THE CORRELATION BETWEEN PRODUCTIVITY AND CROPPING SYSTEMS IN WEST AFRICA : THE CASE OF THE PENSA HYDRO-AGRICULTURAL PERIMETER IN BURKINA FASO

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Submission date: 26-May-2025 11:55AM (UTC+0700)
Submission ID: 2664978995
File name: IJAR-51820.doc (1.26M)
Word count: 9534
Character count: 48925

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Abstract

The drought of the 1970 s led to a proliferation of hydro-agricultural schemes in West African countries to combat water stress. Burkina Faso is no exception. This study is based on the econometric method, using the cross-sectional hypothesis that there is a correlation between cropping systems and productivity in the Pensa hydro-agricultural perimeter. Its aim is to analyse the correlation between cropping systems in the developed perimeter and productivity in the rural commune of Pensa. Carried out in the rural commune of Pensa, the surveys collected quantitative and qualitative information from 188 people (182 producers and 6 resource persons). The data collected were processed using a logit model. The research results indicate that monoculture and polyculture are the two cropping systems developed in the Pensa hydro-agricultural perimeter. The waiting period for the use of phytosanitary products is 5,25 days for monoculture, compared with a waiting period of 5.35 days for polyculture. The farm accounts show that growing Vigna unguiculata (cowpea) is more profitable in the monoculture system (675,9 F CFA/kg). In the mixed cropping system, the production of Allium cepa L (onion) is more profitable (525 F CFA/kg). The coefficient of determination between cropping systems and productivity was 0,8106.

Key words : Correlation, Cropping systems, Econometric method, Pensa, Burkina Faso

Introduction

In the South, farmers have developed crop systems based on the use of agricultural inputs to control biotic and abiotic factors. And on the other hand, cropping systems based on animal and plant species for greater productivity. The development of these specialized cropping systems has led to environmental damage. This orchestrated the implementation of strategies such as optimized input efficiency, planned biodiversity management, and the use of synthetic fertilizers (G Plumecoq and *al*, 2018, p.105). European agrarian systems have undergone profound transformations since the Middle Ages. First, the predation system was initiated. Then, the systems of slash-and-burn cultivation and pastoral systems that have been practiced since Neolithic times. Then there are fallow systems and ploughing, characterized by a transition to new cropping systems. In addition, ploughing, which is characterized by a transition to new cropping systems, and the associativity of agriculture and livestock farming, which is the combination of conditions favorable to both activities. Finally, the first and second phases of the agricultural revolution. These were the strong points in the evolution of European agrarian systems (M Mazoyer, 1977, p.273). The cropping system is a concept that has undergone several metamorphoses since its origin. It was conceived during the emergence of agronomy, more precisely at the end of the 18th century and the beginning of the 19th century. It is based on several aspects : perfect knowledge of agricultural practices in order to make a judgement on the use of natural resources ; the conceptualisation of cultivation methods based on new theoretical knowledge (F Papy, 2008, p.268). Thus, from a global point of view, the notion of cropping system has recently been associated with other concepts such as productivity, intensification of dominant models, etc. This constitutes a problem for the performance of cropping systems. This poses a problem for the performance of production systems. Hence the need to clarify its meaning and take advantage of the productivity of production factors and levels of intensification (J Brossier and *al*, 1997, p.8). In these cropping systems, techniques and practices are used to increase crop yields and control pests. In France, plant protection products are used to control plant pests. In 2004, it ranked 3rd in terms of the quantity of substances sold on the world market for plant protection products, and first in Europe. 90 % of plant protection products are intended for agricultural use. It is the biggest consumer of pesticides in the EU-15 (N Pingault and *al*, 2009, p.63). In Belgium, raising producers' awareness of the use of plant protection products has reduced its use to less than a year. The quantity of plant protection products carried by water has fallen considerably for isoproturon (-7,1 kg), lenacil (-1,8 kg) and diuron (-10 kg). This reduction was small for chloridazon. Atrazine, on the other hand, showed an increase (+0,9 kg). These reduction trends are attested by the evolution of the ratio established between the total quantity of water applied and that found in the watercourse (S Beernaert and *al*, 2001, p.139). In Burkina Faso, and particularly in the hydro-agricultural perimeter of the urban commune of Kaya, farmers use chemical (72,22 %) and organic (27,78 %) products. These products are supplied on the local market. These plant protection products are used without any protective measures. This can damage human health and the environment (P. I Yanogo and *al*, 2024, p.278). Similarly, in the rural commune of Pensa, farmers also use plant protection products to ensure good agricultural yields. Estimates of their use show that 2 % of farmers use organic fertiliser, 28 % use organic and chemical fertiliser, and 70 % use chemical fertiliser alone. This is a very high rate, and it has a negative impact on aquifers through infiltration and surface water through run-off (W. O Nikièma and *al*, 2022, p.318). It is also clear that the agricultural sector plays a key role in Burkina Faso's national economy, contributing 30 % of the country's Gross Domestic Product (GDP). What's more, almost 86 % of the population are farmers, and 60 %

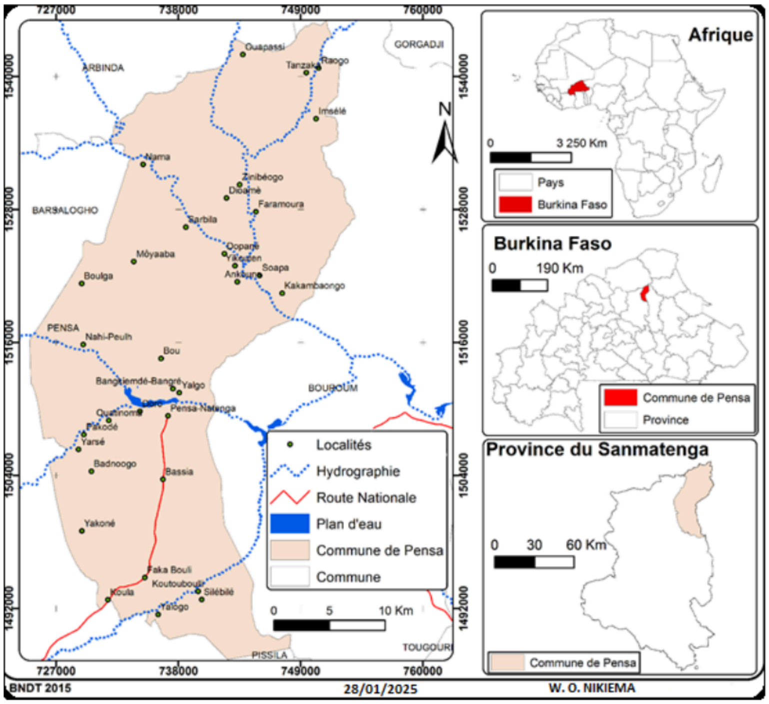
of the cash income of rural households comes from farming (J. M Dipama, 2016, p.11). In the Bagré area, the average income of a fisherman is estimated at 883.628 CFA francs. The cost of renewing equipment is between 4.000 CFA francs and 35.000 CFA francs per year. The annual fee is 7.000 CFA francs per player per month, and the average cost of equipment is around 7.555 CFA francs. Farmers' incomes depend on the agricultural season (P. I Yanogo, 2012, p.224). All the activities developed around hydro-agricultural schemes generate cash income. This cash income is invested in social areas such as health, education, construction, repayment of agricultural loans, etc. (L Ouédraogo, 2012, p.140 ; S Sanogo, 2019 ; W. O Nikièma, 2020, p.96). In the Centre-Nord region, and more specifically in the province of Sanmatnega, the construction of hydraulic structures is used by local people as a pillar of economic development. The rural commune of Pensa in the said province has benefited. Around this hydro-agricultural development, farmers are practising cropping systems to make their productivity more profitable. This raises the following question : how do the cropping systems developed around the Pensa hydro-agricultural scheme influence agricultural productivity ? The aim of this study is to analyse the correlation between cropping systems in the developed perimeter and agricultural productivity in the commune of Pensa. The presentation of the study area, the methodological approach, and the presentation of the results and discussion are the three main points on which this article is based.

1. Methodology

1.1. Presentation of the study area

Pensa is a rural commune located in the province of Sanmatenga, more precisely in the north-eastern part, 90 km from the town of Kaya and 45 km from the commune of Barsalogho. This province is located in the Centre-Nord region. The commune was established as the administrative departmental capital in 1966. It only became operational in 1984. Fifteen (15) villages are attached to the rural commune of Pensa. According to data from the General Population and Housing Census (INSD, 2022), the population is estimated at 52.480 (24.367 men and 28.113 women). The overall population growth rate is 3,2 % per year on average. The geographical coordinates of the study area correspond to 13º 50‘ north latitude and 0º 50’ west longitude. The municipality covers an area of 944,1879 km^2. Geographically, it is bordered to the north by the rural communes of Gorgadji, Tongomyel and Abinda (Sahel region). Pensa is bordered in the south by the rural commune of Pissila. In the eastern part, the commune is bordered by two rural communes (Bouroum and Nabingou). To the west, the rural commune of Pensa borders the rural commune of Barsalogho.

Map1 : Geographical location of the study area



1.2. Sampling procedures

The commune of Pensa was chosen on the basis of its socio-economic and geographical characteristics. Sampling took into account the commune of Pensa where the dam is located and four (04) villages that gravitate around it. These were Bangkiemdé-Bangre, Bou, Doro and Nahi. The people surveyed were chosen on a reasoned basis. Criteria such as the age range (15 years and 60 years and over) and the number of years of experience (at least 3 years) of the producers were taken into account.

1.3. Data collection

Primary and secondary data were collected. Several resources were mobilised to collect this data. The literature review was carried out using scientific documents such as books, dissertations, scientific articles and reports related to the theme of this study. The primary data were collected. For secondary data, interview guides were designed to collect information from producers and resource persons. The Kobo Toolbox software was used for data collection. Pseudonyms were used in order to preserve the anonymity of the people surveyed. Direct observation in the field enabled an understanding of the agricultural practices developed in the hydro-agricultural perimeter.

1.4. The data analysis method

The methodological approach is the basic one on which this research study was based. XLSTAT, 2024 and ArcGis 10.2 software were used for statistical production and mapping. The data collected was analysed using the econometric method. The aim of this method is firstly to compare theoretical explanations with a set of data, which may be temporal, cross-sectional (survey data), etc. Secondly, to quantify the results of the analysis. The second is to quantify the relationships between economic quantities whose existence has been confirmed by theory or experience. In other words, the method makes it possible to determine the direction and intensity of the links between variables. Finally, it can be used to construct forecasting or analytical models to aid decision-making. Two models are based on this method : the simple regression model and the linear regression model (F Carlevaro, 1994, p.7).

1.5. Presentation of the econometric model

This econometric model is used to highlight forecasts or analyses that help decision-making. There are four (04) main phases in econometric modelling, as shown in the diagram below :

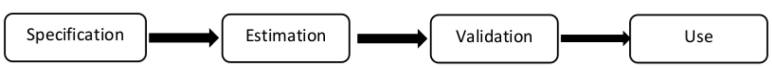


Figure 1 : Diagram showing econometric modelling

There are two main regression models. The simple regression model is identified with a single explanatory variable, x_i. It is written as follows : $y_t = a_1 X_1 + a_0 + \varepsilon_t$ avec t = 1,2,…, T. The multiple regression model is a generalisation of the simple regression model. It has several explanatory variables. It has k explanatory variables and is written as follows : $y_t = a_0 + a_1 X_{1t} + a_2 X_{2t} + \ldots + a_{k-1} X_{(k-1)t} + \varepsilon_t$. The Ordinary Least Squares (OLS) method is used to estimate the vector of coefficients. This consists of always minimising the sum of the squares of the residuals. Hence the following formula : Min $\sum_{t=1}^{T} e_t^2$ = min e'e =

min (Y- Xâ)'(Y- Xâ) = min S where e' is the transpose of the vector e and S denotes the minimum function (H Hamisultante, 2002, p.10). In short, the econometric method is a modelling approach that authors such as R Bourbonnais, 2021 ; J Mairesse and *al*, 2018 ; P Givord, 2014 ; C Despres and *al*, 2011 ; A Trognon, 2003 ; M Armatte, 2001 ; E Malinvaud, 1997 and F Bonnieux, 1983 have used in their research. At best, other types of parameters have been used : the production function and the probabilistic approach.

1.5.1. The production function

This function is based on the quantity of speculation produced in kilograms and the quantity of inputs used. This gives the following formula : $Q = F(K ; L) = L^{\alpha} K_1^{\beta 1} K_2^{\beta 2} \ldots K_n^{\beta n}$

K is the vector made up of all factors other than labour ;

L is labour ;

α and β are the productivity parameters with respect to the various factors.

In addition to these physical factors, this model includes a dummy variable that takes into account the type of farm. Thus, the productivity obtained by the yield at 0.25 hectare is dependent on the quality of work and the use of phytosanitary products. This led to the following formula : $Yield = \alpha_0 + \alpha_1 fertilizer + \alpha_2 herbicide + \alpha_3 age + \alpha_4 age^2 + \beta type + \varepsilon$

ε is the error of the hypothesis being tested. The sign of the variable is necessarily taken into account.

1.5.2. The probabilistic approach

In this approach, the social status of the producers is taken into account, knowing their productivity capacity, the size of the farm plots and their age. In other words, it is a question of determining the probability of a producer owning farm plots and practising mixed farming. This is a binary variability that is equal to 1 if the farmer owns the farm plots and practises mixed farming, and 0 otherwise.

$$Type = \begin{cases} 1 \text{ if the producer is a holder and pratises mixed farming} \\ 0 \text{ otherwise} \end{cases}$$

The probability of holding and practising mixed farming is between 0 and 1 and is expressed by $prob\ (type = 1) = p$. The aim here is to detect the link between this probability and the other variables in the model, i.e. productivity, the size of the farm plots and the age of the producers. Hence : $p = F(X\beta)$ with X the vector of explanatory variables.

$F(X\beta)$ is the distribution function defined on an interval [0 ; 1]. To better transpose the function $F(X\beta)$, probability distributions can be used. These are the exponential law, the normal law, the logistic law and the gamma law. The logistic law is applied in view of the complexity of the dependent variables. This has made it possible to redefine the dependent variability :

$$Type = \begin{cases} 1 \text{ with the probability } \Lambda(X\beta) \\ 0 \text{ with the probability } 1 - \Lambda(X\beta) \end{cases} \text{ with } \Lambda(X\beta) = \frac{e^{x\beta}}{1+e^{x\beta}} = \frac{1}{1+e^{-x\beta}}$$

This gives a Bernouilli distribution whose density function is expressed by :

$$f(type) = [\Lambda(X\beta)]^{type}[1 - \Lambda(X\beta)]^{(1-type)}$$

The maximum likelihood function is given by :

$$L(\beta) = \prod_{i=1}^{n}[\Lambda(X\beta)]^{type\ i}[1 - \Lambda(X\beta)]^{(1-type\ i)}$$

$$L(\beta) = \prod_{i=1}^{n1}[\Lambda(X\beta)]^{type\ i} \text{ if } type = 1$$

$$L(\beta) = \prod_{i=1}^{n2}[\Lambda(X\beta)]^{type\ i} \text{ if } type = 0$$

By applying the logarithm function, the following expression is obtained :

$$\ln L(\beta) = \sum_{i=1}^{n1} type\ i \ln[\Lambda(X\beta)] + \sum_{i=2}^{n2}(1 - type)\ln[1 - \Lambda(X\beta)]$$

By deriving the logarithm function partially as a function of β, this is equivalent to :

$$\frac{\partial \ln L(\beta)}{\beta} = \sum_{type=1} \frac{\lambda(X\beta)}{\Lambda(X\beta)} X + \sum_{type=2} \frac{-\lambda(X\beta)}{[1-\Lambda(X\beta)]} X = 0 \text{ with } \lambda(X\beta) = \frac{e^{x\beta}}{(1+e^{x\beta})^2}$$

The density function of the logistic law ($\lambda(X\beta) = \Lambda'(X\beta)$) ; n_1 and n_2 are respectively the numbers of producers who own plots of land and practise mixed farming and producers who do not own plots of land and practise mixed farming.

The choice of this model is justified by the fact that in the implementation of activities in the hydro-agricultural perimeter, producers use endogenous knowledge to make their productivity profitable. This model was also used by (M B Sangaré and *al*. 2020, p.113) in a study on land tenure and productivity in Mali. According to the authors, « in practice, interpretation of the parameters associated with the explanatory variables in this model is easier than in other models. Similarly, this model is an approximation of the probit model, i.e. the reduced centred normal distribution ».

1.6. Description of variables

As far as the variables are concerned, it is a question of deciding on the cropping systems, the plant protection products and the productivity of these cropping systems. The cropping systems developed are polyculture (practised during the dry period) and monoculture (practised during the wet period). The use of phytosanitary products is identified with the use of organic fertiliser and chemical fertiliser. And the productivity of cropping systems affects agricultural yields. Letters were assigned to the choice of variables : Y : designates the endogenous variable ; X : designates the exogenous variable ; S : minimal function. To better explain the dependent variable (qualitative ordinal variable), this study recommended the use of ordinal logistic regression. The independent variable, which is both quantitative and qualitative, also used this same regression.

Independent variables : these take into account variables such as hydro-agricultural product typologies, product marketing, dam water and socio-economic variables.

Dependent variables : the objective here is to gain a better understanding of the determinants of the use of phytosanitary products in the Pensa hydro-agricultural perimeter. It was established according to the standards of the Libert scale : usually, often, rarely, never (Table 1).

Table 1 : Variabilities selected for the ordinal regression model

Variables	Type	Description
Age	Category	15-30
		31-40
		41-50
		51-60
		61-60
Gender	Sex	Male
		Female
Level of education		Educated
		No-educated
household level	Category	1-5
		5-10
		10-15
Income level	Category	≥ 200 000/year
		≥ 500 000/year
		≥ 800 000/year
		≥ 1 million/year
Level of equipment	Equipment	Low
		High
Climatic variable	Climate	Extreme rain

		Extreme temperature
Surface area of plots	Operating plots	0,25 ha
		0,50 ha
		0,75 ha
		1 ha
Type of marchet	Marketing	Local business
		Trade oriented towards the city
Purposes of the products used	Consumable	Products for local consumption
		Products for urban consumption

Source : Survey data, 2021

2. Results

2.1. Characterisation of producers in the Pensa hydro-agricultural scheme

In the Pensa hydro-agricultural scheme, monoculture is more developed during the winter period (85,95 % of the monoculture system compared with 14, 05% of the polyculture system). The monoculture system can be identified by the fact that only *Zea mays* (maize) or *Vigna unguiculata* (cowpea) is grown on the farm plots, either *Oryza sativa* (rice) or *Abelmoschus esculentus* (okra). However, during the dry season, mixed farming is the dominant crop on the farm plots (100 % of producers). Examples of these systems include system 1 : tomato-cabbage-onion, system 2 : chilli-pepper-eggplant, system 3 : tomato-onion-lettuce, and system 4 : sorrel-cucumber-tomato. One of the particular features of the hydro-agricultural perimeter of the rural commune of Pensa is that the number of women producers is numerically lower than the number of men producers (11,17 % of women producers compared with 88,83 % of men producers). The age range of the producers surveyed is between 15 and 60 and over. The households surveyed numbered between 7 and 15 people (Table 2).

Table 2 : Characteristics of producers in the Pensa hydro-agricultural scheme

	Pensa (N=188)	
	Number	Percentage
Age (years)		
15-30	36	19,15
31-40	45	23,94

41-50	79	42,02
51-60	18	9,57
61 and over	10	5,32
Level of education		
No educated	106	56,38
Primary	74	39,36
Secondary	8	4,26
University	0	0,00
Sex		
Male	101	53,72
Female	87	46,28
Marital status		
Single	32	17,02
Married	156	82,98
Widowide	0	0,00
Ain activity		
Yes	178	94,68
No	10	5,32
Experience		
1-5	96	51,06
5-10	79	42,02
10 and over	13	6,92

Source : Survey data, 2021

2.2. Cropping system typologies

2.2.1. Monoculture developed around the hydro-agricultural perimeter

Monoculture is the cultivation of a single plant species on a farm. This crop is more developed in the rainy season in the rural commune of Pensa. On the left bank, the *Zea mays* cultivation system is the most developed (86 % of growers). On the right bank, it is the *Vigna unguiculata* cultivation system par excellence (100 % of growers). Downstream, *Oryza sativa* is grown by 98% of growers. And upstream of the developed perimeter, 100 % of growers were interested in the *Abelmoschus esculentus* growing system. The predominance of this crop depends on the size of the area under cultivation, climatic conditions, the nature of the soil, local consumption needs and marketing. Rice, maize, cowpeas and okra are the main crops grown during the winter season in the developed area. To achieve this, a range of processes (techniques and resources) are mobilised for the use of the farm plots. The aim is to increase crop yields given the poor soil conditions.

2.2.2. Mixed farming developed around the hydro-agricultural perimeter

Practised during the dry period, polyculture, as its name suggests, consists of growing several plant species on the same farm. It is practised by 100 % of farmers. The age range of those practising polyculture is similar to that of monoculture. Cereal and vegetable crops alternate periodically according to the cropping calendar. Sowing generally begins in September-October for market garden crops. It is also done according to the production period for each product (around 90 days for market garden produce). In the Pensa study area, 37,5 % of growers (33 growers) practise rotation or sequence cropping. This means that just after the market garden crops have been harvested, growers turn to cereal crops (especially maize). Multiple cropping is made up of several crops. They are practised by 52 farmers (59,09 % of farmers). As a reminder, four cropping systems were reported in the commune of Pensa. These are system 1 : tomato-cabbage-onion, system 2 : chilli-pepper-eggplant, system 3 : tomato-onion-lettuce, and system 4 : sorrel-cucumber-tomato. In this polyculture panoply, equipment remains scarce. Human power is used to a greater extent than machines and ploughs. Phytosanitary products are also used. The equipment used is similar to that used in monoculture.

2.3. Balance between the level of use of plant protection products in cropping systems and the profitability of cropping systems

2.3.1.1. Use of plant protection products in monoculture (logit model)

In the developed Pensa perimeter, human power remains the real driving force. Farmers (96,27 % of farmers) do not use machinery to plough their plots, let alone the plough. All but a few (3,73 % of farmers) use ploughs for ploughing. Dabas, hoes and picks are the main types of equipment frequently used. This enabled us to identify 100% of farmers who use this equipment for work on developed plots. With a view to making agricultural production more profitable in the monoculture system, growers use phytosanitary products. These include pesticides, herbicides, fungicides, organic fertiliser, chicken droppings and chemical fertilisers (NPK and urea). The use of these products varies from one farmer to another. This was shown using the logit model (Table 3).

Table 3 : Use of plant protection products in the Pensa hydro-agricultural zone (logit model)

		Monoculture cropping systems					
		Corp	Cowpea	Rice	Okra	Set	p-value
Plant protection product frequency indices	Organic manure	08,1	10,11	07,5	04,08	29,79	> 10 %
	Chicken droppings	1,05	0,52	0,71	1,10	3,38	> 10 %
	Pesticide	1,47	2,26	2,51	1,2	7,44	> 10 %
	Herbicide	3,40	2,59	3,12	2,06	11,17	> 10 %
	Fungicide	4,21	3,98	4,09	2,05	14,36	> 10 %
	NPK et urea	7,32	5,06	14,05	4,43	30,86	> 10 %
Pressure index (kg ma/ha)		5,24	6,58	7,05	4,98	23,85	> 10 %
Waiting period (day)		5,1	5,6	5,4	4,9	5,25	> 10 %

Source : Survey data, 2021

A priori analysis of this table shows that chemical fertilisers such as NPK and urea (30,86 %) are used more in crops grown in the Pensa hydro-agricultural perimeter. Organic fertiliser comes second with 29,79 % use. Fungicides are also used, with a percentage of 14,36, in third place. Fungicides are used on farm plots to treat parasitic fungi that attack plants. Herbicides and pesticides are in fourth and fifth place respectively, at 11,17 % and 7,44 %. Herbicides are applied to weeds. Pesticides are used to combat organisms that are harmful to plant development. Chicken droppings come last at 6,38 %. Hen droppings are a fertiliser rich in nitrogen, phosphorus, potassium and calcium. The frequency indices for plant protection products are well above 10 %. With the exception of hen droppings and pesticides, the ratios are 3,38 % and 7,44 % respectively. The average deficiency period was 5,25 days, with a negligible difference at the 10 % threshold.

2.3.1.2. Use of plant protection products in mixed farming (logit model)

In the developed Pensa perimeter, working conditions in the mixed cropping system seem to be similar to those in the monoculture system. The equipment used is the same, the workforce remains human, and the use of plant protection products is no different. But the amount of dosage differs from one system to another (Table 4).

Table 4 : Use of plant protection products in the Pensa hydro-agricultural perimeter (logit model)

		Polyculture cropping systems					
		Systm1	Systm2	Systm3	Systm3	Set	p-value
Plant protection product frequency indices	Organic manure	10,01	07,21	04,42	02,75	24,39	> 10 %
	Chicken droppings	03,15	04,22	02,72	04,65	11,38	> 10 %
	Pesticide	04,74	03,53	02,77	02,10	13,14	> 10 %
	Herbicide	07,22	04,76	05,16	03,23	20,37	> 10 %
	Fungicide	08,40	07,54	06,10	03,12	25,16	> 10 %
	NPK et urea	08,80	10,66	16,21	07,30	42,97	> 10 %
Pressure index (kg ma/ha)		12,24	10,08	06,05	04,18	32,55	> 10 %
Waiting period (day)		4,9	4,7	5,9	5,9	5,35	> 10 %

Source : Survey data, 2021

This table shows the use of plant protection products according to the different polyculture systems. As in the monoculture system, NPK and urea are used more in the polyculture system (42,97 %). The second most used chemical is fungicide (25,16 %). Organic fertiliser is used in third place (24,39 %). The last three positions are occupied respectively by herbicides, pesticides and hen droppings (20,37 %, 13.14% and 11,38 % respectively). All the frequency indices for plant protection products used have a ratio well above the plus-value (10 %). This means that the use of plant protection products in mixed crop production is in surplus. The average waiting period is 5,35 days, with a negligible difference at the 10 % threshold.

2.3.2. Profitability of cropping systems

In order to quantify the estimates of the various productions according to the cropping system practised in the Pensa hydro-agricultural perimeter, data processing was based on statistical series and the determination and properties of estimators. This made it possible to draw up farm accounts for the various crops grown under the different systems.

2.3.2.1. Income from agricultural products in the monoculture system

The monoculture system practised within the Pensa hydro-agricultural perimeter made it possible to draw up an inventory of operating accounts. These accounts were drawn up for 0.25 ha. It took into account the four main types of production, namely maize, rice, cowpea and okra. The results are shown opposite.

Table 5 : Operating account for rice (*Oryza sativa*) production

Différent stages of production	Quantity	Numbre of people/day	Unit cost in F CFA	Total cost in F CFA
Ploughing for 0.25 ha	-	-	-	5 000
Certified seed for sowing	0,75 kg	-	700	520
Sowing in rows	-	5*1	700	3 500
Remarriage	-	5*1	700	3 500
Weeding	-	5*1/2	300	1 500
Treatment of plots with products	-	-	-	5 000
For treatment of plots	-	1*2	2 000	4 000
Harvest	-	10*1	800	8 000
To place the bundle	-	5*1	300	1 500
Shaking and winnowing	-	3*1	500	1 500
To remove impurities	-	1*1	2 000	2 000
Packaging	1 bag	-	400	400
Total production costs	**-**	**-**	**-**	**30 400**

Average production per 0.25 hectare	1 bag	-	-	80 kg
Production cost per bag	**20 kg**	**-**	**-**	**7 600**
Cost of production	1 kg	-	7 600	380
Price per bag	20 kg	-	20 118	20 118
Producer margin per bag	**20 kg**	**-**	**12 518**	**12 518**
Producer margin per kg	**1 kg**	**-**		**625,9**

Source : Survey data, 2021

Paddy rice (*Oryza sativa*) made a profit of 625.9 CFA francs/kg, giving a profit of 625.900 CFA francs/tonne of rice sold.

In addition to rice, the operating account for maize was also produced. The results are shown in the table below.

Table 6 : Operating account for maize (*Zea mays*) production

Différent stages of production	Quantity	Numbre of people/day	Unit cost in F CFA	Total cost in F CFA
Ploughing for 0.25 ha	-	-	-	5 000
Certified seed for sowing	0,75 kg	-	2 025	6 075
Sowing in rows	-	5*1	900	3 500
Remarriage	-	5*1	900	3 500
Weeding	-	5*1/2	350	1 500
Treatment of plots with products	-	-	-	5 000
For treatment of plots	-	1*2	1 000	4 000
Harvest	-	5*1	900	8 000
To place the bundle	-	5*1	300	1 500
Shaking and winnowing	-	2*1	900	1 500
To remove impurities	-	1*1	1 500	2 000
Packaging	1 bag	-	300	400
Total production costs	**-**	**-**	**-**	**30 400**
Average production per 0.25 hectare	1 bag	-	-	80 kg
Production cost per bag	**20 kg**	**-**	**9 600**	**9 600**

Cost of production	1 kg	-	480	480
Price per bag	20 kg	-	16 500	16 500
Producer margin per bag	**20 kg**	**-**	**6 900**	**6 900**
Producer margin per kg	**1 kg**	**-**		**345**

Source : Survey data, 2021

The operating account for maize production showed that producers made a profit of 345 CFA francs on 1 kg of maize sold. This means a profit of 345,000 CFA francs per tonne of maize sold.

The cowpea operating account was also taken into account in this study. The results are shown in the table below.

Table 7 : Operating account for cowpea (*Vigna unguiculata*) production

Différent stages of production	**Quantity**	**Numbre of people/day**	**Unit cost in F CFA**	**Total cost in F CFA**
Ploughing for 0.25 ha	-	-	-	5 000
Certified seed for sowing	0,75 kg	-	700	520
Sowing in rows	-	5*1	700	3 500
Remarriage	-	5*1	700	3 500
Weeding	-	5*1/2	300	1 500
Treatment of plots with products	-	-	-	5 000
For treatment of plots	-	1*2	2 000	4 000
Harvest	-	10*1	800	8 000
To place the bundle	-	5*1	300	1 500
Shaking and winnowing	-	3*1	500	1 500
To remove impurities	-	1*1	2 000	2 000
Packaging	1 bag	-	400	400
Total production costs	**-**	**-**	**-**	**30 400**
Average production per 0.25 hectare	1 bag	-	-	80 kg
Production cost per bag	**20 kg**	**-**	**7 600**	**8 600**
Cost of production	1 kg	-	430	430
Price per bag	20 kg	-	22 118	22 118

Producer margin per bag	**20 kg**	**-**	**13 518**	**13 518**
Producer margin per kg	**1 kg**	**-**		**675,9**

Source : Survey data, 2021

This table shows that cowpea production generates a profit of 675.9 F CFA/kg. That's 675.900 CFA francs per tonne of cowpea sold. What about the operating account for okra production ?

The operating account for okra has a special feature. The plots are rented. The average cost per crop year is 15.000 CFA francs.

Table 8 : Operating account for okra (*Abelmoschus esculentus*) production

Différent stages of production	**Quantity**	**Numbre of people/day**	**Unit cost in F CFA**	**Total cost in F CFA**
Equipments				
Land (rental) 0.25 ha				15 000
Machetes	2	-	2 000	4 000
Dabas	5	-	1 500	7 500
Pickaxes	5	-	1 500	7 500
Liquid fertiliser equipment	1	-	15 000	15 000
Metal sprayer	1	-	7 500	7 500
Inputs				
Seed	2 kg	-	16 500	33 000
Organic manure	2 carts	-	15 500	31 000
NPK fertiliser	1/2 sac de 50 kg	-	15 000	15 000
Herbicide e.g. Roundup 3	0,5	-	6 000	6 000
Cost of labour (H/D)				
Soil preparation	-	8	2 000	16 000
Sowing	-	4	2 000	16 000
Weeding	-	4	2 000	16 000
Treatment (2 times)	-	1	2 000	2 000
Spreading fertiliser	-	4	2 000	16 000
Transport	-	1	15 000	15 000
Harvest	-	4	2 000	16 000
Unforeseen	-	1	20 000	20 000

Total	**-**	**-**	**-**	**258 500**
Marketing				
Harvest + sale	3 500	-	200	700 000
Production margin per kg	1 kg	-	-	441,5
Profit	**1 tonne**	**-**	**-**	**441 500**

Source : Survey data, 2021

The Dioula okra (*Abelmoschus esculentus L*) grown in the Pensa hydro-agricultural perimeter yields an income of 441,5 F CFA/kg, i.e. 441.500 F CFA/t. It is important to understand that the okra cultivation system is different from the other cultivation systems used for maize, rice and cowpeas. Okra needs both heat and humidity. That's why it's not advisable to grow it in the shade. What's more, the plots on which okra is grown are rented.

An analysis of these four farm accounts shows that of the different crops grown in the monoculture system, cowpea yields the highest profit (675,9 F CFA/kg). This is followed by rice, which yields a profit of 625,9 F CFA/kg. Okra yields 441,5 FCFA/kg. Maize comes last. Its profit is 345 F CFA/kg. In the Pensa hydro-agricultural perimeter, cowpea production is therefore more profitable than the other crops (rice, okra and maize).

2.3.2.2. Income from agricultural products in the mixed farming system

The mixed farming system practised within the Pensa hydro-agricultural perimeter made it possible to draw up an inventory of agricultural yields. The farm accounts were drawn up for 0.25 ha. The four main production systems were taken into account, namely system 1 : tomato-cabbage-onion, system 2 : chilli-pepper-eggplant, system 3 : tomato-onion-lettuce, and system 4 : sorrel-cucumber-tomato.

Yields are given for plots measuring 8 m long by 1 m wide. As far as mixed farming is concerned, onions are the leading crop in the Pensa hydro-agricultural zone (67 kg/plot). Tomatoes and cabbages come second and third respectively (56 kg and 51 kg). Cucumbers and aubergines follow, with production per plot of 39 kg and 37 kg respectively. Peppers come second place (36 kg). Chillies and sorrel come last, with estimates of 29 kg and 28 kg per plot respectively. In short, onions are the most productive crop in the Pensa hydro-agricultural zone. The different proportions are shown in the graph below.

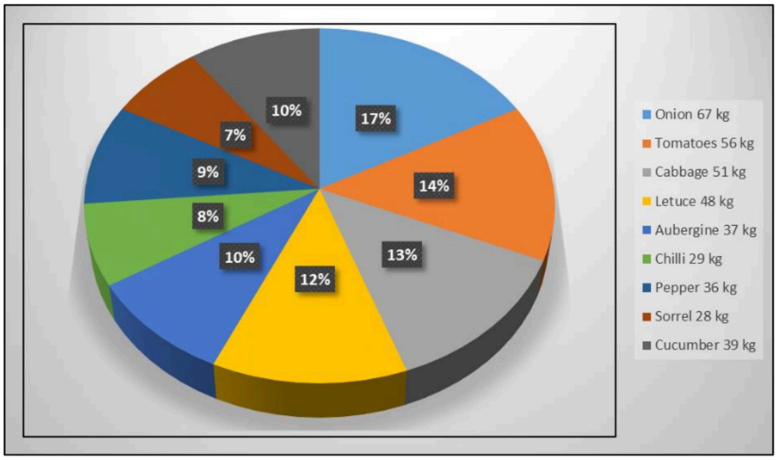


Figure 1 : Estimate of different crops per farm plot

Source : Survey data, 2021

To gain a better understanding of the profitability of mixed crop production, an operating account was drawn up for the two main crops, onions and tomatoes.

Table 9 : Operating account for onion production

Différent stages of production	Quantity	Numbre of people/day	Unit cost in F CFA	Total cost in F CFA
Ploughing for 0.25 ha	-	-	-	5 000
Certified seed for sowing	0,75 kg	-	700	520
Sowing in rows	-	5*1	700	3 500
Remarriage	-	5*1	700	3 500
Weeding	-	5*1/2	300	1 500
Treatment of plots with products	-	-	-	5 000
For treatment of plots	-	1*2	2 000	4 000
Harvest	-	10*1	800	8 000
To place the bundle	-	5*1	300	1 500
Shaking and winnowing	-	3*1	500	1 500
To remove impurities	-	1*1	2 000	2 000

Packaging	1 bag	-	400	400
Total production costs	**-**	**-**	**-**	**30 400**
Average production per 0.25 hectare	1 bag	-	-	80 kg
Production cost per bag	**20 kg**	**-**	**7 600**	**8 000**
Cost of production	1 kg	-	400	400
Price per bag	20 kg	-	18 500	18 500
Producer margin per bag	**20 kg**	**-**	**10 500**	**10 500**
Producer margin per kg	**1 kg**	**-**		**525**

Source : Survey data, 2021

This table shows that onion growing generates a profit of 525 F CFA/kg of onion sold. That's a profit of 525,000 CFA francs per tonne. However, tomato cultivation offers the same estimate ? Unlike the two crops, tomato growing requires less physical effort. It is harvested on a permanent basis up to a certain point (when the plant wilts).

Table 10 : Operating account for tomato production

Différent stages of production	**Quantity**	**Numbre of people/day**	**Unit cost in F CFA**	**Total cost in F CFA**
Ploughing for 0.25 ha	-	-	-	5 000
Certified seed for sowing	0,75 kg	-	700	520
Sowing in rows	-	5*1	700	3 500
Remarriage	-	5*1	700	3 500
Weeding	-	5*1/2	300	1 500
Treatment of plots with products	-	-	-	5 000
For treatment of plots	-	1*2	2 000	4 000
Harvest	-	10*1	800	8 000
To place the bundle	-	5*1	300	1 500
Shaking and winnowing	-	3*1	500	1 500
To remove impurities	-	1*1	2 000	2 000
Packaging	1 bag	-	400	400
Total production costs	**-**	**-**	**-**	**30 400**
Average production per 0.25	1 bag	-	-	80 kg

hectare				
Production cost per bag	**20 kg**	**-**	**7 600**	**7 600**
Cost of production	1 kg	-	502,5	502,5
Price per bag	20 kg	-	19 550	19 550
Producer margin per bag	**20 kg**	**-**	**9 500**	**9 500**
Producer margin per kg	**1 kg**	**-**		**475**

Source : Survey data, 2021

The data in this table show that tomato cultivation generates a profit of 475 F CFA/kg of tomato sold. This equates to a profit of 475.000 CFA francs per tonne. Compared with onions, tomatoes are less profitable than onions.

Analysis of the two cropping systems shows that monoculture is more beneficial in terms of productivity than polyculture. Comparing the operating accounts of the two cropping systems, cowpea production generates a profit of 675 F CFA/kg. By contrast, onion production, a product of mixed cropping, generates a profit of 525 F CFA/kg. This can be explained by the fact that the majority of cowpea production (63 %) is for self-consumption. The rest (37 % of production) is marketed. Onion production shows the opposite trend. The majority of production (86 %) is destined for the market. Only 14 % of production is for local consumption. In terms of proportionality, the monoculture system accounts for 53,19 % of production, compared with 46,81 % for the polyculture system. All crops are used for two purposes : self-consumption and marketing.

2.4. Correlation between cropping systems and cropping system profitability

This was done using a multiple regression model. The correlation between profitability, the monoculture system and the polyculture system shows that the amount of profitability increases as a function of the cropping systems. The more developed the cropping system, the greater the increase in productivity. The various parameters support the estimates of the different proportions.

2.4.1. Estimation of the mixed cropping system equation

Using the Logit model as the reference system, the results are shown in the table below.

Table 11 : Proportions of the estimates for the mixed farming system

Estimation Logit Number of producers = 182

Log likelihood = -72,3065634				LR chi2(3) = Prob > chi2 = 0,000		
Type	Coefficient	Erreur Standard	Z	P > |z|	[96 % Confidence. Interval]	
Age	.6153542,79	.2762454,3	7,455	0,00527	.2916969,19	.9387008,47
Productivity	-3,6499527	.8898696,23	-7,8919	0,00319	-5,07835143	-21217526,83
Area	-21,37297815	4,726463	-6,9183	0,0182	-28,45893693	-4,2711927

Source : field survey, 2021

Analysis of this test of the joint hypothesis shows that the logistic regression is in line with the probability. This means that the prediction of the probability of a producer practising mixed cropping or monocropping rhymes with productivity, the size of the farm plots and the age of the producers. It is therefore necessary to understand that the probability of practising polyculture and monoculture increases with age (0,00527). The probability of practising polyculture and monoculture decreases with age (0,00527), while the probability of practising polyculture and monoculture decreases with productivity (0.,0319) and area (0,0182). Consequently, the older the farmers, the greater the probability that productivity is lower. Furthermore, in the case of farm plots, the probability of a producer owning plots is lower. It should also be noted that productivity has a very negative impact on the confidence interval [-5,07835143 ; -21217526,83]. After analysing the cropping system estimates, it is imperative to look at the marginal effects.

2.4.2. Marginal effects

Taking variables such as age, productivity and farm plot size as a reference, it is important to check whether there are any disturbances between these different variables (Table 12).

Table 12 : Proportionality of marginal effects

Marginal effets after Logit

y = Pro (Type) (prediction)

= .77708561,55

Variable	dy/dx	Erreur	Z	P > |z|	[96	%	Confidence.	X

		standard			Interval]		
Age	.7198758,2	.4815,49	7,2679	0,00735	48274,47	.293477,19	52,47
Productivity	-.4637931	.27657,5	-7,9583	0,00319	-.988000,9	-.33947,43	7,248824 7
Area	-2,1449583	.88986,15	-6,9599	0,00943	-4,8732279	-.816686,63	.36

Source : Field survey, 2021

The figures in this table highlight the marginal effects, which are more explicit. If a farmer's age increases by one notch, i.e. above the average (41,36 years), the probability that he or she owns plots of land and practises mixed and monoculture increases by 0,071. When productivity increases by one kilogram, the probability of owning plots of land increases by 0,071. When productivity increases by one kilogram, the probability of owning farm plots decreases by 0,35. In addition, the area farmed on 0,25 hectares has a negative impact on the probability that the producer owns plots, which is 1,08. However, what estimate can be made between the productivity equation and the mixed cropping and monoculture systems ?

2.4.3. Estimates of the productivity equation between cropping systems

This section involves applying the ordinary least squares method via the robust option. This method is more appropriate for objective correction of any heteroscedasticity. This resulted in the data shown in the following table.

Table 13 : Proportionality of the productivity estimate

Source	SS	Df	MS	Number of producers = 182
Residual	3220,105658	14	644,021131	F (14 ; 168) = 93,25
model	298,9333885	168	6,64296418	Prod > F = 0,0000
Total	3519,0390465	182	650,66409518	R^2 = 0,8106
				Adjustment de R^2 = 0,8106

				MSE Root =	
Performance	Coefficient	Erreur standard	T	P > $|t|$	[96 % Confidence. Interval]
NPK et Urea	.5538207		2,65	0,105	-.085175 .8708567
Fongicides	-.548631	.243037	1,05	0,002	-1.095621 .8945623
Herbicides	.609527	.372278	-1,89	0,003	-.9345890 -.1756325
Pesticides	-.730856	.373376	-2,12	0,004	-2,247527 -.2365548
Chicken droppings	.514789	.153148	-0,9	0,001	.1091868 .2685249
Organic manure	-.849740	.364259	-3,03	0,005	-2,359616 -.3398839
Age	.3010659	.0521908	8,19	0,000	.319060 .4848248
Age2	-.004523	.0008499	-5,73	0,000	-.0050122 -.002036
Type	-.3928538	.8812500	-0,47	0,827	-2,943015 2,370520

Source : Field survey, 2023

The power to explain this model is R^2 = 81,06 %, which is high. This means that cropping systems and productivity are highly correlated in terms of the R^2 value. By entering the data into XLSTAT, 2024 ; the result of the heteroscedasticity test gives the statistical value of *Chi2(1) = 4,82* and the probability value *(Prob > Chi2 = 0,0184)*. These results support the homoscedasticity hypothesis of the model. Variables such as NPK and urea, fungicides, herbicides, pesticides, hen droppings and organic manure and the status of producers did not give statistically significant values. This can be explained by the fact that the quantity of plant protection products used has a positive influence on the yield on 0,25 hectare. Furthermore, the number of years of experience on the hydro-agricultural perimeter also has a positive influence on agricultural yield. The greater the number of years of experience, the greater the quantity of agricultural output. Despite what is said above, productivity is not statistically significant. The negative value of this variable (type) contradicts what was said above (as a reminder, plot holders are more involved in agricultural productivity and produce more than non-plot holders). As a result, it is clear that holding plots of land is not a determining factor in productivity. On the other hand, those who do not own plots of land develop adaptation strategies to increase agricultural yields in production, because the plots of land can be withdrawn the following season. This is not the case with holders of farm plots, who will always own them.

Furthermore, the Ordinary Least Squares (OLS) method indicates that the three variables move in the same direction and show positive values. The correlation coefficient is 162,7520 and the coefficient of determination is 0,8106. This value is very close to 1. This means that productivity, the monoculture system and the polyculture system are highly correlated in the Pensa hydro-agricultural perimeter (Figure 2).

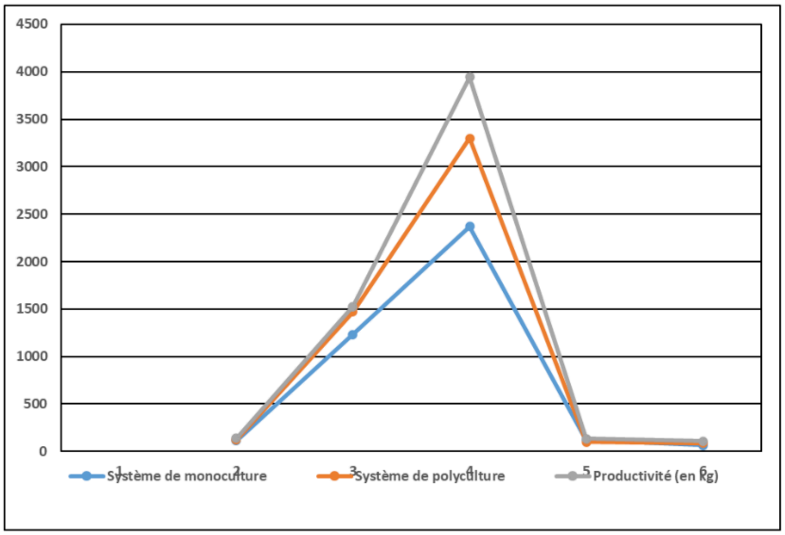


Figure 2 : Changes in the correlation between productivity and the mixed farming system

3. Discussion

The study first showed that in the Pensa hydro-agricultural perimeter, the cropping systems practised are identified as monoculture and polyculture. In the monoculture system, the main crops are Zea mays (maize), Vigna unguiculata (cowpea), Oryza sativa (rice) and Abelmoschus esculentus (okra). These crops are grown during the winter season, with a production ratio of 85,95 %. The mixed cropping system is practised during the dry season. Four systems were reported : system 1 (tomato-cabbage-onion), system 2 (chilli-pepper-eggplant), system 3 (tomato-onion-milk) and system 4 (sorrel-cucumber-tomato). These results are corroborated by the research findings of C Delfoss and *al*, 2020, p.4. Crops in the Marne Valley are diversified. These include 10 ha of alfalfa, 40 ha of cereals, 13 ha of weeds and 2 ha of carrots. These different crops occupy an area of 65 hectares. These results are also similar to the findings of research by W. O Nikièma and *al*, 2022, p.289 in Burkina Faso (commune of Pensa) ; M Kanda and *al*, 2009, p.358 in Togo (peri-urban area of Lomé) ; X LE Roy, 2007, p.6 in Senegal (in the river valley) ; and E Pinot and *al*, 2000, p.5 in Indonesia, more specifically in Malaysia in North Sumatra. Secondly, this research has shown that in the monoculture system, the use of phytosanitary products is topical. Based on the logit model, the frequency indices for phytosanitary products are above 10 % of the surplus value. With the exception of pesticides and chicken droppings, which represent 7.44% and 3.38% respectively. NPK and urea are used more by producers to increase productivity (30,86 %). The negligible difference is at the 10 % threshold, and the average deficiency period is 5.25 days. As for the mixed farming system, the average deficiency period was 5,35 days, with a negligible difference at the 10 % threshold. NPK and urea are used extensively to make productivity more profitable (42,97 %). All the frequency indices for plant protection products used have a percentage that is higher than the plus-value (10 %). This means that phytosanitary products are used in excess in the polyculture system. P. I Yanogo and *al*, 2024, p.277 ; W. O Nikièma and *al*, 2022, p.318 and M Collet, 1987, p.10, found identical results. Similarly, the research findings of N Pingault and *al*, 2009, p.63, show that the use of pesticides is a societal issue. This use can lead to direct or indirect risks for humans and the ecosystem in France. The research results of C Kao and *al*, 2002, p.57, indicate a similarity. In the collection of water from a sub-catchment of more than 320 hectares, of which 71 hectares are drained and around 207 hectares are subject to phytosanitary treatments. The same applies to the results of R Cattan and *al*, p.15, in Gouadeloup. The mobilisation of pollutants spread on plots through agricultural practices is influenced by the fortress of run-off water quantities. Water is the main agent for the diffusion and transport of pollutant molecules spread on plots. This is also the case with the research results of M Sebillotte, 1999, p.145. Industrial phytosanitary products are not found in the composition of plants. These phytosanitary products are used to combat crop 'enemies' such as weeds, fungi and insects. Furthermore, the operating accounts for the four cropping systems showed that in the monoculture system, growing *Vigna unguiculata* (cowpea) is more profitable (675,9 F CFA) in the Pensa hydro-agricultural perimeter. This crop is followed by *Oryza sativa* (rice), *Abelmoschus esculentus* (okra) and *Zea mays* (maize), which yield 625,9 F CFA, 441,5 F CFA and 345 F CFA respectively. In the mixed farming system, onion production was more profitable (525 CFA francs), while tomato production yielded 425 CFA francs. The products from these two systems have two denominations : marketing and self-consumption. These results are echoed in the research work of C Broutin and *al*, 2005, p.27. The study estimated that around 900 people benefited from agricultural activity in the Thiès-Fandène region of Senegal. Economic analyses indicate that peri-urban market gardeners have a monthly income of around 160.000 CFA francs (i.e. more than 4 times the minimum wage of 35.000 CFA francs) and 26.000 CFA francs for the most privileged. For rural market gardeners, the average monthly income is around 24.000 CFA francs. The results of O Felix and *al*, 2022, p.289, show similar results. The operating account drawn up for a group of six (06) crops : onion, tomato, potato, cabbage, green beans and lettuce showed that income varies from one producer to another. For a producer who is a member of an association, the income is 237.962 F CFA. For an individual grower, the income is 232.827 F CFA. And 351.039 F CFA and 338.923 F CFA respectively for a producer belonging to an organisation and for a producer working individually in the Bobo Dioulasso, Ouagadougou and Ouahigouya zones. These results are also identical to those found by M Varenne and *al*, 2021, p.13, in Martinique ; H Sow, 2017, p.24, in the commune of Ziguinchor (Senegal) ; and S Sanogo, 2019, p.384, in the rural commune of Bilanga (Burkina Faso). Finally, a correlation was found between the two cropping systems practised in the Pensa hydro-agricultural perimeter and productivity. Using the ordinary least squares method, all three variables (monoculture system-polyculture-productivity system) show a positive value and move in the same direction. The correlation coefficient was 162,7520, giving a coefficient of determination of 0,8106, which is close to 1. This shows that the monoculture system, the polyculture system and productivity are strongly correlated in the Pensa hydro-agricultural perimeter. The results of J. P Butault and *al*, 2005, p.58, differ from these findings. The percentage growth of farms is too weakly linked to their initial size. The link between the logarithm of the initial size and the percentage growth is significant and almost nullifies the coefficient of determination. The regression coefficient is both significantly positive and close to zero. Hence an increased lightness of disparities. Sensitivity is noted in the results of research by A Sanouna and *al*, 2020, p.469. In the Kourtheye zone in Niger, the correlation between production factors and production is positive. It is significant at the 1 % threshold. The research results of M Armatte, 2001, p.626, offer results that are not identical. In fact, the London session to report on a survey of 15 people shows the correlation coefficient to be low (< 0.3).

Conclusion

This study highlighted the correlation between the cropping systems developed in the hydro-agricultural perimeter and productivity. It showed that the three variables are strongly correlated, with a coefficient of determination of 0,8106. The use of phytosanitary products (NPK and urea) averaged 36,92 % for both cropping systems. All the frequency indices are higher than the plus-value (10 %). The use of phytosanitary products is therefore excessive on the developed site. The monoculture system is more profitable than the polyculture system. Raising the awareness of farmers and providing them with ongoing training in agro-ecological practices could be a key factor in reducing the inconvenient practices developed in the Pensa hydro-agricultural zone. However, what link can be established between agricultural insurance and agricultural productivity in Sanmatenga province ?

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