J. Agr. Sci. Tech. (2017) Vol. 19: ??-??

Swiss Chard (*Beta vulgaris* L.) Water Use Efficiency and Yield under Organic and Inorganic Mulch Application

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ABSTRACT

South Africa is considered as a water scarce country and water shortage is a major constrains that often limits growth, yield, and quality of Swiss chard. A field experiment was conducted on Swiss chard (*Beta vulgaris* L.) in loamy soil to evaluate Water Use Efficiency (WUE), weed control, yield, and quality response to organic and inorganic mulch application during the winter/spring season (June to September). Treatments included bare-soil (control), grass/hay, and newspaper, white-maize-meal bag, white plastic and black plastic mulches. Black plastic, newspaper, and grass/hay mulches suppressed weeds significantly, which were encouraged under bare-soil, white plastic, and maize-meal bag mulch conditions. There was an increase in the number of leaves and leaf fresh mass with white plastic mulch, while bare-soil reduced plant dry mass and leaf area significantly. Leaf area was improved with white plastic, black plastic and maize-meal bag mulches. White plastic and grass/hay mulch improved *WUE* significantly, and exceled above other treatments at 259.9 and 242.0 kg ha^{-1} mm^{-1}, respectively, followed by black plastic mulch at 207 kg ha^{-1} mm^{-1}. Water use efficiency declined in the newspaper, maize-meal, and bare-soil treatments at 179, 130 and 74.7 kg ha^{-1} mm^{-1} *WUE*, respectively. Thus, the study reveals that the use of mulch under drip irrigation has an explicit role in increasing water productivity of Swiss chard.

Keywords: Leaf area, Plant fresh mass, Water applied, Weed control.

INTRODUCTION

Swiss chard (*Beta vulgaris* L.), a leafy biennial vegetable, belonging to the Chenopodiaceae family, is a highly nutritious leafy vegetable and popularly known in many parts of the world for its nutritious properties, all year round availability, low cost and is widely used in many dishes (Gao *et al*., 2009). Its leaves and stalks contain relatively high levels of vitamins A, B, and C, as well as minerals, such as calcium, phosphorus and iron (Pyo *et al*., 2004). Cooked leaves yield 20 kcal per 100 g and are very nutritious (van Wyk, 2005). South Africa is promoting the intake of nutritious leafy vegetables such as Swiss chard to alleviate widespread nutritional deficiencies, especially in rural communities (Faber *et al*., 2007).

South Africa is one of the countries likely to face significant water scarcity due to the absence of strategic water management systems (Mjoli, 2010). This will most likely result in potential conflicts between water requirements for domestic use, agriculture, and industry (Mjoli, 2010). In South Africa, rural communities are constantly affected by increased regulations restricting water usage and severe periods of drought. Improvements in Water Use Efficiency (WUE) in agriculture are needed due to the scarcity of fresh water, increasing input costs, and increasing population growth.

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Water use efficiency in this study is referred to harvested yield per unit area of soil water used, over the entire growing season (Lakew *et al*., 2014; Adams, 1998). The needs for improving *WUE* in crop production and sustainable use of water resources are clearly urgent (Zhang and Oweis, 1999). The solution could be to minimize water evaporation and suppress weeds that compete with crops for water resources.

Previous studies showed that biomass production and yield increased with irrigation (Mohawesh, 2016; Berihun, 2011) with improved *WUE*, crop growth and yield when mulch was applied (Yaghi *et al*., 2013; Tiwari *et al*., 2003). Mulches are differentiated into organic and inorganic mulches. Organic mulches are those derived from animal or plant materials, while inorganic mulches include gravel, crushed rock and synthetic plastic of various colors. Organic mulches, such as dry grass, sawdust and paper, would have an advantage of decomposing into soil at the end of the growing season, thus, gradually contributing to soil organic matter, as well as waste reduction, compared to plastic mulch (Law *et al*., 2006).

Mulching offers the benefit of soil cover, forms a physical barrier against soil water evaporation, retards weed development, results in more efficient use of nutrients, maintains good soil structure, and protects harvested crops from soil contamination (Li *et al*., 2004; Cohen *et al*., 2008) thereby may lead to increases in yield and possibly water use efficiency (Li *et al*., 2009; Berihun, 2011). It also protects the soil from water and wind erosion, as well as hail damage. Mulch funnels excess rain water away from the root zone, thus keeping the moisture regime in the root zone at a more stable level (Kasirajan and Ngouajio, 2012). Although herbicide application is effective in controlling weeds, it may adversely affect soil ecosystems and the environment, such as reducing soil microbial activities and elevating water contamination (Merwin *et al*., 1996).

Mulching is a potential solution to small holder and commercial farmers, depending on the material used, to improve yield and reduce the cost involved in the cultivation of vegetables. The majority of Swiss chard growers in South Africa are still producing in bare-soil and plants are subjected to weeds, soil moisture fluctuation, diseases and leaching of nutrients, especially nitrogen. There is a lack of information on how much water can be conserved when using organic and inorganic mulches for Swiss chard production with a drip irrigation system under South African conditions. Therefore, water conservation programs, such as mulching under drip irrigation to conserve moisture, are expected to play an important role in improving *WUE*. Water deficit often limits growth, yield, and quality of Swiss chard. Therefore, the objectives of this study were to investigate the effect of organic and inorganic mulch on the performance of Swiss chard in terms of water use efficiency, weed control, yield, and quality.

MATERIALS AND METHODS

Experimental Growth Condition

The trial was conducted directly in soil at the Agricultural Research Council-Roodeplaat, South Africa (25, 59 S; 28, 35 E and altitude of 1,200 m above sea level) from 09 May to 24 October, 2014. Climatic conditions of the experimental area are presented in Table 1. Composite soil samples (0-30 cm) collected before planting showed a pH of 7.04, and the available phosphorus was relatively low, while it had a rich content of available potassium. The soil type was sandy clay loam, and comprised of 52.1% sand, 21.9% silt and 26.0% clay, with a bulk density of 1.39 g cm^{-3} in the top 30 cm soil layer, with chemical characteristics as shown in Table 2. Swiss chard was subjected to six mulching treatments, i.e. control (bare-soil), white plastic sheet, black plastic sheet,

Table 1. Average monthly minimum and maximum temperature, rainfall and relative humidity during the experimental season (2014).[a]

Month	Rainfall (mm)	Temperature (°C)		Rh[c] -max (%)	Rh-min (%)
		max[a]	min[b]		
June	0	22.2	1.9	86.2	20.6
July	0	21.1	1.6	81.5	20.7
August	0.02	26.4	7.5	72.4	16.9
Septembe r	0.97	29.2	12.4	77.7	21.3
October	0.96	29.1	11.3	76.9	18.7

[a] Maximum, [b] Minimum, [c] Relative humidity.

Table 2. Chemical composition of the soil used in this experiment (May, 2014).

Parameters	Value
pH	7.04
P (mg kg^{-1})	17.8
K (mg kg^{-1})	204
Ca (mg kg^{-1})	790
Mg (mg kg^{-1})	251
Na (mg kg^{-1})	15.1

maize-meal bag, grass and double layers of newspaper in a plot to cover 2.7 m^2. The experiment was laid out as a randomized complete block design with four replicates. Dry grass mulch of 15 kg was applied around the seedlings to a height of 7 cm. Black and white plastic mulches of a thickness of 20 and 150 µm, respectively, were used. The maize-meal bag was white in color, which is the standard packaging for maize-meal in South Africa. Pre-plant fertilizer application was applied based on soil analysis, i.e. superphosphate (10.5% P) and Limestone Ammonium Nitrate (LAN) (28% N) fertilisers were broadcast at a rate of 23 kg ha^{-1} P and 38 kg ha^{-1} N, respectively. Potassium was not required according to soil analysis results. Four weeks after transplanting, plants were top-dressed by applying 16 kg ha^{-1} N through fertigation and thereafter 16 kg ha^{-1} N was applied every second week after harvest (5 times) using ammonium sulphate. Total amount of N applied was 150 kg ha^{-1}.

Swiss chard seeds of an open pollinated cultivar ('FordHook-Giant', Hygrotech Seed Pty. Ltd., South Africa) were sown in 09 April 2014, in 200 cavity polystyrene trays filled with a commercial growth medium, Hygromix® (Hygrotech Seed Pty. Ltd., South Africa), and covered with a thin layer of vermiculite after sowing. Seedlings were transplanted 28 days after seeding to 15 cm high and 90 cm wide soil ridges, with six rows per ridge. Ridges were 90 cm apart. Seedlings were planted in 3×0.9 m plots, at a plant spacing of 15×30 cm. There were 60 plants per plot (2.7 m^2) in total. Organic and inorganic mulches were applied on the ground on top of the ridges, with edges buried into the soil to hold the mulch (black plastic sheet, white plastic sheet, white maize-meal bag and newspaper mulches) in position, while grass/hay was not buried in the soil at the edges. Newspaper mulch was held in position by soil clods to prevent it from being blown away by wind. Seedlings were transplanted into the soil through holes of 6 cm diameter that had been made in the mulches.

Cultural Practices

Irrigation System and Soil Water Content Monitoring

A drip irrigation system was used to supplement rainfall with drippers placed at a spacing of 0.30 m. Drippers used were 20 mm non-leakage with an application rate of 2 L h^{-1}, at a pressure ranging between 100 and 120 kPa. Soil water content in the root zone was monitored twice a week using a neutron water meter (Campbell Pacific Nuclear Inc., USA, model Hydroprobe-503) that was calibrated for the experimental site.

Readings were taken at an interval of 0.20 m to a soil depth of 1 m by lowering the radioactive source through an access tube that was installed in the middle of each plot. Whenever the plant available water in the soil depleted to 40% level, the profile was refilled to field capacity. Water use (ET), in mm, was calculated using the soil water balance equation:

$$ET = \Delta S + P + I - Dr - R$$

Where, ΔS refers to the change in soil water storage (mm), P= Rainfall (mm), I= Irrigation (mm), Dr= Drainage below the bottom of the root zone (mm) and R= Runoff (mm). P was obtained from the weather data as recoded by the automatic weather station and rain gauges at the site; and I was obtained from water meters. ΔS was calculated from neutron probe measurements (Zhang and Oweis, 1999). Water Use Efficiency (WUE), in kg ha^{-1} mm^{-1}, was then calculated as the ratio of marketable yield (leaf fresh mass) over total water used (ET) per season (Zhang and Oweis, 1999). At transplanting, 20 mm irrigation water was applied to all treatments to bring the soil water content in a 0-60 cm soil depth to field capacity during establishment of transplants.

Swiss Chard Yield Parameters and Weeds Growth

First harvesting was done 42 days after (18 July 2014) transplanting by removing all the outer matured leaves and leaving three small inner leaves, as described by Maboko and Du Plooy (2013). At harvest, leaf area, leaf number, and leaf fresh and dry mass were measured on the harvested yield of 10 data plants per treatment and replicate. Therafter, Swiss chard was harvested every second week (plants were harvested seven times and growing period from transplating was 126 days i.e. 6 June 2014 to 10 October 2014). The leaf area (cm^2) was measured using a leaf area meter (LI-3100 area meter, LI-COR, inc. Lincoln, USA). Leaves were dried in an oven at 70°C for 48 hours for leaf dry mass determination. During Swiss chard harvesting, weeds were uprooted by hand for plant fresh and dry mass determination per plot. However, for the maize-meal bag, black plastic, newspaper, and white plastic mulches, weeds were only removed through the tranplanting holes and, subsequently, at the termination of the experiment.

Nutrient Element Analysis

Leaf minerals contents (N, P, K, Ca, Mg, Fe, and Mn) were determined. Leaf samples from the outer matured leaves were dried in an oven at 70°C for 48 hours and the dried leaf samples, per mulch treatment, were prepared for the analysis of macro and micro nutrients (N, P, K, Ca, Mg, Fe, and Mn) by grinding in a mill with a 1 mm sieve. Nitrogen content was determined on dry milled material using a Carlo Erba NA 1500 C/N/S Analyzer (Thermo *Fisher* Scientific, *Milan*, *Italy*). An aliquot of the digest solution was used for ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometry) for determination of N, P, K, Ca, Mg, Zn, and Fe concentration (Liberty Series II Model, Varian, Analytical West, Inc, CA, USA). All nutrient concentrations were expressed as a percentage on a dry mass basis.

Statistical Analysis

Data were subjected to Analysis Of Variance (ANOVA) using *GenStat*®, ver. 11.1 (Payne *et al*., 2008). Means were separated using Fisher's protected *T*-test Least Significant Difference (LSD) (Snedecor and Cochran, 1980).

RESULTS AND DISCUSSION

Water Applied and Water Use Efficiency (WUE)

Organic and inorganic mulches had a significant effect in reducing water application (Figure 1). The total amount of water applied to Swiss chard was 563.5 mm in the bare-soil treatment, while only 200

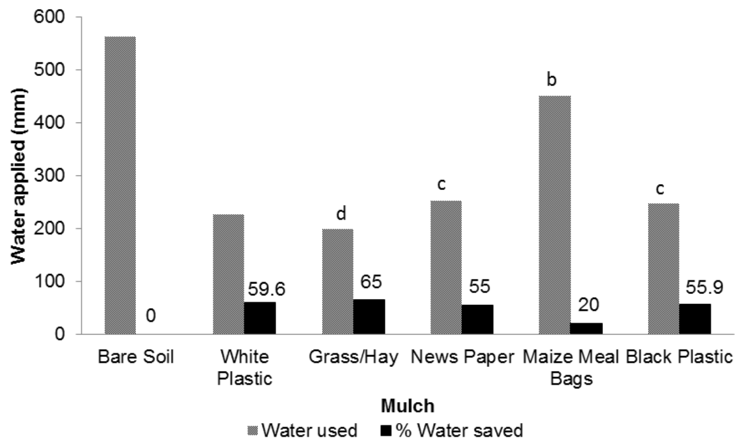

Figure 1. Water saving by different mulch treatments for Swiss chard during winter/spring season (2014).

mm was applied in the grass/hay treatment (Figure 1). Total water applied for white plastic, newspaper, maize-meal bag and black plastic mulches were 227.4, 253.2, 451.4 and 248.5 mm, respectively. The percentage water saving, as compared to the bare-soil, was highest for the grass/hay (65%) and white plastic (60%) mulches, followed by the black plastic mulch (55.9%), then the newspaper mulch (55%) and the maize-meal bag mulch (20%) (Figure 1). The use of mulch does not only conserve water, but will also reduce the cost of energy/electricity to pump water. Water use efficiency was significantly improved by the white plastic and grass/hay mulches. The highest *WUE* of 259.9 and 242 kg ha^{-1} mm^{-1} was obtained with the white plastic and grass/hay mulch treatments, respectively (Figure 2). Results are in line with the conclusion made by Jain *et al.* (2000), who showed that plastic mulch under drip irrigation markedly affected the required volume of water application and *WUE*. The lowest *WUE* was obtained with the bare-soil (74.7 kg ha^{-1} mm^{-1}), which can be ascribed to the high rate of water application (563.5 mm) and relative low yield (Figure 2, Table 3). Rice-straw mulch was reported to increase *WUE* in Swiss chard by 143 and

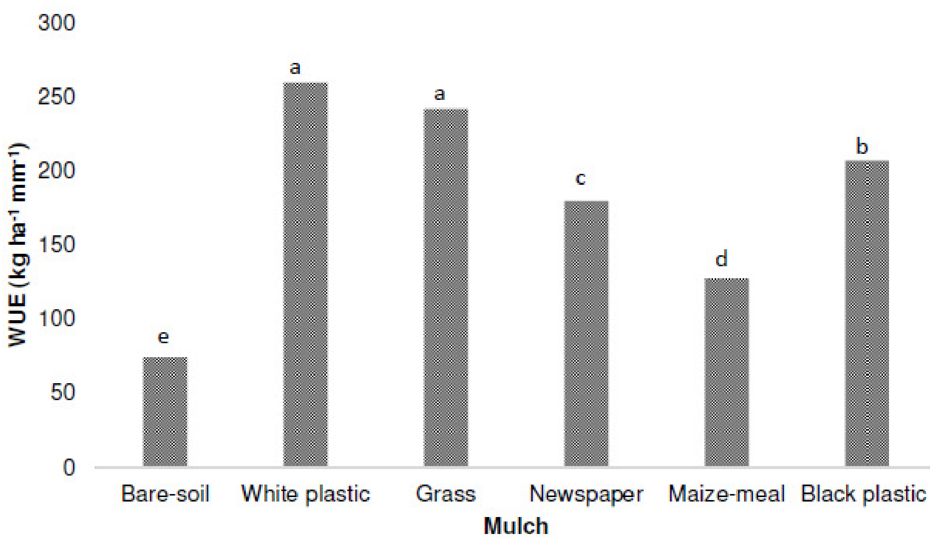

Figure 2. Effect of mulch on Water Use Efficiency (WUE) of Swiss chard during winter/spring season (2014).

Table 3. Effect of mulching on number of leaves, leaf fresh mass, and leaf area and dry mass of Swiss chard during winter/spring season (2014).[a]

Mulch treatment	Number of leaves plant^{-1}	Leaf fresh mass (g plant^{-1})	Leaf area (cm^2 plant^{-1})	Leaf dry mass (g plant^{-1})
Bare-soil	35.73	373	2862c	32.0c
White plastic	37.77	532	3479a	50.0a
Grass/Hay	31.97	437	3131bc	37.0bc
Newspaper	35.17	409	3165b	34.6bc
Maize-meal	34.26	436	3318ab	39.0bc
Black plastic	35.50	461	3581a	41.0b
LSD 0.05	ns	ns	282.1	8.87

[a] Values in a column followed by the same letter are not significantly different, $P \leq 0.05$, using Fishers' protected *t*-test. ns: Not significant, *LSD*: Least Significant Difference.

10%, as compared to the control and gravel mulch treatments, respectively (Zhang *et al*., 2009). Generally, all mulches increased *WUE* to different degrees and also had the advantage of retaining soil moisture. The increased soil moisture content with different types of mulches in this study was mainly due to decreased evaporation from the soil surface compared to the bare-soil.

Weed Control

Weed control measures significantly contribute to increased crop *WUE* by reducing competition for nutrients and moisture in the root zone and for light aboveground (Putnam, 1990). Results in this study demonstrate that the white plastic and maize-meal bag mulches, followed by the bare-soil, produced high weed fresh and dry mass (Figures 3 and 4). White plastic mulch consumed the same amount of water (ˉ200 mm) as grass/hay mulch (Figure 1), but, weed fresh mass (Figure 3) from white plastic as well as maize-meal bag mulches were about 5-fold higher than grass/hay. It appears that white plastic and maize-meal mulches might have induced favorable conditions, such as light, soil temperature, and moisture, conducive to growth and development of weeds. Weed control accounts for a major part of pre-harvest production cost. Weeds fresh and dry biomasses were significantly suppressed by the application of grass/hay, newspaper and black plastic mulches (Figures 3 and 4), which could be due to the interception of the incoming radiation from reaching the soil surface (Tarara, 2000). Newspaper and

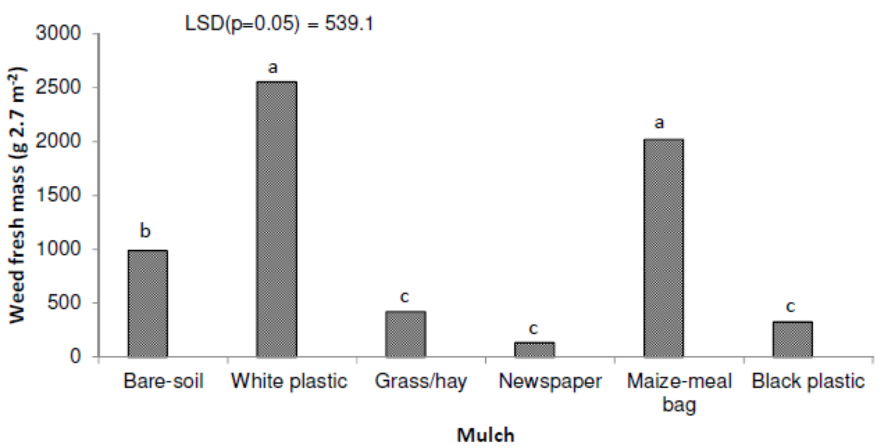

Figure 3. Effect of mulch on weeds fresh mass in Swiss chard trial grown in winter/spring season (2014).

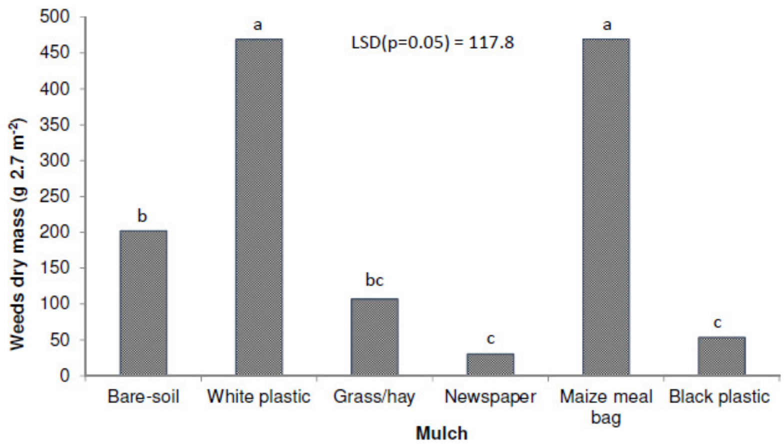

Figure 4. Effect of mulch on weeds dry mass in Swiss chard trial grown in winter/spring season (2014).

grass/hay mulches were equally as effective as black plastic mulch in suppressing the weeds. In terms of newspaper mulch, results are in agreement with Laurie *et al*. (2015), who reported weeds suppression by the use of newspaper mulch on sweet potato. The use of maize-meal bags as mulch should be discouraged because it disintegrates with time and can cause environmental pollution. It was also observed that white plastic mulch and maize-meal bag mulch allowed the growth of weeds below the mulch, and exerted pressure against the mulch as they grow upwards, causing the maize-meal bag mulch to tear apart. Increased moisture and light penetration through the white plastic and maize-meal bag mulches stimulated germination and growth of weeds, compared to bare-soil planting. However, planting during the rainy season, will probably also encourage germination and growth of weed on bare-soil. Although herbicides application is effective in controlling weeds, there are concerns of constraints, such as the cost of chemicals and application thereof (Merwin *et al*., 1996). Furthermore, herbicides will also adversely affect soil ecosystems and the environment, such as reducing microbial activities and increased water contamination (Merwin *et al*., 1996). Manual weeding or spraying of recommended pre-emergence herbicide can be difficult during the rainy season for efficient weed control (Ali *et al*., 2011). In this study, organic mulches, namely, newspaper and grass/hay, offered an alternative method for weed control, and could also be beneficial when decomposing into soil to increase soil organic matter. Although black plastic was more efficient than white plastic and maize-meal bag mulches, it did not eliminate all weeds, as weeds often emerged from the planting holes, even though they were very small in number and size.

Yield

Mulching did not have a significant effect on the number of leaves and leaf fresh mass of Swiss chard (Table 3). However, all the mulch treatments produced higher leaf fresh mass, leaf area, and leaf dry mass, as compared to the bare-soil, with white plastic mulch performing the highest with regard to the number of leaves and leaf fresh mass produced. Leaf area was significantly improved when plants were grown using white and black plastic mulches. Leaf dry mass was significantly higher with white plastic mulch, as compared to other treatments. Although not significant, Swiss chard produced the highest yield (leaf fresh mass) with white and black plastic mulches, as compared to other treatments (Table 3).

Improved Swiss chard yield by the application of rice-straw and gravel mulches was reported by Zhang *et al*. (2009). Although mulching showed a significant effect on *WUE* of Swiss chard (Figure 2), there was no major effect on yield (Table 3). This could be due to the soil profile that was refilled to field capacity when Plant Available Water (PAW) in the soil was depleted to the 40% level, bringing the amount of water to the same level in all treatments. Improved leaf dry mass with white plastic mulch could be related to more light being reflected onto the plants.

Leaf Mineral and Chlorophyll Contents

Application of organic and inorganic mulches did not have a significant effect on leaf minerals content, namely, N, P, K, Ca, Mg, Fe, and Mn of Swiss chard, (results not shown). This is in disagreement with Wien *et al.* (1993) who reported significantly higher N, P, K, B and Cu plant content for tomato plants grown with mulch as compared to plants grown without mulch. This could be due to the fact that plants were not grown during the rainy season, which could have washed/leached away some of the minerals of soil, thus influencing leaf mineral content. Swiss chard plants were irrigated according to soil moisture content to avoid over-irrigation, which would exacerbate nutrient leaching, or under-irrigation, which will affect nutrient uptake.

CONCLUSIONS

This study showed that mulching (grass/hay and white plastic) can improve *WUE* and yield in Swiss chard production. Water savings of up to 65% as obtained in this study can contribute significantly to successful production of Swiss chard in a water scarce country like South Africa. Grass/hay mulch could be an option for both commercial and small scale farmers in improving *WUE* and weeds control. It is recommended that grass/hay be used as a mulch as it has the advantage of being a low cost, easily degradable, alternative to the plastic mulch while it contributs the same production benefits and additionally will improve soil organic matter. Further studies need to be conducted on different colors of plastic mulches and organic mulches to improve yield and *WUE*.

ACKNOWLEDGEMENTS

The authors are thankful for the financial support of Department of Rural Development and Land Reform (DRDLR).

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کارآیی مصرف آب و عملکرد برگ چغندر سوئیسی (*Beta vulgaris* L.) با کاربرد مالچ های آلی ومعدنی

م. م. مابوکو، س. پ. دو پلوی، م. ا. سیتول، و ا. امباو

چکیده

افریقای جنوبی کشوری کم آب است و کمبود آب یکی از عوامل عمده محدود کننده رشد، عملکرد و کیفیت برگ چغندر سوئیسی است. در این رابطه، برای ارزیابی کارآیی مصرف آب(WUE)، کنترل علف های هرز، عملکرد، و واکنش کیفی برگ چغندر قند سوئیسی (Beta vulgaris L.) به استفاده از مالچ آلی و معدنی در طی فصل زمستان/بهار (ژوئن تا سپتامبر)، آزمایشی در یک خاک لومی رسی انجام شد. تیمار ها عبارت بودند از: خاک بدون پوشش(شاهد)، خاک با مالچ علف/کاه، پوشش روزنامه ای، پوشش با کیسه های ذرت خوراکی، ورقه های پلاستیک سفید و سیاه. نتایج حاکی از افزایش تعداد برگ ها و جرم تر برگ ها در تیمار پوشش با پلاستیک سفید بود در حالیکه در تیمارخاک بدون پوشش جرم خشک گیاه و مساحت برگ ها به طور معناداری کم شد. مساحت برگ ها در تیمارهای پلاستیک سفید، پلاستیک سیاه ، و استفاده از کیسه های ذرت خوراکی بهبود یافت. همچنین پلاستیک سفید و پوشش علف/کاه منجر به افزایش معنادار کارآیی آب شدند و مقدار آن به ترتیب ۲۵۹/۹ و ۲۴۲ کیلوگرم در هکتار به ازای هر میلی متر در صدر تیمارهای دیگر قرار داشت و به دنبال آن پلاستیک سیاه در حد ۲۰۷ $kg\ ha^{-1}\ mm^{-1}$ بود. کارآیی مصرف آب در تیمارهای پوشش با روزنامه ، با کیسه ذرت خوراکی و خاک بدون پوشش کاهش نشان داد وبه ترتیب برابر بود با ۱۷۹، ۱۳۰، و ۷۴/۷ کیلوگرم در هکتار به ازای هر میلی متر. به این ترتیب بر اساس نتایج این پژوهش کاربرد پوشش (مالچ) با آبیاری قطره ای نقشی مشخص در افزایش بهره وری آب در گیاه برگ چغندر سوئیسی دارد.