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Estimation of Potential Evapotranspiration and Crop Coefficient of Maize at Rupandehi District of Nepal

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Abstract

This study was conducted to determine the potential evapotranspiration (PET) of maize, the crop coefficient (Kc) under full water requirement as well as the cause of decrease in maize yield. It was determined that the seasonal PET of maize is about 486.6 mm. The Kc under full water supply was found to be: 0.11, 0.35, 1.51 and 0.34 for initial, development, mid-season and the late season stages respectively. The study also revealed that maintenance of sufficient moisture need of maize has a significant effect on growth, development and fruiting of the crop.

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INTRODUCTION

Potential evapotranspiration (PET) is an important factor in the estimation of water requirement of crops. In the FAO Irrigation and Drainage paper No. 24 on Crop Water Requirements, four methods were given by Doorenobs and Pruit (1977) for the calculation of PET ; Blaney-Criddle, radiation, Penman (adjusted) and pan evaporation. Maize (*Zea mays* L.) is the second important crop in Nepal after rice in terms of area and production. It is grown in the sub tropical to cool temperate climates. For higher yields, crop water requirement is 500-600 mm depending upon the climate and duration of the crop, there should be adequate water during the crop establishment period. Water deficit during the grain filling period results in reduced grain weight. However, during the maturity and harvesting period, rainfall has negative impact on maintaining grain quality (Nayava and Gurung, 2010). Maize is grown during April- July in Terai. During this period, about 500 to 800 mm rainfall (R) occur in the Terai. Annual mean temperature (T) during the growing period of maize in Terai is 21^0C to 33^0C. In fact Terai region has only 9.1% of the total maize area and contributes 20.4% of the total maize production in the country. During the last 36 years period from 1970/71 to 2007/08, the production of maize in the Terai region increased from 230,700 MT to 383,141 MT. It is interesting to note that the maize yield in Terai was initially low. In Terai, area under maize increased by 60% and its yield increased only 71%. The average yield of maize from 1970/71 to 2007/08 in Rupandehi district is 1822 kg ha^{-1}. The yield of maize in Rupandehi district is observed lowest in 1996 and the highest in 1976 which is 934 kg ha^{-1} and 3241 kg ha^{-1} respectively (MoAC, 2007). Maize is planted in all three seasons (summer, winter and spring) in the Terai region. The planting of summer maize starts from April to May and harvests on August to September. The growing season of winter maize covers from November / December to March/ April. Similarly, the growing season of spring maize is in March/April and harvests on June to early July. For the summer and winter crops, farmers prefer to grow long duration varieties, where as for the spring maize short duration varieties are preferred. Winter and spring maize is planted, wherever the irrigation facilities are available. After the introduction of high yielding varieties, the yield increased in Terai comparatively more than those of the hills and mountain (Nayava and Gurung, 2010).

The maintenance of low plant population in maize fields is one of the major factors affecting low productivity of maize in Nepal. Since yield of a crop is the result of final plant population, the establishment of optimum plant population is essential to get maximum yield. The competition between plants may not occur, and resources are not efficiently used at very low plant population. Under low plant population, grain yield is limited by inadequate number of plants whereas at higher plant population, it declines mostly because of an increment in the number of aborted kernels and/or barren stalks. At higher plant population, the rate of yield reduction is in response to decreasing light, moisture nutrient and other environmental resources available to each plant. Nepalese farmers have been practicing broadcasting method of seed sowing, which can not maintain uniform plant population in the field. The maintenance of plant population of maize in farmer's field condition is lower than the recommended level; and hence the yield is reduced. This is one of the causes of lower maize yield in Nepal (Shrestha and Timsina, 2011).

Recently the effect of climate change to agriculture in Nepal was studied by different researchers. The Asia Pacific Network report shows, when the temperature rises up to 1^0C, there is a positive role in percentage change in maize yield in all the agro-ecological zones. When the temperature rises up to 2^0C and at the same time carbon dioxide is doubled, the yield will decrease in Terai, hills will not be much affected. On the contrary, mountain environment will have better yield if the carbon dioxide is doubled and temperature rises up to 4^0C, the maize yield in Terai will suffer 25% lesser than the present yield (Nayava and Gurung, 2010). Overall rainfall during summer monsoon of the year 2005-06 and 2006-07 was about 16% below the normal which reduced cultivation area of agricultural production in the country (MoE, 2011).

Scientific statements regarding changing climate of Nepal are pronouncedly focused on temperature rise at 0.06 ^{o}C per annum. Such a rise in average temperature is variable across the country (Gautam and Pokhrel 2010), higher in the mountains and Himalaya (0.08^{o}C) as compared to low-lying Terai (0.04^{o}C). As a result, series of speculation have been reported such as days and nights becoming warmer, retreating snow lines, increased evapotranspiration and peak runoff, decreasing regular water discharge in streams and recharge of natural water stores, changing water tables and changing pattern of precipitation in terms of form, season, duration and amount (MoE, 2010 a; Gautam and Pokhrel, 2010). Also reported are decreasing total rainy days and increasing number of drier days (evapotranspiration>precipitation) and days receiving over 100 mm rain (MoE, 2010 a; Practical Action, 2009). Precipitation, though not much varying in total amount, is mentioned being erratic and ill timed (Gurung, 2008). Weather variability associated with rising temperature and changing pattern of precipitation is expected to have utmost adverse impacts on various components of agricultural systems. The impacts, though expected to become higher in the mountains compared to low lying terai region, are detrimental to both the regions and ultimately to agricultural production, food security and people's economic sustenance.

The aim of this study is to estimate Kc; Aridity index, AI; and PET of maize using a Lysimeter and Blaney-Criddle method that could be used in Nepal.

MATERIALS AND METHODS

General description of the study area and a lysimeter.

The study area was located at National Wheat Research Program (NWRP), Bhairahawa in Rupandehi district as shown in Figure 1. It is situated between 27^{o} 32' N latitude and 83^{o} 25' E longitude. It is 105 m above the sea level.

In the terai, mostly sandy loam and loam types of soils are reported. Farmers reported black clay as the most fertile soil. However, this soil is not suitable for maize cultivation except in drier years, as it holds water longer than other soil types and tends to waterlog. Land preparation is difficult in clay soils, especially red clay. Brown and gray colored loams are the most suitable for maize cultivation (Paudyal *et al*., 2001). Loam and clay loam soil textures are the dominant soils of the study area. Loamy soil is easy to plow but yield declines substantially if rainfall is low.

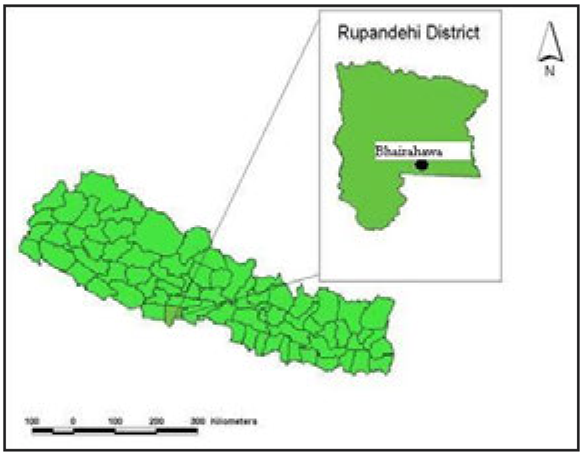

Figure 1: Location map of the study area in a Rupandehi district, Nepal

Experimental design and field layout

A lysimeter is made from readily available materials, plastic bucket with an area of 5811 square centimeter and 10 cm deep and is kept at one corner of the maize growing plot. The first bucket (B1) with tiny holes is completely filled with soil and leveled to the ground surface and holds maize seeds and the second bucket (B2) underground with a hole is connected with a pipe to pass out the infiltrated water to the receiving vessel which is kept deep underground as shown in figure a and b respectively. The receiver vessel kept underground and the B2 are connected with a water pipe so as to collect the percolated water. (Figure a and b)

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Figure a: Water pipe connecting to B2 bucket


Figure b: A completely installed lysimeter


Figure b: B1 bucket with sowed maize seeds and a receiver vessel over B2 bucket which is connected with a receiver vessel

Planting

Rampur Composite, a major downy mildew disease resistance variety of maize is sown on 22 May, 2011 as in fig a. Screening of this variety against downy mildew disease was carried out at Suwan farm, Thailand in 1981/82 (Rajbhandari, 1982). (Figure a and b)


Figure a: Sowed maize seeds

Growth stages

Four growth stages are considered. They are initial stage, developmental stage, mid-season stage, and late season stage. The initial stage lasted for 10 days (May 22 – May 31, 2011). The developmental growth stage lasted for 30 days (June 1– June 30, 2011). The mid-season growth stage (flowering and fruiting) stage lasted for 31 days (July 1 – July 31, 2011) and the late season stage lasted for 14 days (August 1– August 14, 2011). (Figure a and b)


Figure a: Mid-season growth stage


Figure b: Late season stage

Irrigation regime

One liter of water is maintained daily except the rainy days so as to provide the sufficient moisture for the growth of maize in a lysimeter. Irrigation days amounted to 42 days and rainy days amounted to 43 days out of the 85 days of the total growing period. The percolated water is used for the irrigation to conserve the chemical composition of the soil.

Potential evapotranspiration

Evapotranspiration is one of the major contributors of the total irrigation water requirement. The amount of evapotranspiration is largely governed by weather parameters. Evapotranspiration might be potential or actual. Potential evapotranspiration assumes the continuous supply and no deficit of moisture in the air (WMO, 1994).

The measurement of PET includes the moisture evaporated to the atmosphere from plants and soil. As the soil and vegetation is confined within a small tank (the lysimeter) the measurements are made of the water input: Rainfall (R) and Additional water (A) and output: Percolated water (P) collected in the receiving vessel, PET can be estimated from the equation below:

PET=R+A-P…………………………….. (1)

Crop coefficient

K_c is calculated by using the value of PET (as obtained in equation 1) in a Blaney-Criddle formula (as in equation 2)

PET =2.54 Kc F………………………… (2)

and $F = \sum Ph\ Tf/100$,

where,

K_c = an empirical coefficient, depends on the type of the crop

P_h = monthly percent of annual day time hours, depends on the latitude of the place

T_f = mean monthly temperature in ^oF

F= sum of monthly consumptive use factors for the period

Aridity Index

AI represents the severity of dryness of a region. Aridity is defined as the more or less repetitive climatic condition, which is characterized by a lack of water (Perry, 1986). It should be noted that aridity can be considered on seasonal or monthly basis (Coughlan, 2003). The AI ranges from 0.05 to 0.65 for the dry seasons. AI less than 0.65 correspond to Dry lands that, according to the United Nations Convention to Combat Desertification (UNCCD), may suffer desertification processes. So, AI should be greater than 0.65 during the maize growing seasons. In this study, UNEP aridity index (Hare, 1993) is used to estimate the AI which can be expressed as:

AI = P/PET……………………………….. (3)

where, P=Precipitation in mm and PET=Potential Evapotranspiration in mm.

Other data collected

Five plants are selected randomly from the field and compared with the five plants of the lysimeter to compare the different parameters.

Height and width: Plant height and width of stalk is measured by a measuring tape.

Corn yield: Late April planted corn yields the highest and produces the most profit per hectare. Yield potential is lower when corn is planted late. Number of cobs and grains was determined by counting them respectively.

Grain and biomass weight: Grain weight and dry biomass was determined by using electronic analytical balance.

Statistical analysis

Data collected were subjected to analysis of mean and standard deviation by using MS Excel and SPSS. It is a non-restrictional design in the sense that there is no blocking and any treatment can be replicated any number of times. Five maize plants are selected randomly from the lysimeter and agricultural land as control group and experimental group respectively. Such random assignment of items to two groups is technically described as principle of randomization. Thus, this design yields two groups as representatives of the population. As the experimental units are homogenous, completely randomized design (CRD) has been used for the data analysis and interpretation of results.

Source of Inputs

Seed, fertilizers, and manure are the major inputs used for maize. The Agricultural Inputs Corporation (AIC), a public sector undertaking, was the only institution marketing fertilizers until a few years ago, when its monopoly ceased following changes in government policy. It was envisioned that the private sector would step into supply these inputs, but this has not come to pass. The private sector does supply inputs to Terai districts, but supplies limited quantities in the eastern and central midhills and almost none in the mid-western and far-western midhills and highhills. Some NGOs have been supplying seed, fertilizer, and plant protection chemicals in some areas for vegetable cultivation, but not for maize. Negligible amounts of pesticides are used in maize production in the midhills and highhills. However, pesticide use is common among farmers in the central Terai. All of the pesticide used, especially in the Terai, is purchased from agrovets in nearby markets. Agrovets supply a limited amount of hybrids and improved maize seeds in comparatively accessible areas. Their interest, however, remains on hybrid seed, which has higher profit per unit of seed sold.

Farmyard manure is one of the inputs that every household uses in maize fields. Though farmyard manure is also used for other crops, the largest part of the manure is used for maize production (Paudyal *et al*., 2001). Soil application of 60:30:0 kg NPK/ha is used to get high yield (Dhital *et al*., 1990). The grain yield increases significantly with the increasing dose of nitrogen (Tripathi and Pathak, 1984). The chemical fertilizer especially nitrogen fertilizer is universally accepted as a key component to higher corn yield and optimum economic return (Gehl, *et al.,* 2005). The loss of soil fertility and lower use of fertilizer input is also another important factor responsible for low yield of maize. The amount of nitrogen to be applied depends largely on the plant population/unit area of land. Optimum plant population can result in increased production only if there is proper supply of nutrients, particularly nitrogen. Srivastav *et al*., (2002) found non-significant response of early and late varieties to three levels of N (60, 90 and 120 kg ha^{-1}) and plant densities (53000, 71000 and 95000 plants ha^{-1}) during summer but a significant response during winter season. Adhikari, *et al.*, (2004) reported that the highest grain yield of 9352 kg ha^{-1} was produced when the crop was fertilized with 120 kg N ha^{-1} on the crop planted under the plant population of 53,333 plants ha^{-1}; and they noted the lowest yield (6657 kg ha-1) with the crop supplied with 60 kg N ha^{-1} under plant population of 44,444 plants ha^{-1}.

Problems encountered

1- Southern leaf blight, a new disease of maize is a great threat in the Terai. This disease has reduced plant height, grain yield, biomass and grain weight.

2- Army worm, blister beetle, cut worm, moth, stem borer, termite, weevils, white grub etc are the agents causing damage to maize at different stages in Terai.

3- Erratic rainfall

4- Drought is prolonging year after year in Nepal. Development of drought tolerant varieties is the answer to the drought problem. Adjustment of planting season could help to escape the critical stage of crops to escape from the drought.

RESULTS AND DISCUSSIONS

The results obtained from this study shows that when the maize is given its full water requirement, 486.6 mm of water is required. The maximum amount of water i.e. 318 mm is required and utilized at the mid stage (flowering and fruiting). However, for higher yields, crop water requirement is 500-600mm depending upon the climate and duration of the crop, there should be adequate water during the crop establishment period (Nayava and Gurung, 2010).

In this study, K_C is 0.11, 0.35, 1.51 and 0.34 for initial, development, mid-season and the late season stages, respectively as indicated in Table 1. However, values of Kc depend on the month and locality. The range of monthly values is 0.50-0.80. Average value of Kc for the season for maize is 0.65 (Subramanya, 2007). Similarly, the crop coefficient value was found to be higher as the number of days increases. The

Table 1: PET, T, R, Kc and AI

Months/Stages	R (mm)	PET (mm)	Kc	T in ⁰F	AI
May/Initial	44.00	24.00	0.11	85.35	1.83
June/Crop development	202.10	74.10	0.35	87.04	2.73
July/Mid	429.90	317.90	1.51	85.47	1.35
August/Late	106.60	70.60	0.34	86.43	1.51

Potential evapotranspiration, PET; Temperature, T; Rainfall, R; Crop coefficient, Kc and Aridity index, AI

PET increases as increase in the amount of rainfall and temperature and vice versa as shown in figure 2 and figure 3. However, the PET at mid season has been observed maximum due to the increase amount of rainfall and decrease in temperature. The AI increases with the increase of temperature and observed to be maximum at the crop development stage and minimum at mid stage as shown in table 1.

The crop coefficient (K_C) is affected by a number of factors, which include: the type of crop, stage of growth of the crop and the cropping pattern (Allen *et al.,* 1998). Doorenbos and Pruitt (2000) indicated that plant height and total growing season influence crop coefficient values. The higher the plant height and the longer the growing season the higher the crop coefficient values and vice versa.

Yield components

The relationships between crop yield and water use are complicated. Yield may depend on the timing of water application or on the amount applied. Information on optimal scheduling of limited amounts of water to maximize yields of high quality crops are essential if irrigation water is to be used most efficiently (Anac *et al.,* 1997). Timing, duration and the degree of water stress all affect crop yield.

In this study, height, number of grains, 1000 grains weight and biomass of maize grown in a lysimeter was found to be greater than that of field maize as shown in Table 2. The average yield of maize is estimated to be 1044 kg ha^{-1} when amount of water is provided enough. About 50% reduction in the yield (580 kg ha^{-1}) is observed when there is the scarcity of water. However, the number of grains of maize in a lysimeter and field was negatively affected by the emergence of southern leaf blight disease and other insects and could not reach maximum.

Table 2: Different parameters of Maize

Parameters	Field	Lysimeter
Average plant height (cm)	218	236.2
No. of cobs	4	3
Width of plant with cobs (cm)	6.5	5.75
Grains of a plant/cob	162	216
1000 grains weight (gm)	160	281
Biomass (gm)	649.9	716.99

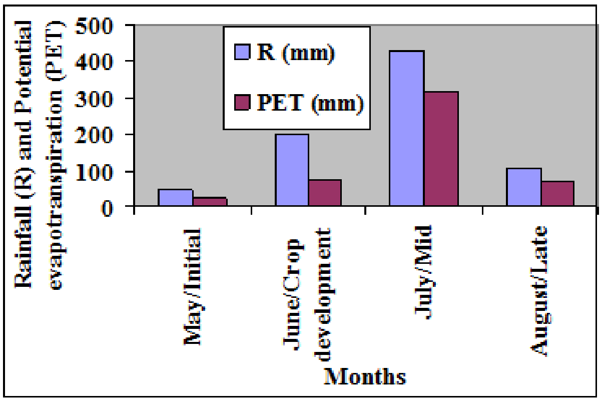

Figure 2: Rainfall and PET at different stages of maize growing period

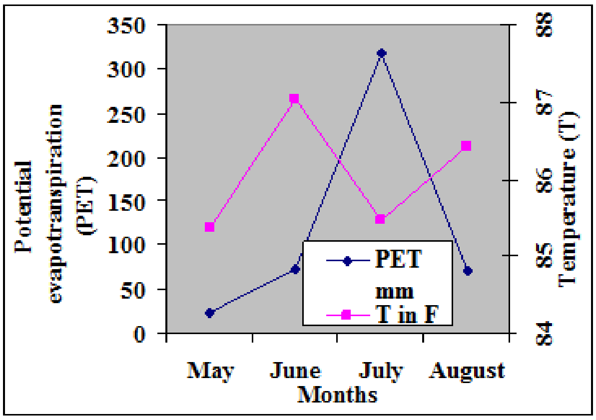

Figure 3: Temperature and PET at different stages of maize growing period

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CONCLUSION

Crop coefficient is 0.11, 0.35, 1.51 and 0.34 for initial, development, mid-season and the late season stages respectively. So the range of monthly values of crop coefficient of maize is found to be 0.11-1.51. Potential evapotranspiration is 24 mm, 74.1 mm, 317.9 mm and 70.6 mm for initial, development, mid-season and the late season stages respectively. The total PET is 486.6 mm. The PET of maize is more dependent on rainfall and temperature besides other factors. The PET increases as the amount of rainfall increases. Maintenance of sufficient moisture in a lysimeter has resulted higher yield and therefore the yield of maize can be increased by providing sufficient moisture and manure, controlling disease and pests during initial, crop development and mid season.

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