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The Effect of Different *in-situ* Water Conservation Tillage Methods on Growth and Development of Taro (*Colocasia esculenta* L.)

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Abstract: Taro (*Colocasia esculenta* L.) is an important food crop in the diet of Swazi people. However, there is dearth of information in the country on appropriate agronomic practices which can adequately conserve soil moisture to meet taro crop water requirements. The effects of *in-situ* water conservation practices on growth, development and yield of taro were investigated. Five *in-situ* water conservation methods/treatments [tied ridges, ridges, half moon, flat (not irrigated) and flat (irrigated)] were evaluated. The flat (irrigated) treatment served as a control. The experiment was conducted in a sandy clay loam soil at Luyengo. The treatments were laid in a randomized complete block design (RCBD) replicated three times. Each plot measured 5.0 m x 5.0 m with inter-row spacing of 0.9 m and intra- row plant spacing of 0.3 m for flat seedbeds. The ridges were 0.3 m high and 1 m apart, and ties were 0.2 m high spaced at 0.5 m intervals. The half moons had a diameter of 0.5 m. Planting was done in October 2009 using corms. The plants were rainfed, except for the irrigated treatment where irrigation was done to field capacity when soil moisture matric potential reached 10 bars. Parameters measured included soil moisture, plant emergence, plant height, number of leaves, leaf length and leaf width. Leaf area and Leaf Area Index (LAI) were calculated. The fresh yield of corms was measured at 24 weeks after planting. The results showed plant emergence rate after three weeks being highest under the half moon, at 94% followed in decreasing order by irrigated flat at 90%, tied ridges at 85%, ridges at 82% and lastly flat (not irrigated) at 80%. The various treatments did not show significant ($p>0.05$) differences in plant height throughout the growing period. However plants grown in irrigated flat plots consistently exhibited significantly ($p<0.01$) the highest number of leaves compared to other treatments. A similar trend was also observed with LAI. Taro corm yield were significantly ($p<0.01$) affected by water conservation method used. The highest yield was obtained from the irrigated flat treatment (11 t/ha), followed in deceasing order by tied ridges (9.14 t/ha), ridges (7.87 t/ha), half moon (6.83) and lastly the lowest yield (4.98 t/ha) was recorded from the rainfed flat treatment. It can be concluded that growth parameters and yield of taro were highest under irrigation of flat land followed in decreasing order by tied-ridges, ridges, half moon and under rainfed flat conditions.

Key words: *Colocasia esculenta,* conservation tillage, controlled flooding, soil moisture conservation

INTRODUCTION

Agronomy of taro: Taro (*Colocasia esculenta* L.) is a perennial plant grown as an annual crop. The plant comprises a main stem with several suckers. The edible portion, the corm, is an erect, starchy, underground stem, which grows to over 30 cm. Estimates indicate that taro cultivation in the wet east tropical India dates back to 5000 B.C. and that the crop was further transported westward to ancient Egypt, where it was regarded by Greek and Roman historians as an important food crop (Jeri and Berry, 2000). About 10% of the world's population uses taro or taro-like plants (*Araceae*) as a staple in their diets, and for 100 million people this is an important daily food (Jeri and Berry, 2000). Hawaii alone has over 300 varieties of taro. Though not a major crop in Swaziland, it is an important food security crop in the diet of the Swazi people. Taro is particularly grown in the wetlands of the Highveld and Middleveld ecological zones. An estimated 20 ha is put under taro production (Nxumalo, 2002). Production is mainly done by smallholder subsistence farmers who grow the crop particularly for household consumption with little excess sold as fresh corms at local vegetable markets. The need for research on taro's agronomic needs under local conditions has been reported elsewhere (Tumuhimbise *et al.*, 2009; Ndon *et al.*, 2003; Goenaga *et al.*, 1995) and is necessary in Swaziland.

There are two main production systems used in taro cultivation; flooded or wetland taro production and dry-

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land (un-flooded) or upland taro production. Traditionally taro and rice have been produced in wetlands in Swaziland, Zimbabwe and other parts of southern Africa. Recently distribution and utilization of wetlands in Swaziland has been reported (Masarirambi *et al*., 2010). Flooded taro cultivation is appropriate in situations where water is abundant. The water may be supplied by irrigation, by the swampy nature of the terrain, or from diverted rivers and streams. Apart from rice and lotus, taro is one of the few crops that can be grown under flooded conditions. The large air spaces in the petiole permit the submerged parts to maintain gaseous exchange with the atmosphere. It is also important that the water in which the taro is growing is cool and continuously flowing, so that it can have adequate levels of dissolved oxygen. Warm stagnant water results in low oxygen content, and causes basal rotting of the taro (Jeri and Berry, 2000). Whatever the source, water supplied in adequate amounts remains a critical resource for taro production. This has previously been reported for other crops (Payero *et al*., 2008; Zhao *et al*., 2010).

Taro grown under controlled flooding tends to have a higher yield and minimal weed infestation than upland taro. However, flooded taro takes a longer time to mature, and involves a considerable investment in infrastructure development and operational costs. Due to continuous water availability, the time of planting is usually not critical in flooded taro production. Planting can be done at virtually any time of the year as long as ambient temperatures are conducive. Many producers take advantage of this phenomenon by staggering their planting dates in various plots. Thus they can have corms for sale virtually all year round, and have opportunities to fetch higher prices during off-season periods. Despite its advantages, flooded taro is restricted only to certain locations where the economics of production and water availability permit the system to be viable. By far the largest area and production of taro in the Asia/Pacific region occurs under dry-land conditions. Taro's high water requirements may demand supplemental water addition through irrigation. However most irrigation water in Swaziland is used for sugar cane production (Mhlanga *et al*., 2006; Peter *et al*., 2008) and various horticultural crops including citrus and pineapple. The potential of taro competing for water with other crops makes it imperative that alternative ways of obtaining or conserving this resource be looked into. The challenge of food security in the 21st century is likely to be intricately linked to the water scarcity and competition among various water uses (Rosegrant *et al*., 2002). Water conservation practices which include tillage techniques to manipulate land forms (Mupangwa *et al*., 2006; Twomlow *et al*., 2008) need to be investigated for their appropriateness in taro production.

Dry-land taro production implies that the taro planting time depends on rainfall and is usually done at the onset of the rainy season. In Swaziland, the rainy season normally begins in October/ November but climate variability and fluctuations of the rainfall pattern makes it unwise to stick to tradition (Manyatsi *et al*., 2010). The rainy season must last long enough (6-9 months) to enable the taro crop to mature. Planting dry-land taro involves opening up the soil with a spade or digging stick, inserting the corms (seed), and closing up by slightly compacting the soil on the sides and leaving the top surface relatively loose. Dry-land taro matures earlier than flooded taro, but the yield is much lower and the production inputs are also relatively less. In areas where there is a defined alternation of dry and wet seasons, planting is generally done at or shortly before the beginning of the rainy season (Chay-Prove and Goebel, 2006).

Taro performs well under daily average temperatures of 21 to 27ºC and soil pH ranging from 5.5 to 7. The highest taro yield is obtained under full sunlight intensity, however, most taro varieties appear to be more shade tolerant than most other crops (Onwueme, 1999). Pests and diseases that affect taro include the taro beetle and taro leaf blight disease. Spacing of approximately 90 cm by 60 cm is common, and a slightly wider spacing may be used where humid conditions are frequent and growing conditions not optimum (Chay-Prove and Goebel, 2006). Cultivation for weed control should be minimized to avoid damaging the roots and the developing corms. Yields vary between 4 and 20 t/ha. However, yields up to 70 t/ha have been recorded in Hawaii with heavy fertilisation.The global average is about 6.2 tons/ha while the African average is 5.1 tons/ha (FAO, 2008).

Nutritional value of taro: Taro is similar to the Irish potato (*Solanum tuberosum*) in many nutritional properties, and is sometimes referred to as the "potato" of the humid tropics. Compared to Irish potatoes, taro has higher protein content (1.5-3.0%), calcium, and phosphorus; has a trace of fat, and is rich in vitamins A and C. Moreover, taro is 98.8% digestible, because of its small starch grains (FAO, 2008). Over the past decades, Swaziland has been experiencing food shortages and malnutrition emanating from increased frequency of droughts, fluctuating rainfall patterns, floods, increased ambient temperatures and shifting of growing seasons (Manyatsi *et al*., 2010). As a result the country needs to diversify its food production and embrace water conservation methods for food production. Considering the nutritional importance of taro and the need to adapt to droughts caused by climate change and climate variation there is urgent need to improve agronomic practices pertaining to growing taro especially soil moisture conservation. Taro thrives under constant supply of ample amounts of water.

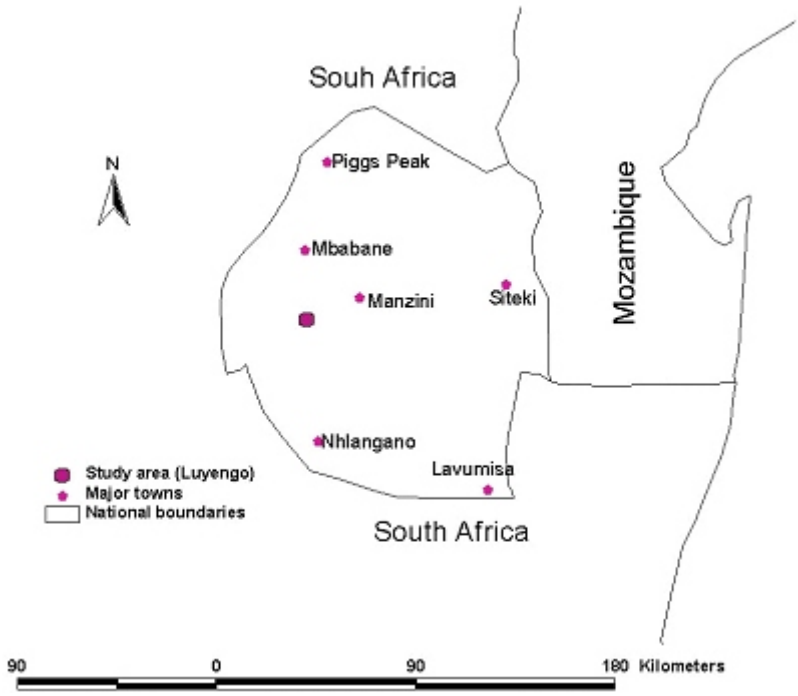

Fig. 1: Map of Swaziland showing location of study area

The objective of this study was to evaluate the growth and yield of taro under different *in-situ* water conservation tillage methods as an adaptation strategy under uncertain rainfall and irrigation supply water conditions.

MATERIALS AND METHODS

Study area and experimental design: This study was conducted at the University of Swaziland, Luyengo Campus, in the Agricultural and Biosystems Engineering Department Experimental plot between October 2009 and April 2010. Luyengo is located at latitude 26º34′44″ S and longitude 31º10′26″ E in the Middleveld ecological zone (Fig. 1). The average altitude of this area is 750 m. The mean annual rainfall of the study site is 980 mm with most rain falling between October and April. Drought hazard is about 40%. The average summer temperature is 27ºC and winter temperature is about 15ºC. The soils of Luyengo are classified as ferrasolic to fersialitic soils, with soil texture being predominantly sandy clay loam (Murdoch, 1970).

A single factor experiment consisting of five *in-situ* water conservation methods; tied ridges, ridges, half moon, flat (not irrigated) and flat (irrigated) was conducted in a sandy clay loam soil at Luyengo. A randomized complete block design was used for the experiment with three replications for each treatment. Each plot measured 5.0 m x 5.0 m with inter- and intra-row spacing of 0.9 and 0.3 m for flat seedbeds, respectively.

Seedbed preparation: The land was ploughed using a tractor-drawn disc plough and ridges were made with a wing ridger. The ridges were 0.3 m high and 1 m apart, and the ties were 0.2 m high spaced at 0.5 m intervals. The half moons had a diameter of 0.5 m. The ties and half moons were made using hand hoes.

Planting and crop management: Planting was done on the 7th of October 2009 using corms obtained from a farmer in the Highveld ecological zone. Compound fertilizer [2.3.2 (22)] was incorporated into the soil three weeks after planting at a rate of 300 kg per ha. The plants were top dressed 13 weeks after planting using limestone ammonium nitrate (LAN 28% N) at a rate of 200 kg/ha. The experiment was rain fed except for the treatment that was irrigated. A hose pipe was used to manually irrigate the flat (irrigated) treatment and this was done whenever the soil moisture matric potential reached 10 bars. The moisture content was measured using a soil moisture probe (Soil Moisture Equipment Corp. Santa Barbara, CA, USA). Weeding was regularly done with hand hoes to keep the crop weed free.

Data collection: Rainfall was recorded on a daily basis using a rain gauge installed at the edge of the experimental plots. Soil moisture content was measured

every three days using a soil moisture probe. Shoot emergence was observed and recorded two weeks after planting. Plant height, leaf length, leaf width and number of leaves per plant were recorded at three-week intervals.

The leaf area was determined using the leaf length, width, and a crop coefficient, and was expressed in cm^2. The linear measurements were made in centimeters and leaf area computation was done using Eq. (1):

$$\text{Leaf area} = \text{leaf length} \times \text{leaf width} \times 0.85 \text{ (crop factor)} \quad (1)$$

The leaf area index (LAI) was calculated using Eq. (2):

$$\text{Leaf Area Index (LAI)} = \text{Leaf area} / \text{Ground area occupied by the plant} \quad (2)$$

Corm yield was determined at 24 weeks after planting. Five plants were randomly sampled for harvesting in each plot.

RESULTS AND DISCUSSION

Meteorological data: The total rainfall received during the study period was 937.8 mm. The highest rainfall (191.8 mm) was received in the third quarter (15-18 weeks) of the growing period. The least rainfall (54 mm) was received between the 21st and the 24th Week after Planting (WAP). The rainfall received (937.8 mm) was slightly below the average of 980 mm. The mean temperature was 26.5ºC which was within the optimal range of 21 to 27ºC for taro growth (Onwueme, 1999). Figure 2 shows the rainfall received during the duration of the experiment.

Moisture retention: A highly significant ($p<0.01$) difference was observed in soil moisture conservation among the treatments. The tied ridges treatment was the most effective in conserving soil moisture compared to the other dry-land treatments (Fig. 3). The flat (irrigated) treatment was almost kept at field capacity all the time hence had the lowest moisture stress. The tied ridges treatment retained the greatest amount of water, in decreasing order followed by ridges, half moon and lastly flat (not irrigated) treatment. Similar results were reported by Twomlow *et al.* (2008) who observed higher concentrations of rainwater in planting basins than the rest of the plot.

Plant emergence and growth parameters: The plant emergence percentage was above 80% in all treatments. The half moon had the highest emergence percentage of 97% followed in decreasing order by flat (irrigated), tied ridges, ridges and flat (not irrigated) at 90, 85, 83 and 80 % respectively (Fig. 4). However, these differences were

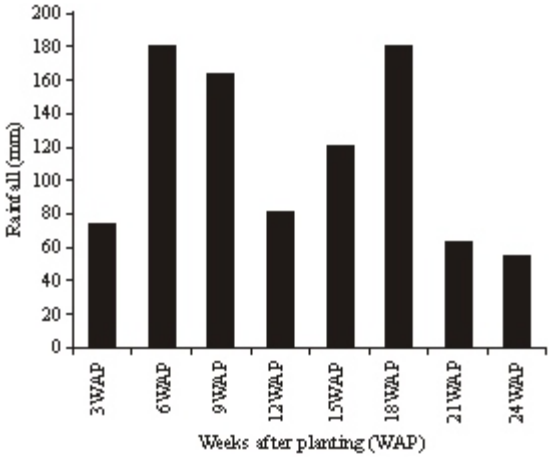

Fig. 2: Rainfall received during the period of study

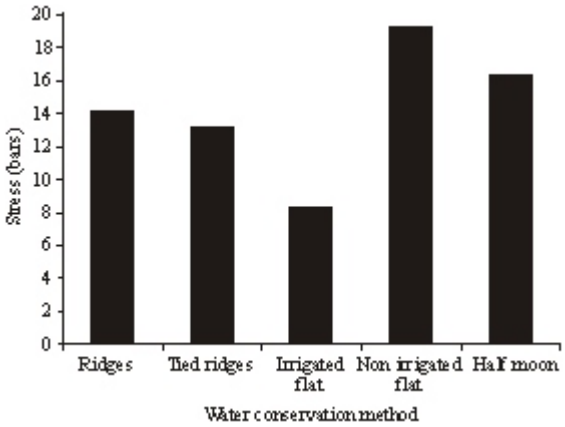

Fig. 3: Average moisture stress as affected by soil moisture conservation method during taro growth

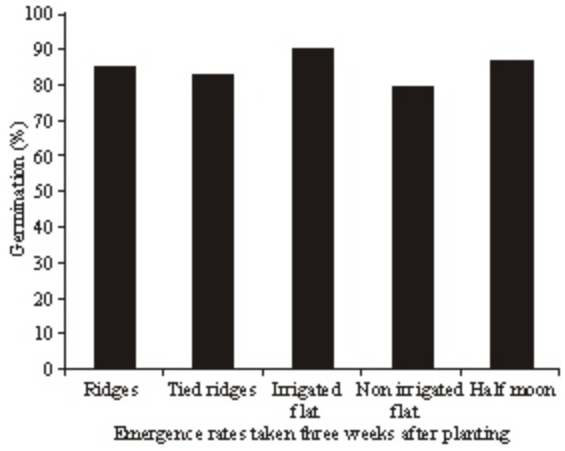

Fig 4: Emergence rates taken three weeks after planting

not significant ($p>0.05$), most likely because the corms in all treatments had enough resources including water to

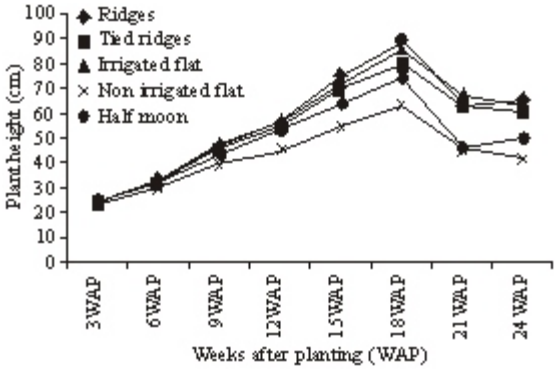

Fig. 5: Taro plant height at different stages of growth measured at three week intervals

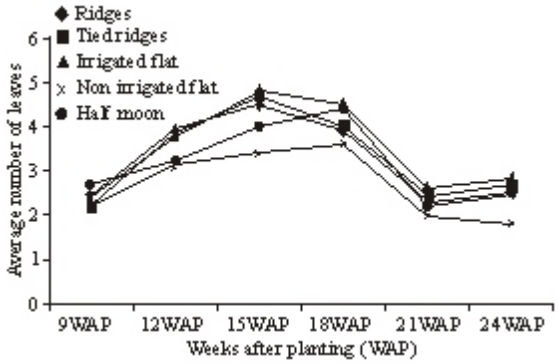

Fig. 6: Taro leaf number measured at three week intervals during the duration of the experiment

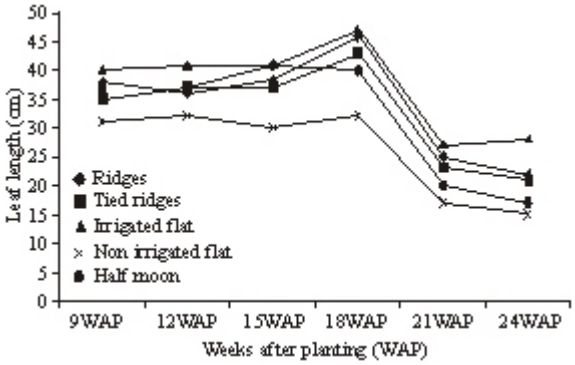

Fig. 7: Taro leaf length measured at three week intervals during the duration of the experiment

effect the physiological processes associated with shoot emergency requirements.

Plant height: The plants planted on ridges treatment were the tallest followed in decreasing order by those on tied ridges, flat (irrigated), half moon with those on flat (not irrigated) being the shortest. Plants reached their peak heights at 18 WAP (Fig. 5). There was, however, no significant ($p>0.05$) difference in plant height among the treatments. The decrease in plant height towards physiological maturity was when the leaves were dying and the plant was completing its seasonal growth cycle.

Number of leaves: There was a significant difference ($p<0.05$) in the number of leaves per plant between the flat (not irrigated) and the other treatments. The number of leaves per plant increased with time reaching a peak at around 15 WAP with the flat (irrigated) treatment exhibiting the highest number of leaves (4.9 leaves/plant) (Fig. 6). These results confirm the importance of water to plant growth in a semi-arid environment (Payero *et al*., 2008; Zhao *et al*., 2010) as shown by varying extends in leaf production where water was conserved or supplied through irrigation.

Leaf length: There were significant ($p<0.05$) differences in leaf length among treatments. Flat (irrigated) treatment had the longest leaf length for the duration of the experiment followed in decreasing order by tied ridges which alternated with ridges and half moon and lastly flat (not irrigated) treatment produced plants with the shortest leaf length (Fig. 7). The extremes of the results obtained are expected. What is interesting however is the fact that moisture conservation methods helped to increase leaf lengths of taro to varying extends during the growth periods measured at three-weekly intervals. At 18 WAP all the treatments had their longest leaf length and there after there was a decrease in the leaf length.

Leaf width: The leaf width results were collected at nine WAP due to the hail storms that occurred during the first 6 weeks of planting. During the duration of the project the leaf width increased in all treatments until the 18th week where it decreased until the end of the experiment. There were no significant ($p>0.05$) differences among the treatments. The flat (irrigated) treatment had the highest leaf width followed by ridges, tied ridges, half moon and the least was flat (not irrigated) treatment (Fig. 8).

Leaf area: The influence of treatments on leaf area was highly significant ($p<0.01$) as indicated in Fig. 9. On average the flat irrigated treatment had the highest leaf area, followed by ridges and tied ridges. The flat (not irrigated) treatment had the least average leaf area of 1498 cm^2. The highest leaf area was achieved at 18 WAP. However, there were no significant differences among plants planted on half moon, ridges and tied ridges which may imply that these treatments could have equally conserved the harvested rain water.

Leaf area index: As observed in leaf area, the differences in LAI were highly significant ($p<0.01$) among the treatments. The leaf area index was computed from the leaf area and the ground area that was occupied by the

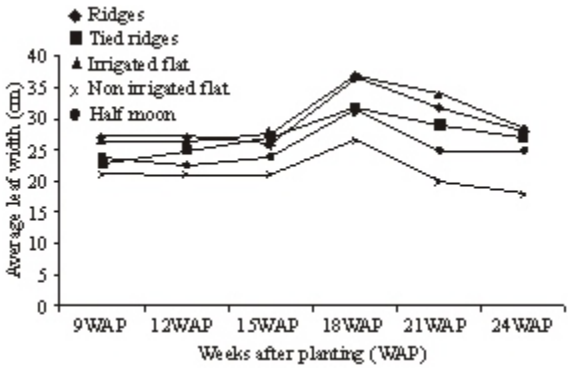

Fig. 8: Taro leaf width measured at three week intervals during the duration of the experiment

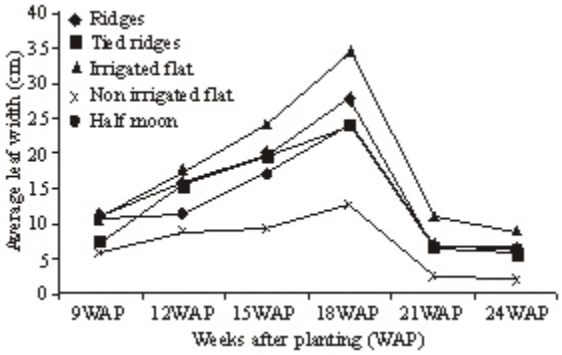

Fig. 9: Taro leaf area measured at three week intervals during the duration of the experiment

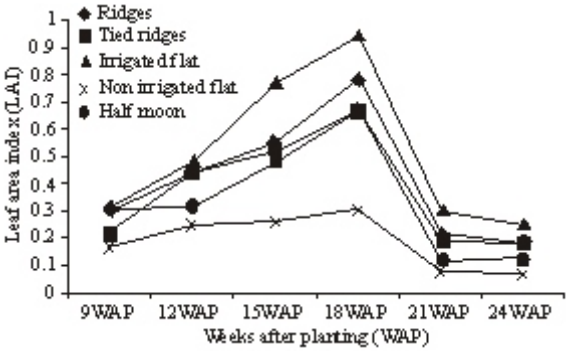

Fig. 10: Taro leaf area index (LAI) calculated at three week intervals for the duration of the experiment

plant. The flat (irrigated) treatment had the highest average leaf area index of 0.49 and the lowest was on the flat (not irrigated) treatment (Fig. 10). The trends in vegetative growth of taro (number of leaves, leaf length, leaf width, leaf area and leaf area index) suggest positive correlation with soil water availability. Similar results of higher LAI and higher growth parameters with increased water compared to less water availability to plants have been reported previously (Hassio, 1993; Shongwe *et al*., 2008).

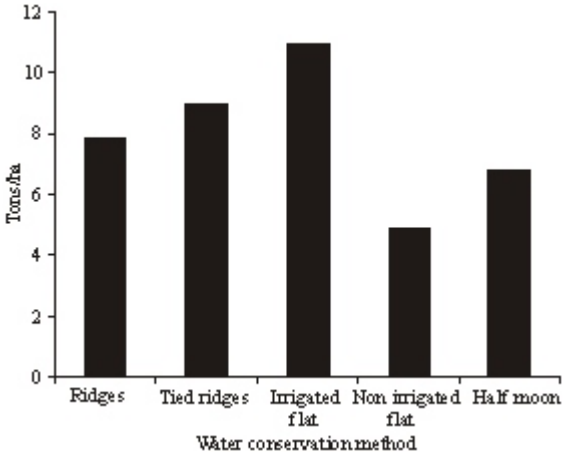

Fig. 11: Taro average yields obtained from the various water conservation treatments

This is because with increased water availability to plants the rate of metabolic processes in the plants increases and this leads to increased subsequent growth.

Yield of corms: The effect of treatments on yield was highly significant ($p<0.01$) among the treatments. The highest yield was obtained under the flat (irrigated) treatment which had a yield of 11 tons/ha followed in decreasing order by ridges (9.14 tons/ha), tied ridges (7.87 ton/ha), half moon (6.83 tons/ha) and flat (not irrigated) (4.98 tons/ha) (Fig. 11). The irrigated flat treatment and the treatments that conserved soil moisture (ridges, tied ridges and half moon) had yields above the global and African averages of 6.2 and 5.1 tons/ha, respectively (FAO, 2008). A similar trend was observed in vegetative growth parameters. Vegetative growth and corm yield of taro were influenced by soil water availability which depended on water harvesting and conservation practice used as previously described. Other than upland production of taro described here there is great opportunity for the country to grow the crop under flooding where water is abundant. The crop can be grown judiciously in wetlands found in Swaziland's four ecological zones. The wetlands have been identified and an attempt has been made to take stock of their inventory and current utilization with emphasis on environmental and biodiversity preservation (Masarirambi *et al*., 2010). Increased yields of crops brought about by conservation agriculture techniques which include rainwater harvesting and conservation have previously been reported and encouraged in these years of uncertain climate change (Rost *et al*., 2009; Mlipha, 2010; Manyatsi *et al*., 2010).

CONCLUSION

It can be concluded that the *in-situ* moisture conservation methods tested influenced soil water

availability and subsequent vegetative growth and yield of taro. Therefore, there is potential to improve dry-land taro production in Swaziland by adopting rainwater harvesting and soil moisture conservation tillage techniques. The yields obtained from the studied moisture conservation treatments, other than the flat (not irrigated) treatment, were above the average African yield of 5.1 tons/ha. The tied ridges and ridges seem to have greater potential to effectively conserve adequate soil moisture for taro production in the country. There is a need to further develop the tied ridging and ridging techniques to suite different farming conditions in the various ecological zones with consideration of farmer resource endowment.

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