Performance of supplementary irrigation systems for corn silage in the sub-humid areas

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Abstract: In the humid and sub-humid areas, agricultural production is largely rain fed and this needs to be urgently supplemented by irrigation practice if the country is to meet its food demand. A two years study was carried out at the experimental site of the Institute of Agricultural Technology and Biosystems Engineering, Johan Heinrich von Thünen Institute (vTI), Braunschweig, Germany to compare performance of maize crop for silage production using three different irrigation systems; rain fed, drip and rain-gun sprinkler. Growth parameters such as plant height, stem diameter were measured. The total yields of silage were obtained for all treatments at the harvesting. The experimental results reveal that total yields obtained from different treatments were 25.76, 24.23 and 9.30 Mg ha^{-1} in drip, rain-gun and rain fed irrigated maize, respectively. The results also showed that the water use efficiency reached 11.01 kg m^{-3} for drip irrigation in while it was 8.84 kg m^{-3} for rain-gun system.

Keywords: Silage, performance, drip, rain-gun, rain-fed irrigation, water use efficiency

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1 Introduction

Water is the one of the most dominant limiting factor for crop production worldwide. The competition for the limited water resources for domestic and industrial needs is increasing considerably. It is therefore essential to formulate an efficient, reliable and economically viable irrigation management strategy in order to irrigate more land with the available water.

The objective of agricultural irrigation in the humid climate areas such as Germany is to compensate individual cases of precipitation deficits during the vegetation period with artificial water supplies in order not only to improve but also to save crop and crop quality. In Germany, irrigation is mainly applied to areas of intensive agricultural and horticultural activities with total average annual rainfall of 770 mm with extremes as low as 500 mm and as high as 2,000 mm (Venus et al., 2011). It is estimated that about 531×10^3 ha of land, (3% of the agricultural acreage) today is irrigated. The irrigation methods employed are mainly sprinkler systems, for which generally groundwater is extracted. The annual amount of irrigation water used varies between 80 and 150 mm yr^{-1} (Destatis, 2011).

Due to the importance of water to plant survival and substance, the amount applied during irrigation, time and method of application, water holding capacity of the soil and the water condition of the environment are factors that greatly influence plant growth, yield and general performance of crops.

Hose reel irrigator (rain-gun irrigation method) as a common supplementary method for irrigation in Germany, through which water is applied to the soil in the form of spray via rain gun and pumps. It is a kind of an artificial rain and therefore may give better results.

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The hose reel irrigator consists of a reel, a polyethylene hose, a driving mechanism, a sprinkler cart, a large sprinkler, an automatic drive shut-off and a chassis. For the drip irrigation system, water is slowly and directly applied to the root zone of the plants, thereby minimizing the losses by evaporation and percolation. Water oozes out of those drip nozzles uniformly at a very small rate, directly into the plant root zone (Abou Kheira, 2005; Grag, 2007).

Maize silage production plays an important role in satisfying the nutritional needs of livestock in many parts of the world. Due to climatic reasons, maize in the European Union is mainly produced in the form of whole plant silage. In Germany, maize production has increased but more in the form of whole plant silage which now is a highly valued substrate for biogas production. Temporary forages are mainly maize silage with nearly 50% in all regions. In Germany, as a whole, maize grain made 21.3% of maize production. In the year 2010, the amount of maize grain has increased to 464×10^3 ha and maize silage even rose to 1.846×10^3 ha (Destatis, 2011; Venus et al., 2011).

Maize has high irrigation requirements and is very sensitive to water stress (Rhoads and Bennett, 1990; Akhtar and Nadaf, 2002). The water use efficiency for well-watered maize ranged from 1.2 to 3.5 kg m^{-3} (Musik and Duesk, 1980; Mohammad and Ayadi, 2004).

Fully irrigated maize typically receives 500 to 600 mm irrigation water. Accurate estimate of ETc on a daily or seasonal basis can be valuable for best management of maize irrigation both in-season irrigation and for strategic irrigation planning and management (Payero et al., 2008).

Good irrigation scheduling decisions and appropriate evaluation of the economic impacts at farm level are the main constraints of the adoption of irrigation strategies (El Amami et al., 2001). Deficit irrigation creates water stress that can affect the growth and development of maize plants. It is very important to estimate yield reduction due to applying irrigation strategies (Payero et al., 2006a; Payero et al., 2006b). The response of maize plants to water stress has been shown to change with hybrid (Lorens et al., 1987a; Lorens et al., 1987b) and can be affected by improving technological level (Dale and Daniels, 1995).

Effects of water stress on maize include the visible symptoms of reduced growth, delayed maturity, and reduced crop yield. Trooien et al. (1999) found water use efficiency (WUE) to be greater for limited irrigated crops, but full irrigation of maize was more profitable than limited irrigation.

For silage, whole plant moisture at harvest ideally should be between 65% and 70%. If the silage is too wet, seepage losses and the risk of acidity will increase. If too dry, packing of the silage can become more of an issue and oxygen exclusion will be difficult leading to dry matter losses. Traditionally, maize was harvested when the milk line of the grain had moved halfway to the base of the kernel (Alkhamisi et al., 2011).

Effective irrigation influences the entire growth process of crop from seedbed preparation to germination, root growth, nutrient utilization, flowering, yield and quality. Therefore the main objective of this study was to compare the performance of rain fed, drip and rain-gun irrigation systems on maize crop (*Zea mays L.*) to identify the yield component and water use efficiency of maize silage.

2 Methodology

The experimental work was conducted for two seasons at the Institute of Agricultural Technology and Biosystems Engineering, Johan Heinrich von Thünen Institute (vTI), Braunschweig, Germany. It is located between latitudes of 52°1752, 80”N - 52°1802,41”N, and longitudes of 10°2708,39”E-10°27370,27”E, respectively. The physical and chemical characteristics of the soil at the experimental site are summarised in Table 1. The soil type was characterized by a loamy sand texture in the upper 30 cm of the soil. The average weather conditions in this region are shown in Table 2.

Table 1 Description of the soil parameters at the experimental site

Soil parameters	Organic matter /%	Clay /%	Silt /%	Sand /%	pH
Soil depth (0-50 cm)	1.4	6.3	46.7	47	5.5

Table 2 The average weather conditions at the experimental site (the German Weather Station "DWD", www.dwd.de)

Parameters	Average from 1961 to 2011				
	May	June	July	August	September
Precipitation/mm	57	70	57	68	51
Temperature/°C	13.1	15.9	20.4	19	16
Potential ET/mm $month^{-1}$	88	91	94	99	97

2.1 Experimental setup

Three separate crop areas A, B and C each of 30 m by 300 m were selected for all irrigation systems: rainfed, drip and rain gun (Figure 1), respectively.

Figure 1 Rain gun machine

Two blocks of size 15 m by 15 m were selected for each plot: one at 100 m and the second at 200 m distance from the field head as shown in Figure 2.

All plots were transplanted with maize in the third week of May for both two seasons. Maize seeds were planted at a spacing of 0.10 m within row and 0.75 m between rows. The soil was tested for essential fertilizer requirements and was fertilized accordingly. Weed controls were carried out when the crop was at six-leaf stage. Drip lines were set up at plot B during the third week of planting where each drip line with 40 cm spacing between the drippers (0.6 L h^{-1}) sited for two rows. A hose reel irrigation machine was used for the third plot (C).

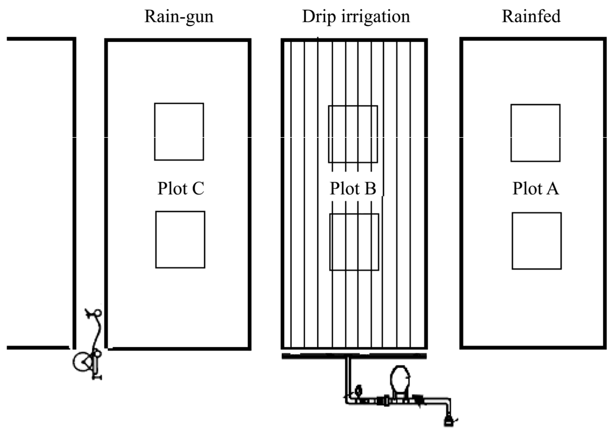

Figure 2 Schematic experimental field systems

The timing to apply irrigation was decided based on soil moisture conditions, where irrigation was applied when soil moisture content at 10 cm depth was below 25% (vol.). The harvest was done when whole plant moisture was between 65% and 70% moisture (at the end of September to beginning of October).

Soil volumetric water content, agronomic parameters, and water use efficiency, were used to evaluate the overall performance of each irrigation method.

Soil moisture content (M.C., vol.) measurements were taken throughout the experiment. For each block, the daily M.C. was measured using a hand-held 0.20 m soil moisture probe (Hydrosense probe). By using the data of weather station (DWD) located next to the experimental site, the irrigation controller model AMBER (developed by DWD) was used to monitor the daily changes of precipitation rate, temperature, evapotranspiration and create the irrigation balance and a 5 d forecast of the demand for water enabled the further targeted irrigation use.

To calculate the amount of applied water, two water meters were used, one installed at the beginning of the main line of drip network, and the other installed on the reel hose machine. Agronomic parameters such as plant height, stem circumference, number of leaves and steps per plant were taken directly before harvesting. Ten plants were tagged for growth rate measures. The plant height was measured using a ruler weekly 21 d after planting to calculate the growth rate of the treatments.

The growth rate was calculated using Equation (1) (Abdelrahman et al., 2009) as follows:

$$R_n = \frac{(X_n) - (X_n - 1)}{7} \quad (1)$$

where, R_n = Growth rate in the week n /cm d^{-1} per week; n = Number of the week from the starting of the experiment; X_n = Plant height (cm) in the week n; X_n−1 = Plant height (cm) in the previous week of the week n and 7 = Constant, number of days per week /d.

To create the harvesting, whole plant moisture at harvest ideally should be between 65% and 70%. The way to accurately evaluate whole-plant moisture was to collect plant samples and has them tested. Moisture content for the plants was measured according to ASHRAE (1997). The materials were put in the drier at a constant weight. Equation (2) was used to calculate the plant MC (%):

$$MC\ (\%) = \frac{(W_m - W_d)}{W_d} \times 100 \quad (2)$$

where, MC = Moisture content, %; W_m = Moist weight, kg; W_d = Dry weight, kg.

On determination of yield of maize, all plots A, B and C were harvested separately by combining harvesting machine (which cut and chop plants and placed on containers that can be weighed).

3 Results and discussion

Rainfall pattern during the experiment is shown in Figure 3. Days with effective rainfall were observed constantly but with certain intervals until 30 d after transplanting. After this period, there was a semi dry spell for one month. After that, considerable amount of rainfall was measured until harvest. The total seasonal precipitation was 124 mm during both growing seasons.

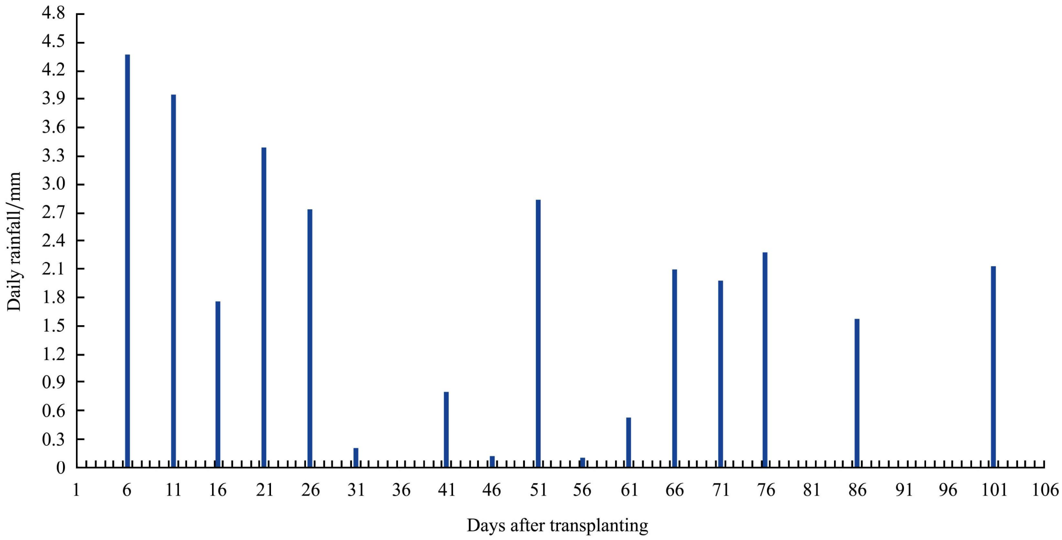

Figure 3 Pattern of average daily rainfall during experimental period for two seasons

According to the decision based on rainfall pattern and soil moisture content, number of days with irrigation varied by treatment. Rain-gun irrigation treatment received the largest irrigation amount during the experimental period (169 mm), followed by drip irrigation treatment (149.5 mm).

Rain fed maize clearly differed from supplementary rain fed irrigation on soil moisture content. Figure 4 shows the relationship between average soil moisture content for all rain fed, rain gun and drip irrigation treatments. Rain fed significantly differed from Rain fed with supplementary irrigation on all days observed. According to the experiment limitation, where irrigation was applied when soil moisture content at 0.10 m depth was below 25%, the soil moisture content was in that range until 32 d after sowing for all plots. Starting from the fifth week of sowing, water stress was observed under rain fed conditions while the supplementary irrigation started at both B and C treatments until harvesting.

The growth parameters were focused upon plant height, growth rate, leaf area, plant circumference and number of leaves per plant. The growth of plants increased slowly during the first 5 weeks in all treatments (Figure 5). From the sixth week onward the growth started increasing rapidly. The growth rate factor in terms of plant height for all treatments is shown in Figure 6. The rate of growth decreased in the eleventh week for some treatments since during that time the crop had reached the flowering stage. Treatments with elevated amounts of water resulted in higher growth rates. Plants irrigated with drip and rain-gun had similar trend and higher development rates in comparison with those rain fed irrigated suggesting the decrease of available soil moisture. This is similar to results reported by others (Alkhamisi et al., 2011; Oya et al., 2012).

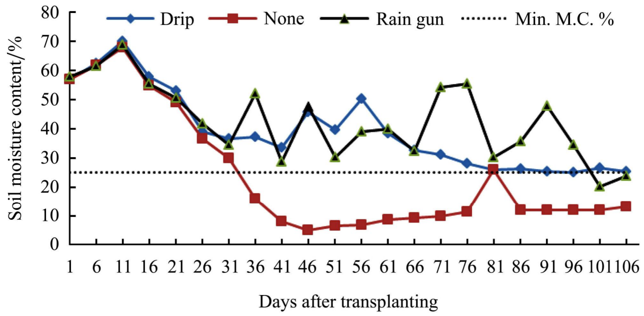

Figure 4 Change in soil moisture content during experimental period for all systems

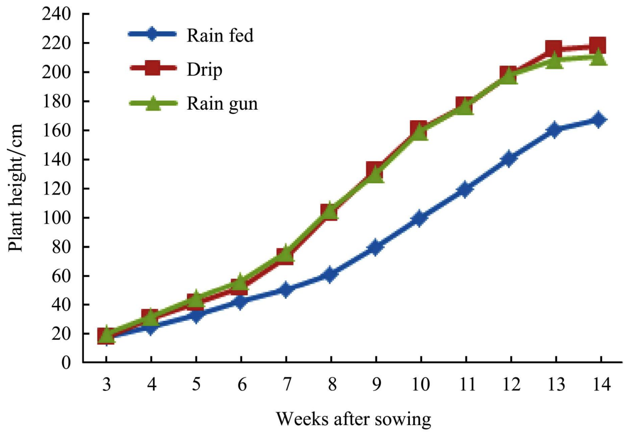

Figure 5 Plant height of maize

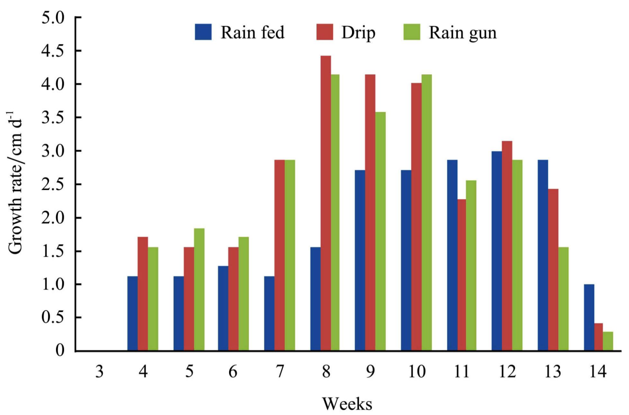

Figure 6 Growth rates represented in plant height of silage maize

Table 3 represents growth parameters of maize as affected by the three irrigation systems. It shows that the highest value of plant height was 218 cm achieved with the drip irrigation system. The lowest value of plant height was 167 cm with the rain fed irrigation system. Drip irrigation recorded the highest values of leaf area and value of plant circumference, which were 857.2 cm^2 and 9.93 cm, respectively, but the number of leaves per plant was 17 for both drip and rain gun. Also, the Table shows that the lowest values of leaf area, plant circumference and the number of leaves per plant were 503.4 cm^2, 7.44 cm and 16, respectively, obtained with rain fed. This is in line with the assertion of Singh and Singh (2002) that depth, extent of root system, size and total area of leaves, number and location of stomata, shoot growth and vigour of maize are affected by rainfall or water availability.

Table 3 Average values of growth parameters of maize under irrigation systems

Growth parameters	Irrigation system		
	Rain fed	Drip	Rain gun
Plant height /cm	167	218	210
Leaf area/cm^{2*}	503.4	857.2	856.8
Plant circumference /cm	7.44	9.93	9.92
Leaves per plant	16	17	17

Note: *Leaf area = 0.75 (max. width × length of the leaf) (Abou Kheira, 2009).

The relationship between irrigation levels and the yield of silage was similar for the used irrigation system, where the yield of silage decreased as the soil moisture level decreased. However, the decrease in the yield differed from one system to the other. The data obtained in Table 4 illustrate that the highest value of silage yield was 25.76 mg ha^{-1} obtained with drip irrigation followed by 24.23 mg ha^{-1} with rain gun irrigation and 9.30 mg ha^{-1} with rain fed. Crop water use efficiency as related to irrigation system and irrigation levels was calculated (Table 4). They show that the highest value of total irrigation water use efficiency (9.42 kg m^{-3}) was obtained with drip irrigation followed by rain gun irrigation (8.26 kg m^{-3}) that calculated as the total amount of water (rain + irrigation). The lowest value of water use efficiency was (7.50 kg m^{-3}) recorded with rain fed irrigation. It is also evident that, the actual water use efficiencies according to supplementary irrigation were higher than the total WUE, where it reached 11.01 kg m^{-3} for drip irrigation in comparison with 8.83 kg m^{-3} in case of rain gun system.

Table 4 Average yield and water use efficiency for the treatments under study

Treatment	Total rain fed/mm	Irrigation amount/mm	Total yield /mg ha^{-1}	Total WUE* /kg m^{-3}	WUE ** /kg m^{-3}
Rain fed, A	124	0	9.30	7.50	-
Drip, B	124	149.5	25.76	9.42	11.01
Rain gun, C	124	169	24.23	8.26	8.83

Note: *calculated as total water applied (rain fed + irrigation amount).
**calculated as increase in yield/irrigation amount.

Comparing between drip and rain gun from the point of view of the recorded crop water use efficiency, it is clear that the drip system has an advantage in the beneficial use of water. This is because of higher values of crop water use efficiency recorded with drip than those recorded with the rain gun system. This may be due to the uniform distribution of moisture in the effective root zone of maize in the soil observed with drip irrigation system according to a related study done by Sourell et al. (2011).

4 Conclusions

A comparative performance of maize silage under both drip and rain-gun systems of irrigation as complementary irrigation was conducted. It was established that drip irrigation system proved to be more efficient and gave higher yield than the rain-gun irrigation system. Thus, the overall efficiency of water use within this experiment is high, particularly under drip irrigation. High efficiency of water use is extremely important to farmers in water scarce areas as well as in sub-humid areas.

Using supplementary irrigation in maize silage production per ha is more than 160% and 177% for both rain-gun and drip system, respectively. So, supplementary irrigation in critical period of maize growth is an effective way to increase yield in the sub-humid regions. It is, therefore, suggested that optimum production of maize could be achieved by rain fed supplementary irrigation.

The effectiveness of the prompt irrigations allowed by hose reel rain-gun machines did not prevent them from the criticism of some working characteristics. The quite high energy required, average uniformity of distribution, the impact of big drops on crop and soil, were considered as peculiar to the rain-gun machines. Due to these reasons, and probably to the increasing diffusion of micro irrigation, the hose reel machines were often stereotyped because of their limits by sector literature and popular beliefs. Since modern irrigation must pay attention to water saving.

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