JOURNAL LA MULTIAPP

VOL. 01, ISSUE 05(001-009), 2020
DOI: 10.37899/journallamultiapp.v1i5.247

Design of Automated Rainout Shelter to Conduct Experiment on Drought Tolerant Maize Genotype

Shiva Kumar Jha[1], Mahendra Tirpathi[2], Balram Bhandari[2], Bhanu Pokharel[3], Tika Bahadur Karki[4] and Keshab Babu Koirala[2]

[1]Nepal Agricultural Research Council, National Agricultural Engineering Research Centre, Khumaltar, Lalitpur, Nepal
[2]Nepal Agricultural Research Council, National Maize Research Program, Rampur, Chitwan, Nepal.
[3]Nepal Agricultural Research Council, National Rice Research Program, Janakpur, Dhanusha, Nepal
[4]Nepal Agricultural Research Council, Planning Division, Singhdurbar, Kathmandu, Nepal

**Corresponding Author: Shiva Kumar Jha*
Email: jhashiva25@yahoo.com

Article Info

Article history:
Received 5 December 2020
Received in revised form 25 December 2020
Accepted 31 December 2020

Keywords:
Rainout Shelter
Drought
Maize Genotype
Irrigation Practices
Drip Irrigation

Abstract

Uneven and low precipitation areas of Nepal are continuously suffering from drought and received low productivity because of unavailability of suitable drought tolerant maize genotype. An attempt has been made first time in Nepal by constructing an automated rainout shelter with soil moisture based automated drip irrigation system at National Maize Research Program in 2018-2019 to conduct an experiment on drought tolerant maize genotype. The rainout shelters automatically covers the cropping area as soon as the rain sensor received a single drop of precipitation and also if the light intensity decreased to value set in the control panel. Likewise, the soil water level in different treatments were maintained on the basis of the treatment controlled with automatic drip irrigation system set to irrigate at threshold value set in the microcontroller. The complete system had found very useful in determining accurate amount of water required to cultivate drought tolerant maize genotype. We have tested drought tolerant variety RampurSo3Fo8 under 10 level of irrigation and it was determined that 495.2 mm of water is maximum level of water to produce highest yield of 3.32 t/ha whereas 445.6 mm to 247.6 mm of water could can be manage to produce competitive yield without any reduction. An experiment under such kind of infrastructure provide useful information on irrigation management practices required for drought variety in the natural environment. The research output also guides farmers and agriculturist in making Nepalese agricultural more sustainable, mechanized and productive.

Introduction

Delay in monsoon during planting, uneven distribution of rainfall and prolonged drought during crop season may affect the crop yield adversely (Adhikari 2018). The water stress due to drought is probably the most significant abiotic factor limiting plant and also growth and development (Zhang et al., 2015). Consequently, the duration and severity of stress event, as well as the development stage of the plant constitutes the ultimate impact on yields and yield

ISSN: 2716-3865 (Print), 2721-1290 (Online)

attributing parameters (Choudhury & Kumar 1980; Dolferus et al., 2011; Fischerab & Maurerac 1978; Singh & Malik 1983). In 1994, about 35 districts of Nepal's in the western hilly and Terai was severely affected by drought. In 2008/2009 Nepal received less than 50 percent of its average precipitation during the winter season. It has reported that during the season significant yield and quality losses has been encountered and created food deficit in those regions. These are only few example to explain that water stress can significantly reduce the yield and losses the quality of grain. If drought tolerant crop genotype will be developed for the particular regions, could produce significant yield even if there will be no rain. Thus it is necessary to select crop genotype for the location which can optimize the yield with less applied water. Development of such genotype can be selected with conducting an experiment where uncertain rain events can be controlled. This is only possible if we able to create an artificial structure which can cover the crop if precipitation occurs during crop period. Kant et al. (2017) has illustrated that the rainout shelters provide the way to control water stress environments with excluding uncertain rain events. Kreyling et al., (2017) concluded that Rain-out shelters artifacts on plant responses were no significant. Rain-out shelters remain a viable tool for studying ecosystem responses to drought. Many structural design of rainout shelter is possible ranging from simple fix structure to complex retractable types. Several type of fixed structural having stationary frame and roof design of rainout shelter has been used by (Clark & Reddell, 1990; English et al. 2005; Heisler-White et al. 2009; & Reynolds et al. 1999). In contrast, retractable rainout shelter designs include a permanent frame or footings with a rolling or sliding cladding to allow plants exposer to open in field conditions and cover the cropping area during rain events. Some earlier retractable designs have features shed-like shelters, which moves on ground-based rail mechanism (Dubetz, et al. 1968; Hiller 1969; R. R. Bruce & human 1962). In this research an automatic retractable rain-out shelter with rail mechanism has been designed to develop the drought tolerant maize genotype. Maize (Zea mays L.) is the second most important staple food crop after rice in Nepal and the principal food, feed, fodder, fuel crop and source of energy in hills and Terai (NMRP 2017). This kind of advance methodology to develop a drought tolerant maize genotype has been first time introduced in Nepal. This kind of innovative research and development could enhance the Nepalese research system and play vital role in food security specially in the areas where drought is severe and farmers are looking for the maize genotype that can be cultivate with less amount of water.

Method

The National Maize Research Program (27^{o}39$^/$ N, 84^{o}20$^/$ E and 186 m altitude) is one of the National program of Nepal Agricultural Research Council (NARC), located at Rampur, in Chitwan district of Nepal. The station has mandate to coordinate the research for maize crop in Nepal and reduce the yield gap of maize cultivation between research station and farmers field. Since the research has focus on maize crop the rainout shelter has been constructed at this research station to conduct the experiment, to develop drought tolerant maize genotype. The drip irrigation system with precise water meter has been installed under the rainout shelter to facilitate measurable irrigation amount, whereas one of the treatment plot were facilitated with automatic drip irrigation system working on the basis of available soil moisture set as threshold value. The subtropical humid climate has dominant the research station with cool winter and hot summer. Average annual precipitation is 2215 mm with a distinct monsoon having more than 75% of its annual rainfall from Mid-June to mid-September (NMRP 2017; Upadhyay et al. 2016). The acidic soil with pH 5.2 having light texture and sandy loam were filled in the cropping area of rainout shelter. The research station has been well facilitated with weather station near by the rainout shelter. The station has all other research facilities required for maize research and development. Since the research has been conducted in open environment surrounded by maize cultivated area.

Design and Development of Rainout Shelter

ISSN: 2716-3865 (Print), 2721-1290 (Online)

The rainout shelter has been designed to fulfill the minimum requirement for conducting the experiment on irritation and water management practice. The size of the rain-out shelter has been considered to be 50 m long and 9 m wide, the whole area ware split into two part as 25 m x 9 m for cropping area and same 25 m x 9 m for parking of rain out shelter as shown in the plan of Figure. 1. The side view explained the wall section as well as the rail system on which the rainout shelter moves. The detail of the wall section and the rail mechanism are shown in Figure. 2

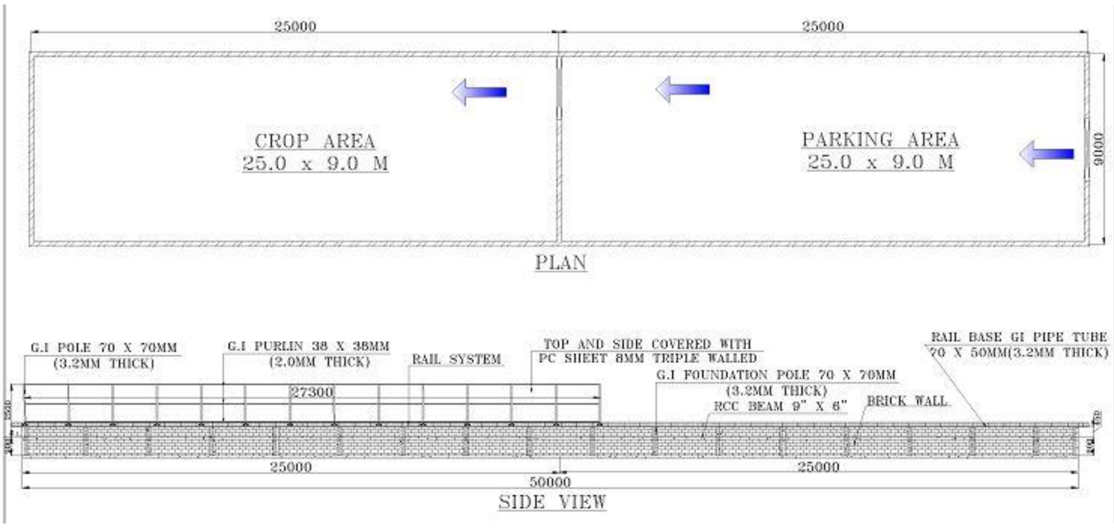

Figure1. Plan of rain-out shelter along with side view or rail system

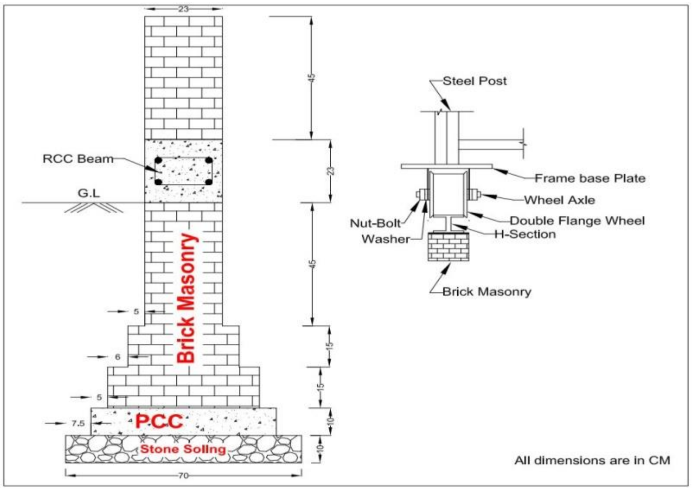

Figure 2. Wall section on which railway trach has been fixed and x-section of rail system

The rainout shelter has been designed here for maximum Nepal wind load (absolute strength). The wall sections are constructed with perfect strength to withstand the load of rainout shelter on which the railway track has been fixed. The double wheel mechanism facilitated with ball and bearing were designed for smooth rolling on railway track. The rolling base of the railway track has been made of mild steel, T-section of suitable size as shown in Figure 2. The rolling wheels were made of caster wheels with high stress bearing designed as taper roller bearing/ball bearing with proper lubrication system. The cross section of rainout shelter and the dimension of truss has been shown in Figure.3. The shape of rainout shelter has been designed as Dome/Skylight. Anti-corrosive, humidity resistant GI pipe with zinc coated were used for the structural arrangement of rainout shelter for fixing the polycarbonate sheet as glazing.

ISSN: 2716-3865 (Print), 2721-1290 (Online)

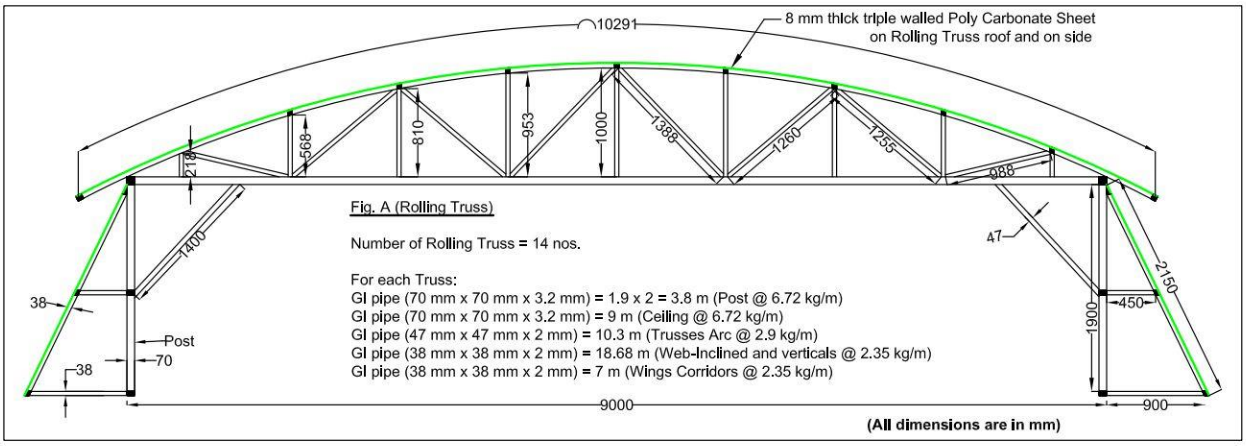

Figure 3. Cross-section of rolling truss of rainout shelter

The clear width of the rainout shelter is 9 m whereas, the 3 m clear height of the rainout shelter were designed considering the average plant height of the maize crop. The roof and sides has been covered with Poly-Carbonate sheet with necessary folding arrangements to open from four sides and provision leak proofed (against entry of rainwater between two joints of the sheets sealed with silicon sealant applicant). Also the cut edge of the poly carbonate sheet has been sealed. The poly carbonate sheet used for glazing has designed with following properties.Thickness: 8 mm tripled layer walled, Sheet Structure: 8/3 (8 mm triple wall), UV aborting properties (Certified to DIN EN ISO 9001, quality and DIN EN ISO 14001 (environment), U-value 3.4 W/m^{2}k, Coefficient of linear thermal expansion α = 0.09 mm/m^{o}C, Possible expansion due to heat and moisture 6 mm/m, Max.

Permanent service temperature without load 700^{o}C, Weighted sound reduction index (estimated) 23 db, Minimum permissible cold-curving radious 1,200 mm, Warranty: 10 years Fixing arrangement: Fixed with aluminum pressure plates with gasket, Size of pressure plate: 50 mm x 2 mm andWeight of pressure plate: 1.25 kg/12 feet. The rolling truss were perfectly cut, bended, jointed, fixed, welded and erected in perfect line and length as shown in Figure.3 and Figure.4. The dimension of foundation post (70 mm x 70 mm x 3.2 mm), trusses arc, bracing joints and truss bottom (47 mm x 47 mm x 2 mm), rafter verticals and web inclined (38mm x 38 mm x 2 mm), track bottom (70mm x 50mm x 3.2mm) etc and other dimensions are as shown in the Figure. 3 and Figure.4. The rolling mechanism has been power operated geared motor mechanism with lock by that shade cannot move due to wind force to move the rainout shelter to and fro as shown in Figure 4. The motorized rolling mechanism on wheels on rails with arrangements for easy movement, quick locking and unlocking, latches and adequate safety features while operating. Housing of the motor and other electrical components has been fixed in a separate box with rain protection. The complete motorized rolling mechanism including control panel, motor drive etc. shall have a redundant backup system so that moving facility shall keep working with standby arrangement even during failure of primary drive mechanism.

ISSN: 2716-3865 (Print), 2721-1290 (Online)

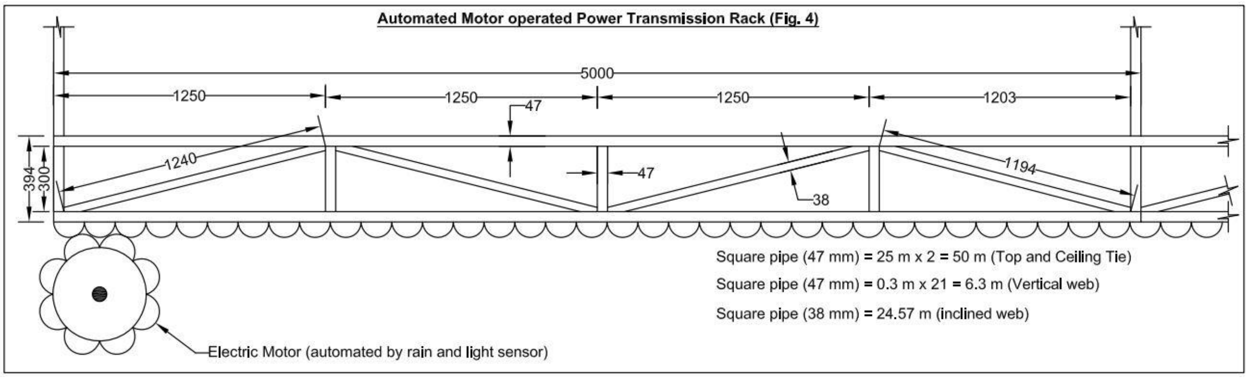

Figure 4. Motorized retractable gear mechanism to move the rainout shelter to and fro

Working mechanism of rain-out shelter:

Rain sensor with advanced technology for controlling the automatic movement of rain-out shelter on rain and or receiving different intensity of light with data logger has been facilitated. The rain sensors sense rain/dew whereas light sensor monitors different intensity of light and then it will give signal to motor to move the structure from one end to another end and then the motor will automatically stop as soon as weather becomes normal and go back in parking area. It has designed to operated always automatically without any need of person to be there to switch on or off. A power back up of 10 KVA DG set standard make, 3 phases connections with IS standard electrical parts has been connected and set to operated automatic. The DG set system switched on after unavailability of electricity in the national grid line connected to rainout shelter and again switched off as soon as the electricity is available from the national grid line. The power backup was satisfied with environmental clearance certificate, all weather acoustic enclosure, panel board, etc complete housed in rain protected arrangement with necessary UG Cables and change over switch. In this way the rain-out shelter has electrically driven motor controlled by microprocessor controller digital, rain and light sensor.

Treatment design under rain-out shelter

The irrigation treatment design to test the tolerance of drought for pipe line drought tolerant maize genotype has been considered with two replications because of limited area under the rainout shelter. The water stress tolerance of cultivated maize genotype was teste against ten irrigation treatment as described below:

T1 = Irrigate every day with irrigation amount equivalent to ET
T2 = Irrigate every day with irrigation amount equivalent to (T1)/2
T3 = Irrigate @ 7 days with irrigation amount equivalent to $(\sum_1^7 T1)\ X\ 1.0$
T4 = Irrigate @ 7 days with irrigation amount equivalent to $(\sum_1^7 T1)\ X\ 0.9$
T5 = Irrigate @ 14 days with irrigation amount equivalent to $(\sum_1^{714} T1)\ X\ 0.8$
T6 = Irrigate @ 14 days with irrigation amount equivalent to $(\sum_1^{14} T1)\ X\ 0.7$
T7 = Irrigate @ 21 days with irrigation amount equivalent to $(\sum_1^{721} T1)\ X\ 0.6$
T8 = Irrigate @ 21 days with irrigation amount equivalent to $(\sum_1^{721} T1)\ X\ 0.5$
T9 = Irrigate @ 28 days with irrigation amount equivalent to $(\sum_1^{728} T1)\ X\ 0.4$
T10 = Irrigate @ 28 days with irrigation amount equivalent to $(\sum_1^{28} T1)\ X\ 0.3$

All the treatments are randomized within a block (Replication) and each treatment plots include four rows. All the treatments were replicated twice and one meter working footpath at the center of rainout shelter has been separated. The intermediate two rows of each treatment are considered for data measurement and remaining two rows consider as a border between the treatments. The row to row spacing has taken as 60 cm and the plant to plant spacing are 25 cm. All the plots were flooded and allowed to bring the soil moisture at field capacity before

ISSN: 2716-3865 (Print), 2721-1290 (Online)

planting the crop. An automatic drip irrigation was installed for the treatment T1, and the threshold value in the microcontroller was set to field capacity for treatment T1. Hence the amount of water applied automatically to keep the soil moisture at field capacity in the treatment T1 were measured every day. Every rows contains each separate drip lateral line fitted with flow regulation valve. The main line contains precise water meter, facilitate to allow the calculated amount of irrigation water in the specific drip lateral line. The amount of water applied in other treatment are as illustrated above in treatment design. The irrigation scheduling and the amount of water applied in each treatment are shown in Figure 5:

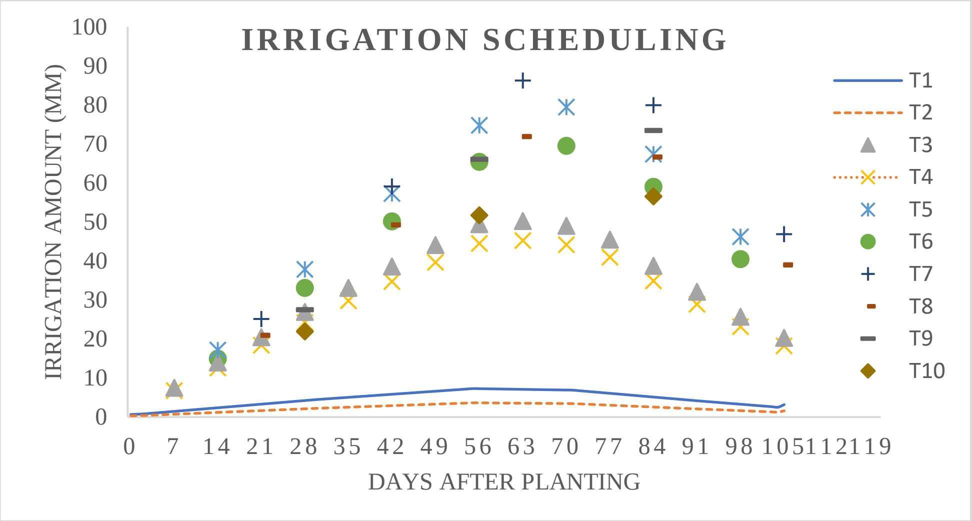

Figure 5. Irrigation scheduling and amount of irrigation water applied in each treatments

Results and Discussion

A well automatic rainout shelter has been constructed first time in Nepal to conduct an experiment to determine minimum amount of water required to cultivate drought tolerant maize genotype cultivated in the area where rainfall pattern is very low. To conduct this kind of experiment the water required by crop should be controlled keeping all other environment as natural as grown in natural environment. The detail working mechanism and the output of the experiments are described below.

Rain-out Shelter

Considering all the design parameter as discussed in the material and methods a rain-out shelter has been constructed as shown in the Figure. 6. The rain-out shelter mostly remains in the parking area and covers the cropping area as soon as a single drop of water fall on the rain sensor installed outside of the shelter. Similarly, the shelter also run to cover the cropping area if the light intensity sense by light sensor become less than the value set in the control panel. In this way rainout shelter work automatic to cover the cropping area and go back to parking area as soon as the rain sensor become dry (i.e. rain stop) and light intensity become more than the light intensity set in control panel. Since the shelter were covered with polycarbonate sheet having 80 % light transparency, it allows crop to develop naturally even during rain, restrict rain water and make possible to grow crop with the applied irrigation water. The Figure. 6 shows the rainout shelter in the working condition conducted with experiment.

ISSN: 2716-3865 (Print), 2721-1290 (Online)

Figure 6. Rainout shelter in working condition covering the cropping area

Water Management

Irrigation water applied were according to the treatment designed as mentioned in the material and methods section. There is no rain in the cropping area and amount of irrigation water applied do not exceed the crop evapotranspiration, which mean that the soil water content of each treatment should remain less than the field capacity. The treatment designed shows that the crop has been grown from no water stress condition in treatment T1 and the water stress in crop gradually increased in other treatments. Likewise, irrigation interval also increased to allow the crop remains in water stress for longer as mentioned in treatment T2 to treatment T10. It has considered that there is no drainage beyond the root zone and all the applied water is utilized by crop. The table 1 shows the total amount of water utilized by crop and number of irrigation for each treatments.

Table 1. Number of irrigation, total amount of water applied and yield in each treatment

Treatment	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Fequency of Irrigation	Every day	Every day	7 days	7 days	14 days	14 days	21 days	21 days	28 days	28 days
Number of Irrigation	105	105	15	15	7	7	5	5	3	3
Total Irrigation Amount (mm)	495.2	247.6	495.2	445.6	379.9	332.4	297.1	247.6	166.9	130.1
Yield (t/ha)	3.32±0.20a	3.28±0.24a	2.56±0.20ab	2.40±0.07abc	1.97±0.11bcd	1.32±0.19cde	1.14±0.15de	0.85±0.06e	0.69±0.15e	0.31±0.07e

It has found that the maximum amount of water required to grow drought tolerant maize genotype (RampurSo3Fo8) is 495.2 mm under no water stress condition and lowest amount of 130.1 mm in treatment T10 keeping dry for 28 days and applied only 30% of water used in now water stress condition. The result found in this experiment is quite equivalent to the amount of seasonal PET of maize 486.6 mm determined by Bhandari (2012) under full water requirement. The amount of water applied every day (8:00 AM) in the treatment T1 to bring the soil moisture at field capacity was measured and the amount of water required to applied in other treatments are the sum of this daily water for the defined interval. Thus, the irrigation water applied in other treatment were carried out by measuring daily water loss in treatment

ISSN: 2716-3865 (Print), 2721-1290 (Online)

T1 for the irrigation interval defined in the treatment design. The water required decreased gradually either keeping soil in water stress condition for longer or applying less amount of water than that applied in no water stress condition. The effects of water stress on crop development and yield were monitored as described below.

Effects of water stress on yield

The main purpose of this research was to determine the yield of drought tolerant maize genotype (RampurSo3Fo8) under different water stress condition. As mentioned in treatment designed section the crop was put under different water stress condition and it has found that the water stress limits the yield for certain irrigation period only. The yield (t/ha) for each treatment are shown in table 1. The tabulated data shows that there is no significant reduction of yield if the crop could keep irrigated every 7 days' interval with the amount equal to 90% of its ET. The yield remains statically non-significant between the treatments while reducing the irrigation amount 90% to 80% of ET and prolong the water stress till for 14 days. Irrigating the field daily with an amount equal to 50% of ET could save irrigation water 50% with no reduction in yield but daily application of irrigation water by the farmers is practically impossible. Thus, management practice according to treatment T2 has not been recommended. Furthermore, the water stress created either by reducing the amount of water less than 70% of ET or keeping the field dry for more than 14 days significantly reduce the yield. The maximum yield in this experiment was found to be 3.32 t/ha while keeping the field at field capacity and applying water equivalent to the amount that could be loss in a day. The yield remains statically similar 3.28 t/ha for irrigating everyday with the amount 50% of ET whereas the drastically reduction of yield has found in the treatment T8 (0.85 t/ha) to treatment T10 (0.31 t/ha) as a lowest yield. The yield observed in this experiment is quite similar to the yield determined by Prasai et al. (2015) for drought tolerant maze genotype.

Conclusion

The water management practice under rainout shelter has first time conducted in Nepal. It has observed that the rainout shelter working automatically on precipitation can facilitate to conduct water management activity. The size 25 m x 9 m for cropping area and same area for parking is sufficient to manage 10 number of treatment with two replications. Automatic operation of rainout shelter prevent rainfall to fall in the treatment and make easier to manage irrigation water according to the designed treatment. It has concluded that keeping the field under water stress condition for longer time have more tendency to reduce the yield rather than applying less amount of water frequently. Applying water 50% of ET daily could save water 50% without any reduction in yield by it is practically impossible to manage irrigation daily. Thus, if the farmers can manage irrigation every 7 days with an amount 80% of cumulative ET will save 20% water with no significant loss in yield. But if the water availability is more scarce than irrigating at 14 days interval with an amount 70% of cumulative ET is recommended.

References

Adhikari, S. (2018). Drought impact and adaptation strategies in the mid-hill farming system of western nepal. *Environments*, *5*(9), 101.

Bhandari, G. (2012). Estimation of Potential Evapotranspiration and Crop Coefficient of Wheat at Rupandehi District of Nepal. *International Journal of Agricultural Management and Development (IJAMAD)*, *2*(1047-2016-85456), 41-47.

Bruce, R. R., & Shuman, F. L. (1962). Design for automatic movable plot shelter.

Choudhury, P. N., & Kumar, V. (1980). The sensitivity of growth and yield of dwarf wheat to water stress at three growth stages. *Irrigation Science*, *1*(4), 223-231.

ISSN: 2716-3865 (Print), 2721-1290 (Online)

Clark, G. A., & Reddell, D. L. (1990). Construction details and microclimate modifications of a permanent rain-sheltered lysimeter system. *Transactions of the ASAE*, *33*(6), 1813-1822.

Dolferus, R., Ji, X., & Richards, R. A. (2011). Abiotic stress and control of grain number in cereals. *Plant science*, *181*(4), 331-341.

Dubetz, S., Thurston, E. W., & Bergen, H. J. (1968). Automatic rain shelter for small outdoor plots. *Canadian agricultural engineering*, *10*(1), 40-41.

English, N. B., Weltzin, J. F., Fravolini, A., Thomas, L., & Williams, D. G. (2005). The influence of soil texture and vegetation on soil moisture under rainout shelters in a semi-desert grassland. *Journal of Arid Environments*, *63*(1), 324-343.

Heisler-White, J. L., Knapp, A., Collins, S., Blair, J., & Kelly, E. (2008). Contingenet Productivity Responses to More Extreme Rainfall Regimes Across a Grassland Biome. *AGUFM*, *2008*, B21C-0389.

Hiler, E. A. (1969). Quantitative evaluation of crop-drainage requirements. *Transactions of the ASAE*, *12*(4), 499-0505.

Kant, S., Thoday-Kennedy, E., Joshi, S., Vakani, J., Hughes, J., Maphosa, L., ... & Spangenberg, G. (2017). Automated rainout shelter's design for well-defined water stress field phenotyping of crop plants. *Crop Science*, *57*(1), 327-331.

Kreyling, J., Khan, M. A. A., Sultana, F., Babel, W., Beierkuhnlein, C., Foken, T., ... & Jentsch, A. (2017). Drought effects in climate change manipulation experiments: quantifying the influence of ambient weather conditions and rain-out shelter artifacts. *Ecosystems*, *20*(2), 301-315.

NMRP. 2017. *Annual Report 2073/74 (2016/17)*. Vol. 74. National Maize Research Program, Chitwan, Nepal.

Prasai, H. K., Sharma, S., Kushwaha, U. K. S., & Shrestha, J. (2015). Evaluation of Quality Protein Maize and Drought Tolerant Maize in Far Western Hills of Nepal. *International Journal of Applied Sciences and Biotechnology*, *3*(3), 387-391.

RA, F., & Maurer, R. (1978). Drought resistance in spring wheat cultivars. I. Grain yield responses. *Aust. J. Agric. Res.*, *29*, 897-907.

Reynolds, J. F., Virginia, R. A., Kemp, P. R., De Soyza, A. G., & Tremmel, D. C. (1999). Impact of drought on desert shrubs: effects of seasonality and degree of resource island development. *Ecological Monographs*, *69*(1), 69-106.

Singh, T., & Malik, D. S. (1983). Effect of water stress at three growth stages on the yield and water-use efficiency of dwarf wheat. *Irrigation Science*, *4*(4), 239-245.

Zhang, X., Guo, H., Yin, W., Wang, R., Li, J., & Yue, Y. (2015). Mapping drought risk (wheat) of the world. In *World atlas of natural disaster risk* (pp. 227-242). Springer, Berlin, Heidelberg.

ISSN: 2716-3865 (Print), 2721-1290 (Online)