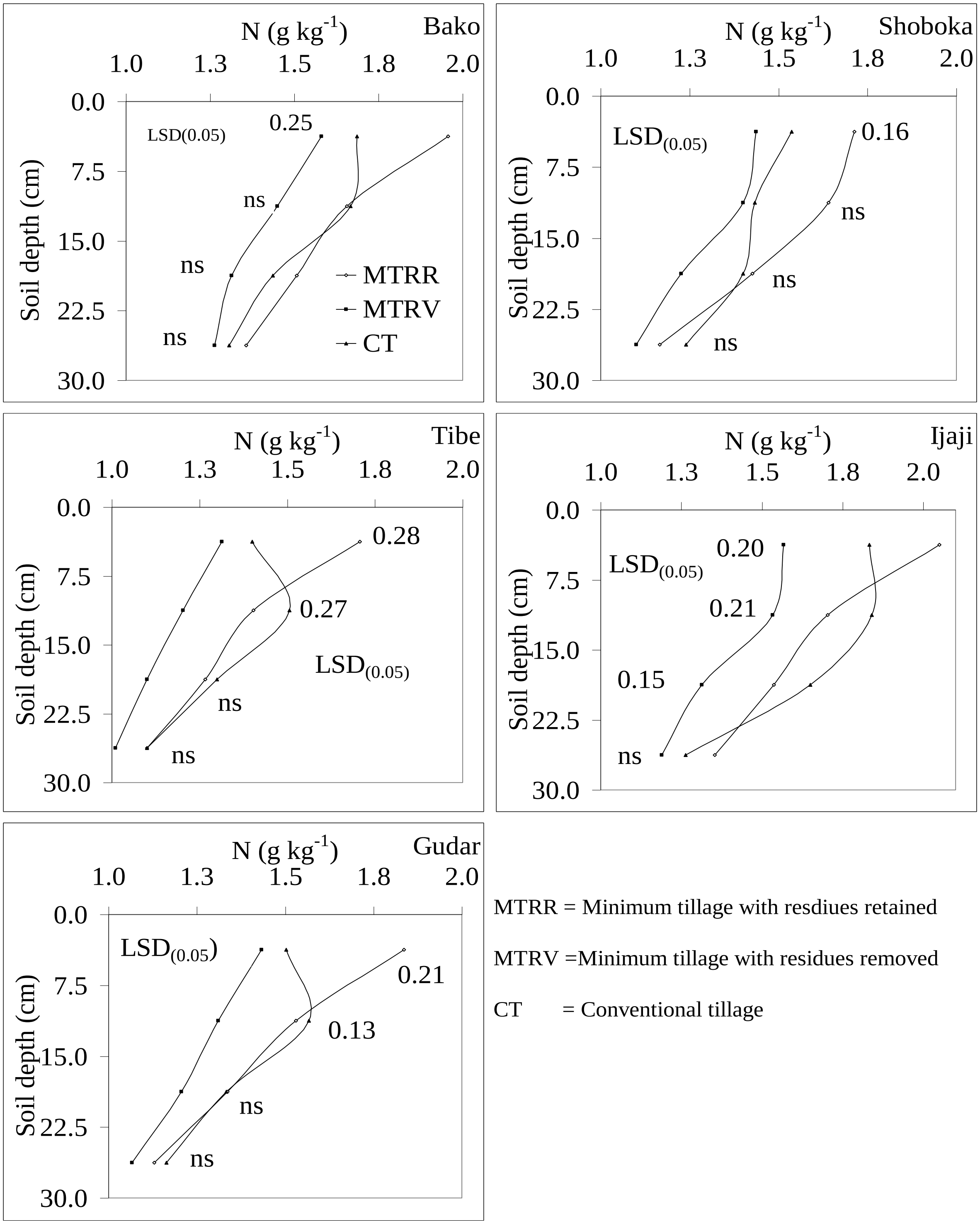

Figure 7. Effect of tillage system on total N measured after harvesting in the 0 to 7.5 cm, 7.5 to 15 cm, 15 to 22.5 cm and 22.5 to 30 cm layers of Nitisols at the five experimental sites in 2004.

quality and promote plant, animal and human health which is essential for enhancing the sustainability of the rural community in the region.

The initiation phase of MTRR when additional N fertilization is usually needed seems favourably short based on recorded grain yield (Tolessa et al., 2007) and fertilization efficacy (Tolessa et al., 2009) over the 5 years trial period. During the final 2 years there was no

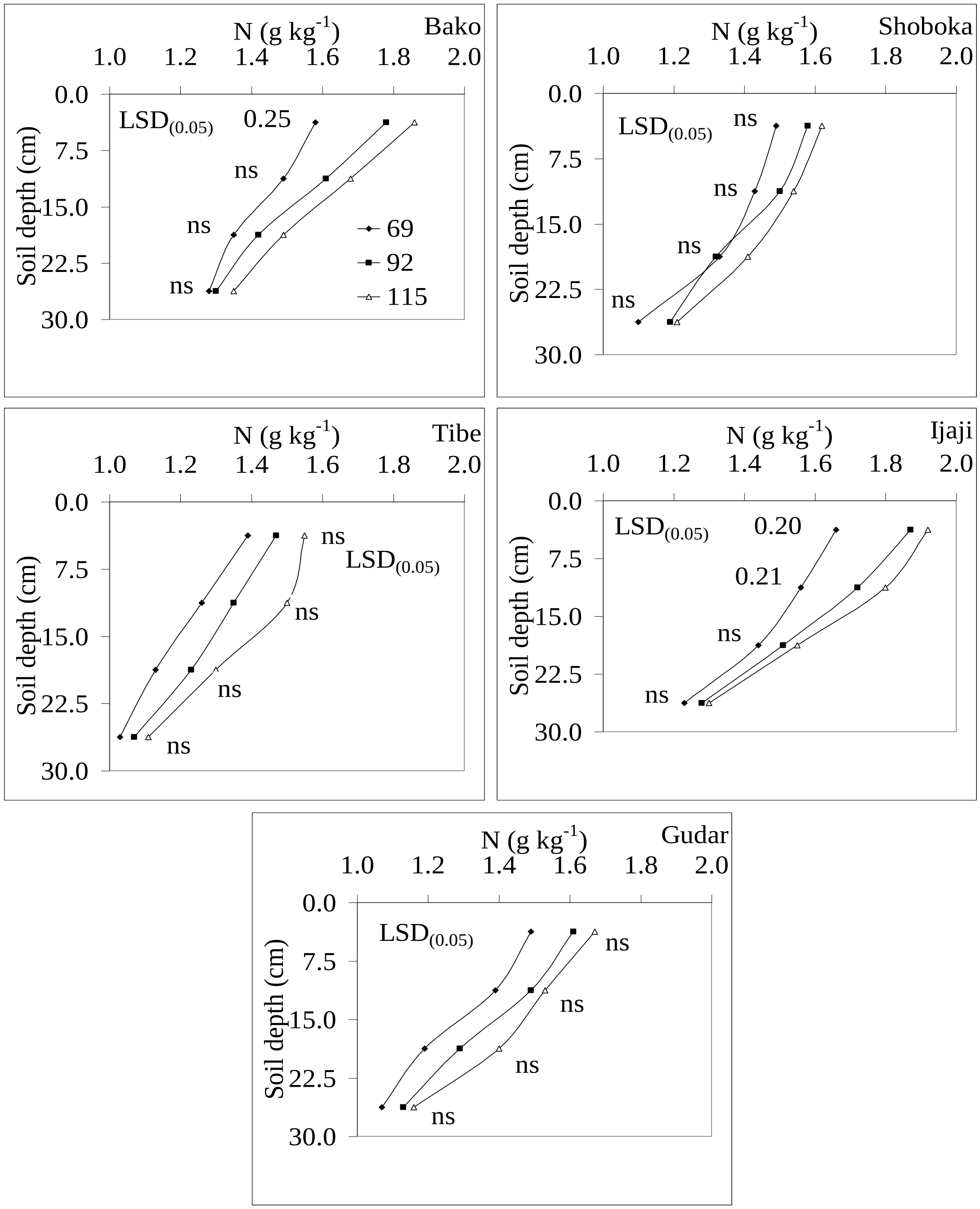

Figure 8. Effect of nitrogen fertilization on total N measured after harvesting in the 0 to 7.5 cm, 7.5 to 15 cm, 15 to 22.5 cm and 22.5 to 30 cm layers of Nitisols at the five experimental sites in 2004.

significant difference in grain yield between MTRV and CT and both were significantly inferior to MTRR (Table 3). The agronomic and recovery efficient use of applied N were also higher with MTRR than with either MTRV or CT. In 2004, MTRR, MTRV and CT had an agronomic efficiency of 16.0, 11.8 and 9.4 kg grain kg N applied^{-1} and a recovery efficiency of 47.7, 34.8 and 33.2%,respectively.

The replacement of CT with MTRV is not an option at all if the aim is to increase organic matter in the degraded Nitisols of Western Ethiopia. This is because MTRV exhausted the organic matter of these soils even more than CT, probably due to the removal of the crop residues.

We believe that the findings of this study could be extrapolated to the remaining highland regions of

Table 3. Effect of tillage system [minimum tillage with residue retention (MTRR), minimum tillage with residue removal (MTRV) and conventional tillage (CT)] on mean maize grain yield of the five sites for each year.

Tillage system	Grain yield (kg ha^{-1})				
	2000	2001	2002	2003	2004
MTRR	7538^{a}	6249^{a}	6307^{a}	5898^{a}	6374^{a}
MTRV	7499^{a}	6545^{a}	5787^{ab}	4955^{b}	5577^{b}
CT	6724^{b}	5832^{b}	5410^{b}	5125^{b}	5752^{b}

Means within a column followed by the same letter(s) are not significantly different at p = 0.05.

Ethiopia as well as those of other African countries like Cameroon, Congo and Kenya. In these countries, cropping on Nitisols is common, notably at altitudes of more than 1200 m above sea level. The estimated area of Nitisols in the highlands of Africa is 100 million ha.

Conclusions

Tillage systems and concomitant crop residue management significantly affected organic C and total N. This change in organic C and total N was confined to the upper 0 to 7.5 cm layer. Both organic C and total N increased steadily over the trial period with MTRR and decreased with MTRV, and that of CT was intermediate to MTRR and MTRV. Higher contents of organic C and total N were recorded with higher fertilizer N applications irrespective of tillage system. There was however over time a steady (115 kg ha^{-1} N level) to decreasing (69 and 92 kg N levels) trend in organic C and total N. Based on these results CT can be replaced with MTRR and in addition proper fertilization, especially N is of utmost importance to improve soil quality and secure sustainable crop production in Western Ethiopia. These findings may be applicable also to the remaining highland regions of Ethiopia as well as those of other African countries where cropping on Nitisols is common

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

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