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Effect of different irrigation intervals on water saving, water productivity and grain yield of maize (*Zea mays* L.) under the double ridge-furrow planting technique

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Surface irrigation is the traditional irrigation method applied in about 80% of the irrigated area in Egypt with greater water losses leading to profile drainage. The double ridge-furrow planting technique (DRFI) uses a practical way to reduce the applied water quantities. Therefore, field experiments were conducted in 2010 and 2011 (maize growth seasons) to study the effects of DRFI with two irrigation intervals – 7 days and 14 days – on maize yield, water saving, water productivity and some economic parameters such as net return and investment ratio compared with the conventional ridged-furrow planting technique (RFI) with irrigation at 14-day intervals. Optimal irrigation interval for maize under DRFI was also determined. Regardless of irrigation intervals, smaller depth of applied water was observed with DRFI treatments compared to RFI treatment. Consequently, with DRFI treatments, more water could be saved compared with RFI treatment in both seasons. Double ridged-furrow planting with irrigation at 7-day intervals proved superior to increase the grain yield and water productivity compared to the 14-day interval and the conventional treatment. It also increased the investment ratio and net return of maize crop. Therefore, double ridge-furrow planting with irrigation at 7-day intervals will practically be the optimal choice under the conditions of the studied area.

Keywords: corn; ridged-furrow planting; double-ridged furrow planting; irrigation intervals; water productivity; net return

Introduction

Water resources in Egypt are limited, which restrict crop production in the newly reclaimed lands because of the present intensive agricultural production in the Nile Delta and valley area. Agriculture in Egypt relies heavily on irrigation. The agricultural sector consumes more than 84% of the available water resources (El-Beltagy & Abo-Hadeed 2008).

Maize is one of the major cereal crops in Egypt. It is the most important foodstuff after wheat, which provides the daily bread for the indigenous population of rural areas. Egypt is the 14th largest producer of maize in the world, producing an average of 5682 thousand metric tons per year (USDA 2012).

Surface irrigation is the traditional method of irrigation of about 80% of the irrigated area in Egypt. It is characterized by lower water application efficiency (45–50%) compared to the other methods, mainly because of water loss due to deep percolation. Farmers are commonly seen to over-irrigate their fields, which leads to greater losses leading to profile drainage, which in turn increases water storage that cannot be taken up by plants. Therefore, optimal

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irrigation application, throughout the growing season, is important for increasing maize productivity per unit of water applied without additional costs (Swelam & Atta 2011).

Double ridge-furrow planting technique (DRFI), with the common name being beds, has been developed as a practical way to reduce applied water quantities. Their advantage is that more plant rows are possible on each ridge, therefore facilitating manual weeding (Brouwer et al. 1988). When using the bed technology, higher yield, lower water application and higher gross production water use indices for maize crop can be achieved (Fahong et al. 2003; Hassan et al. 2005; Ahmad et al. 2009; Akbar et al. 2010; Ahamd et al. 2011; Zhang et al. 2012). In addition, maize crop, under bed planting, reached 29% less irrigation depths with 42% greater grain yield and 68% greater water use efficiency compared to flat basin irrigation (Shafiq et al. 2003). Furthermore, net returns from the maize-wheat system were higher than in the no tillage and permanently raised beds than with conventional tillage (Ram et al. 2012). Regardless of irrigation intervals, several studies have shown the potential of the beds technique in saving irrigation water and improving water use efficiency for different crops, e.g. sugar beet (Taleghani et al. 2004), oilseed rape (Buttar et al. 2006) and potato (Harms & Korschuh 2010).

Therefore, this study was conducted at the Middle Delta of Egypt (1) to study the effects of DRFI (beds) with two irrigation intervals – 7 days and 14 days – on maize yield and economic parameters such as economic efficiency for capital investment and investment ratio compared to the conventional ridged-furrow planting technique (RFI) with irrigation at 14-day intervals and (2) to determine the optimal irrigation interval for maize under DRFI.

Materials and methods

Description of the studied area

The field experiment was conducted at a private farm (latitude 30° 79' 0", longitude 30° 99' 0" and altitude of 22 m above sea level) located 15 km north of Tanta city, Al-Gharbiya governorate, Egypt, during the 2010 and 2011 seasons. The soil of the studied area is mostly clay (36–43%) with very low salt content ($EC < 1.43 \text{ dS m}^{-1}$). It was classified as a Vertic Torrifluvents (El Baroudy 2011). Field capacity, wilting point, and bulk density values were 39%, 21% and 1.37 g cm^{-3} , respectively. The climate is characterized by a cool winter with a mean air temperature of around 16 °C. Summer is hot, with no rain, and mean air temperature of about 28°C during June, July and August with mean relative humidity of 68% during the daytime for these months. Pan evaporation reaches about 8 mm d^{-1} in June.

Irrigation treatments and experimental design

The irrigation treatments were as follows:

- (1) RFI with irrigation at 14-day intervals (RFI_{14}), farmer's conventional method, furrows width (centre to centre) was 65 cm (top width of ridge-35 cm; and of furrow-30 cm), with one row of plants and 25 cm in between (Figure 1(a)).
- (2) DRFI with irrigation at 7- and 14-day intervals (DRFI_7 and DRFI_{14}), furrows width (centre to centre) was 130 cm (top width of bed-100 cm; and of furrow-30 cm), with two rows of plants and 25 cm in between (Figure 1(b)).

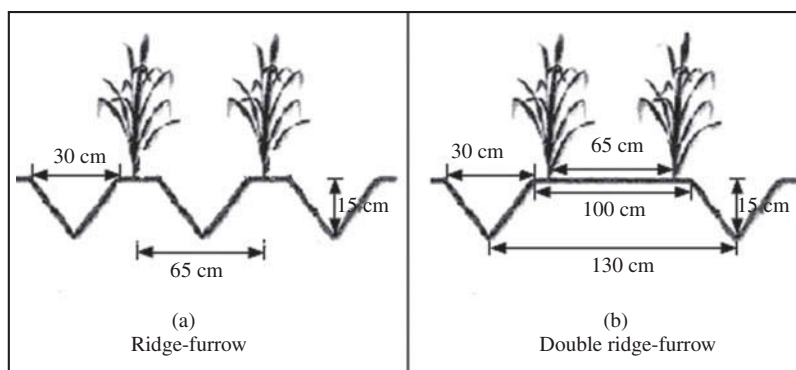


Figure 1. The schematic diagram showing (a) ridge-furrow technique (RFI) and (b) double ridge-furrow technique (DRFI).

The adopted treatments were assessed using the randomized complete block design (RCBD) with three replicates. The experimental plot size was 48 m² (6 m wide × 8 m long). The experimental plots were separated by earthen banks (1.3 m wide and 0.5 m high).

Irrigation management

Irrigation water was conveyed to the experimental plots through an open channel using a circular orifice (15 cm diameter) to measure the total amount of applied water (James 1988), as follows:

$$Q = 0.61 \times 0.334 \times A\sqrt{h} \quad (1)$$

where Q is the quantity of irrigation water (L sec⁻¹), A is the area of the orifice (cm²) and h is the effective water head over the orifice centre (m).

In each application water was added until it reached 95% of the run length, on an average of all furrows. This complies with the local farmer's practice in the area. Time was recorded using a stopwatch to estimate the amount of water applied to each plot. Furrows were open ended, yet the water does not exceed the edge of the plot because it flows through the parallel furrows. The water in the channel was controlled to maintain a constant head and to realize adequately the inflow rate during irrigation events using a fixed bar. The channel was connected at the end to a drainage ditch to release excess water. The RFI₁₄ and DRFI₁₄ plots received three and two irrigation events for the initial and mid-season stage, respectively, and one irrigation event for each of the development and the late season stage, whereas the DRFI₇ plots received three irrigation events for each of initial, development and mid-season stage, respectively, and two irrigation events for the late season stage. Only for the first irrigation, an equal amount of water was applied to all treatments until puddling occurred.

Water measurements

Amount of applied water (Aw)

The orifice discharge and the duration of the irrigation determine the depth of water applied using the following formula:

$$d = Qt \times 1000/A \quad (2)$$

where d is the water depth (mm), Q is the discharge of orifice ($\text{m}^3 \text{min}^{-1}$), t is the time (min) and A is the plot area (m^2).

The depth of total applied water (A_w) varies according to the time taken under each treatment of irrigation. Total depth of A_w was calculated by adding the amounts of water applied at each irrigation event during the entire growing season.

Water productivity

Water productivity (WP), expressed as the weight of grain yield per cubic meter of irrigation water applied, was calculated according to Rodrigues and Pereira (2009) as follows:

$$WP = GY/A_w \quad (3)$$

where WP is the water productivity (kg m^{-3}), GY is the grain yield (kg ha^{-1}) and A_w is the total depth of water applied ($\text{m}^3 \text{ha}^{-1}$).

Agronomic practices

Maize (*Zea mays* L.) cultivar of three way cross 324 (T.W.C. 324, developed by Maize Research Section, Field Crops Research Institute, ARC, Giza, Egypt) seeds were planted on 25 May in the growing seasons of 2010 and 2011 at the rate of 36 kg ha^{-1} . Grains were planted on the top of ridges to attain $61,539 \text{ plants ha}^{-1}$. Immediately after planting all plots were irrigated (planting irrigation). Because of the clayey texture of the experimental field, a complementary irrigation was applied on the 10th day after planting (DAP) to ensure complete seed germination (first pre-treatment irrigation). Prior to the second pre-treatment irrigation (35 DAP), the plants were thinned to one per stand to attain the recommended plant densities. Nitrogen fertilizer, in the form of ammonium nitrate (240 kg N ha^{-1}), and potassium fertilizer, in the form of potassium sulphate (47 kg K ha^{-1}), were applied at 35 DAP simultaneous to irrigation. Phosphorus fertilizer, in the form of single super phosphate (16 kg P ha^{-1}), was incorporated into the soil during land preparation. The experimental treatments were imposed after the second pre-treatment irrigation in both seasons. All other agricultural operations, including pesticide and hand weeding, were carried out uniformly and simultaneously for all treatments.

Plant measurements

At physiological maturity, 10 plants were taken at random from the middle ridges of each plot to determine plant height and 100-kernel weight. Maize was harvested at 123 DAP by cutting the aboveground biomass, and left for further drying before removing the cobs from the stalks. Then, the ears were shelled and the grains were weighed and adjusted to 14% moisture content to obtain the grain yield (GY) in kg ha^{-1} .

Economic analysis

Price inputs and outputs were calculated for the various irrigation treatments. The cost of irrigation for the different treatments was calculated based on rental of a water pump

(Kubota, total power requirements = 7.7 horsepower) that discharges at $90 \text{ m}^3 \text{ hr}^{-1}$ at a cost of pumping $1.36 \text{ US\$ hr}^{-1}$ (exchange rate: EGP (LE) $\approx 0.17 \text{ US\$}$; rate, in 2011) by calculating the irrigation costs as follows:

$$C_i = C_t / \text{GY} \quad (4)$$

where C_i is the cost of irrigation per ton grain ($\text{\$ t}^{-1}$), C_t is the total cost of irrigation in the whole season and GY is the grain yield (t ha^{-1}).

Economic efficiency for capital investment (%) was computed as follows:

$$(\text{Net profit} / \text{Total outlay}) \times 100 \quad (5)$$

Investment ratio ($\text{\$ per \$}$) was calculated as follows:

$$(\text{Total price return} / \text{Total outlay}) \times 100 \quad (6)$$

Statistical analysis

The data were analyzed statistically using MSTATC™ version 2.0. The significant differences between means were tested using Duncan's Multiple Range Test (DMRT) at 5% level of probability (Duncan 1955).

Results and discussion

Water measurements

Total applied irrigation water (Aw) was significantly affected by irrigation treatments (Table 1). In the first and second seasons, applied irrigation water amounted to 8500 and $9100 \text{ m}^3 \text{ ha}^{-1}$, respectively, for the conventional RFI₁₄ treatment, followed by 7800 and $8300 \text{ m}^3 \text{ ha}^{-1}$, respectively, for the DRFI₇ treatment, whereas it amounted to 4900 and $5300 \text{ m}^3 \text{ ha}^{-1}$ for the DRFI₁₄ treatment, respectively. Clearly, the conventional RFI₁₄ treatment required considerably more Aw than the double ridged-furrow treatments

Table 1. Total applied water (Aw), water save (Ws), water productivity (WP) and increasing of WP as affected by irrigation treatments in the two seasons of 2010 and 2011.

Treatments	Aw		Ws		WP kg m ⁻³	Increasing of WP %
	mm	m ³ ha ⁻¹	m ³ ha ⁻¹	%		
Season, 2010						
RFI ₁₄	850 a	8500	–	–	0.74 c	–
DRFI ₇	780 b	7800	700	8.24	0.91 b	23.29
DRFI ₁₄	490 c	4900	3600	42.35	1.09 a	47.33
Season, 2011						
RFI ₁₄	910 a	9100	–	–	0.70 c	–
DRFI ₇	830 b	8300	800	8.79	0.87 b	23.16
DRFI ₁₄	530 c	5300	3800	41.76	1.03 a	46.37

Notes: RFI₁₄, ridged-Furrow Irrigation with 14-day intervals; DRFI₇, double ridged-furrow irrigation with 7-day intervals; DRFI₁₄, double-ridged-furrow irrigation with 14-day intervals. Means column under each subheading followed by different letter (a,b,c) are significantly different from each other at $P \leq 0.05$.

(DRFI₁₄ and DRFI₇). This indicates that less pumping time was required with both DRFI₁₄ and DRFI₇ treatments. The total irrigation duration for conventional RFI₁₄ treatment with 97.8 hr ha⁻¹ was higher than that for DRFI₇ and DRFI₁₄ treatments with 56.62 and 89.7 hr ha⁻¹, respectively, where almost half of the soil surface is wetted. This might be due to the reduction of surface evaporation in the DRFI compared to the RFI technique. On the other hand, smaller depth of Aw was recorded with DRFI₁₄ compared to DRFI₇ treatment. This might be due to the more frequent irrigation (11 events) in the DRFI₇ treatment than in the DRFI₁₄ treatment (seven events). Therefore, there will be higher evaporation from the soil surface, especially during the early part of the growing season, with incomplete ground cover and decreased plant water content. From the above mentioned data, it is seen that applying water through the DRFI₁₄ treatment saved about 42% (mean over two seasons) of the water applied, comparable with the conventional RFI₁₄ treatment, whereas the DRFI₇ treatment saved about 8% (mean over two seasons) of the water applied; however, the reduction in percentage of water saving in DRFI₇ was less than that of the DRFI₁₄ treatment in both seasons. Hence, if irrigation practices are shifted from RFI₁₄ treatment to DRFI₁₄ treatment, from the amount of water saved per hectare of the farmer's field (3700 m³ ha⁻¹, mean over two seasons) an extra 0.73 ha of maize crop can be irrigated. However, if this treatment DRFI₁₄ is applied, there might be a minor yield reduction in maize crop (15% over two seasons compared to RFI₁₄; but 25% reduction compared to DRFI₇). However, if irrigation practices are shifted from RFI₁₄ treatment to DRFI₇ treatment, from the amount of water saved per hectare of the farmer's field (750 m³ ha⁻¹, mean over two seasons) an extra 0.1 hectare of maize crop can be irrigated, with a yield increase of about 13% (mean over two seasons).

WP was significantly positively affected by DRFI₇ and DRFI₁₄ irrigation treatments (Table 1). The highest WP (1.06 kg m⁻³, mean over two seasons) was noted with the DRFI₁₄ treatment, followed by 0.89 kg m⁻³ with the DRFI₇ treatment, whereas the lowest WP (0.72 kg m⁻³) was noted with the conventional RFI₁₄ treatment. The increase in WP of the DRFI₁₄ treatment was 47.35% mean over two seasons. This was due to the less irrigation frequency and the highest water saving produced with the DRFI₁₄ treatment. On the other hand, the increased WP with the DRFI₇ treatment over the conventional RFI₁₄ treatment was due to the highest grain yield produced with the DRFI₇ treatment. These results are supported by Ahamd et al. (2011) that 'under bed-furrow planting WP increased from 50% to 75%, saving considerable irrigation water (30–40%) as compared to the traditional ridge-furrow practice.' In addition, Swelam and Atta (2011) reported that in Egypt, 'using 160 cm beds with two rows of maize plants in the bottom of each furrow led to increase water saving by 53%, WP by 1.73 kg m⁻³, and net profit by 32%, grain yield by 9%, with parallel decrease irrigation cost.' In addition, Karrou et al. (2012) observed that in Egypt 'beds in maize are more a promising technique, saving 1600 m³ of water per hectare and increased WP by 2 kg m⁻³'. Moreover, 'double row planting on 75 cm-wide ridges resulted in higher maize yield and irrigation WP compared to conventional single row planting on 75 cm ridges' (Moayeri et al. 2011).

Generally, based on the greater amount of water saving with higher production and hence higher water productivity, it seems that planting maize in double ridge-furrow, where the water was applied at 7-day intervals, permitted better and continuous distribution of irrigation water around the roots and maintained the soil moisture content closer to the optimum level. Both DRFI₇ and RFI₁₄ treatments had better utilization of irrigation water and nutrients. On the other hand, a prolonged non-irrigation period of up to 14 days (DRFI₁₄) during the whole season, independent of plant growth stages, might have

Table 2. Plant height, 100-kernel weight and grain yield (GY) of maize as affected by irrigation treatments in the two seasons of 2010 and 2011.

Treatments	Plant height (m)	100-kernel weight (g)	GY (kg ha ⁻¹)	Increase or decrease of GY (%)
Season, 2010				
RFI ₁₄	2.66 b	32.68 b	6305 b	–
DRFI ₇	2.96 a	36.93 a	7133 a	13.13
DRFI ₁₄	1.91 c	26.80 c	5355 c	–15.07
Season, 2011				
RFI ₁₄	2.70 b	33.21 b	6405 b	–
DRFI ₇	2.98 a	37.25 a	7195 a	12.33
DRFI ₁₄	1.95 c	27.32 c	5460 c	–14.75

Notes: RFI₁₄, ridged-furrow irrigation with 14-day intervals; DRFI₇, double ridged-furrow irrigation with 7-day intervals; DRFI₁₄, double-ridged-furrow irrigation with 14-day intervals. Means column under each subheading followed by different letter (a,b,c) are significantly different from each other at $P \leq 0.05$.

resulted in greater stress during reproductive and generative development, which had negative effects on both crop growth and yield.

Plant measurements

Plant height, 100-kernel weight and grain yield (GY) were differently affected by RFI₁₄, DRFI₇ and DRFI₁₄ treatments (Table 2). The highest plant height and 100-kernel weight were recorded with DRFI₇ in both seasons, whereas the lowest values were recorded with DRFI₁₄. The DRFI₇ treatment resulted in the highest grain yield, which reached 7164 kg ha⁻¹ (mean over two seasons), whereas the DRFI₁₄ treatment exhibited the lowest grain yield, which reached 5408 kg ha⁻¹ (mean over two seasons). The reduced plant height and 100-kernel weight were the main reasons for decreased grain yield as shown in Table 2. Grain yield with the conventional RFI₁₄ treatment was found to be higher than that obtained from the DRFI₁₄ treatment, which reached 6355 kg ha⁻¹ (mean over two seasons). The DRFI₇ treatment proved more effective in increasing grain yield by 13% (mean over two seasons) compared to the conventional RFI₁₄ treatment. The reasons could be because DRFI₇ treatment provided sufficient soil water conditions for proper root development for water and nutrient acquisition, it ensured the water requirements of maize were fulfilled, and the efficient use of irrigation water and nutrients for proper growth and development, which doubtless reflected on the final grain yield. Parvizi et al. (2011) has also reported that ‘for optimum irrigation management and increasing water use efficiency and yield of maize, the suggested irrigation interval is 6 days during the last vegetation growth stage and initial tussling stage, and 8 days in the other growth stages.’ On the other hand, the DRFI₁₄ treatment showed a substantial 15% and 33% reduction in grain yield (mean over two seasons) compared with the conventional RFI₁₄ and DRFI₇ treatments, respectively. This was due to the lesser amount of applied irrigation water, which did not meet full maize water requirements, caused water stress and consequently reduced crop yield. Maize yield was significantly affected when using the DRFI treatment with different irrigation intervals, even though irrigation water supply was significantly less than the quantity applied by farmers in RFI, where the yield increased with the decrease of irrigation intervals. Ibrahim and Hala Kandil (2007) found that the highest values of plant height, ear characters (length, diameter and weight) as well as grains yield of corn plants

were obtained under an irrigation interval of 10 days followed by 14 and 18 days; generally prolonging the irrigation interval to 18 days decreased the growth, yield and chemical constituent of corn plants, which is in agreement with our results. Dahmardeh (2011) found that ‘the highest seed yield was obtained under irrigation interval of 9 days but the highest biological yield under irrigation interval of 7 days, generally, yield of corn plants was decreased by temporal extent the irrigation interstice to 15 days.’ In addition, Hulugalle et al. (2010) showed that ‘under cotton-based cropping systems sown on permanent beds in an irrigated Vertisol, drainage was higher when irrigation frequency was higher (14–21 day irrigation interval),’ which supports our argument.

Economical return

This is clearly seen in Table 3, which indicates that the costs of irrigation were higher in both treatments of RFI₁₄ and DRFI₇ and have the same value (0.02 \$ t⁻¹), whereas the lowest cost of irrigation was observed with the DRFI₁₄ treatment (0.01 \$ t⁻¹). However, DRFI₇ treatment provided the best economical return for investment followed by the RFI₁₄ treatment. Compared to the RFI₁₄ treatment, the net profit increment was 27% less than with the DRFI₇ treatment and 24% higher than with the DRFI₁₄ treatment. Moreover, the highest investment ratio (2.26 \$ \$⁻¹) was observed with the DRFI₇ treatment, followed by the RFI₁₄ treatment (1.98 \$ \$⁻¹), whereas the lowest (1.80 \$ \$⁻¹) was observed with the DRFI₁₄ treatment. This was due to the higher grain yield obtained with both DRFI₇ and RFI₁₄ treatments, which resulted in both increased net profit and investment ratio. In summary, the higher economical returns resulted from a combination of higher production and less applied water. Swelam and Atta (2011) observed that ‘using 160 cm beds with

Table 3. Inputs and outputs items of maize crop as affected by RFI₁₄, DRFI₇ and DRFI₁₄ irrigation treatments (mean over 2010 and 2011).

Economical items	Characters	Unit	Irrigation treatments		
			RFI ₁₄	DRFI ₇	DRFI ₁₄
List of inputs	Land preparation and cultivation	\$ ha ⁻¹	32	32	32
	Seed price		26	26	26
	Mineral fertilizers		90	90	90
	Pest control		11	11	11
	Labour costs		28	28	28
	Cost of irrigation in whole season		133	122	77
	Harvesting		26	26	26
	Land rent		529	529	529
	Total cost ha ⁻¹ season ⁻¹	\$ ha ⁻¹	875	864	819
List of outputs	Grain yield	kg ha ⁻¹	6355	7164	5408
	Farm gate price (locally price)	\$ kg ⁻¹	0.272	0.272	0.272
	Total profit	\$ ha ⁻¹	1729	1949	1471
	Net profit	\$ ha ⁻¹	854	1085	652
	Cost of irrigation ton ⁻¹	\$	0.02	0.02	0.01
	Economic efficiency for capital investment	%	97.55	125.53	79.61
	Investment ratio	\$ \$ ⁻¹	1.98	2.26	1.80

Notes: RFI₁₄, ridged-furrow irrigation with 14-day intervals; DRFI₇, double ridged-furrow irrigation with 7-day intervals; DRFI₁₄, double-ridged-furrow irrigation with 14-day intervals. (Exchange rate: EGP (LE) ≈ 0.17 US\$, rate in 2011.)

two rows of maize plants at the bottom of each furrow led to net profit increase by 32% with parallel irrigation cost decrease,' which is supported by the results of our two seasons' experiment. In addition 'maize planted on beds achieved 54% increase in net profit' (Hassan et al. 2005), which again supports our argument.

Conclusions

From the data obtained, it can be concluded that the DRFI₇ treatment is a suitable practice of irrigation without grain yield reduction risk. Moreover, this treatment increased markedly the investment ratio and net return and considerably saved irrigation water. The choice between DRFI₇ treatment and other treatments depends on the value of water in relation to crop return. Therefore, it is recommended that if water is available at no high cost and excess water delivery to the field does not require additional expense, then DRFI with 7-day intervals will practically be the optimal choice under the conditions of the studied area.

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