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Strategies of Differential Evolution for Optimum Cropping Pattern

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Abstract: Differential Evolution (DE) as a novel optimization technique is applied to determine the optimum cropping pattern in the Lower Orange catchments of South Africa. Three different cropping patterns are studied to determine the best cropping pattern for the study area in terms of maximum total income generated from farming, irrigation water use and total man-days required on the farm. The farmlands of 60, 70, 75 and 135 ha are distributed to the farmers in the study area by the management. The objective of the study is to explore the 10 different strategies of DE to determine the optimum cropping pattern in each of the farmlands studied. Each farmland is studied to determine the best DE strategy for this model. From the analysis of the results, DE strategies with binomial crossover method outperform DE strategies with exponential crossover method. It is suggested that DE/best/1/bin is the best strategy for this model taking the minimum number of iterations before convergence and the maximum total net benefit generated as criteria. It can be concluded that DE can be used for determining optimum cropping pattern in a water scarce environment with necessary modifications to this model.

Key words: Cropping pattern, differential evolution, optimization, irrigation

INTRODUCTION

In many areas of the world, water is limited in supply. Agriculture is the largest consumer of water. Water resources are becoming scarce. The share of available water for irrigation has reduced. This calls for rational use of water. Moreover, viable cropping patterns for a given area and available resources are necessary. The main hydrological planning problem in the basins of South Africa is due to a water resources deficit. This is aggravated by low rainfall in the country. Since, the building of more hydraulic regulation works, mainly large dams are very expensive, water demand management can be of immense help. These management ideas come from the change of attitude in the management of irrigation water by quantifying the profitability of irrigation water in much the same way as other economic products (Reca *et al*., 2001). Farmers must take into account the most profitable cropping patterns given water availability restrictions imposed by the existing hydrological system and the potential yields reached in each irrigation district as a function of its productive characteristics, irrigation efficiency and economic scenario. Optimization methods are widely used in business and sciences for decision-making process. Several studies have used both linear and non linear optimization models to determine the optimum cropping pattern. Singh *et al*. (2001) have formulated a Linear Programming (LP) model to suggest the optimal

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cropping pattern. Amir and Fisher (1999) used an optimizing linear model for analyzing agricultural production. Reca *et al*. (2001) developed a non linear objective function to optimize water allocations and they transformed it into a linear problem by approximating the benefit function to a discrete function. Raju *et al*. (2006) employed Kohonen neural networks (KNN) based classification algorithm to sort non dominated irrigation planning strategies into smaller groups. In their study, four-phase methodology is employed. In phase 1, separate linear programming (LP) models are formulated for the 3 objectives, namely, net economic benefits, agricultural production and labour employment. In phase 2, non dominated irrigation planning strategies are generated using the constraint method of multiobjective optimization. In phase 3, Kohonen Neural Networks (KNN) based classification algorithm is employed to sort non dominated irrigation planning strategies into smaller groups. In phase 4, multicriterion analysis (MCA) technique, namely, compromise programming is applied to rank strategies obtained from phase 3. The methodology is effective for modelling irrigation planning problems.

Karterakis *et al*. (2007) presents differential evolution optimization method for the optimal management of fresh water resources in coastal regions based on environmental criteria. The study focuses on the determination of an optimal pumping scheme that will ensure adequacy of portable water demand inn coastal regions without deteriorating the quality of the fresh water due to the seawater intrusion. The problem is formulated as the maximization of the total extracted fresh water volume from the pumping wells subject to a set of constraints. Vasan and Raju (2007) employ the 10 strategies of Differential Evolution (DE) to assess the ability of DE for solving higher dimensional problems as an alternative methodology for irrigation planning. It was suggested that DE/rand-to-best/1/bin strategy is the best strategy giving maximum benefits taking minimum CPU time.

Irrigation represents over 90% of all the water use in the Lower Orange area excluding environmental requirements and river losses. The total irrigated area along the Orange River amounts to about 107 000 and 48 000 ha in the Fish/Sundays basin. In the Orange River basin, 2 irrigation water use types are identified. These are controlled irrigation and diffuse irrigation. Controlled irrigation is associated with purpose-built storage and conveyance structures for the reliable supply of regulated quantities of water. Such irrigation usually forms part of government water schemes and irrigation boards and is regulated by means of scheduled irrigation areas and water quotas. Diffuse irrigation is associated with smaller and usually individual irrigation development. This includes farm dams and direct abstraction from uncontrolled rivers, typically with intermitted and unreliable flows.

This study is based on controlled irrigation which accounts for about 95% of irrigation water use in the study area. In this irrigation scheme, high value crops are grown because of greater reliability of water supply. The cropping patterns in the study area can be grouped into 3 main categories: annual field/cash crops, fodder crops and orchard crops. The crops are Lucerne, fodder+pasture, maize, wheat, cotton, legumes, vegetables + potatoes, grape and fruit+citrus. Many of the crops currently grown under irrigation in this area yield low financial returns. It is now important for a study that will determine the optimum cropping pattern that will increase production returns. Differential evolution is used to solve the optimization model in this study.

Differential Evolution (DE) is an improved version of Genetic Algorithm (GA), a type of Evolutionary Algorithm (EA) for faster optimization (Price and Storn, 1997). The DE is simple to implement and has demonstrated better convergence performance than other EA. It handles continuous, discrete and integer variables. In terms of constraints, DE can handle multiple constraints. It is one of the most promising EAs in terms of efficiency, effectiveness

Table 1: Formulation of the ten different strategies of differential evolution

Strategy	Description	Formulation
1	DE/rand/1/bin	$v(g, i, j) = x(g, r_3, j) + F^* [x(g, r_1, j)-x(g\ r_2, j)]$
2	DE/best/1/bin	$v(g, i, j) = x(g, best, j) + F^* [x(g, r_1, j)-x(g\ r_2, j)]$
3	DE/best/2/bin	$v(g, i, j) = x(g, r_3, j) + F^* [x(g, r_1, j)+x(g, r_2, j)-x(g\ r_3, j)-x(g\ r_4, j)]$
4	DE/rand/2/bin	$v(g, i, j) = x(g, r_5, j) + F^* [x(g, r_1, j)+x(g, r_2, j)-x(g\ r_3, j)-x(g\ r_4, j)]$
5	DE/rand-to-best /1/bin	$v(g, i, j) = x(g, i, j) + F^* [x(g, best, j)-x(g, i, j)] + F^* [x(g\ r_1, j)-x(g\ r_2, j)]$
6	DE/rand/1/exp	$v(g, i, j) = x(g, r_3, j) + F^* [x(g, r_1, j)-x(g, r_2, j)]$
7	DE/best/1/exp	$v(g, i, j) = x(g, best, j) + F^* [x(g, r_1, j)-x(g, r_2, j)]$
8	DE/best/2/exp	$v(g, i, j) = x(g, r_5, j) + F^* [x(g, r_1, j)+x(g, r_2, j)-x(g\ r_3, j)-x(g\ r_4, j)]$
9	DE/rand/2/exp	$v(g, i, j) = x(g, r_5, j) + F^* [x(g, r_1, j)+x(g, r_2, j)-x(g\ r_3, j)-x(g\ r_4, j)]$
10	DE/rand-to-best/1/exp	$v(g, i, j) = x(g, i, j) + F^* [x(g, best, j)-x(g, i, j)] + F^* [x(g\ r_1, j)-x(g\ r_2, j)]$

and robustness. The principal difference between GA and DE is that (1) GA relies on uniform crossover, a mechanism of probabilistic and useful exchange of information among solutions to locate better solutions and (2) DE uses a non uniform crossover in that the parameter values of the child vector are inherited in unequal proportions from the parent vectors. This can take child vector parameters from one parent more often than it does from others. By using components of existing population members to construct trial vectors, recombination efficiently shuffles information about successful combinations, enabling the search for an optimum to focus on the most promising area of solution space (Onwubolu and Babu, 2004). The descriptions and working principles of DE are widely available in the literatures (Storn and Price, 1995, 1997; Abbass and Sarker, 2002; Madavan, 2002; Rakesh and Babu, 2005; Babu *et al*., 2005; Price *et al*., 2005; Fan *et al*., 2006; Onwubolu and Davendra, 2006). The formulations of different strategies are given in Table 1.

The objective of the study is to explore the 10 different strategies of DE to determine the optimum cropping pattern in each of the farmlands in the study area. Each farmland is studied to determine the best DE strategy for this model. Three different cropping patterns are studied to determine the best cropping pattern for the study area in terms of maximum total income generated from farming, irrigation water use and total man-days required on the farm. The farmlands of 60, 70, 75 and 135 ha are distributed to the farmers in the study area by the management.

MATERIALS AND METHODS

Farmers in the study area are allocated farmlands by the management of Orange River catchments. The study was conducted from July, 2008 to August, 2009. The allocated farmlands are 60, 70, 75 and 135 ha. The irrigation water supplied to the farms is 7 143 $m^3\ ha^{-1}$. The objective of the farmers is to maximize their profit using the available irrigation water maximally. The objective function of the model is formulated to maximize the TNB in monetary value derived from planting different crops on farm units.

The objective function can be expressed as:

$$\text{Maximize}\left(\sum_{i=1}^{N}\sum_{j=1}^{M}\left(TB_{i,j} * A_i\right)\right)-\left(cw * TVOL\right) \tag{1}$$

$$TB_{i,j} = \left(yield_{i,j} * price_{i,j}\right) - Exp_{i,j} \tag{2}$$

Where:

N = Number of farm units on a farm

M = Number of crops on the farm unit i
$Tb_{i,j}$ = Total benefit from farm unit i (ZAR)
A_i = Farm unit i (ha)
cw = Cost of irrigation water (8.77 cents)
TVOL = Total irrigation water allocated to the farm
$Yield_{i,j}$ = Yield of crop j planted on farm unit i (tons ha^{-1})
$Price_{i,j}$ = Price of crop j planted on farm unit i (ZAR/ha)
$Exp_{i,j}$ = Expenses on crop j planted on farm unit i (ZAR/ha)

The constraints of the problem are as follows:
The total area is equal to the sum of areas of farm units on a farmland

$$\sum_{i}^{N} A_i \leq A \tag{3}$$

where, A can be 60, 70, 75 and 135 ha for each of the farms modeled.

The irrigation release for the whole year is equal to the irrigation release per hectare per year multiplied by the area of the farm in hectares. We have 4 different areas for each of the farm units.

$$TVOL <= (A * 7143) \tag{4}$$

The volume of water available is equal to the total of crop water requirement for each crop multiplied by the area where the crop is grown.

$$\sum_{i}^{N}\sum_{j}^{M}\left[CWR_{i,j} * A_i\right] * 10 < TVOL \tag{5}$$

Where:
$CWR_{i,j}$ = Crop water requirement for crop j on farm unit i (mm)
A_i = Area of farm unit where crop, i is grown in ha

To make sure that all the crops are grown, then each area, A_i of farm units must be equal or greater than 2.5 ha. With this constraint, it is certain that all the crops will be grown in at least 2.5 ha of land. Minimum planting areas are essential to make farming survive financially. Large farming units are capable of rendering adequate financial surpluses. Models with large irrigated lands yield acceptable financial returns. In the selection of planting areas, account was taken of the maximum area which if planted nationally, would not lead to a market collapse through over-production.

$$Ai >= 2.5 \ (i = 1, 2, ...4) \tag{6}$$

Double cropping is used in this study and will help the farmers to generate more benefit from the irrigated land. Also, many crops are planted on more than an area of land.

To take account of labour requirements on the farm, the following parameters were used. For annual and fodder crops, the labour requirement is 1.3 labour days per 1000 m^3. For high percentage of orchard crops, the labour requirement is 20 labour days per 1000 m^3. These values are taken from a previous study (DWAF, 2004).

RESULTS AND DISCUSSION

The objective function and the constraints are solved using the 10 strategies of DE to compare the results and find out which strategy is the best for this model using the number of iterations before convergence and maximum total income generated as criteria. The total farm income is maximized, constrained by land and water availabilities. From the sensitivity analysis that was performed to determine the best combination of population size (NP), crossover constant (CR) and weighting factor (F) that is the best for this model, it was found that NP, CR and F of 40, 0.95 and 0.5, respectively are the best for the model. This is in agreement with Price and Storn (2008) that suggested that NP should be chosen as 10 times the number of parameters, CR to be slightly above or below 1.0 for fast convergence and F to be taken from 0.1 to 0.9. The model is run for each farmland of 60, 70, 75 and 135 ha. The cropping patterns are varied from A (wheat/groundnut, drybean/maize, cotton/drybean and wheat/carrot), B (wheat/potatoes, onions/watermelon, lucern and pecan) to C (wheat/groundnut, drybean/maize, olive and citrus) with the corresponding crop(s) in each pattern planted on farm units of A1, A2, A3 and A4, respectively as single or double cropping.

The 10 strategies of DE have different formulations. These formulations are presented in Table 1. Strategies 1 to 5 have binomial crossover and strategies 6 to 10 have exponential crossover. The 10 strategies are tested with the model in this study.

In Table 2, the number of iteration, total income, total area and total man-days for planting area 60 ha for each of the strategies are presented. Table 3 shows the results of cropping pattern A for farmland of 70 ha. Also the number of iteration, total income, total area, total volume and total man-days for the farmland are presented. Table 4 presents the results of different strategies of DE, iterations before convergence, total income generated, total planting areas, total volume of water, total man-days and 4 different planting areas of cropping pattern A for farmland of 75 ha. Table 5 presents the results of cropping pattern A

Table 2: Results of cropping pattern A for planting area 60 ha

Strategy No.	No. of iteration	Total income (ZAR)	Total area (ha)	Total volume (m^3)	Total man-days	Wheat/ groundnut	Drybean/ maize	Cotton/ drybean	Wheat/ carrot
1	458	889160	60.000	512400	99427	17.00	20.00	20.00	3.00
2	153	889160	60.000	512400	99427	17.00	20.00	20.00	3.00
3	327	888470	60.000	514120	100000	17.57	19.43	20.00	3.01
4	461	889160	60.000	512400	99427	17.00	20.00	20.00	3.00
5	661	889160	60.000	512400	99427	17.00	20.00	20.00	3.00
6	805	887500	59.955	512050	99348	17.09	19.95	19.79	3.12
7	980	888840	59.993	512850	99587	17.18	19.83	19.99	3.00
8	345	888920	60.000	512990	99624	17.20	19.81	19.99	3.00
9	771	888700	42.791	512860	99601	17.19	19.80	19.99	3.00
10	741	888670	60.000	512900	99593	17.28	19.85	19.87	3.00

Table 3: Results of cropping pattern A for planting area 70 ha

Strategy No.	No. of iteration	Total income (ZAR)	Total area (ha)	Total volume (m^3)	Total man-days	Wheat/ groundnut	Drybean/ maize	Cotton/ drybean	Wheat/ carrot
1	592	999000	70.000	601500	116470	20.00	20.00	20.00	10.00
2	209	999000	70.000	601500	116470	20.00	20.00	20.00	10.00
3	367	994780	70.000	601640	116430	19.97	19.73	19.58	10.71
4	537	999000	70.000	601500	116470	20.00	20.00	20.00	10.00
5	854	999000	70.000	601500	116470	20.00	20.00	20.00	10.00
6	713	994850	69.993	600390	116000	19.12	19.97	19.95	10.96
7	558	998160	69.977	601330	116430	19.93	19.94	19.99	10.11
8	925	991620	69.999	600760	116040	18.77	19.58	19.97	11.68
9	332	996170	69.987	601680	116490	19.86	19.71	19.91	10.51
10	210	998360	70.000	601620	116500	19.96	19.91	20.00	10.13

Table 4: Results of cropping pattern A for planting area 75 ha

Strategy No.	No. of iteration	Total income (ZAR)	Total area (ha)	Total volume (m^3)	Total man-days	Wheat/ groundnut	Drybean/ maize	Cotton/ drybean	Wheat/ carrot
1	452	1106375	75.000	639000	123640	20.00	25.00	25.00	5.00
2	322	1106200	75.000	639030	123650	20.07	25.00	24.93	5.00
3	190	1106400	75.000	639000	123640	20.00	25.00	25.00	5.00
4	470	1106375	75.000	639000	123640	20.00	25.00	25.00	5.00
5	663	1106375	75.000	639000	123640	20.00	25.00	25.00	5.00
6	694	1104300	74.992	641980	124650	21.31	24.03	24.65	5.00
7	933	1103200	74.992	646190	126070	22.53	22.60	24.87	5.00
8	597	1102700	74.997	647320	124160	22.94	22.24	24.82	5.00
9	849	1105300	74.997	641180	124380	20.81	24.28	24.91	5.00
10	755	1105300	74.945	638950	123690	20.16	24.85	24.94	5.00

Table 5: Results of cropping pattern A for planting area 135 ha

Strategy No.	No. of iteration	Total income (ZAR)	Total area (ha)	Total volume (m^3)	Total man-days	Wheat/ groundnut	Drybean/ maize	Cotton/ drybean	Wheat/ carrot
1	517	1967100	135.000	1143000	219460	30.00	45.00	45.00	15.00
2	208	1967100	135.000	1143000	219460	30.00	45.00	45.00	15.00
3	375	1961000	135.000	1158900	224810	35.29	39.72	44.99	15.00
4	483	1967100	135.000	1143000	219460	30.00	45.00	45.00	15.00
5	723	1967100	135.000	1143000	219460	30.00	45.00	45.00	15.00
6	998	1962400	134.966	1145500	220340	32.05	44.23	43.66	15.03
7	1000	1964500	134.999	1148400	221270	31.98	43.24	44.78	15.00
8	832	1964800	134.999	1147100	220830	31.64	43.70	44.66	15.00
9	911	1966500	134.993	1144100	219850	30.44	44.61	44.95	15.00
10	566	1962300	134.960	1150400	221980	33.04	42.50	44.41	15.00

Table 6: Results of cropping pattern B for planting area 60 ha

Strategy No.	No. of iteration	Total income (ZAR)	Total area (ha)	Total volume (m^3)	Total man-days	Wheat/ potatoes	Onions/ watermelon	Lucerne	Pecan
1	344	2845500	60.000	707940	3709900	3.00	19.87	10.00	27.13
2	470	2845400	60.000	716830	3853600	3.00	18.52	10.00	28.47
3	161	2845500	60.000	717070	3857300	3.00	18.49	10.00	28.51
4	255	2845500	60.000	707410	3701500	3.00	19.95	10.00	27.05
5	488	2845500	60.000	711390	3765800	3.00	19.35	10.00	27.65
6	554	2843400	59.962	708710	3727400	3.01	19.66	10.00	27.29
7	495	2834100	60.000	713410	3771600	3.93	18.37	10.00	27.70
8	390	2844800	59.993	713800	3804700	3.03	18.95	10.00	28.02
9	73	2840700	59.994	708250	3705300	3.37	19.54	10.00	27.08
10	905	2831200	59.993	703330	3605200	4.11	19.74	10.01	26.13

for farmland of 135 ha. The number of iteration, total income, total area and total man-days for planting area 135 ha are presented.

Table 6 presents the results generated by all the strategies of DE for cropping pattern B for farmland of 60 ha. In this table, the different planting areas for the 4 different crops are presented. The total income, total area, total volume and total man-days are also presented. In Table 7, the results generated by the 10 strategies of DE for cropping pattern C for farmland of 70 ha are presented with the planting areas for each of the crops. Table 8 shows the results of cropping pattern B for farmland of 75 ha generated by the DE strategies. In this table, the total income, total area, total volume and total man-days are presented. Table 9 presents the results generated by the 10 DE strategies for cropping pattern B for farmland of 135 ha with the planting areas for each of the crops or crop combinations.

In Table 10, the results of cropping pattern C for farmland of 60 ha by the 10 strategies of DE are presented. Table 11 presents the results of cropping pattern C for farmland of 70 ha. Results of cropping pattern C for farmland of 75 ha are presented in Table 12. In Table 13, the results for the 10 different strategies of DE for cropping pattern C for farmland

Table 7: Results of cropping pattern B for planting area 70 ha

Strategy No.	No. of iteration	Total income (ZAR)	Total area (ha)	Total volume (m^3)	Total man-days	Wheat/ potatoes	Onions/ watermelon	Lucerne	Pecan
1	118	3041450	70.000	768000	3696732	5.00	25.00	20.00	20.00
2	64	3041450	70.000	768000	3696732	5.00	25.00	20.00	20.00
3	150	3041500	70.000	768000	3696732	5.00	25.00	20.00	20.00
4	204	3041500	70.000	768000	3696732	5.00	25.00	20.00	20.00
5	257	3041500	70.000	768000	3696732	5.00	25.00	20.00	20.00
6	981	2994100	69.987	771880	3776600	6.04	22.86	21.09	20.00
7	943	3034500	70.000	768820	3702400	5.37	24.55	20.08	20.00
8	763	2988100	69.993	771350	3818000	5.10	23.23	21.66	20.00
9	922	3036500	69.994	768410	3702800	5.17	24.74	20.08	20.00
10	661	3029700	69.990	769560	3697200	5.91	24.08	20.00	20.00

Table 8: Results of cropping pattern B for planting area 75 ha

Strategy No.	No. of iteration	Total income (ZAR)	Total area (ha)	Total volume (m^3)	Total man-days	Wheat/ potatoes	Onions/ watermelon	Lucerne	Pecan
1	245	3246200	75.000	819000	3705800	10.00	25.00	20.00	20.00
2	123	3246200	75.000	819000	3705800	10.00	25.00	20.00	20.00
3	141	3246200	75.000	819000	3705800	10.00	25.00	20.00	20.00
4	269	3246200	75.000	819000	3705800	10.00	25.00	20.00	20.00
5	342	3246200	75.000	819000	3705800	10.00	25.00	20.00	20.00
6	726	3208300	74.852	819350	3783800	9.72	24.06	21.07	20.00
7	778	3243800	74.998	819290	3706300	10.16	24.83	20.01	20.00
8	789	3239100	75.000	820040	3706000	10.58	24.42	20.00	20.00
9	368	3241600	74.997	819640	3705900	10.37	24.63	20.00	20.00
10	925	3227500	74.989	821060	3720100	10.99	23.81	20.19	20.00

Table 9: Results of cropping pattern B for planting area 135 ha

Strategy No.	No. of iteration	Total income (ZAR)	Total area (ha)	Total volume (m^3)	Total man-days	Wheat/ potatoes	Onions/ watermelon	Lucerne	Pecan
1	202	6067200	135.000	1578900	8196400	15.00	35.55	30.00	54.45
2	81	6067200	135.000	1561500	7915900	15.00	38.18	30.00	51.82
3	176	6067200	135.000	1531300	7429100	15.00	42.75	30.00	47.25
4	236	6067200	135.000	1571400	8075600	15.00	36.68	30.00	53.32
5	388	6067200	135.000	1578500	8189800	15.00	35.61	30.00	54.39
6	593	6040700	134.961	1550500	7692800	16.84	38.39	30.06	49.68
7	585	6051300	134.958	1615100	8755300	16.11	29.15	30.00	59.70
8	829	6065800	134.999	1571600	8080700	15.00	36.62	30.04	53.34
9	570	6056100	135.000	1610400	8700400	15.42	30.34	30.19	59.05
10	152	6054800	134.971	1587100	8315100	15.73	33.66	30.06	55.52

Table 10: Results of cropping pattern C for planting area 60 ha

Strategy No.	No. of iteration	Total income (ZAR)	Total area (ha)	Total volume (m^3)	Total man-days	Wheat/ groundnut	Drybean/ maize	Olive	Citrus
1	362	2475300	60.000	627300	4169500	3.00	3.00	24.00	30.00
2	130	2475300	60.000	627300	4169500	3.00	3.00	24.00	30.00
3	294	2416500	60.000	606850	3806900	6.15	3.01	20.84	30.00
4	321	2475300	60.000	627300	4169500	3.00	3.00	24.00	30.00
5	419	2475300	60.000	627300	4169500	3.00	3.00	24.00	30.00
6	705	2449500	59.817	615430	4028700	3.23	3.84	22.80	29.95
7	377	2470400	59.981	627400	4163100	3.11	3.00	23.99	29.89
8	784	2468700	60.000	625000	4128800	3.36	3.00	23.64	30.00
9	608	2455000	59.881	619730	4054900	3.88	3.00	23.00	30.00
10	862	2458700	59.827	619270	4078900	3.18	3.44	23.22	29.99

of 135 ha are presented. In Table 10-13, the number of iterations, total income, total area, total volume and total man-days are presented.

Figure 1 shows the study area. Figure 2 presents the maximum total incomes in South African Rand (ZAR) generated for different cropping patterns on each of the farmlands. Figure 3 shows the minimum total irrigation water for different farmlands of 60, 70, 75 and

Table 11: Results of cropping pattern C for planting area 70 ha

Strategy No.	No. of iteration	Total income (ZAR)	Total area (ha)	Total volume (m^3)	Total man-days	Wheat/ groundnut	Drybean/ maize	Olive	Citrus
1	517	2729500	70.000	751500	4873600	3.00	7.00	30.00	30.00
2	233	2729500	70.000	751500	4873600	3.00	7.00	30.00	30.00
3	310	2726000	70.000	760330	4876400	5.94	4.06	30.00	30.00
4	529	2729500	70.000	751500	4873600	3.00	7.00	30.00	30.00
5	771	2729500	70.000	751500	4873600	3.00	7.00	30.00	30.00
6	827	2724000	69.736	751450	4869600	3.70	6.08	29.96	30.00
7	983	2726400	69.938	753520	4867900	3.99	6.00	29.94	30.00
8	975	2723400	69.944	752380	4848500	4.13	6.04	29.77	30.00
9	874	2721800	69.917	757140	4853900	5.67	4.44	29.81	30.00
10	996	2724500	69.978	749490	4844700	3.17	7.06	29.75	30.00

Table 12: Results of cropping pattern C for planting area 75 ha

Strategy No.	No. of iteration	Total income (ZAR)	Total area (ha)	Total volume (m^3)	Total man-days	Wheat/ groundnut	Drybean/ maize	Olive	Citrus
1	191	3209100	75.000	690000	4389600	5.00	5.00	20.00	45.00
2	84	3209100	75.000	690000	4389600	5.00	5.00	20.00	45.00
3	179	3209100	75.000	690000	4389600	5.00	5.00	20.00	45.00
4	158	3209100	75.000	690000	4389600	5.00	5.00	20.00	45.00
5	311	3209100	75.000	690000	4389600	5.00	5.00	20.00	45.00
6	744	3196300	74.883	689830	4266100	5.16	5.00	20.00	44.72
7	439	3186300	74.998	692340	4369400	5.54	5.00	20.05	44.40
8	545	3189100	74.998	691710	3910200	5.50	5.00	20.00	44.50
9	186	3201100	74.992	690610	4381000	5.19	5.00	20.00	44.80
10	857	3176800	74.899	691700	4355800	5.68	5.00	20.00	44.22

Table 13: Results of cropping pattern C for planting area 135 ha

Strategy No.	No. of iteration	Total income (ZAR)	Total area (ha)	Total volume (m^3)	Total man-days	Wheat/ groundnut	Drybean/ maize	Olive	Citrus
1	303	5325900	135.000	1255500	7304400	15.00	15.00	35.00	70.00
2	129	5325900	135.000	1255500	7304400	15.00	15.00	35.00	70.00
3	186	5325900	135.000	1255500	7304400	15.00	15.00	35.00	70.00
4	331	5325900	135.000	1255500	7304400	15.00	15.00	35.00	70.00
5	416	5325900	135.000	1255500	7304400	15.00	15.00	35.00	70.00
6	711	5227000	134.231	1217900	6764200	18.95	15.00	30.31	69.97
7	610	5221700	133.415	1216300	6728500	19.32	15.00	30.00	69.10
8	943	5284100	134.984	1234300	7032300	15.39	16.95	32.64	70.00
9	854	5297300	134.960	1250600	6424900	16.13	15.00	34.14	69.70
10	623	5249000	134.801	1230100	6872600	18.65	15.00	31.28	69.87

135 ha. In Fig. 4, labour requirement in man-days for maximum profit in each of the farmlands are presented.

Figure 5 shows the total incomes in South African Rand (ZAR) generated from different strategies of DE for farmland 60 ha using cropping pattern C. Figure 6 shows the total incomes in South African Rand (ZAR) generated from different strategies of DE for farmland 70 ha using cropping pattern C. In Fig. 7, the total incomes in South African Rand (ZAR) generated from different strategies of DE for farmland 75 ha using cropping pattern C are presented. The total incomes in South African Rand (ZAR) generated from different strategies of DE for farmland 135 ha using cropping pattern C are presented in Fig. 8.

From Table 2, it can be found that strategy 2 (DE/best/1/bin) is the best with the lowest iterations before convergence of 153, highest total income of ZAR 889 160, maximum total area of 60 ha, minimum total volume of 512 400 m^3 and lowest total man-days of 99 427. The corresponding planting areas are 17, 20, 20 and 3 ha for A1, A2, A3 and A4, respectively. Though other strategies performed well with equal total income, total area, total volume and total man-days, strategy 2 has the lowest iterations before convergence. In Table 3, strategy 2 also performed better than other strategies with only 209 iterations before convergence.

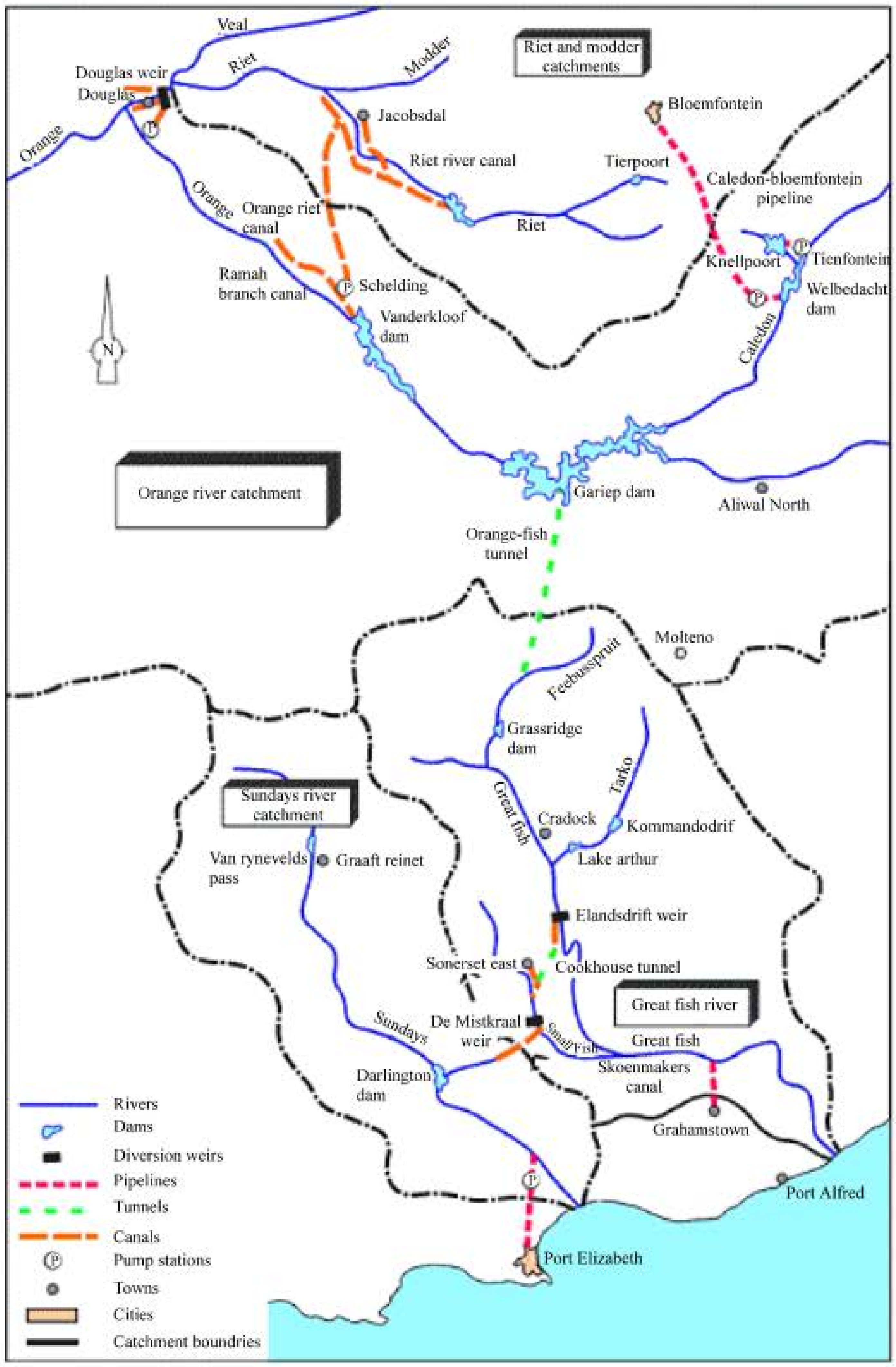

Fig. 1: The study area

Table 4 shows that strategy 3 outperformed other strategies including strategy 2 with 190 iterations before convergence and maximum total income of ZAR 1 106 400 against ZAR 1 106 200 for strategy 2. In Table 5, strategy 2 with 208 iteration before convergence outperformed others with ZAR 1 967 100 total income. Some strategies have very high iterations before

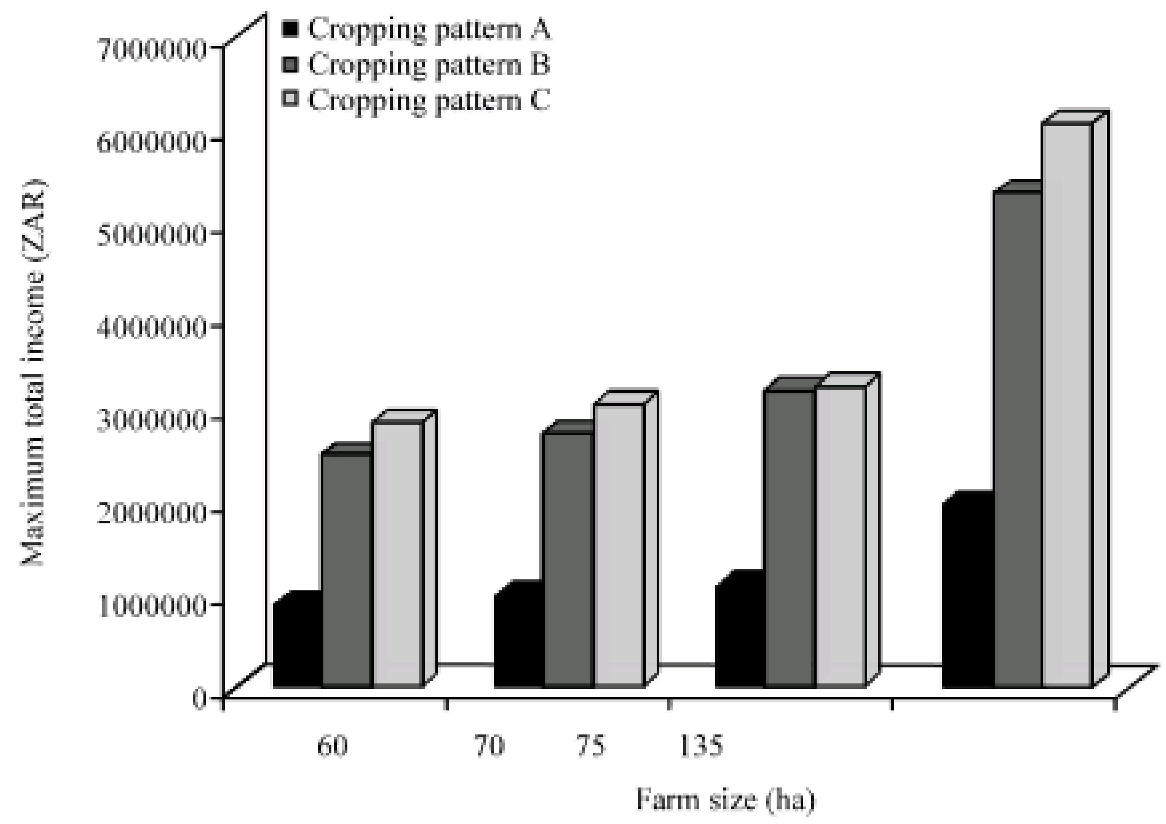

Fig. 2: The maximum total incomes in South African Rand (ZAR) generated for different cropping patterns on each of the farmlands

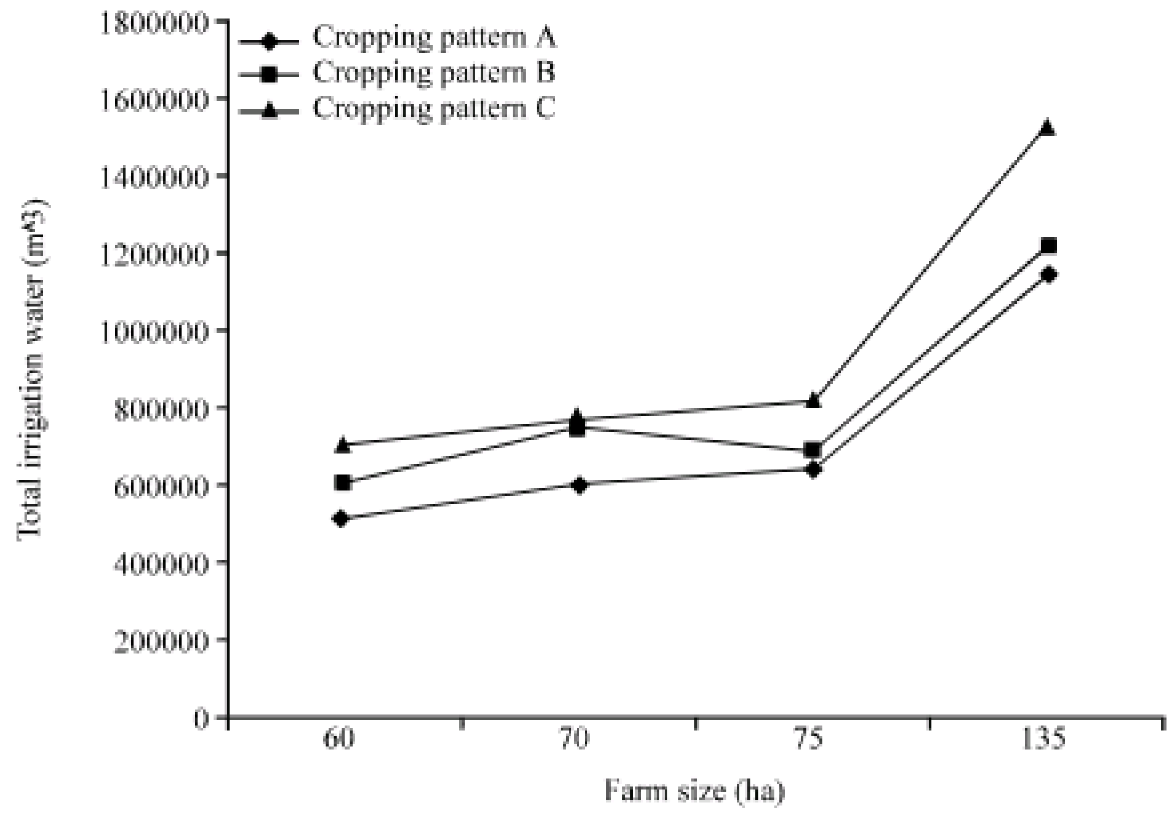

Fig. 3: The minimum total irrigation water for different farmland of 60, 70, 75 and 135 ha

convergence like strategy 7 with 1000 iterations. Results in Table 6 shows that strategy 3 outperformed others with 161 iterations before convergence. Though strategy 9 has only 73 iterations before convergence, it fails to generate the highest total income. In Table 7, strategy 3 outperformed other strategies with maximum total income of ZAR 3 041 500 and 64 iterations before convergence. Though strategy 2 converged only after 64 iterations, it fails to generate the highest maximum total income. In Table 8, the results show that strategy 2 outperforms other strategies with 123 iterations before convergence and maximum total income of ZAR 3 246 200. Strategy 3 generated the same maximum total income but with higher iterations of 141. Results in Table 9 show that strategy 2 is the best strategy with only 81 iterations before convergence and total income of ZAR 6 067 200. Though strategies 1, 3, 4 and 5 generated the same total income, they have higher iterations of 202, 176, 236 and 388,

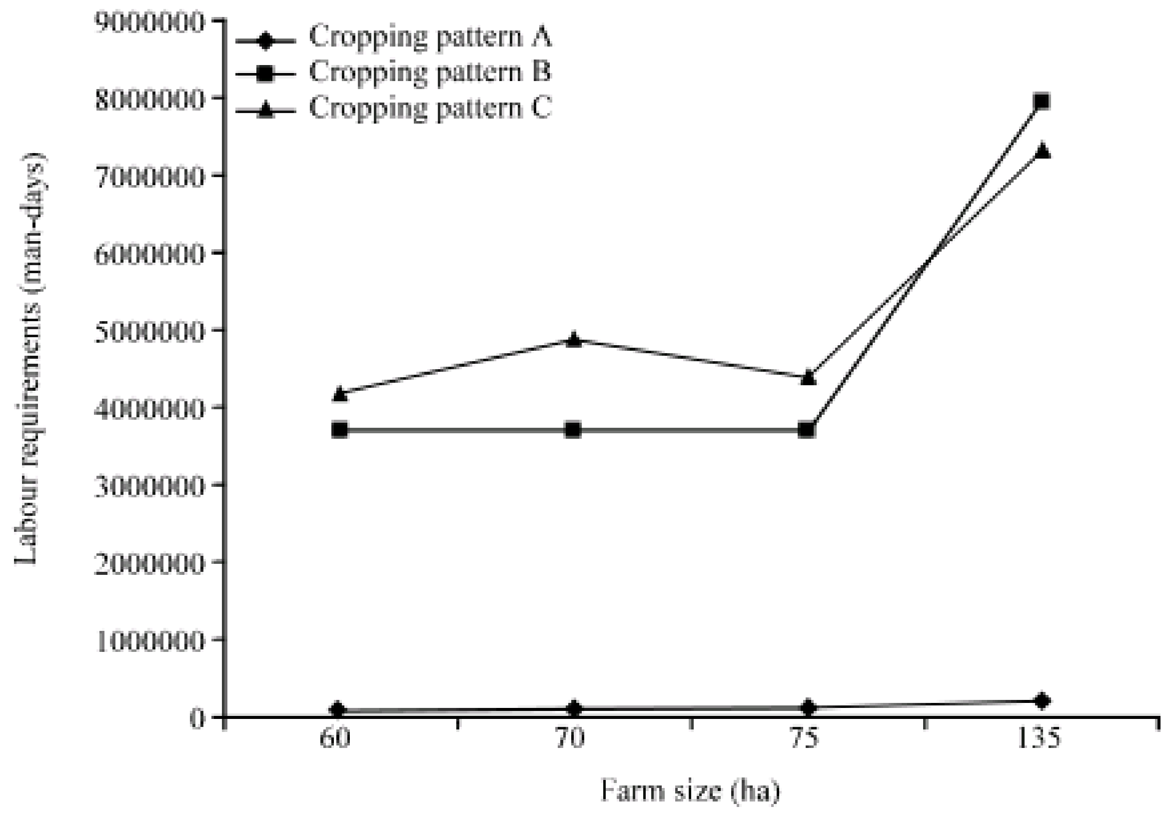

Fig. 4: The labour requirements in man-days for maximum profit in each of the farmlands

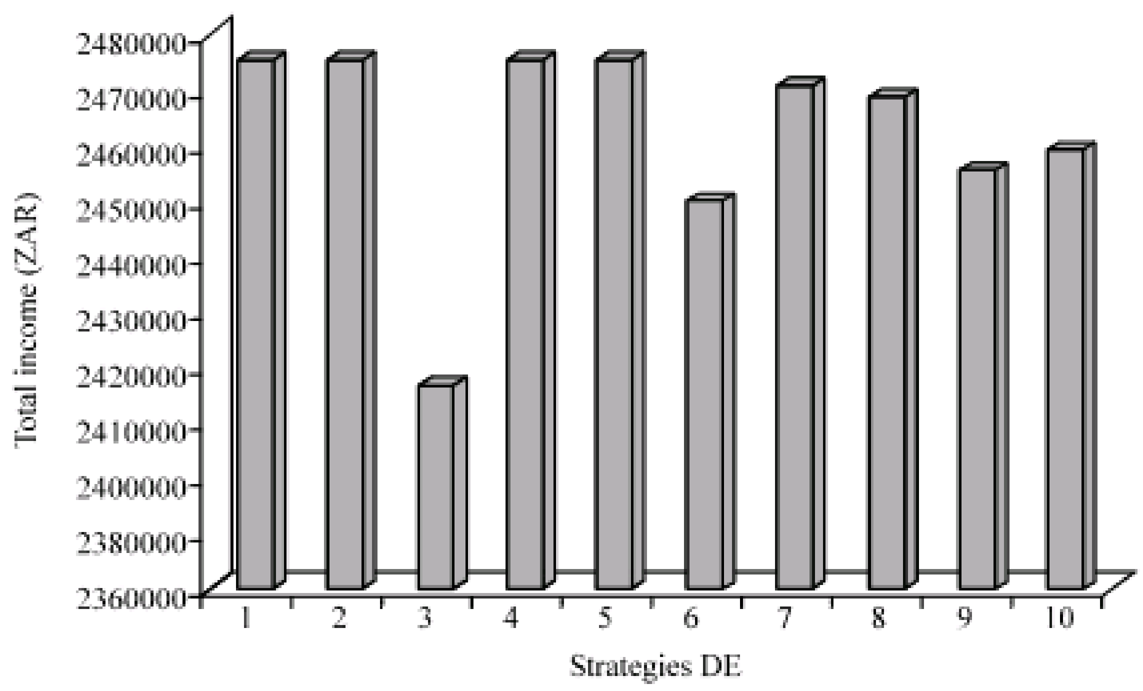

Fig. 5: The total incomes in South African Rand (ZAR) generated from different strategies of DE for farmland 60 ha using cropping pattern C

respectively. In Table 10, it is found that strategy 2 is the best DE strategy with 130 iterations before convergence and total income of ZAR 2 475 300. Strategies 1, 4 and 5 generated the same total income but higher iterations of 362, 321 and 419, respectively.

Strategy 2 with total income and iterations of ZAR 2 729 500 and 233, respectively is the best strategy in Table 11. Strategies 1, 4 and 5 have equal total income but higher iterations of 517, 529 and 771, respectively. Results in Table 12 show that DE strategy 2 with 84 iterations and ZAR 3 209 100 total income outperformed other DE strategies. Other DE strategies with binomial crossover method have the same total income but higher iterations of 191, 179, 158 and 311 respectively. This shows that DE strategies with binomial crossover method (strategies 1 to 5) are better than the strategies with exponential crossover (strategies 6 to 10) in this model. This can also be seen in the results presented. This is supported by the study by Vasan and Raju (2007) that suggest that DE/rand-to-best/1bin strategy which is also a binomial crossover method is the best giving maximum benefit taking minimum CPU time for their model.

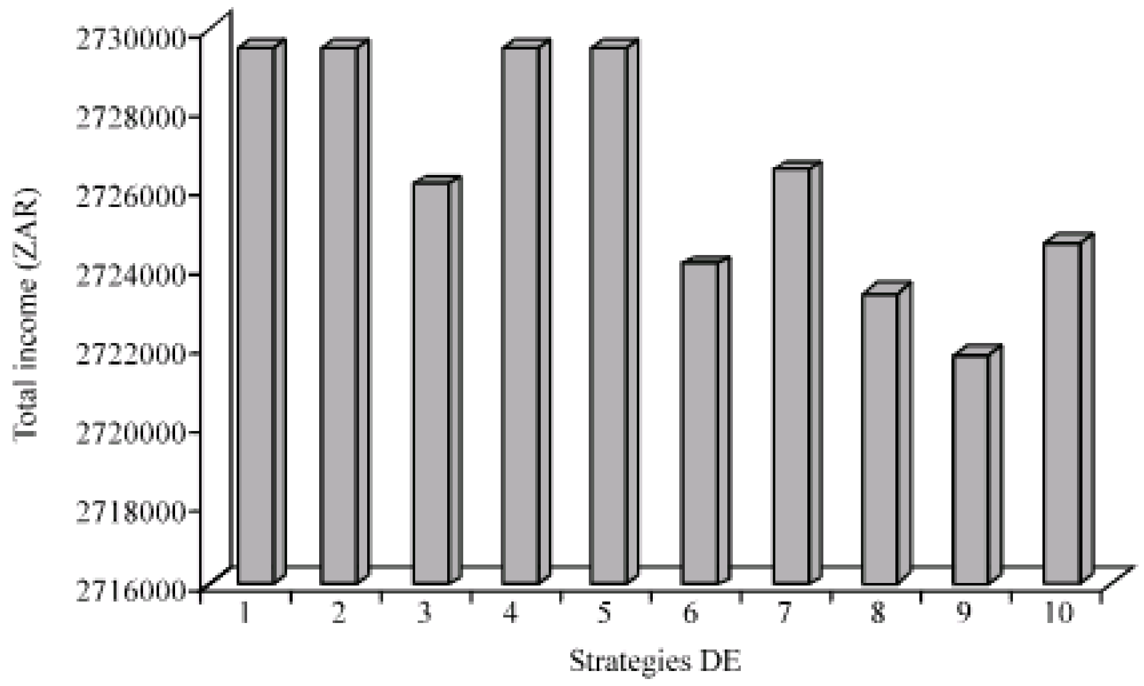

Fig. 6: The total incomes in South African Rand (ZAR) generated from different strategies of DE for farmland 70 ha using cropping pattern C

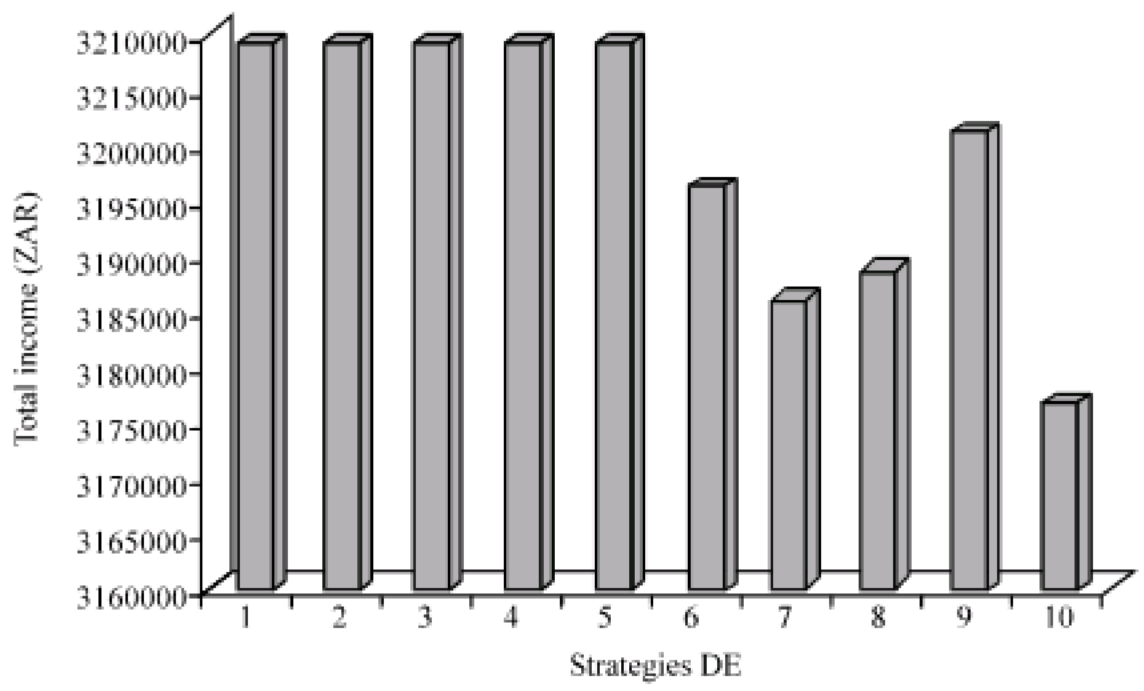

Fig. 7: The total incomes in South African Rand (ZAR) generated from different strategies of DE for farmland 75 ha using cropping pattern C

In Table 13, strategy 2 with iterations of 129 and maximum total income of ZAR 5 325 900 outperforms other strategies. It can also be seen that other strategies with binomial crossover method generated the same total income with higher iterations. It can be concluded from the results in Table 2-13 that DE strategies with binomial crossover and particularly, strategy 2 is the best for this model followed by strategy 3.

In Fig. 2, it is found that cropping pattern C is the best for all the farmlands in terms of maximum total income generated. It is found that cropping pattern A generated the lowest maximum total income in all the 4 farmlands. In farmland 75 ha, the maximum total income for cropping patterns B and C are nearly the same. It can be concluded that cropping pattern C is recommended for farmers in the study area to generate maximum total income.

In Fig. 3, it is found that cropping pattern C uses the highest volume of total irrigation water of all the cropping patterns. In the farmland 70 ha, both cropping patterns B and C use the same volume of total irrigation water. It can be concluded that cropping pattern C can only be advisable if enough irrigation water is available otherwise, cropping pattern A and B will be preferred because of less irrigation water that will be used.

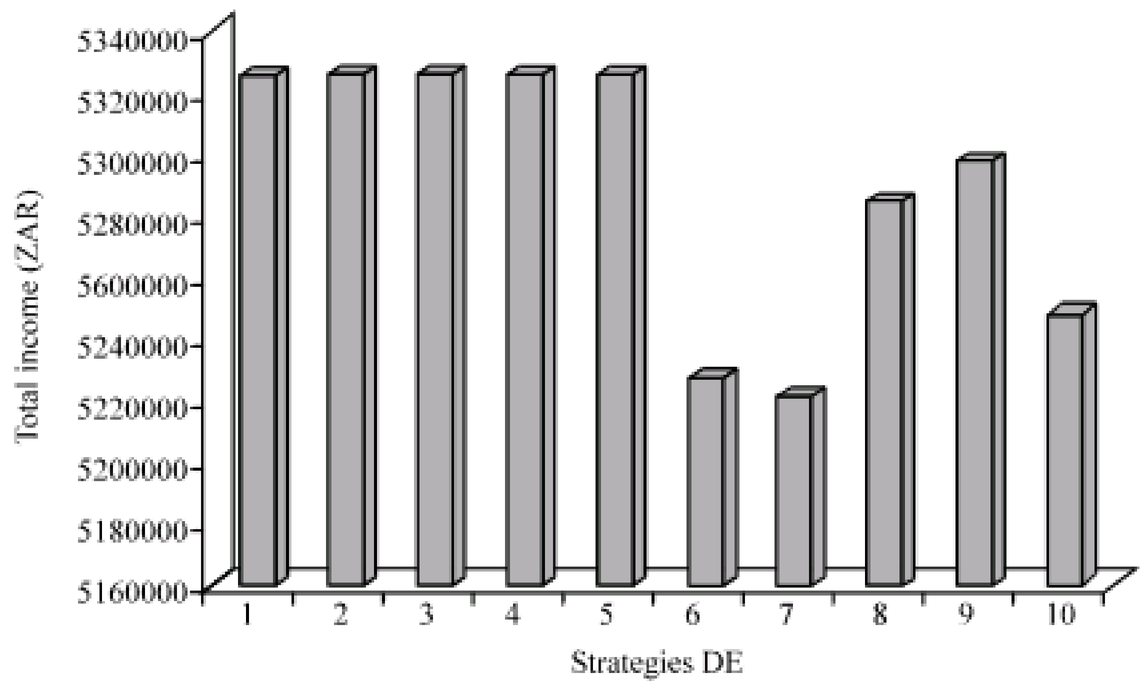

Fig. 8: The total incomes in South African Rand (ZAR) generated from different strategies of DE for farmland 135 ha using cropping pattern C

In Fig. 4, it is found that in cropping pattern C, labour requirement is the highest in all the farmlands except farmland 135 ha where cropping pattern B has the highest labour requirement. In fact, in farmland 70 ha, the labour requirement for cropping pattern C is abnormally high. It can be concluded that cropping patterns B and C can only be preferred by farmers who have enough available man power on the farm. Where there are limited workers on the farm, cropping pattern A will be preferred by the farmers.

Since cropping pattern C is preferred to others in terms of total income generated, only cropping pattern C is studied to find the most suitable DE strategy of all the 10 strategies for the model in terms of total income generated. In Fig. 5, it can be seen that strategy 3 generated the lowest total income of ZAR 2 416 500 and strategies 1, 2, 4 and 5 generated total income of ZAR 2 475 300 for farmland 60 ha. It can be seen that all the strategies with binomial crossover method except strategy 3 generated the same total income. Therefore, binomial crossover method is the best for this model. Also, strategy 3 is the worst of all the strategies for the farmland 60 ha in this model.

In Fig. 6, it is found that strategies 1, 2, 4 and 5 have the highest total income of ZAR 2 729 500. Strategy 9 generated the lowest total income of ZAR 2 721 800. Also it is concluded from the results that strategy 3 is the worst strategy of all the strategies with binomial crossover and strategies with binomial crossover are the best for the model in terms of total income generated.

In Fig. 7, it can be seen that all the strategies with binomial crossover (strategies 1 to 5) generated equal total income of ZAR 3 200 100. They all perform equally in terms of total income generated. Strategy 10 is the worst with only ZAR 3 176 800 total income generated.

From the results in Fig. 8, total income of ZAR 5 325 900 is generated by strategies 1 to 5 on the farmland 135 ha. Strategy 7 generated the lowest total income of ZAR 5 221 700. In this Fig., it can be concluded that strategies 1 to 5 with binomial crossover method are better than the ones with exponential crossover method (strategies 6 to 10) in this model.

In summary, DE is a good optimizer for determining crop pattern in a water scarce environment. Previous results on the application of DE to irrigation planning and crop planning show that DE strategies with binomial crossover are the best for the models (Reddy and Kumar, 2007b; Janga and Nagesh, 2008). This is in support of this study that finds strategies with binomial crossover the best for determining the optimum cropping pattern. This study was able to determine the optimum cropping patterns that will increase production returns in the Lower Orange River catchments as proposed.

CONCLUSIONS

The 10 strategies of DE are applied to the cropping pattern model in the Lower Orange irrigation areas to determine the best strategy for the optimization model. The irrigation areas are divided into farmlands of 60, 70, 75 and 135 ha by the management of Lower Orange River catchments and distributed to farmers in these catchments. In this study, 3 different cropping patterns are studied to determine the best cropping pattern for the study area in terms of maximum total income generated from farming, irrigation water use and total man-days required on the farm. It is found from the results that DE strategy 2 (DE/best/1/bin) outperformed other strategies. Also, it can be concluded that DE strategies with binomial crossover method (strategies 1 to 5) outperformed DE strategies with exponential crossover method (strategies 6 to 10).

It can be concluded that if enough irrigation water is available for farming in the study area, cropping pattern C is the best for farmers to generate the highest total income. Enough farm workers must also be available to consider cropping pattern C. It is found from this study that cultivating larger area of land may not necessarily imply higher profit for the farmers. A small area with good cropping pattern can generate more profit. Therefore crop planning is essential in a farming business and this model is a good choice for cropping pattern in a water scarce environment like South Africa. The whole catchments can be further studied to find the optimum cropping patterns that will be suitable for each sub-area. Moreover, reservoir operation can be incorporated to the study to find appropriate release policy that will satisfy all the water users downstream of the dam including the farmers.

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