Utilisation of nutrient-enriched waste water from aquaculture in the production of selected agricultural crops

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Abstract

A comparison is made of the water efficiency of two types of drip-irrigation systems and one micro- and one flood irrigation system, using nutrient-enriched water, in the production of selected vegetable and maize crops. Results showed the micro- and drip-irrigation systems to be the most economical in terms of water usage. Of these, the drum-drip-irrigation system was the most efficient and probably the system of choice to be developed further for community-based sustainable food production systems in predominantly rural areas of South Africa.

Introduction

Calculations of South Africa's potential surface and underground water resources revealed that this country can only support 80 m. people, and that large-scale shortages of food can be expected under such conditions. This may then lead to the outbreak of serious nutritional diseases, especially amongst the country's rural communities (Frankish, 1978; Kirsten, 1974; Steyn et al., 1995).

Although the agricultural output of South Africa can potentially increase much more to meet the demand for food for the immediate future, the ultimate constraint in the long term will remain the availability of water and its optimal use. With an average annual precipitation of approximately 497 mm (which is well below the world average of 860 mm), storage dams are continuously being constructed to retain some of the surface runoff water to meet the increasing demand for domestic, industrial and agricultural use. Although it has already become necessary to recycle water for industrial purposes in some parts of the country because of the shortage of water, there still remains considerable scope for extending the food production potential of water available to agriculture. One way to achieve this is to integrate aquaculture with traditional agricultural practices, where the same water can first be used to grow fish before being used to irrigate crops. The contribution of aquaculture towards food production in South Africa, however, is at this stage still insignificantly small, with an estimated income of about R18 m. per year (DWAF, 1996).

One of the first serious attempts in South Africa at the development of a community-scale poultry-fish-vegetable integrated aquaculture-agriculture system aimed at sustainable food production in rural areas, was that of Prinsloo and Schoonbee (1987). Nutrient-enriched wastewater from duck-fish ponds was used to successfully produce a variety of vegetable crops. Yields were significantly higher using this water compared to those of the same type of vegetables irrigated with freshwater. Since then, a number of similar vegetable production trials were undertaken using wastewater from water-recirculating intensive fish production systems which, in some cases, was again reused for integrated poultry-fish production prior to its utilisation as irrigation water for vegetable production (Prinsloo et al., 1999 a,b,c,d). The same water was then used to evaluate the efficiency of four different methods of irrigation in the production of selected agricultural crops.

In this paper the efficiency of drip, drum-drip, micro- and flood irrigation systems, using nutrient-enriched water in the production of cabbage, spinach, lettuce, beetroot, carrots, green beans and maize is compared.

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Materials and methods

Irrigation water used

Two types of nutrient-enriched irrigation water were used for the drip, drum-drip and micro-irrigation systems and for flood irrigation, respectively. In the first case, nutrient-enriched wastewater was obtained from a recirculating intensive fish production unit stocked with tilapia *Oreochromis mossambicus* (Peters) and the sharptooth catfish *Clarias gariepinus* (Burchell) at densities which ranged between 200 and 400 fish/m^3 of water (unpublished data).

This same water was also pumped into integrated fish-poultry ponds where chicken sheds were suspended over the fish ponds which then received a further enrichment of the water as a result of the nutrients emanating from chicken droppings and waste chicken food (Prinsloo et al., 1999d). This water was used in the flood irrigation programme. Physical and chemical analyses were undertaken on both types of water during both the summer and winter crop production cycles.

Physical and chemical conditions of waste water

As mentioned, routine physical and chemical analyses were undertaken on the two types of wastewater used for irrigation purposes during both the summer and winter crop production periods. Analyses were performed according to standard international procedures (*Standard Methods*, 1995). Water temperatures (°C) were measured using Thies hydro-thermographs. Dissolved oxygen concentrations (mg/ℓ) of the wastewater were determined using an oxy 92 meter. pH values were determined with a portable Hanna 8244 pH meter. The electrical conductivity (µS/cm) was recorded with a Hanna HI 8633 conductivity meter. Ammonia (NH_3-mg/ℓ), nitrite (NO_2-mg/ℓ), nitrate (NO_3-mg/ℓ), orthophosphate (PO_4-mg/ℓ), as well as turbidity (NTU) were all determined using a Hach spectrophotometer. Mean values, as well as ranges for each parameter, were determined and tabulated.

Plate 1 (top left)
Vegetables under drip-irrigation

Plate 2 (top right)
Six different vegetable crops under micro-sprinkler irrigation

Plate 3 (bottom left)
A drum-drip irrigation unit showing the three irrigation lines leading from each drum

Plate 4 (bottom right)
Flood irrigation of vegetables using nutrient-enriched water from an integrated fish-poultry production unit

Irrigation systems employed

As mentioned earlier, four types of irrigation systems were investigated. Three of these required comparatively small volumes of water namely:

- A commercially available 1.5 kPa Hydrodrip II integral lateral drip system provided with in-line 375 mm Super Amiad filters to remove solids from the wastewater and to prevent blocking of the drippers.
- A self-designed drum-drip system consisting of a 200 ℓ drum fitted with a valve and three lines of 30 mm plastic tubing 20 m in length each and punctured at 300 mm intervals with 0.3 mm sized perforations.
- A Rondo medium-range mini sprinkler which was employed as a third alternative of low dosage water irrigation system. The sprinklers were evenly spaced at distances of 1.5 m along the water distribution lines.

Table 1 **Water Quality Conditions of the Irrigation Water From Water Recirculating Intensive Fish Production Units, Used During the Summer-autumn Vegetable Production Cycle (December 1996 - April 1997)**						
Analysis	**Consecutive months (December 1996 - April 1997)**					
		December N = 1	**January N = 5**	**February N = 4**	**March N = 2**	**April N = 1**
Temperature (°C)	$\bar{x}$ range	24.2	24.5 (23.1-25.7)	25.4 (23.5-27.4)	20.2 (19.9-20.4)	20.0
Dissolved oxygen ($mg \cdot \ell^{-1}$)	$\bar{x}$ range	10.7	8.9 (6.1-10.9)	12.3 (8.5-17.2)	4.4 (3.8-5.1)	4.9
pH	$\bar{x}$ range	9.84	7.32-9.41	9.05-9.54	7.00-7.04	7.88
Conductivity ($\mu S \cdot cm^{-1}$)	$\bar{x}$ range	137.0	135.6 (133.0-139.0)	124.2 (114.0-140.0)	155.5 (155.0-156.0)	156.0
Ammonia (NH_3 $mg \cdot \ell^{-1}$)	$\bar{x}$ range	0.85	1.22 (0.70-1.69)	0.53 (tr-0.98)	3.93 (3.11-4.76)	2.48
Nitrite (NO_2 $mg \cdot \ell^{-1}$)	$\bar{x}$ range	tr	0.448 (0.356-0.578)	0.347 (tr-0.611)	0.883 (0.611-1.155)	0.762
Nitrate (NO_3 $mg \cdot \ell^{-1}$)	$\bar{x}$ range	tr	7.82 (7.00-8.80)	5.86 (tr-8.80)	12.3 (11.4-13.2)	9.2
Orthophosphate (PO_4 $mg \cdot \ell^{-1}$)	$\bar{x}$ range	8.09	10.501 (5.845-16.375)	15.117 (12.450-17.925)	8.912 (4.650-13.175)	0.450
Turbidity (NTU)	$\bar{x}$ range	-	33.2 (20.0-51.0)	35.2 (21.0-50.0)	41.0 (32.0-50.0)	80.0

- Flood irrigation was employed using a 50 mm diameter plastic pipe fitted with a valve. Water was siphoned from each pond and discharged into the different vegetable plots.

Size of plots and crops cultivated

The drip-irrigation system consisted of a 600 m^2 unit made up of 12 x 50 m rows. The complete drum-drip system was made up of 3 units, each with 3 rows of 20 m in length. The surface area covered by one such system was 180 m^2. The micro-irrigation system comprised 3 units of 10 rows each of 35 m in length and covered a total surface area of 1 050 m^2. The flood irrigation system consisted of 5 units of 15 rows each, covering 10 m in length with a total surface area of 750 m^2. Any one of these systems could be expanded depending on the specific needs of particular agricultural crops and water availability.

Seven different crops, including maize, were planted under one or more of the four different irrigation systems. Cabbage, spinach, lettuce, green beans and maize were cultivated under drip-irrigation. In the case of drum-drip-irrigation, carrots were added to the list. Micro- and flood irrigation had a total of seven different crops which included cabbage, spinach, lettuce, beetroot, carrots, green beans and maize.

A standard chemical fertiliser programme was followed for all vegetable plots, irrespective of the type of water used.

Harvesting of crops

All crops were harvested and weighed at the end of each production period. In the case of cabbage, carrots and beetroot, excessive leaves were first removed. In the case of maize, two production cycles under the different irrigation systems, were investigated. In one cycle, green mealies (cobs) and in the other cycle the production of dry maize grain was evaluated.

Evaluation of water usage efficiency of the various irrigation system

The total volumes of water used by each of the irrigation systems over a period of irrigation time, were accurately determined to obtain the efficiency in terms of water usage by particular systems. In the case of the drip-irrigation system, a number of drippers were selected at random and the quantities of water discharged were then collected and measured. A calculation was then made of the total number of drippers in use over the total surface area and for the duration of the irrigation time. A similar procedure was followed for the micro-irrigation system. In the case of the drum-drip system, the calculation was relatively simple as the total volume of water used could be accurately determined. For the flood irrigation, there was a constant flow of water through the pipe. The irrigation time for each vegetable plot could then be used to calculate the actual volume of water used for a specific duration of irrigation.

During sufficient precipitation in summer, there was no irrigation. This was taken into consideration in the calculation of the

TABLE 2 WATER QUALITY CONDITIONS OF THE IRRIGATION WATER FROM WATER RECIRCULATING INTENSIVE FISH PRODUCTION UNITS, USED DURING THE WINTER-SPRING VEGETABLE PRODUCTION CYCLE (MAY - SEPTEMBER 1997)						
Analysis	**Consecutive months (May - September 1997)**					
		May N = 4	**June N = 3**	**July N = 5**	**August N = 2**	**September N = 3**
Temperature (°C)	$\bar{x}$ range	17.2 (13.9-22.4)	13.4 (12.5-14.4)	13.8 (11.8-15.4)	14.2 (11.9-16.6)	18.4 (16.6-19.9)
Dissolved oxygen ($mg \cdot \ell^{-1}$)	$\bar{x}$ range	9.9 (7.8-12.3)	10.3 (10.0-10.8)	4.0 (2.1-6.9)	6.8 (6.3-7.3)	6.5 (3.2-9.0)
pH	$\bar{x}$ range	8.22-8.98	8.73-9.15	6.63-7.03	6.80-7.13	7.02-9.15
Conductivity ($\mu S \cdot cm^{-1}$)	$\bar{x}$ range	124.2 (112.0-133.0)	111.0 (108.0-114.0)	123.2 (109.0-144.0)	110.5 (109.0-112.0)	110.0 (97.0-118.0)
Ammonia (NH_3 $mg \cdot \ell^{-1}$)	$\bar{x}$ range	0.72 (0.49-0.95)	0.64 (0.51-0.78)	2.55 (2.00-3.15)	2.54 (1.63-3.45)	0.85 (0.55-1.40)
Nitrite (NO_2 $mg \cdot \ell^{-1}$)	$\bar{x}$ range	0.385 (0.363-0.416)	0.270 (0.264-0.274)	0.272 (0.198-0.356)	0.127 (0.040-0.214)	0.066 (0.021-0.096)
Nitrate (NO_3 $mg \cdot \ell^{-1}$)	$\bar{x}$ range	4.85 (1.80-7.00)	5.10 (3.50-6.60)	7.74 (5.30-13.60)	7.05 (6.20-7.90)	4.53 (2.60-5.70)
Orthophosphate (PO_4 $mg \cdot \ell^{-1}$)	$\bar{x}$ range	4.706 (0.120-8.940)	5.393 (5.030-5.795)	6.400 (4.525-7.590)	4.069 (3.908-4.230)	4.561 (4.065-5.188)
Turbidity (NTU)	$\bar{x}$ range	18.2 (13.0-21.0)	16.3 (8.0-21.0)	6.4 (4.0-10.0)	4.5 (4.0-5.0)	12.0 (6.0-23.0)

actual volumes of water used for each irrigation system, between planting and harvesting.

To evaluate the economy of water used by each of the systems, a water conversion factor (WCF) was created, expressed as the volume of water used to produce 1 kg of each specific crop. In the case of green mealies, it was the volume of water used in the production of 1 cob.

Results

Water chemistry of waste water used for irrigation

The physical and chemical conditions of the wastewater used for the drip, drum-drip and micro-irrigation during summer and winter vegetable production cycles, are summarised in Tables 1 and 2.

A comparison of the summer and winter temperatures of the water suggested a moderately warm winter and mild summer. None of the ponds, during any of the months, showed anoxic conditions to prevail in the pond water. Lowest mean winter dissolved oxygen (DO) values were measured in June (4 mg/ℓ) (Table 2). In summer the lowest mean DO concentrations occurred in March (4.4 mg/ℓ) and April (4.9 mg/ℓ) (Table 1). The pH of the nutrient-enriched water seldom declined below 7 (June and July in Table 2) and generally remained alkaline during both vegetable production cycles. Conductivity values suggested a slight build-up of dissolved solids in the water during summer with a maximum value of 156 µS/cm during March and April. In the winter cycle there was in fact a decline towards the end of the winter production cycle probably due to the addition of freshwater to the reservoir ponds. The concentrations of ammonia, nitrite and nitrate were not excessively high during either of the two seasons with individual and mean ammonia levels seldom exceeding 4 mg/ℓ. The soluble reactive phosphorus (orthophosphate) concentrations were clearly highest during the summer production cycle, with mean and individual phosphate concentrations exceeding 10 mg/ℓ during January, February and March (Table 1). The irrigation water was also more turbid during the summer months.

The water chemistry of the wastewater used for flood irrigation is summarised in Tables 3 and 4. In terms of temperature and DO conditions, the values were very similar to those recorded in the wastewater reservoir used for the drip- and micro-irrigation programmes. Mean water temperatures exceeded 11°C during all the winter months, and DO concentrations never declined below 2 mg/ℓ. In fact, in most cases the wastewater used during both seasons was generally well oxygenated, despite the organic loads released into these waters. pH also declined only on two occasions to slightly below 7 (March, Table 3 and July, Table 4). Conductivity values, reflecting the amount of solids in the flood irrigation water were slightly higher during both winter and summer than was the case for the drip- and micro-irrigation water (compare Tables 3 and 4 with Tables 1 and 2). Concentrations of ammonia, nitrite and nitrate were generally similar to those of the drip- and micro-irrigation waters with no excessively high individual or mean values recorded for any of the months concerned. The values of soluble reactive phosphorus (orthophosphate) also showed highest concentrations during some of the summer months with a mean

TABLE 3 WATER QUALITY CONDITIONS OF THE FISH POND WATER USED DURING THE SUMMER-AUTUMN CYCLE HOUSING THE LAYING HENS OVER A PERIOD OF FIVE MONTHS (DECEMBER 1996 - APRIL 1997)						
Analysis	**Consecutive months (December 1996 - April 1997)**					
		December N = 5	**January N = 25**	**February N = 20**	**March N = 10**	**April N = 5**
Temperature (°C)	x̄ range	22.0 (21.8-22.1)	23.0 (21.3-24.7)	23.9 (21.4-25.9)	18.9 (18.7-19.2)	18.8 (18.1-19.0)
Dissolved oxygen ($mg \cdot \ell^{-1}$)	x̄ range	11.6 (11.1-11.8)	7.8 (4.2-11.8)	10.1 (7.5-13.5)	7.1 (4.1-8.5)	6.7 (4.8-9.2)
pH	x̄ range	8.89-9.79	7.11-9.20	8.15-9.30	6.98-7.80	7.77-8.65
Conductivity ($\mu S \cdot cm^{-1}$)	x̄ range	169.8 (150.0-209.0)	180.6 (131.0-269.0)	131.3 (113.0-138.0)	165.0 (142.0-183.0)	158.6 (142.0-180.0)
Ammonia (NH_3 $mg \cdot \ell^{-1}$)	x̄ range	0.83 (0.37-1.46)	0.75 (0.37-4.33)	0.40 (tr-1.34)	2.83 (0.43-5.74)	0.49 (0.40-0.59)
Nitrite (NO_2 $mg \cdot \ell^{-1}$)	x̄ range	tr (tr-tr)	0.127 (0.007-0.574)	0.043 (tr-0.330)	0.354 (tr-0.891)	0.022 (0.010-0.046)
Nitrate (NO_3 $mg \cdot \ell^{-1}$)	x̄ range	0.1 (tr-0.5)	6.5 (4.8-8.8)	6.1 (tr-17.6)	6.3 (4.4-8.8)	7.2 (6.2-9.2)
Orthophosphate (PO_4 $mg \cdot \ell^{-1}$)	x̄ range	6.688 (4.985-9.010)	16.627 (3.480-54.750)	17.963 (11.613-34.175)	11.273 (7.775-21.225)	0.905 (0.525-1.250)
Turbidity (NTU)	x̄ range	-	79.2 (36.0-114.0)	69.1 (31.0-139.0)	65.3 (56.0-79.0)	63.0 (42.0-82.0)

peak of 17.96 mg/ℓ during February (Table 3). The water was slightly more turbid during the summer months.

Vegetable production

Cabbage production during both seasons for all four types of irrigation exceeded the average for agriculture in South Africa (Coertze, 1996). The best crops were obtained by means of the summer drip-, micro- and flood irrigation systems, where a mean production of more than 10 000 kg/1 000 m^2 land was produced (Table 5).

Spinach production was clearly superior to the mean agricultural production recorded for all four types of irrigation. Best lettuce production was obtained for the winter flood irrigation system with a production of 4 294 kg/1 000 m^2 compared to the agricultural average of 1 500 kg. The mean production of lettuce for agriculture (Table 5) was also exceeded by the micro-irrigation, winter drum-drip and winter drip-irrigation systems respectively. Only in the summer drum-drip-irrigation was the mean production slightly inferior to the agricultural average namely 1 310 kg/1 000 m^2. Beetroot was only produced under micro- (both seasons) and flood irrigation systems (winter season). Superior results were obtained for the summer micro- and winter flood irrigation systems when the production exceeded more than 4 000 kg/1 000 m^2. The winter micro-production for beetroot was disappointingly low (1 179 kg/1 000 m^2).

Carrots were produced with the drum-drip (summer), micro- (winter) and flood irrigation systems (both seasons). The winter micro- and flood irrigation yielded superior crops, exceeding 6 000 kg/1 000 m^2 land in both cases. Green beans were produced during the summer seasons in all four types of irrigation systems. Production was only slightly higher than the agricultural average of 1 000 kg/1 000 m^2 in the case of the drip-, micro- and flood irrigation systems. Yields obtained using the drum-drip irrigation system were, however, clearly lower with 867 kg/1 000 m^2.

Extremely promising results were obtained with green mealies, providing a yield of more than 5 000 cobs/1 000 m^2 in the case of drip-, drum-drip and flood irrigation systems, compared to the agricultural average of 2 500 cobs (Oosthuizen, 1995). Even in the case of the micro-irrigation system, a yield of 4 446 cobs/1 000 m^2 was achieved. Dry maize grain was produced by using the drip, drum-drip and flood irrigation systems during the summer season only. The drum-drip irrigation system yielded 1 044 kg/1 000 m^2 of land followed by 922 kg/1 000 m^2 for flood irrigation, with the lowest yield of 620 kg/1 000 m^2 for drip-irrigation, compared to the agricultural average of 748 kg/1 000 m^2.

Evaluation of the water utilisation efficiency of the various irrigation systems

Cabbage, spinach and maize (cobs) were evaluated in terms of water used to produce 1 kg or 1 cob (Table 6). Lowest volumes of water to produce 1 kg of cabbage were achieved using the drip-, drum-drip and micro-irrigation systems (Table 6). Only 8.6 ℓ of water was required with the drum-drip-irrigation to produce 1 kg of cabbage, compared to 178 ℓ in the case of flood irrigation. An

TABLE 4
WATER QUALITY CONDITIONS OF THE FISH POND WATER USED DURING THE WINTER-SPRING CYCLE HOUSING THE LAYING HENS OVER A PERIOD OF SIX MONTHS (MAY - OCTOBER 1997)

Analysis		Consecutive months (May 1996 - October 1997)					
		May N = 20	June N = 15	July N = 30	August N = 10	September N = 10	October N = 5
Temperature (°C)	x̄ range	14.0 (10.4-18.9)	11.3 (9.9-12.8)	12.2 (9.8-15.4)	12.0 (9.7-14.4)	16.7 (13.7-20.1)	18.5 (18.3-18.6)
Dissolved oxygen (mg·ℓ^{-1})	x̄ range	10.0 (6.7-13.3)	8.0 (6.3-9.3)	10.0 (2.6-14.4)	9.5 (5.1-12.9)	6.5 (3.1-10.0)	5.2 (2.1-7.8)
pH	x̄ range	7.78-9.75	7.07-8.96	6.88-9.32	7.02-8.90	7.07-8.94	7.28-9.31
Conductivity (µS·cm^{-1})	x̄ range	146.2 (137.0-165.0)	149.9 (130.0-175.0)	147.5 (120.0-183.0)	149.9 (124.0-204.0)	138.8 (110.0-166.0)	178.8 (118.0-245.0)
Ammonia (NH_3 mg·ℓ^{-1})	x̄ range	0.79 (0.08-1.20)	0.99 (0.73-1.35)	2.13 (0.16-6.20)	2.11 (1.12-5.40)	1.77 (0.98-3.22)	4.17 (1.06-7.98)
Nitrite (NO_2 mg·ℓ^{-1})	x̄ range	0.218 (0.007-0.343)	0.106 (0.009-0.201)	0.104 (0.013-0.231)	0.070 (tr-4.000)	0.369 (tr-3.301)	0.0006 (tr-0.017)
Nitrate (NO_3 mg·ℓ^{-1})	x̄ range	2.28 (0.90-7.50)	1.51 (tr-6.60)	1.09 (tr-7.00)	3.57 (tr-10.60)	5.29 (1.80-8.00)	5.36 (3.10-8.80)
Orthophosphate (PO_4 mg·ℓ^{-1})	x̄ range	4.737 (0.098-10.910)	8.217 (5.935-10.390)	7.280 (3.253-10.085)	3.463 (2.208-3.988)	5.069 (2.738-8.815)	6.801 (3.625-10.360)
Turbidity (NTU)	x̄ range	30.6 (18.0-45.0)	39.5 (27.0-62.0)	56.6 (12.0-102.0)	62.9 (16.0-94.0)	44.9 (12.0-63.0)	64.4 (24.0-112.0)

almost similar situation existed where spinach was produced under drum-drip, micro- and flood irrigation, where 37 to 39 ℓ of water was required for drum-drip and micro-irrigation to produce 1 kg of spinach compared to 617 ℓ in the case of flood irrigation. In the case of maize production, the quantities of water used by the drip-, drum-drip and micro-irrigation systems to produce 1 cob were significantly lower than the volume of water used under flood irrigation, with a lowest volume of 15.9 ℓ/cob (drum-drip) compared to 405 ℓ/cob (flood irrigation).

Discussion

A number of vital problems exist concerning the most economic utilisation of our available water resources for domestic, agricultural and industrial use in South Africa. Apart from a general scarcity in areas where water is mostly needed, in particular in the densely populated rural regions of the country, there is also a serious demand for the most economical production of good quality animal protein and vegetables to provide in the essential nutritional needs of the inhabitants.

Numerous investigations have been made into the practical application and economics of various types of irrigation water in agriculture (Fisher and Nel, 1990; Eckard et al., 1991; Oosthuizen, 1991; Van der Ryst, 1991; Van Riet et al., 1994; Walker et al., 1995). Little has, however, been done to assist the small-scale rural farmer in the most viable and beneficial use of the limited quantities of water available for sustainable food production. This is especially the case where the re-utilisation of water in agriculture is concerned. The present study aimed at providing some directives for the implementation of community-scale integrated fish-cum-poultry-cum-crop production in which different alternatives of low-volume application of nutrient-enriched water to vegetable crops are compared in terms of their production potential. Nutrient-enriched water enabled crop yields which exceeded, in the majority of examples, the average yields obtained for some selected crops in agriculture (Oosthuizen, 1995; Coertze, 1996). The actual contribution of nitrogen and phosphorus in the irrigation water, although not specifically evaluated, at least partially accounted for the favourable production results recorded during this investigation.

In terms of the most economical use of water in crop productions expressed as WCF i.e. to produce 1 kg vegetables or 1 mealie cob, the drip-, drum-drip as well as the micro-irrigation systems all clearly showed these alternatives to be some irrigation systems of choice for rural crop production where a scarcity of water exists, in contrast to the volumes of water required in flood irrigation (Table 6). Of these, the drum-drip system, which is of simple construction and, in its operation, was especially economical for crops such as cabbage and maize with WCFs of 8.6 and 15.9 ℓ, respectively.

Shortcomings of the micro- and drip-irrigation systems mainly lie in the clogging of drippers and nozzles by suspended solids present in the nutrient-enriched irrigation water. This specific problem was overcome by the incorporation of standard in-line filters which were routinely cleaned during the irrigation process. This prevented any blockages of the water supply lines. However, the continuous medium- to long-term application of nitrogen- and phosphate-rich irrigation water from integrated aquaculture-agriculture systems appeared to have some negative effects on soil conditions. This aspect requires further investigation, especially where this type of effluent water is used in flood irrigation where

TABLE 5
VEGETABLE PRODUCTION (kg/1 000 m²) UNDER DRIP-, DRUM-DRIP, MICRO- AND FLOOD IRRIGATION SYSTEMS DURING SUMMER AND WINTER PRODUCTION CYCLES. VALUES FOR MAIZE ARE EXPRESSED IN TERMS OF NUMBER OF COBS/1 000 m² AND DRY GRAIN YIELDS (kg/1 000 m²) RESPECTIVELY.

Vegetable and maize	Vegetable production in kg/1 000 m² – Irrigation systems								Average production in agriculture (Coertze, 1996)
	Drip		Drum-drip		Micro		Flood		
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	
Cabbage	11095 (9740-12360)	5976 (4758-8960)	9610 (8740-10480)	7267 (3160-9505)	11382 (10965-11130)	5586 (3972-7096)	10244 (7630-12768)	8517 (5946-12408)	5000
Spinach	-	3751 (974-8688)	2114 (815-4520)	1732 (350-4613)	3305 (675-5935)	5947	1945 (1430-2460)	2997 (958-5184)	1200
Lettuce	-	2260	1310 (1010-1610)	2500 (1632-3773)	2103 (1900-2305)	-	-	4294	1500
Beetroot	-	-	-	-	4122 (1965-5852)	1179 (1124-1235)	-	4025 (2788-4792)	3000
Carrots	-	-	2247 (1146-3257)	-	-	6063 (5591-6635)	3915 (1483-6347)	6598 (5150-8047)	3000-4000
Green beans	1380	-	867	-	1179	-	1113	-	1000
Maize (cobs)	5490	-	5236	-	4446	-	5100 (4940-5280)	-	2500*
Maize (grain)	620	-	1044	-	-	-	922	-	748*

* According to Oosthuizen (1995)

much larger volumes of water are required in the irrigation process.

Investigations showed that the soil of the agricultural land at the ARU is of a sandy-loam nature with a clay content of 11% and a 66% sand. It has a very rapid hydraulic conductivity and all pH values of the soils remained acidic for all the irrigation plots. There is no apparent relationship between soil pH and the amount of phosphorus present in the particular irrigation soils which may well be affected by the continuous applications of abnormally high concentrations of soluble reactive phosphorus in the nutrient-enriched irrigation water. The very fact that elevated pH levels in the sandy soils may exceed the limits for optimal crop production, particularly so in the flood- and micro-sprinkler irrigation plots, suggests that the long-term continuous use of nutrient-enriched water on the soils may well become detrimental to the cultivation of vegetable crops. In order to rectify this problem, the application of EM technology (effective micro-organisms) (Prinsloo et al., in

TABLE 6 **WATER CONVERSION FACTOR (WCF) FOR THE SUMMER PRODUCTION OF CABBAGE AND SPINACH (ℓ/kg) AND MEALIES (ℓ/COB)**			
Irrigation systems	**WCF* for the various summer crops (in ℓ/kg except for mealies = ℓ/cob)**		
	Cabbage Star 3301	**Spinach (Fordhook giant)**	**Mealies (cobs) (TX 9)**
Drip (1.5 bar)	16.1	-	38.1
Drum drip	8.6	38.7	15.9
Micro	10.9	37.1	30.3
Flood	178.3	616.9	405.2
* Values excluding rainfall.			

preparation) to restore the chemical and microbial imbalances in these soils, have already been implemented.

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