Quantification of long-term precipitation use efficiencies of different maize production practices on a semi-arid ecotope in the Free State Province

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Abstract

Precipitation use efficiency (PUE) was estimated for four production practices, i.e. conventional tillage with November planting (CTN), conventional tillage with January planting (CTJ), in-field rainwater harvesting with November planting (WHBN), and in-field rainwater harvesting with January planting (WHBJ), over 80 maize seasons for a semi-arid ecotope in the central Free State Province of South Africa. An empirical yield prediction model was used to obtain maize grain yields. PUE was expressed as the ratio of transpiration: rainfall for each growing season (PUE_T), while transpiration was calculated from total biomass yield, vapour pressure deficit and a transpiration efficiency coefficient for maize. The following equation, based on 10 years of measured data, was developed to estimate daily vapour deficit pressure for the 80 seasons from daily maximum temperature: $Vd = 0.163 \times T_{max} - 2.88$ ($R^2 = 0.73$). Mean PUE_T values over the 80 seasons were: 0.260 for CTN, 0.320 for WHBN, 0.334 for CTJ, and 0.400 for WHBJ. These results confirmed and quantified the advantage of in-field rainwater harvesting over conventional tillage, and the advantage of January planting over November planting. PUE_T results were also expressed as cumulative probability functions. Significance tests showed that PUE_T for in-field rainwater harvesting was significantly better than PUE_T for conventional tillage, and that January planting was significantly better than November planting. It was concluded that the advantage of in-field rainwater harvesting over conventional tillage was mainly due to the absence of runoff and reduced evaporation in the former practice. The use of a short-growing cultivar, which flowers during the month with the most favourable climate, i.e. March, probably resulted in the advantage of January planting over November planting.

Keywords: conventional tillage, in-field rain water harvesting, planting date, transpiration, vapour pressure deficit

Introduction

Water availability is the most important limiting factor for rain-fed crop production in semi-arid areas. Maximising precipitation use efficiency (PUE) is therefore important. This can be achieved by identifying and employing the crop production practice with the highest PUE for that specific ecotope. The ecotope concept is defined by MacVicar et al. (1974).

Water use efficiency (WUE) has been widely used in the past to calculate crop water use efficiency (Hillel, 1972; Tanner and Sinclair, 1983):

$$WUE = \frac{Y}{E+T} \text{ kg·ha}^{-1}\text{·mm}^{-1} \quad (1)$$

where:

- Y = grain yield (kg·ha^{-1})
- E = water lost from the soil surface through evaporation during the growing season (mm)
- T = water used for transpiration during the growing season (mm)

WUE is a measure of the efficiency with which a crop uses water to produce a certain yield. Although valuable in certain cases, WUE does not enable the comparison of different production practices. This is because certain water loss processes, which can be minimised by using suitable water conservation tillage (WCT) practices to improve the efficiency of rainwater use in crop production, are not taken into account. These losses include runoff, evaporation and deep drainage, during the growing and fallow seasons. Precipitation use efficiency (PUE_Y) is considered to be a more appropriate parameter to describe the overall efficiency with which rainwater is used in rain-fed cropping, since the named losses are taken into account (Hensley et al., 1990):

$$PUE_Y = \frac{Y}{P_g + P_f + \left(\theta_{h(n-1)} - \theta_{h(n)}\right)} \text{ kg·ha}^{-1}\text{·mm}^{-1} \quad (2)$$

where:

- PUE_Y = precipitation use efficiency for a particular year, including the fallow season, based on the grain yield (kg·ha^{-1}·mm^{-1})
- Y = grain yield (kg·ha^{-1})
- P_g = precipitation during the growing season (mm)
- P_f = precipitation during the fallow season (mm)
- $\theta_{h(n)}$ = water content of the root zone at harvest in year n (mm)
- $\theta_{h(n-1)}$ = water content of the root zone at harvest in year n-1 (mm)

PUE_Y is therefore the grain yield per unit of total rainfall associated with a particular crop, during a particular year. It is necessary to include P_f in Eq. (2) because certain WCT practices result in improved water conservation during the fallow season as well as during the growing season. Such practices generally result in more plant available water at the start of the following growing season than where WCT practices had not been applied

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