Research Journal of Applied Sciences 2 (5): 617-622, 2007
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Optimal Crop Combination in Small-Scale Vegetable Irrigation Farming Scheme: Case Study from Niger Republic

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Abstract: This study examines the optimal crop combination in small-scale vegetable irrigation farming in Niger republic. A total of 35 small-scale vegetable irrigators were randomly selected from 6 irrigation schemes, under the Nigerien Agency for the Promotion of Private Irrigation (ANPIP). Primary data were collected from selected farmers during the 2002 farming season and were analyzed using descriptive statistics and linear programming approaches. The analysis shows that the optimal crop combination was the tomato-based crop mixtures, consisting of tomato/cucumber/onion/okra/watermelon. The optimal value of the programme was CFA 329,681. The carrot-based system was the second most profitable enterprise while the onion-based system was the least profitable enterprise. Land was a limiting resource in vegetable farming. Labour, irrigation water and capital were non-limiting resources. Farmers were advised to concentrate and intensify the cultivation of the tomato-based enterprise because of its higher profitability. Government should assist farmers by preparing land and giving it to vegetable farmers at affordable prices while also empowering them financially to be able to increase their farm sizes for increased vegetable production.

Key words: Irrigation farming, vegetables, linear programming, optimal farm plan, Niger Republic

INTRODUCTION

Niger is a Sub-Saharan country of West Africa. It is a land-locked country, which is around 1000 km from the sea. Niger is located between latitudes 12° and 24° N and longitude 0° and 16° E. It is bordered by Algeria and Libya in the north, Chad on the east, Nigeria on the south, Benin and Burkina Faso on the southwest and Mali on the west. Niger has a total land area of 1,267,000 km^2, making it one of the largest countries in Africa in terms of land area (FAO, 1995a). The total population of Niger was about 10 million people in 1999 and the average population density was approximately 8 persons per square kilometer (Charles *et al*., 2000). The country can be divided into three zones; the north, center and the south. The northern zone covering about two-third of the total surface area is located within the Sahara desert. It is an elevated region formed by plateaus and mountains and with the exception of some isolated oasis, vegetation is rare in this zone. The center zone is part of the sahel (the Tenere region). It is a semi-arid region with few trees. The southern zone is tropical and the only zone with fertile and wooded vegetation where there are enough rains for food crop farming. The southwest part is characterized by periodic floods from the Niger River. The climate of Niger is hot and in most areas dry. The rainy season lasts from June to October in the southern zone, with maximum rainfall of about 800 mm in August. The dry season lasts from November to May, during which it is very hot and dry. The mean rainfall is about 500 mm per annum in the southern zone and this decrease northward to an average of 200 mm per annum. The average annual temperature is about 29°C (Charles *et al*., 2000).

Agriculture is the mainstay of the economy of Niger. The agricultural sector contributes about 34.8% of the GDP and employs about 85% of the work force. It is the country's largest foreign exchange earner and the major raw material producer for the industries. Agricultural production is largely small-scale and at subsistence level. The principal food crops are millet, sorghum, cassava, rice, sugarcane and vegetables. The major export crops are beans, cotton and peanuts. Livestock rearing is a principal agricultural activity. Livestock reared include, cattle, sheep and goats from which beef, dairy products and animal skin are exported for foreign exchange. Fishing is carried out in rivers and lakes in Niger republic and a

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sizeable proportion of the population also finds employment in the fishing industry. The total catch increased from about 2000 metric tones in 1985 to 4000 metric tones in 1991 (FAO, 1995a).

Rockstrom *et al.* (1999) stated that food production in semi-arid regions of Africa is seriously reduced by water scarcity. This scarcity of water has more effects on countries such as Ethiopia, Sudan and Niger and this has led to hunger and famine in these countries. International food assistance, particularly after droughts have become integral to Niger's agricultural economy. In June 2005, it was reported that about 3 million people are suffering from hunger and requires food aids in Niger republic (CNN, 2005). With a population of over 10 million people and an average annual growth rate of 3.3%, Niger has to provide food for nearly 300,000 extra people annually. Rain fed agriculture is possible in a narrow belt running across the southern part, approximately parallel to the frontier with Nigeria. The food produced in this belt is not sufficient to feed people in the region let alone the other regions. The challenge of providing food for its population coupled with the scarcity of rainfall has led to the development of irrigated agriculture in Niger republic (Charles *et al.*, 2000). FAO (1995a) reported that irrigation can play an important role in raising and stabilizing food production, especially in the less-developed parts of Africa south of the Sahara. However, many obstacles have hindered the rapid development of irrigation potentials in this part of the world. Some of these obstacles according to Charles *et al.* (2000) include inadequate water resources, unfavourable topography, inadequate infrastructure, lack of credit and general poor or ineffective planning. These obstacles have led to disparity between actual area under irrigation and irrigation potential in many African countries including Niger Republic.

The irrigation sector in Niger republic: Irrigation has been practiced in Niger republic over the past 40 years. The irrigation potential of Niger is estimated to be 270,000 ha, of which 140,000 ha (about 51.8%) are situated in the Niger River valley. The total area presently developed for irrigation is about 78,000ha, which is equivalent to 2% of the total cultivated land in the country (FAO, 1999a). Cultivation of rice along the Niger River valley using traditional methods began to be replaced by modern irrigation techniques in the 1960s. There are now about 42 of these modern irrigation systems and their total nominal area is 9,700 ha, so the average system size is 230 ha. Majority of the irrigation systems were designed on the assumption that rice will be the dominant crop and in most cases, the only crop. A double-crop system is assumed, with the wet season crop being transplanted in early July and harvested in November, while the dry season crop is expected to be transplanted in early January and harvested in May. Some irrigation systems are not designed for rice production but for vegetables. Such systems use the more permeable terrace soils, which are farther from the River and at higher elevations. Water is pumped from the River by electrically powered pumps and distributed to the fields through canal networks that are usually lined.

The Niger River is the major source of surface water for irrigation in Niger. Groundwater resources are also significant and are utilized in some regions. However, the country's lack of indigenous energy resources and the high cost of imported energy restrict the use of ground water for irrigation. The republic of Niger shares the Niger River with Guinea and Mali upstream and Benin and Nigeria downstream. The length within Niger is about 550 km or 13% of the whole length of the River. The River has numerous tributaries in Niger. These tributaries are small in relation to the main River, but they have significant impact on the irrigation systems in the country. Since the Zinder seminar of 1982 (Republique du Niger, 1982) government policy has been to promote irrigator organizations at each of the river valley irrigation systems and to transfer the responsibility of operating and maintaining the facilities to these organizations. To coordinate this policy ONAHA (Office National des Amenagements Hydro-Agricoles), was established. ONAHA was the national office for irrigation systems and was given the mandate of constructing irrigation facilities and delivering operational support services to them after construction. The major source of financing however had been through funds given by foreign donors (Kabore *et al.*, 1994). In addition to ONAHA, government established the Niger Agricultural Research Institute (INRAN), with the objective of promoting irrigation technologies among small-scale irrigation farmers in Niger. To cope with the increasing needs for private irrigation projects, government established ANPIP (Nigerien Agency for the Promotion of Private Irrigation). ANPIP set out to coordinate and give to farmers, irrigation technologies that they can easily apply on their own.

As mentioned earlier, majority of the irrigation projects in Niger were set up for rice production along the Niger River valley. However, recently the demand for irrigated crops other than rice has been growing. Charles *et al.* (2000) submitted that local demand for irrigated vegetables and fruits in the Niamey markets have increased and subsequently the private-sector small-scale irrigators who pump water from the river near Niamey do not use it only for rice cultivation, but also for vegetables and fruits. The attraction for growing

vegetables was borne out of the need to supply fresh vegetables to the nearby Niamey markets or directly selling from roadside stalls. Norman and Walter (1994) reported that some of the farmers, given the option would prefer growing only vegetables to get quick returns and be able to meet households cash requirement. The cultivation of vegetables along the Niger River by private irrigators is not without its problems. First is the risk of flood from the river and second is that, the extension of irrigation water for unofficial use is considered as illegal because no corresponding fees are paid for the water used (Charles *et al*., 2000). Despite these problems however, small-scale vegetable farming has continued to expand along the Niger River valley. The objectives of this study are to examine the socio-economic characteristics of small-scale vegetable irrigators under the Nigerien Agency for the Promotion of Private Irrigation (ANPIP) and to determine the optimal crop combination model for vegetable farmers along the Niger River valley.

MATERIALS AND METHODS

Data for this study were collected from 35 small-scale vegetable irrigators who were selected randomly from 6 irrigation schemes under the Nigerien Agency for the Promotion of Private Irrigation (ANPIP). The data were collected through cross-sectional survey using a standard questionnaire, during the 2002 farming season. ANPIP is located in Niamey, the capital of Niger republic. Most small-scale private irrigation schemes in Niger are under the coordination of ANPIP. The climate of Niamey state where the study was conducted, is tropical and the vegetation traditionally savanna. The rainy season starts from June and ends in October, with mean annual rainfall of about 800 mm. The dry season starts by November and last till May. The mean annual temperature in this region is about 30°C. Food crops grown in the state include millet, sorghum, cowpea, rice and maize. Vegetables grown in the irrigation schemes include pepper, tomato, onion, cabbage, watermelon, okra, garden egg, cucumber and lettuce. The number of farmers chosen from each irrigation scheme was in proportion to the estimated total number of vegetable growers in each scheme. The distribution of respondents from each of the irrigation scheme is shown in Table 1.

Descriptive statistics were use to analyze the socio-economic characteristics of vegetable irrigators in the selected irrigation schemes. The optimal crop combination was determined by using the linear programming model.

Table 1: Distribution of respondents based on irrigation schemes

Irrigation schemes	Number of farmers	Percentage of total
Dareyna	4	11.43
Zoumbou	7	20.00
Karegorou	8	22.85
Tibiri	7	20.00
Kobague	5	14.29
Canguel	4	11.43
Total	35	100.00

Source: Field survey, 2002

The linear programming model: Linear programming tool find easy application in optimization problems, where the aim is to maximize or minimize a linear objective function subject to a set of linear constraints. For optimal crop combination problem, the linear programming model is considered appropriate because the farmer is interested in a crop combination that maximizes his or her gross margin. Thus, the solution of the linear programme represents the profit maximizing crop combination under the present cropping system and this solution can be tested for changes in resource availability under alternative crop combinations (Okuneye, 1985b). The general linear programming model can be expressed as;

$$\text{Maz } Z = C_1X_1+C_2X_2+\ldots\ldots\ldots+C_nX_n \qquad (1)$$

Subject to:

$A_{11}X_1+A_{12}X_2+\ldots\ldots+A_1nXn = B_1$

$A_{21}X_1+A_{22}X_2+\ldots\ldots+A_2nXn = B_2$

$Am_1X_1+Am_2X_2+\ldots\ldots+AmnXn = Bn$

$X_1, X_2, \ldots\ldots Xn = 0$

Where:

- Z = The objective function (gross margin)
- m = Number of resources
- n = Number of activities
- X_j = Number of units of activity j, for j = 1, 2, …… n
- B_i = Amount of resource I available for I = 1, 2, ……m
- C_j = Contribution of Z for each unit of activity j for j = 1, 2, …. n
- A_{ij} = Amount of ith resource consumed by each unit of activity j.

The data were divided into enterprises based on five groups of vegetable enterprise combinations that were identified. These are pepper-based, carrot-based, onion-based, tomato-based and cabbage-based enterprises. The crop combination under each enterprise is shown in Table 2.

RESULTS AND DISCUSSION

The summary of the socio-economic characteristics of vegetable growers is presented in Table 2. Socio-economic analysis of the respondents shows that a little

Table 2: The crop combination under each enterprise

Variable	Enterprise combinations
X_1	Pepper/tomato/cucumber/watermelon
X_2	Carrot/potato/pepper/onion/garden egg
X_3	Onion/watermelon/tomato/okra
X_4	Tomato/cucumber/onion/okra/watermelon
X_5	Cabbage/lettuce/pepper/onion

Table 3: Summary of the socio-economic characteristics of vegetable irrigators

Characteristic	Frequency	(%)
Age (years)		
1-15	0	0.0
16-30	7	20.0
31-45	9	25.7
46-60	12	34.3
Above 60	7	20.0
Household size		
1-5	7	20.0
6-10	11	31.4
11-15	17	48.6
Farm size (ha)		
0.01-0.04	5	14.3
0.05-0.08	6	17.1
0.09-0.12	9	25.7
0.13-0.16	7	20.0
0.17-0.20	8	22.9
Enterprises combination		
Pepper/tomato/cucumber/watermelon	23	23.7
Carrot/potato/pepper/onion/garden egg	16	16.5
Onion/watermelon/tomato/okra	19	19.5
Tomato/cucumber/onion/okra/watermelon	29	30.0
Cabbage/lettuce/pepper/onion	10	10.3
Irrigation methods		
Sprinkler method	11	31.4
Furrow method	4	11.4
Combination of sprinkler and furrow	20	57.2

Source: Field survey, 2002

less than half (45.7%) of the farmers were 45 years and below. 34.3% were between 46 and 60 years and 20% were more than 60 years old. The overall average age was 47 years. The result shows that while about half the population of vegetable irrigators, were still young and able-bodied, one-fifth (20%) were already old. The larger proportion of young farmers notwithstanding, the farm sizes were small. This could be because farmers in this region also engage in other activities such as rain fed agriculture, fishing, mining and animal rearing which equally demands for their labour time. About 51.4% of the farmers have household sizes ranging between 1 and 10, while 48.6% have between 11 and 15 persons in their household. The average household size was 10 persons. While high household sizes could be an incentive for increased land cultivation (especially where all members are adult and participate in farming activities), this result shows a contrary situation among vegetable irrigators in the study area. This could probably be attributed to the fact that some member of large households might not be involved in vegetable farming but rather in other activities like fishing and animal rearing which according to Charles *et al*. (2000) are predominant in the study area.

The farm size distribution shows clearly the small-scale nature of vegetable irrigators in the area. All the sampled farmers cultivate less than 1.0 ha of vegetables. Majority (77.1%) cultivates between 0.01-0.16 ha and only 22.9% or eight farmers cultivate between 0.17-0.20 ha. The average farm size was 0.11 ha. The distribution of farmers according to types of vegetable enterprises shows that the tomato-based (30.0%) enterprise was the most common among vegetable farmers in the study area. This was followed by the pepper-based enterprise (23.7%). The least common enterprise was the cabbage-based enterprise (10%). The distribution based on methods of irrigation shows that more than half the population of farmers (57.2%), used a combination of sprinkler and furrow irrigation systems. The least common method was the furrow irrigation method (11.4%).

The linear programming model: The linear programming matrix was constructed based on the 5 identified prominent vegetable enterprises in the area. The matrix showing the enterprises' gross margins, the available resources and the used resources are given below in Table 4. The linear programme was analyzed using the ''solver'' software programme. The solution of the linear programme is presented in Table 5.

Table 5 indicates that only tomato-based enterprise (X_4) entered the final cropping plan. The optimal value of the linear programming solution is CFA329,681. This is the value of the programme, which was obtained by cultivating 0.165 hectare of the enterprise at a gross margin of CFA1,998,069 ha^{-1}. Enterprises X_1, X_2, X_3 and X_5 did not enter the final plan, since they have non-zero opportunity cost indicating that these enterprises were not in the best competitive positions as compared to enterprise X_4. This result shows that the best crop combination in vegetable cropping system in the study area is the Tomato-based cropping system.

The opportunity cost of resources used in vegetable cropping systems indicates that land was the only limiting resource. Labour, irrigation water and capital were non-limiting resources in vegetable farming in the area. There were 1,589.7 man-days of unused labour, 405.7 ha cm^3 of unused water and CFA107,444.8 of unused capital. The shadow price of land was CFA1,998,069, indicating that by increasing land cultivation by one hectare, the gross margin would increase by CFA1,998,069. This result contradicts other studies such as Tanko (2003) which concluded that land was not a limiting resource in vegetable farming. However, the fact that land was a limiting resource in vegetable farming in the area could probably be due to the fact that, vegetable farming is carried out along the Niger river, which leads to high competition for fertile land close to the river bank. To

Table 4: Linear programme matrix of vegetable irrigators

Gross margin (CFA/ha)	110,7296	1,266,337	17,776	1,998,069	160,501	Used resources	Available resources
Enterprises	X_1	X_2	X_3	X_4	X_5		
Land (ha)	1.0	1.0	1.0	1.0	1.0	3.0	0.17
Labour (man-days)	3,018	1,872	1,175	1,862	1,191	9,116	1,897
Irrig. Water ($hacm^3$)	819.3	329.0	129.7	450.0	472.1	2200.1	479.4
Capital (CFA)	61,815	159,449	82,956	119,383	143,944	567,547	127,143

Source: Field survey, 2002. Note: 1 US Dollar = 495 CFA

Table 5: Linear programming result of vegetable cropping systems in Niger republic

Enterprises combination	Final value	Opportunity cost
Pepper/tomato/cucumber/watermelon	0	890,773
Carrot/potato/pepper/onion/garden egg	0	731,732
Onion/watermelon/tomato/okra	0	1,980,293
Tomato/cucumber/onion/okra/watermelon	0.165	0
Cabbage/lettuce/pepper/onion	0	1,837,568
Resources		
Land	0	1,998,069
Labour	1,589.77	0
Irrigation water	405.74	0
Capital	107,444.80	0

Maximized objective (Z) = CFA329,681. Source: From linear programming solution, Note: 1 US Dollar = 495 CFA

Table 6: Relative profitability of vegetable enterprises in Niger republic

Enterprises combination	Gross margin ha^{-1}	Gross margin/ man-day
Pepper/tomato/cucumber/watermelon	1,107,296	366.90
Carrot/potato/pepper/onion/garden egg	1,266,337	676.50
Onion/watermelon/tomato/okra	17,776	15.10
Tomato/cucumber/onion/okra/watermelon	1,998,069	1,073.10
Cabbage/lettuce/pepper/onion	160,501	134.80

Source: Field survey, 2002. Note: 1 US Dollar = 495 CFA

Table 7: Shadow prices of excluded enterprises in the linear programming solution

Excluded enterprises	Reduced income (CFA)
Pepper/tomato/cucumber/watermelon	890,773
Carrot/potato/pepper/onion/garden egg	731,732
Onion/watermelon/tomato/okra	1,980,293
Cabbage/lettuce/pepper/onion	1,837,568

Source: By-product of the linear programming solution. Note: 1 US Dollar = 495 CFA

achieve increased vegetable production in the study area, more land should be put into production as it was the only limiting resource.

Relative profitability of vegetable enterprises: Two parameters were used to assess the profitability of the five identified vegetable cropping enterprises in the area. These are gross margin per hectare and gross margin per man-day. Table 6 shows the relative profitability of the 5 vegetable enterprises.

Gross margin per hectare measures the monetary value, per hectare of the entire farm produce without deducting the cost of fixed items and without allowing for depreciation on tools and equipment. Gross margin is a parameter that interests the peasant farmers more than the net margin because they often disregard the cost of owned produced inputs used in farm operations even though it is not a pure measure of profitability (Tanko and Mbanasor, 2006). Table 6 shows that the gross margin per hectare is highest for the tomato-based enterprise followed by the carrot-based enterprise. The gross margin per hectare is lowest for the onion-based enterprise. This result confirms that the most profitable vegetable enterprise is the tomato-based enterprise while the least profitable is the onion-based enterprise.

The gross margin per man-day was calculated to aid in comparative analysis of labour utilization, another important input in vegetable farming. The gross margin per man-day is highest in the tomato-based enterprise (CFA1,073.1) and this is followed by the carrot-based enterprise (CFA676.5). The gross margin per man-day is lowest in the onion-based enterprise (CFA15.1). This results shows that labour obtained the highest return in the tomato-based enterprise followed by the carrot-based enterprise. Labour earns the least return in the onion-based enterprise.

Shadow prices of excluded enterprises: Shadow prices are marginal returns to increments of available resources. In a maximization problem, shadow prices are income penalties. They indicate the amount by which, farm income would be reduced if any of the excluded activities is forced into the programme (Tanko and Mbanasor, 2006). Generally, only excluded enterprises and limiting resources have positive shadow prices. The higher the shadow price of an excluded enterprise, the lower is its chance of being included in the final plan. The shadow prices of the excluded enterprises in vegetable farming in the study area are shown in Table 6.

Table 7 shows that the onion-based enterprise had the highest shadow price of CFA1,980,293. Carrot-based enterprise had the lowest shadow price of CFA731,732. This result indicates that for vegetable irrigators to maximize gross margin, the carrot-based enterprise is the next to be considered after the tomato-based enterprise. This is because of all the excluded enterprises, the carrot-based system would decrease gross margin the least if included in the final plan.

CONCLUSION

This study has shown that for small-scale vegetable irrigation farming in Niger republic, the tomato-based enterprise is the most profitable with a gross margin of CFA1998069 ha^{-1}. The study further shows that of all the excluded enterprises, the carrot-based system had the lowest shadow price, which makes it the second best alternative to the tomato-based system in the study area. While land was a limiting resource in vegetable farming, labour, irrigation water and capital were non-limiting. Given the outcome of this study, it is suggested that vegetable irrigators in the study area should concentrate and intensify their effort on the cultivation of the tomato-based crop mixture, which entered the optimal farm plan. More land should be put into the cultivation of this enterprise to increase returns to the farmers. Farmers should take advantage of unlimited labour, irrigation water and capital to achieve increased vegetable production while government should provide needed incentives such as tractor and more land to farmers so that they can increase their vegetable cultivation.

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