POSSIBILITIES FOR OBTAINING HIGH YIELDS FROM ROW CROPS IN WATER DEFICIT CONDITIONS: A CASE STUDY IN BULGARIA

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ABSTRACT

The contemporary warming and drought tendencies are a serious reason for application of water saving and of high water use efficiency irrigation technologies. Since last years, wide-spaced furrow irrigation was tested on different soil types in Bulgaria – vertisols, chromic luvisols and drained fluvi-calcaric fluvisols. The field experiments were conducted with maize (grain) and soybean. Both crops gave around 85% of the maximum yield when irrigated in every-other furrow with 50% of the optimum irrigation depth. The water use efficiency was increased with 71-79% at maize (grain) and 61% at soybean. In the paper, yields, moisture profiles, water use efficiency and yield losses are presented and analyzed. The every-other-furrow irrigation technology is recommended on clay-loamy soils as appropriate for increasing WUE, allowing application of less irrigation water and giving the chance for reducing the production costs.

Keywords: Wide-spaced furrow irrigation, Soil moisture distribution, Yields, Water use efficiency, Maize (grain), Soybean, Bulgaria

1. INTRODUCTION

Insufficient and unstable water supply is peculiar for Bulgarian climatic resources. In 75% of the years, crop water needs are satisfied at certain shortage of water. The contemporary warming and drought constant decrease of crops yields and set limits to the supplementary water supply by irrigation (Slavov and Moteva [1, 2]). Due to economic and social reasons during the last 30 years, the water losses along the irrigation networks have terrifically increased. Therefore, the farmers are greatly interested in water saving and technically simplified irrigation technologies with low investments in the irrigation set of their fields. In this sense, a very appropriate for row-crops is the wide-spaced irrigation technology, in which small irrigation depths are distributed in every other or third furrow. Like the localized, the wide-spaced irrigation maintains the soil relatively dry. It avoids water losses from evaporation and deep percolation, protects soil structure, contributes for relatively uniform watering over the irrigated territory, enables high water use and labor efficiency, etc. Evidence for the higher absorption of the irrigational water by soil are the results from Sepaskhah and Afshar-Chamanabad [3] experiments. They have established that the infiltration parameters of the every-other furrow irrigation (EOF) are higher than those of the ordinary every furrow irrigation (EF). Hodges et al. [4] have obtained 0.68 to 0.81 times smaller rate of advance of water down the furrow at the EOF irrigation than that at the EF irrigation, depending upon soil type and slope. High yields can be obtained by wide-spaced irrigation with small irrigation depths – that is the standpoint of Stone et al. [5]. They have established that maize and soybean give yields like the maximum ones by 50-80% of the optimum irrigation depths. The 73% relative water applied by Sepaskhah and Kamgar-Haghighi [6] provided for 16% more yield if water is applied as EOF rather than as EF.

Some authors developed the idea of the wide-spaced irrigation with some variation of the application number (Sepaskhah and Kamgar-Haghighi [6]), i.e. different duration of the irrigation intervals and volume of the application depth, and with alternation of the wetted furrows (Stone et al. [5], Kang et al. [7], Crabtree et al. [8]). In the first type of investigations, EOF with a smaller amount of irrigation water at 10-day irrigation intervals under sugar beet caused some yield reduction. However, frequent EOF at 6-day intervals produced a similar root yield to that of EF irrigation at 10-day intervals and saved about 23% of irrigation water. About 43% higher water use efficiency (WUE) was obtained at more frequent EOF than at less frequent EF intervals, because of reduction of the evapotranspiration losses by 20 to 50%. In the second type of investigations the alternate furrow irrigation (AF) of maize (grain) with up to 50% reduction of the irrigation amount contributed for enhanced root development and high grain yield than the every other fixed-furrow-irrigation (EOFF) and EF irrigation did. Hence the irrigational water use efficiency (WUE) has been substantially increased.

The highest irrigation water use efficiency under maize (grain) by EOF irrigation in Bulgaria was obtained by 50% of the optimum irrigation depth (at maintaining 80% of field capacity) – 4.23 kg/m^3 (Moteva [9]).Furthermore, irrigation impact on the yield of maize (grain) was theoretically proved at the most 2.8 m between the wetted furrows. The economic results of irrigation of maize (grain) depend as on the irrigation depth, so on the pre-irrigation soil moisture. Most efficient is irrigation in every other furrow with 50% of the maximum irrigation depth (Moteva [9]; Moteva and Stoyanova [10], Vidinova and Moteva [11]).

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2. MATERIAL AND METHODS

Three field experiments in every other furrow irrigation (EOF) were conducted in Southern Bulgaria. The crops tested were the following: two hybrids of maize (grain) – an early one (FAO 200-300) and a midseason one (FAO 500-600), and an early variety of soybean (MG 000-IV). The experiment with the midseason maize (grain) hybrid was conducted in the region of Sofia during the periods 1987-1989, 1996-1998 on chromic luvisols. The experiment with the early maize (grain) hybrid was conducted the region of Stara Zagora during the period 2004-2006 on vertisols. The experiment one with soybean was conducted in the region of Plovdiv during the same 2004-2006 period on drained fluvi-calcaric fluvisols. A variant of rainfed crop growing was a standard at all three experiments. EF variants were used as irrigation standards. The variants of irrigation are described in Table 1. EF variants of 100% and EOF variants of 50% of the application/irrigation depth (as to the optimum for each crop pre-irrigation soil moisture) were applied to all crops. EF variants of 50% appl./irr. depth were applied to maize (grain) FAO 500-600 and to soybean. The optimum pre-irrigation soil moisture under maize is accepted to be 80% of field capacity (FC) with corresponding application depth – 60 mm at both soil types, and for soybean – 75% of FC and 80 mm application depth at the relevant soil type.

Table 1 Variants of irrigation

Variants of space irrigation	Crop	Variety/Hybrid	100% application depth [mm]	50% application depth [mm]
Every furrow (EF)	Maize (grain)	Early season FAO 200-300	60	
		Mid-season FAO 500-600	60	
	Soybean	Early season- MG (000 to IV)	80	
	Maize (grain)	Mid-season FAO 500-600		30
	Soybean	Early season MG (000 to IV)		40
Every other furrow (EOF)	Maize (grain)	Early season FAO 200-300		30
		Mid-season FAO 500-600		30
	Soybean	Early season MG (000 to IV)		40

The soil types are clay-loamy and are supposed to hold a great water amount as available for crops. They have also good capillary properties and moderate hydraulic conductivity with good side infiltration, hence they tare appropriate for wide-space irrigation. The greatest water capacity at FC has the soil in Stara Zagora region - vertisols (Table 2).

Soil moisture has been periodically evaluated by means of a gravimetrical method. The moisture contours of the soil profiles were drawn using scatter measurements in a cross-section to the furrow direction plain. The soil samples were taken under the wetted furrow, under the tangent to it row and under the next dry furrow.

Table 2 Soil hydraulic properties

Soil Layer	Chromic Luvisols		Vertisols		Drained Fluvi-Calcaric Fluvisols	
	Bulk Density	FC	Bulk Density	FC	Bulk Density	FC
	[Mg/m^3]	[% of abs. dry matter]	[Mg/m^3]	[% of abs. dry matter]	[Mg/m^3]	[% of abs. dry matter]
0–10	1.40	21.9	1.17	36.8	1.24	31.4
10–20	1.52	21.3	1.20	36.0	1.24	31.4
20–30	1.47	22.0	1.23	36.7	1.40	30.9
30–40	1.45	22.4	1.28	35.1	1.42	29.8
40–50	1.49	22.6	1.30	34.9	1.44	28.9
50–60	1.47	22.5	1.31	34.5	1.45	28.0
60–70	1.51	22.2	1.33	34.0	1.47	27.5
70-80	1.54	21.6	1.35	33.8	1.47	27.5
80–90	1.56	21.9	1.38	33.5	1.49	26.9
90-100	1.60	19.9	1.41	33.2	1.49	26.9
0-100	1.47	21.8 (327 mm)	1.30	34.8 (452 mm)	1.41	28.9 (407.5 mm)

The yields obtained were statistically rated by a variance analysis.

The meteorological conditions were the most varied – from very dry and extremely warm years, through middle, to wet and cool.

3. RESULTS

The number of applications varies in dependence of the atmospheric water deficit and the distribution of the rainfalls during the vegetation season. They are 3 to 5 in at FAO 500-600 maize (grain) hybrid. The irrigation depth in EF 100% appl. depth variants varies from 180 mm to 300 mm, and in EF 50% appl. depth ones - from 90 mm to 150 mm (Table 3). The number of applications of FAO 200-300 maize (grain) hybrid occurred to be 2-3. The irrigation depths in EF 100% variants are 120-180 mm and in EF 50% ones - 60-90 mm (Table 4). Soybean was irrigated by 1 to 2 applications with irrigation depths amounting to 80-160 mm at EF 100% variants, and– to 40-80 mm at EF 50% variants (Table 5).

Table 3 Irrigation depths of FAO 500-600 maize (grain) [mm]

Variants	Application depth	1987	1988	1989	1996	1997	1998
EF	100%	300	240	180	180	180	180
EF	50%	-	-	-	90	90	90
EOF	50%	150	120	90	90	90	90

Table 4 Irrigation depths of FAO 200-300 maize (grain) [mm]

Variants	Application depth	2004	2005	2006
EF	100%	180	120	180
EOF	50%	90	60	90

Table 5 Irrigation depths of soybean MG (000 – IV) [mm]

Variants	Application depth	2004	2005	2006
EF	100%	160	80	160
EF	50%	80	40	80
EOF	50%	80	40	80

The distribution of the application water in the soil profiles of EF 50% variants (Fig. 1-3) shows that chromic luvisols and vertisols tend to accumulate the readily available water in their 40-100 mm layers. Though maintaining water deficit by reducing the application depths to 50%, the water supply after the last application is higher than 80% of FC.

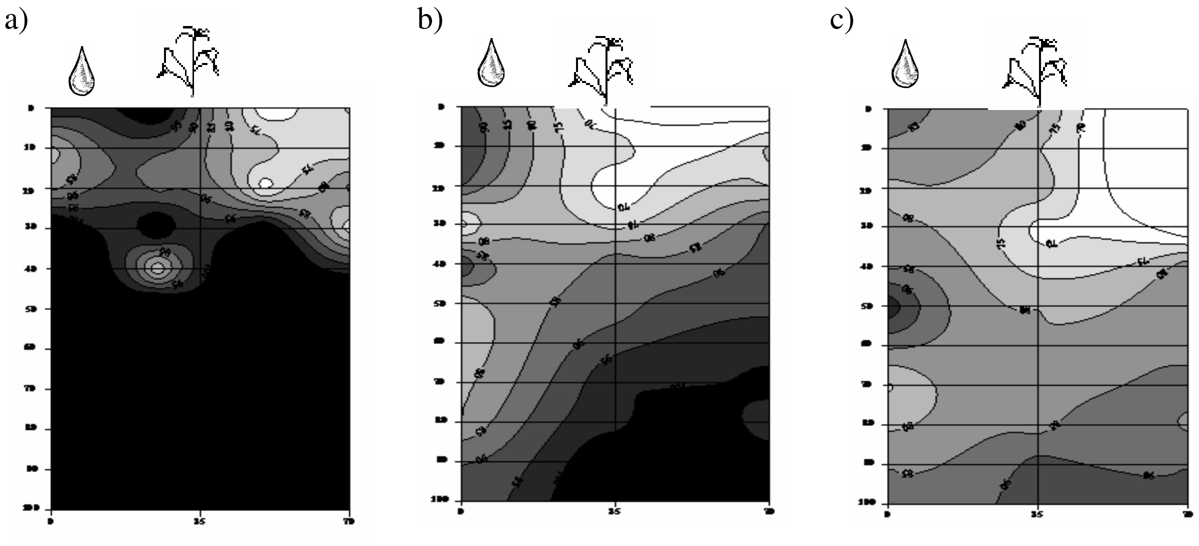

Fig. 1 Moisture distribution in the profile of chromic luvisols after: a) first application; b) second application; c) third application of FAO 500-600 maize (grain) in the EOF 50% appl. depth variants

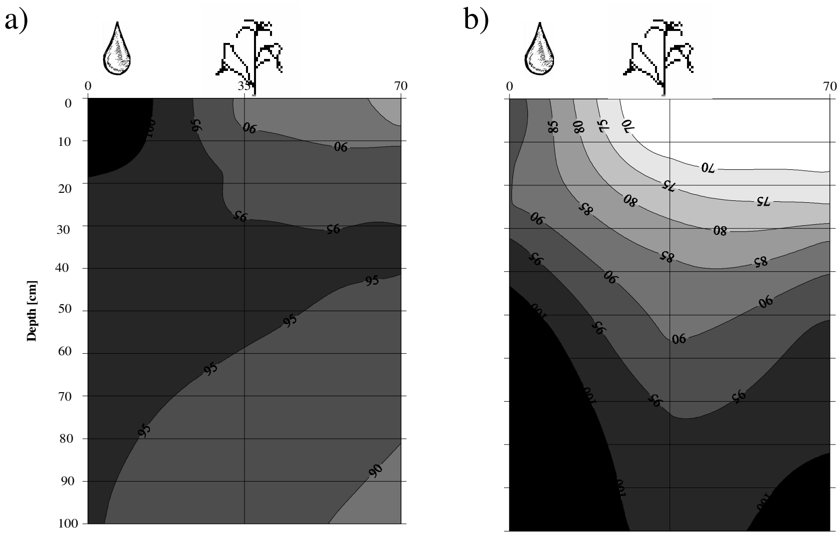

Fig. 2 Moisture distribution in the profile of vertisols after: a) first application; b) second application of FAO 200-300 maize (grain) in the EOF 50% appl. depth variants

Just on the contrary for the drained fluvi-calcaric fluvisols, the moisture in the lower parts of its profile hardly reaches 90% of FC. Still after the second application, water supply in combination with the infiltration properties of the top 30-cm layer is not enough to moisturize it higher than 70% of FC.

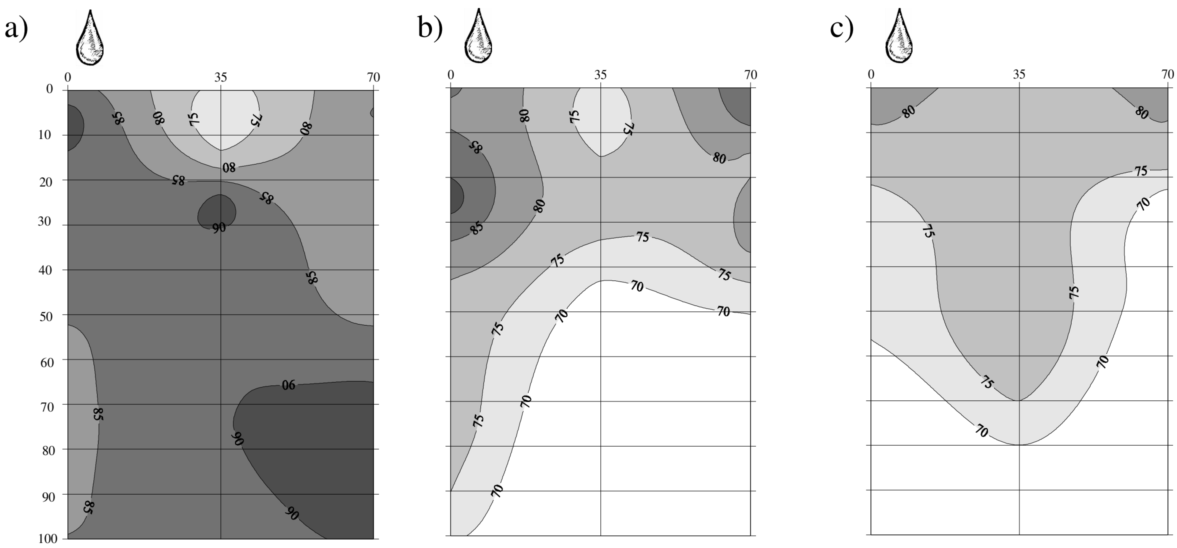

Fig. 3 Moisture distribution in the profile of Drained Fluvi-Calcaric Fluvisols after: a) first application; b) second application; c) third application of soybean MG (000–IV) in the EOF 50% appl. depth variants

All yields, obtained by irrigation are significatly higher than those under rainfed conditions (Tables 6-8). The yield increase of FAO 500-600 maize hybride when given 100% irr. depth varies from 1.39 to 10.64 Mg/ha (average 6.17 Mg/ha) and when given 50% irr. depth in every other furrow - from 0.58 to 7.93 Mg/ha (average 4.44 Mg/ha), dependent on moisture conditions of the year. The yield increase of FAO 200-300 maize hybrid is analogous – from 1.21 to 2.51 Mg/ha (average 1.91 Mg/ha) and from 0.72 to 1.49 Mg/ha (average 1.09 Mg/ha) respectively. When irrigated by 100% irr. depth soybean has given 0.88-1.39 Mg/ha more (average 1.11 Mg/ha) than under rain-fed condition and 0.52-0.62 Mg/ha more (average 0.57 Mg/ha) when given 50% irr. depth in every other furrow.

The yield increase percentage of the midseason maize hybrid averages to 163% at EF 100%, 53% at EF 50%, and 117% at EOF 50% irrigation. The same percentage of the early maize hybrid averages to 191% at EF 100% and 109% at EOF 50% irrigation. It is seen that the two hybrids react similarly to the tested optimal and deficit irrigation. Soybean gives an average of 67% yield increase at EF 100%, 39% - at EF 50% and 34% at EOF 50% irrigation.

In spite of the yield reduction caused by maintained water deficit, the smaller irrigation depths are, the higher WUE is (Fig. 4). It is 36-86% (average 57%) higher at FAO 500-600 maize hybrid when applying EF 50% irr. depth and 51-93% (average 71%) when applying EOF 50% irr. depth. WUE is 0-17% (average 10%) higher at EOF 50% in comparison with EF 50% (Fig 4a).

FAO 200-300 maize hybrid demonstrates the same WUE tendencies. It is 78-80% (average 79%) higher at EOF 50% in comparison with EF 100% (Fig. 4b).

Table 6 Yields and confidence intervals of FAO 500-600 maize (grain) [Mg/ha]

Variants	Application depth	1987	1988	1989	1996	1997	1998
Rain-fed		2.69	3.70	6.91	4.13	7.14	5.21
EF	100%	12.24	14.34	9.34	9.79	8.53	12.57
EF	50%	-	-	-	7.52	7.95	8.55
EOF	50%	9.25	11.63	9.01	8.80	7.72	9.98
$GD_{5\%}$		*1.08*	*1.11*	*0.51*	*0.78*	*0.59*	*1.01*
$GD_{1\%}$		*1.46*	*1.50*	*0.69*	*1.05*	*0.80*	*1.38*
$GD_{0,1\%}$		*1.94*	*1.99*	*0.92*	*1.41*	*1.07*	*1.85*

Table 7 Yields and confidence intervals of FAO 200-300 maize (grain) [Mg/ha]

Variants	Application depth	2004	2005	2006
Rain-fed		7.56	3.36	7.83
EF	100%	9.57	4.57	10.34
EOF	50%	8.61	4.08	9.32
$GD_{5\%}$		*0.17*	*0.15*	*0.07*
$GD_{1\%}$		*0.23*	*0.20*	*0.08*
$GD_{0,1\%}$		*0.31*	*0.27*	*0.11*

Table 8 Yields and confidence intervals of soybean MG (000 – IV) [Mg/ha]

Variants	Application depth	2004	2005	2006
Rain-fed		1.50	2.34	1.47
EF	100%	2.89	3.22	2.53
EF	50%	2.39	2.65	2.14
EOF	50%	2.12	2.92	1.99
$GD_{5\%}$		*0.18*	*0.45*	*0.20*
$GD_{1\%}$		*0.25*	*0.66*	*0.28*
$GD_{0,1\%}$		*0.38*	*0.97*	*0.41*

The soybean variety tested has increased its WUE with 64-69% (average 66%) at EF 50% and with 47-81% (average 61%) at EOF 50% than at EF 100%. Apparently, the wide-space irrigation has no impact on the water use by soybean plants (Fig. 4c).

The water losses of the midseason maize hybrid, caused by 50% reduced irrigation depths, vary from 7 to 32% (average 21%) at EF and from 4 to 24% (average 14%) at EOF (Fig. 5a). They are around 10% at EOF for the early maize hybrid (Fig. 5b). Soybean yield losses amount to average 17% and 19% under EF and EOF respectively (Fig. 5c). These losses for all three crops are approximately 50% lower than the losses under rainfed growing conditions. The slightly lower losses at the EOF show that water is more efficiently used at EOF rather than at EF distribution.

4. CONCLUSIONS

The every-other-furrow irrigation technology is appropriate for applying in the sub-humid climate and main soil types of Southern Bulgaria. Applied to maize (grain) and soybean it can reduce irrigation water and increase water use efficiency. Consistent water savings of 50% are realized under deficit irrigation scheduling with yield reductions of 14% of mid-season maize (grain) hybrid, 10% of early-season maize (grain) hybrid and 19% of an early-season variety of soybean as compared to the normal water supply. Our case study indicated that water use efficiency increases with 71-79% at mid- and early-season maize hybrids respectively and 61% at soybean. It is obvious that both crops are well suited to water scarce conditions under the impact of the water-accumulating peculiarities of the soils and give high yields, close to their potentials. The impact of every-other-furrow irrigation (100% irrigation depth), compared to every-furrow irrigation (50% reduced irrigation depth) is greater for maize, grown on chromic luvisols and is none for soybean, grown on drained fluvi-calcaric fluvisols. All these results suggest that every-other-furrow irrigation on clay-loamy soils is appropriate for increasing WUE, allowing application of less irrigation water and giving the chance to reduce the production costs.

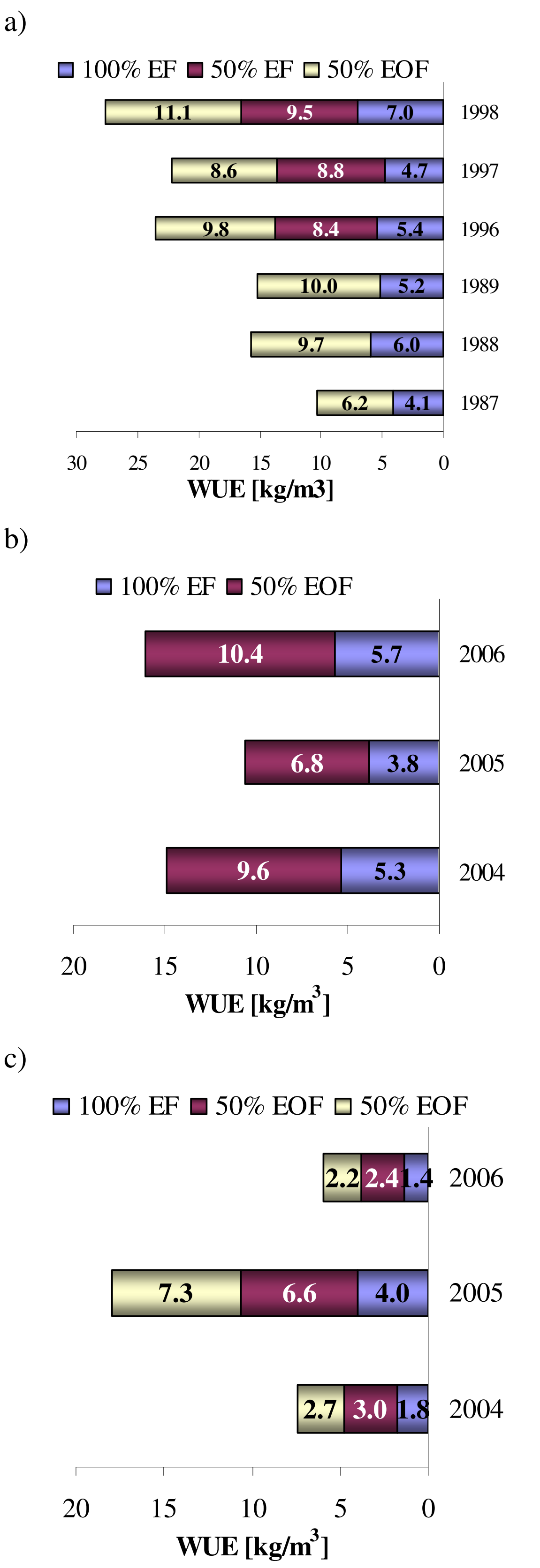

Fig. 4 Water use efficiency: a) FAO 500-600 maize (grain); FAO 200-300 maize (grain); soybean MG (000-IV)

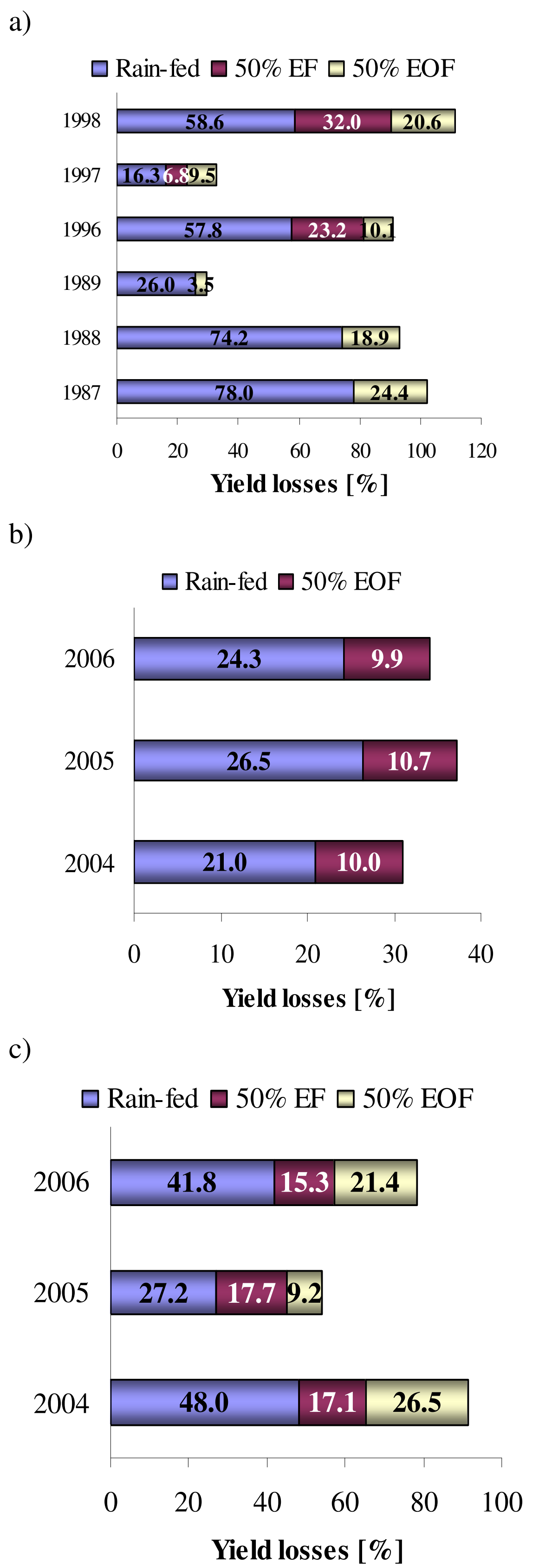

Fig. 5 Yield losses: a) FAO 500-600 maize (grain); FAO 200-300 maize (grain); soybean MG (000-IV)

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