AGRICULTURAL WATER MANAGEMENT 90 (2007) 45–55

available at www.sciencedirect.com

journal homepage: www.elsevier.com/locate/agwat

Crop-yield/water-use production functions of potatoes (*Solanum tuberosum*, L.) grown under differential nitrogen and irrigation treatments in a hot, dry climate

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ARTICLE INFO

Article history:
Accepted 11 February 2007
Published on line 6 April 2007

Keywords:
Irrigation
Water-use
Production functions
Potatoes
Nitrogen
Hot dry climate
N.E. Portugal

ABSTRACT

During two consecutive years (1988–1989) field experiments were conducted in the region of Trás-os-Montes, N.E. Portugal. The work formed part of a wider research programme assessing the effects of water and nitrogen (N) on the productivity of potatoes in a hot, dry environment. Line-source experiments were carried out using potato crops (*Solanum tuberosum*, L.) subjected to four N levels (N_0, N_1, N_2 and N_3) and five irrigation (I) treatments (I_4–I_0). The main aims were to characterise crop productivity and develop the drought response factor K_y and the crop yield production functions in relation to rainfall and irrigation ($P + I$) and to total water-use (ET_c), that could be used to assess the benefits of irrigation and fertilisation practices in the region. ET_c was monitored by intensive field measurement of soil water content using a neutron probe device. Single values of total water applied ($P + I$) ranged from 148 to 387 mm in 1988 and from 295 to 724 mm in 1989. By contrast, single values of ET_c (including the contribution from soil water storage), ranged from 230 to 504 mm in 1988 and from 330 to 802 mm in 1989. Full irrigation increased mean yields of fresh tubers from 11.8 to 24.7 t/ha in 1988 and from 13.6 to 49.8 t/ha in 1989. Total fresh tuber yield from droughted crops tended to decline with increasing N fertiliser up to 80 kg/ha. Yield responses to $P + I$ (52–91 kg/(ha mm)) and to ET_c (62–105 kg/(ha mm)) varied with fertiliser application. In both years, the relative values of K_y were similar for all three fertilised crops (N_1, N_2 and N_3) regardless of nitrogen dosage. The mean K_y value in 1988 was 0.71 and 1.12 in 1989.

1. Introduction

Recent publications (FAO, 2004) have shown the importance of the potato (*Solanum tuberosum*, L.) as a global food crop, ranking fourth among other crops with an overall annual production of nearly 327 million tonnes and about 19 million ha planted. Since its introduction into Europe during the last quarter of the 16th century (Hawkes, 1992), it rapidly became the staple food of most people living on the continent. Portugal is no exception and the entire production of potatoes accounted for almost 6% of the Gross National Agricultural Product and in the N.E. region (Trás-os-Montes and Alto Douro) 22% of the Gross Agricultural Product (Martins, 1990). However, in a past report (Ferreira, 1996), comparison of potato yield values from Portugal for the 15-year period of 1979–1994, to corresponding values from other European Community countries, showed

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0378-3774/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.agwat.2007.02.012

Portugal ranking last with an average of 10 t/ha. Historical data from 1889 to 1941 compiled by Martins (1990) show a wide range of variation from as little as 5.4 up to 20.4 t/ha. Over the last decade, time trend technological improvement, especially in water and fertiliser management, has been responsible for an increase in potato yields in Portugal.

In the Trás-os-Montes and Alto Douro province of north-eastern Portugal (ca. 41–42°N and 7–8°W) the potato is also an important subsistence crop. However, locally, productivity is constrained on one hand by the severe soil water deficit which invariably develops during the hot dry climate that prevails during the summer season and on the other hand by the low water holding capacity and low organic matter content of the local soils. The soils around north-eastern Portugal have been cropped for years in a rotation system involving a cereal crop, potatoes and pasture and in the past, it was a common practice to fertilise these with animal manure (Moreira, 1984). However, with the advent of mineral fertilisation, farmers have been shifting from organic to mineral fertilisation with the consequent degradation of the soil's structure. Due to its complex topography and mountainous nature, winter rainfall in this region is much heavier than summer, resulting in frequent leaching of any residual fertiliser that may have been left in the soil from the previous crop. Rainfall during the summer (May–September) accounts for only 20–30% (150–250 mm) of the annual total, and the majority of crops experience severe water stress (Ferreira et al., 1996). Irrigation is therefore practiced to overcome this condition and to raise the productivity of crops, in particular of potatoes, which are sensitive to mild water deficits (Lynch et al., 1995; Wright and Stark, 1990). Due to the scarcity of water during summer season and the high-energy costs, this activity involves high financial risks to the grower, requiring before-hand knowledge of the likely benefit-to-cost ratio.

One practical way of assessing the financial benefits of irrigation in a given climatic environment and husbandry condition, is through the development of the relationship between tuber yield and water supply (Patel and Rajput, 2007). This approach allows field quantification of water-use efficiency for a given crop in a given environment and can be assessed by developing local crop-yield/water production functions of which the simplest is the yield responses to rainfall plus irrigation. Though the latter is an empirical approach, it also provides a simple means of judging the likely benefits of irrigation (Onder et al., 2005). The responses of potatoes described by such yield/irrigation water applied production functions developed in temperate climates (e.g., UK) showed values varying from 0.30 to 0.02 t/(ha mm) with an increase in irrigation application (Carr, 1983). These responses described by crop yield/water-use production functions are also commonly referred to as water-use efficiency (WUE) and the reported values for potatoes grown elsewhere in the world vary from 0.063–0.085 t/(ha mm) (Fabeiro et al., 2001) to 0.14 t/(ha mm) (Onder et al., 2005). Although this represents an improved means of assigning economic values to the total water-use, they bear a certain degree of uncertainty, shown by the two-fold variability, mainly due to the relative importance of soil evaporation and transpiration. Soil evaporation can represent up to 50% (Ferreira and Carr, 2002) of the total water used by potatoes in the climate conditions where this study is carried out. Therefore to allow for differences in actual rates of water-use and actual yield between sites and years, the use of yield response factors to drought (K_y) are recommended (Stewart et al., 1977). Values of K_y represent no more than a crop sensitivity factor to drought and they have been empirically derived by Stewart et al. (1977) and Doorenbos and Kassam (1986) for a range of crops including potatoes. However, the sensitivity of potato crop to drought in this region has not yet been determined, particularly under varying irrigation and nitrogen fertilisation. The knowledge of such a sensitivity factor can be of great use to help determine a managerial strategy for the optimum husbandry under a given local environmental condition.

The overall objective of the study was to examine the constraints to potato productivity imposed by the hot, dry climate prevailing in this region, particularly when cropping under varying levels of water and nitrogen fertiliser. Details of actual water use have been presented in a previous paper (Ferreira and Carr, 2002). Therefore, in this paper, an outline is given of crop-yield responses of potato crops to water applied and water-use and the corresponding crop yield response factors to drought, obtained under varying levels of irrigation and nitrogen fertilisation.

2. Methodology

2.1. *Site, experimental design and crop management*

Two trials were carried out during the summers of 1988 and 1989 in adjacent small (0.5 ha) fields, in north-east Portugal (latitude: 41°49′N; longitude: 6°46′W; altitude: 720 m) at Santa Apolónia Farm, Bragança Polytechnic. The experiments were carried out in previously fallow fields which were covered by grass for the previous three years, each with a total area of around 5000 m^2. In 1988, the soil at Site 1 (S1), characterised by a soil mass made of alluvial deposits, was classified as a Gleyi-Umbric Fluvial. In 1989 the soil at the adjacent Site 2 (S2), characterised by a good fertile mantle of loose material was classified as Eutric Regosol (FAO-UNESCO, 1988). The soils in both fields were described as silt-loams with organic matter content decreasing from 3% at the surface to 0.5% at depth of 1 m. Both fields showed total nitrogen content varying (1988–1989) from 0.16–0.20 (%) at the surface to 0.030–0.050 (%) at 1 m, with pH varying between 5.3 and 5.7 at both sites. Corresponding values of organic carbon content varied from 1.32 to 1.66 (%) at the surface to 0.30–0.50 (%) at depth of 1 m. These values are representative of a soil from regions where winter rainfall is heavier than summer rains (Brady, 1974) and are within those found by Martins (1987) for other sites in N.E. Portugal where potato is cropped. The soil water holding capacity varied between 150 mm/m on Site 1 (1988) and 200 mm/m on Site 2 (1989). There was no sign of the water table at 1.8 m depth.

Both experiments were based on the line-source design first described by Hanks et al. (1976) with four main nitrogen treatments (0 (N_0), 80 (N_1), 160 (N_2) and 240 (N_3) kg/ha) replicated four times, two on either side of a central pipe. There were five differential irrigation/drought treatments ranging from the fully irrigated (I_4) to un-irrigated, rainfall-only (I_0), with three