Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/sjar

Spanish Journal of Agricultural Research 2007 5(4), 587-592
ISSN: 1695-971-X

Agronomic response of maize to limited levels of water under furrow irrigation in southern Spain

M. Aguilar*, F. Borjas and M. Espinosa

Consejería de Agricultura y Pesca de la Junta de Andalucía.
Instituto de Investigación y Formación Agraria, Alimentaria y Pesquera (IFAPA).
Centro de Investigación y Formación Agraria (CIFA) «Las Torres-Tomejil».
Apartado Oficial. 41200 Alcalá del Río (Sevilla). Spain

Abstract

The yield response to limited irrigation is a major concern where water resources are limited. The objective of the work was to know the agronomic response of 12 maize hybrids cultivars under full and limited irrigation levels. Full irrigation consisted in 5 to 7 furrow irrigations events (90 mm) applying a total depth of 450-630 mm. In the limited irrigation treatment, three irrigations (90 mm) were applied, beginning 2-3 weeks before silking and ending 3-5 weeks after it. Results indicated a mean yield loss of 17% due to limited irrigation. The main effect of limited irrigation was a reduction of the ears per plant and 1,000 kernel weight. Maize yield decreased as season length was reduced. The main effect of season length reduction was a reduction of kernels per ear. Limited or regulated deficit irrigation is one way of maximizing productivity of total applied water (PAW); thus, the limited irrigation treatment reached a higher PAW value (2.66 kg m^{-3}) than full irrigation (1.90 kg m^{-3}). In both irrigation levels, PAW was higher as the growth cycle increased. It can be concluded that, in the conditions of Southern Spain, reduced irrigation provided larger yields when applied to long cycle cultivars (FAO 700-800), with increased PAW values.

Additional key words: crop yield, FAO cycles, productivity of applied water.

Resumen

Respuesta agronómica del maíz a riego normal y precario en el sur de España

La respuesta agronómica al riego deficitario es un asunto de gran importancia en regiones donde los recursos hídricos son limitados. El objetivo de este estudio fue conocer la respuesta agronómica de 12 variedades híbridas de maíz al riego convencional y al riego deficitario. El riego convencional consistió en 5-7 riegos (de 90 mm) con un aporte total de 450-630 mm. El riego deficitario constaba de 3 riegos (de 90 mm), aplicados desde 2-3 semanas antes del inicio de la floración femenina hasta 3-5 semanas después de la misma. Los resultados indican unas pérdidas medias de rendimiento del 17% bajo riego deficitario. El número de mazorcas por planta y el peso de 1.000 granos fueron los componentes más afectados. Los rendimientos del maíz disminuyeron a medida que la longitud del ciclo se acortaba. El efecto principal de la reducción del ciclo fue una reducción del número de granos por mazorca. El riego deficitario es una vía para maximizar la productividad de los aportes hídricos totales (PAW); por ello, el riego deficitario alcanzó mayores valores PAW (2,66 kg m^{-3}) que el riego convencional (1,90 kg m^{-3}). En ambos sistemas de riego el índice PAW fue mayor cuanto mayor fue el ciclo del cultivo. Podemos concluir que, bajo las condiciones del sur de España, los mayores rendimientos bajo riego deficitario se obtuvieron con las variedades de ciclo más largo (FAO 700-800), con unos índices PAW incrementados.

Palabras clave adicionales: ciclos FAO, producción, rendimiento del agua aplicada.

Introduction

The Food and Agriculture Organization (FAO, 1988) estimated that almost two-thirds of the increase in crop production needed in the next decades must come from higher yields. In the past, crop irrigation requirements did not consider limitations of the available water supplies. Improving water productivity is urgently needed in water-scarce dry areas. To minimize input cost and environmental damage, farmers will likely produce maize with less irrigation water in the future.

* Corresponding author:
manuel.aguilar.portero@juntadeandalucia.es
Received: 23-10-06; Accepted: 31-10-07.

Limited irrigation means that a soil water deficit is induced at non-critical stages of crop growth while supplemental irrigation is provided at critical stages of growth. It is a system of crop management in which dryland cultivation is integrated with a limited water supply in an irrigation network that is only able to supply part of the water needed for crop growth (Shan *et al*., 2000). The main approach in limited (deficit) irrigation is to save water, labour and energy, by eliminating those irrigations with minimal effects on yield. The subject of deficit irrigation and the effect of water stress in crop yield has been widely reported (Doorenbos and Kassan, 1979; English *et al*., 1990; FAO, 2002). For the same crop, the effect of limited irrigation may vary with location as it strongly depends on soil type, which dictates the available water for plant uptake, and on climate, which determines crop evapotranspiration.

Maize (*Zea mays* L.) grain yield is closely linked with «kernel number at maturity», with kernel number being determined by the physiological status of the crop around flowering (Otegui and Andrade, 2000). According to Andrade *et al*. (2002) and Bänziger *et al*. (2002) crop water stress imposed during flowering has an adverse effect on the physiological status of the crop through diminished photosynthetic rates, assimilate supplies, and plant growth rates. This in turn adversely affects the capacity of the plant to set kernels during critical reproductive period, with kernel number and ultimately grain yield being negatively impacted. Consequently, maize is relatively insensitive to soil moisture deficits imposed during early vegetative growth stages because water demand is relatively low and plant can adapt to water stress to reduce the impact of subsequent periods of water stress (Shaw, 1977). However, maize grain yield is sensitive to water stress from just before silking through grain filling (Westgate and Boyer, 1986), with the greatest degree of sensitivity occurring during the period of kernel number determination (Andrade *et al*., 1999). Hall *et al*. (1981) indicated that kernel number was most sensitive to stress from tasseling to just after silking. Tollenaar *et al*. (1992), comparing the response of stress-tolerant hybrids with sensitive hybrids, found different relationships between kernel number and crop physiological status, with stress-tolerant hybrids setting more grains than susceptible hybrids under similar levels of watering stress.

While maize performs best on well-drained silt loam soils, when irrigated, it can be grown profitably on deep sands. Low air humidity and high air temperatures increase crop water requirement. Moreover, long season cultivars require more water. When seasonal rainfall is less than 750 mm, maize yield appears directly related to precipitation (Waldren, 1983). In modelling the effects of soil depth and climatic factors on maize yield, Swan *et al*. (1987) found a significant interaction effect on grain yield between climate and soil water-holding capacity. Gardner (1983) noted that a combination of plant, soil and climatic factors controls efficient water use.

According to Molden (1997) the productivity of total applied water (PAW) is defined as crop yield per unit of volume of water supplied to the crop, being estimated by dividing crop yield by the total applied water (rainfall + irrigation). Many irrigation experiments involving different irrigations levels showed that deficit irrigation usually has higher PAW than full irrigation (Zhang, 2003).

Limited irrigation has been widely tested in maize with different degrees of success. Water deficit during differentiation and beginning of ear growth reduced the grain yield from 23 to 34% due to the decrease of the number of grains per ear from 15 to 26%. Likewise, an evapotranspiration reduction (13%) during grain filling reduced the kernel weight by 17% (Reta and Faz, 1999). Musick and Dusek (1980) advised that limited irrigation of maize should not be practiced in the high evaporative demand environment of the southern high plains, due to the sensitivity of maize to water stress. Dogan *et al*. (2003) stated that field information generally indicated substantial yield losses due to deficit irrigation. On the contrary, in Turkey, Kanber and Kirda (1994) noted that the same or an even higher level of yield could be obtained with three irrigations, at early tasseling, milking and ripening stages, compared with the usual four irrigations.

Maize is a major irrigated crop in southern Spain. It requires supplemental irrigation, about 500 to 600 mm, to attain maximum yields (Aguilar and López Bellido, 1996). The objective of this research was to compare the agronomic responses of 12 maize hybrid cultivars, grouped by season length, to full and limited (regulated deficit) irrigation levels under Mediterranean conditions.

Material and Methods

A field study was conducted in Alcalá del Río, Seville (37°22'N and 6°10'W, 6 m above sea level), on a loamy-sandy (Typic Xerofluvent) soil, where furrow irrigated cropping is the standard practice. The soil was 7 m in depth, with the phreatic stratum 4 m deep. Field capacity is reached at 27.1% while wilting point is 16.5%. The study took place over a 4-yr period (2001 through 2004). The agronomic performance of 12 commercial maize hybrid cultivars, the most commonly grown in the area, under two irrigation levels was studied. Hybrid cultivars were grouped by season length: shorter season (FAO 300-400), Florencia, Furio, Dunia and Eden; medium season (FAO 500-600), Landia, Cecilia, Tempra and Tundra; longer season (FAO 700-800), Dracma, Eleonora, Selva and Triana.

The experiment was designed as a randomised complete block with a split-plot arrangement and three blocks. Main plots were the irrigation level (full and limited irrigation), and subplots were the maize cultivars group (long, medium and short season). The area of each sub-plot was 120 m^2 with 16 lines (12 m long, 0.15% gradient) distributed among four cultivars (four lines each).

Land preparation included the following tillage operation: mollboard plough, ridge formation for furrow irrigation, rake before planting and roller after planting. Fertilisation was applied to recommended levels based on soil tests and consisted each year on 800 kg ha^{-1} of 8N-15P_2O_5-15K_2O applied before seeding, and 500 kg ha^{-1} of urea (46%) applied as side dress. Regarding insecticide treatments, 10 kg ha^{-1} of 48% Clorpyrifos were applied at seeding. Weed control was ensured applying 6 L ha^{-1} of Alachlore (30%) + Atrazine (18%). Seeding was performed using a precision drill aiming to get a high plant density, on the following dates: 20 March 2001, 23 March 2002, 7 March 2003 and 16 March 2004. After emergence, plants were thinned to establish a density of 85,000-90,000 plants ha^{-1}.

Imposed irrigation regimes were: full irrigation, consisting in an average of six water applications throughout the crop season at a dose of 90 mm, as maize is customarily irrigated in the region, and limited irrigation, consisting in three water applications at the same dose of 90 mm per irrigation. In the full irrigation treatment, irrigations were scheduled so that the crop could receive supplemental irrigation above crop water requirements at critical growth stages. In the limited irrigation treatment, only three irrigations were applied, from 2-3 weeks before silking through 3-5 weeks after that phenological stage. Total applied irrigation water was 540 mm and 270 mm, respectively. Water was applied by furrow irrigation, as maize is commonly irrigated in the region. A 2 m buffer zone was used to reduce the lateral water movement between the plots of both irrigation levels. The volume of applied water was measured using a propeller flow meter (mod. Tecnidro SVL Genoa). Table 1 shows the corresponding seeding, irrigation and harvest dates for the 4-yr experiment.

Measured parameters in the experiment were plants per hectare, ears per plant, kernels per ear, 1000 kernel weight (g) at 14% water content, and yield at 14% grain water content. All measurements were made in the two central rows of each hybrid cultivar within each subplot. Grain yield was determined by harvesting the two central rows in a length of 10 m, on the following dates: 27 Aug 2001, 28 Aug 2002, 17 Aug 2003 and 23 Aug 2004.

Annual data for each parameter over the whole 4-yr period were subjected to analysis of variance (ANOVA), using a year-combined randomized complete block design according to McIntosh (1983). Treatment means were compared using Fisher's protected least significant

Table 1. Water balance of the maize crop in the four trial years

	Water input (mm)															
	2001				2002				2003				2004			
	Full	Lim.	Rain	Et_c	Full	Lim.	Rain	Et_c	Full	Lim.	Rain	Et_c	Full	Lim.	Rain	Et_c
February			0	19			50	19			13	15			0	18
March			0	36			29	40			27	42			32	37
April			41	92			41	77			24	72			67	83
May	180	90	17	123	90	90	65	141	90	90	18	143			72	123
June	180	90	39	199	180	180	16	201	180	90	2	186	180	180	0	214
July	180	90	2	203	180		0	230	180	90	0	209	270	90	0	236
August	90		0	109	90		0	118			1	126	90		0	126
Total	630	270	98	583	540	270	201	621	450	270	84	574	540	270	171	618

difference (LSD) test at $P \leq 0.05$. LSDs for different main effect and interaction comparisons were calculated using the appropriate standard error terms following Gómez and Gómez (1984). The Statgraphics Plus v. 7.0 software suite (Magunistic, 1993, Rockville, MD) was used for this purpose.

Results

Mean temperature values in the period March-May was 16.2°C, while during maize critical period (June-August) these values increased to 25.4°C, through the four trial years. Rainfal, water supplies by full and limited irrigation, and crop evapotranspiration (ET_c) are shown in Table 1.

There was a consistent effect of the irrigation treatment on grain yield (Table 2), with an average yield decrease of around 17.4% associated with deficit water levels. However, there was variability between years. Thus, deficit irrigation did not decrease maize yield the year with the highest rainfall (2002), but decreased the yield by 38% in the driest year (2003). Grain yield was affected by the cultivar group, with longer cultivars producing more than shorter cultivars. The interaction between the irrigation treatment and the cultivar group was statistically significant only in one (2003) of four years, which indicates that all cultivar groups were similarly affected by water stress. However, in 2003 the yield of the short and medium season cultivar was less diminished (28% and 34%, respectively) by the limited irrigation than the longer cultivars (48% decrease). Yield was significantly influenced by year. In case of limited irrigation, there was a significant positive correlation ($r = 0.76$ *) between yield and summer (June-August) rainfall.

The main effect of irrigation levels and cycle groups on yield components and PAW is presented in Table 3. The results showed that ears per plant and kernel weight were reduced under limited irrigation. The cycle affected the kernels per ear. The lowest value of kernels per ear was reached by the short cycle group (365), with no significant differences between medium (452) and long cycle group (485).

Under full irrigation the PAW was lower than under deficit irrigation (Table 3). The PAW significantly increased as crop cycle increased.

Discussion

Yield results are consistent with previous work (Musik and Dusek, 1980; Dogan *et al*., 2003) but are different to findings reported by Kanber and Kirda (1994). The fact that ears per plant and kernel weight were the yield components most vulnerable to limited irrigation is likely explained by the fact that limited watering was scheduled mainly during maize reproductive phase and plants only suffered water stress during both vegetative and grain ripening phases. Similar findings were noted

Table 2. Maize grain yield values as affected by irrigation level and cultivar group in the four trial years

Effect	Level	Trial year 2001	2002	2003	2004	Mean
		S[1]	NS[2]	S	S	S
Irrigation	Full	16,133 a	12,701	10,670 a	10,528 a	12,508 a
	Limited	14,823 b	12,289	6,613 b	7,688 b	10,353 b
		S	S	S	S	S
Cultivar group	Short season (300-400)	13,689 c	11,769 c	7,920 c	8,383 c	10,440 c
	Medium season (500-600)	15,528 b	12,640 b	8,506 b	9,112 b	11,446 b
	Long season (700-800)	17,217 a	13,077 a	9,499 a	9,829 a	12,405 a
		NS	NS	S	NS	NS
Irrigation × cultivar group	Full-Short (300-400)	14,057	11,697	9,247 b	9,569	11,143
	Full-Medium (500-600)	16,157	13,166	10,257 b	10,395	12,494
	Full-Long (700-800)	18,184	13,241	12,505 a	11,619	13,887
	Limited-Short (300-400)	13,320	11,840	6,593 a	7,196	9,737
	Limited-Medium (500-600)	14,898	12,114	6,755 a	7,829	10,399
	Limited-Long (700-800)	16,250	12,913	6,492 a	8,039	10,924

[1] S: significant. [2] NS: non significant. For each effect and year values followed by different letters are significantly different at the $P = 0.05$ level.

Table 3. Yield components and productivity of total applied water (PAW) values as affected by irrigation level and cultivar group in maize. Values are mean of four years trials (2001-2004)

Effect	Level	Yield components					PAW ($kg\ m^{-3}$)
		Plants ha^{-1}	Ears $plant^{-1}$	Kernels ear^{-1}	1,000 kernel weigth (g)*	$kg\ ha^{-1}$ [(a)]	
		NS[(b)]	S[(c)]	NS	S	S	S
Irrigation	Full	88,056	1.06 b	444	353 b	12,508 b	1.90 b
	Limited	87,130	1.02 a	424	315 a	10,353 a	2.66 a
		NS	NS	S	NS	S	S
Cultivar group	Short season (300-400)	87,847	1.05	365 b	352	10,440 c	2.09 b
	Medium season (500-600)	86,979	1.01	452 a	319	11,446 b	2.28 a
	Long season (700-800)	87,951	1.05	485 a	332	12,405 a	2.46 a
		NS	NS	NS	NS	S	NS
Irrigation × cultivar group	Full-Short (300-400)	87,778	1.06	370	364	11,143 b	1.69
	Full-Medium (500-600)	87,639	1.04	458	340	12,494 b	1.89
	Full-Long (700-800)	88,750	1.07	503	356	13,887 a	2.11
	Limited-Short (300-400)	87,917	1.05	359	341	9,737 b	2.50
	Limited-Medium (500-600)	86,320	0.98	446	297	10,399 b	2.67
	Limited-Long (700-800)	87,153	1.02	468	307	10,924 a	2.80

[(a)] 14% grain water content. [(b)] NS: non significant [(c)] S: significant. For each effect and year values followed by different letters are significantly different at the P = 0.05 level.

by Grant *et al*. (1989) and Reta *et al*. (1990). In contrast and for the same reason, kernel number per ear was not significantly affected in the present regulated deficit furrow irrigation conditions. In this way, Stone *et al*. (2001) observed that there was no crop growth stage that was particularly sensitive to moisture stress, but yield components changed with timing of deficit.

Compared with other crops, maize has a relatively high PAW of about 1.2-1.5 kg m^{-3} (Zhang, 2003), but climate, soil characteristics and irrigation levels strongly influence PAW values. For instance, Howell *et al*. (1997), in Texas, noted that two-thirds of full irrigation increased PAW from 1.42 to 1.53; however, one-third of full irrigation decreased PAW to 1.21, because of very low grain yield.

The rapid decline in grain yields with decreases in irrigation in maize hybrid cultivars of different FAO cycles supports similar conclusions to that reported by Musick and Dusek (1980) in the sense that limited irrigation of maize should be used with caution. This is likely to be due to both the strong sensitivity of maize to plant water stress and the high evaporative demand in southern Spain maize growing conditions. Measurements of performance and yield components in maize hybrids grown under different deficit water conditions could provide additional insights regarding limited furrow irrigation under Mediterranean climate. It is also recommended that further research work be carried out to evaluate the economic and environmental benefit associated with limited irrigation.

Acknowledgements

The authors wish to acknowledge basic support from the *Dirección General de Investigaciones Agrarias* of the Autonomic Government of Andalusia (*Junta de Andalucía*).

References

AGUILAR M., LÓPEZ-BELLIDO L., 1996. Growth and yield of irrigated maize under Mediterranean conditions: the effect of cultivar and plant density. Cereal Res Com 4(24), 499-505.

ANDRADE F.H., VEGA C.R., UHART S.A., CIRILO A.G., CANTANERO M., VALENTINUZ O., 1999. Kernel number determination in maize. Crop Sci 39, 453-459.

ANDRADE F.H., ECHARTE L., RIZZALLI R., DELLA MAGGIORA A., CASANOVAS M., 2002. Kernel number prediction in maize under nitrogen or water stress. Crop Sci 42, 1173-1179.

BÄNZIGER M., EDMEADES G.O., LAFITTE H.R., 2002. Physiological mechanisms contributing to the increased N stress tolerance of tropical maize selected for drought tolerance. Field Crops Res 75, 223-233.

DOGAN E., CLARK G.A., ROGERS D.H., VANDERLIP R.L., 2003. Various irrigation effect of corn grain yield and CERES-Maize simulation for South Central Kansas. ASAE Annual Meeting, Las Vegas, Nevada, USA, 27-30 July, paper 032138.

DOORENBOS J., KASSAN A.H., 1979. Yield response to water. FAO Irrigation and Drainage Paper No. 33, FAO, Rome, Italy. 193 pp.

ENGLISH M.J., MUSICK J.T., MURTY V.V.N., 1990. Deficit irrigation. In: Management of farm irrigation systems (Hoffman G.J., Howell T.A., Solomon K.H., eds). ASAE, St. Joseph. pp. 631-655.

FAO, 1988. World agriculture toward 2000: an FAO study (Nikos Alexandratos, ed). FAO and Printer Publishers, London. 316 pp.

FAO, 2002. Deficit irrigation practice. Water Reports No. 22, FAO, Rome, Italy. 100 pp.

GARDNER W.R., 1983. Soil properties and efficient water use. In: Limitations to efficient water use in crop production (Taylor H.M. *et al*., eds). ASA, CSSA, and SSSA, Madison, WI.

GÓMEZ K.A., GÓMEZ A.A., 1984. Statistical procedures for agricultural research. Wiley, New York.

GRANT R.F., JACKSON B.S., KINIRY J.R., ARKIN G.F., 1989. Water deficit timing effects on yield components in maize. Agron J 81, 61-65.

HALL A.J., LEMCOFF J.H., TRAPANI N., 1981. Water stress before and during flowering in maize and its effects on yield, its components, and their determinants. Maydica 26, 19-38.

HOWELL T.A., STEINER J.L., SCHNEIDER A.D., EVETT S.R., TOLK J.A., 1997. Seasonal and maximun daily evapotranspiration of irrigated winter wheat, sorghum and corn: southern high plains. T ASAE 40, 623-634.

KANBER R., KIRDA C., 1994. Evaluation of deficit irrigation programmes for cotton, maize, wheat and soybean. Proc Int Conf of Land and Water Resources Management in the Mediterranean Region. Istituto Agronomico Mediterraneo Bari-Italy, 4-8 Sept., no. 5, pp. 117-133.

MAGUNISTIC, 1993. Statgraphics 7.0. Manugistic, Rockville, MD, USA.

McINTOSH M.S., 1983. Analysis of combined experiments. Agron J 75, 153-155.

MOLDEN D., 1997. Accounting for water use and productivity. SWIM paper 1, International Irrigation Management Institute, Colombo, Sri Lanka.

MUSICK J.T., DUSEK D.A., 1980. Irrigated corn yield response to water. ASAE 23, 92-98, 103.

OTEGUI M.E., ANDRADE F.H., 2000. New relationships between light interception, ear growth and kernel set in maize. In: Physiology and modeling kernel set in maize (Westgate M.E., Boote K., eds). pp. 89-102.

RETA D.G., FAZ R., 1999. Maize response to different soil moisture levels. I. Grain yield and yield components. TERRA Latinoamericana, 004 (17). Universidad Autónoma Chapingo, Chapingo, Mexico. pp. 309-316.

RETA S., RETA R.S., MARTÍNEZ M.A., 1990. Influencia de diferentes niveles de humedad en el suelo sobre el rendimiento en grano y la producción de materia seca del maíz. ITEA 86, 37-45. [In Spanish].

SHAN L., HUANG Z.B., ZHANG S.Q., 2000. Water-saving agriculture. Tsinghua University Press, Beijing.

SHAW R.H., 1977. Climatic requirement. In: Corn and corn improvement (Sprague G.F., ed). Agron Monogr 18. ASA, CSSA, and SSSA, Madison, WI.

STONE P.J., WILSON D.J., REID J.B., GILLESPIE R.N., 2001. Water deficit effects on sweet corn. I. Water use, radiation use efficiency, growth and yield. Aust J Agric Res 52, 103-113.

SWAN J.B., SHAFFER M.J., PAULSON W.H., PETERSON A.E., 1987. Simulating the effects of soil depth and climatic factors on corn yield. Soil Sci Soc Am J 51, 1025-1032.

TOLLENAAR M., DWYER L.M., STEWART D.W., 1992. Ear and kernel formation in maize hybrids representing three decades of grain yield improvement in Ontario. Crop Sci 32, 432-438.

WALDREN R.P., 1983. Corn. In: Crop-water relations (Teare I.D., Peete M.M., eds.. John Wiley & Sons NY. pp. 187-211.

WESTGATE M.E., BOYER J.S., 1986. Reproduction at low silk and pollen water potentials in maize. Crop Sci 26, 951-956.

ZHANG H., 2003. Improving water productivity through deficit irrigation: examples from Syria, the North China Plain and Oregon, USA. In: Water productivity in agriculture: limits and opportunities for improvement (Kijne J.W., Barker R., Molden D., eds). CAB International, Wallingford, UK.