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Water Use Efficiency in Dryland Grain Sorghum Grown Under Wide (1m) and Narrow (0.33m) Row Spacing in a Vertisol

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ABSTRACT: Under a water limiting situation, the grain yield of a dryland crop could be best be analysed as the product of water use (Es + T), water use efficiency (WUE) and harvest index (HI). In a series of experiments conducted in subtropical Australia, row spacing did not affect Es + T but WUE was always higher in narrow rows (NR) and the hypothesis was tested that lower WUE in wide rows (WR) was the result of higher soil evaporation (Es).

During early crop growth WUE was always higher in NR. When soil surface was wet and radiation intercepted by the soil was lower in NR, Es was lower under NR which contributed to higher WUE. When soil surface was dry, Es was not affected by row spacing, but lower transpiration efficiency in WR contributed to its lower WUE. Es could not provide an overall explanation of the difference in WUE between WR and NR.

INTRODUCTION

The amount of water lost from a crop field *i.e.* evapotranspiration (Es + T) and the amount of biomass produced per unit of this water *i.e.* water use efficiency (WUE) both contribute to the level of grain yield (GY) and can be expressed in the following form.

$$GY = (Es + T) \times WUE \times HI \qquad (1)$$

Harvest index (HI) is the proportion of total above ground biomass that is partitioned to grain. Any crop management that reduces soil

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evaporation (Es) makes more water available for transpiration. This may not change the value of Es + T but will increase the level of WUE and raise grain yield. Similarly if the rate of water use in early crop growth could be reduced, there should be more water available in the soil for transpiration during the grain filling period. In a water limiting situation the grain yield could be analysed critically using the following equation (Passioura, 1976).

$$GY = T \times TE \times HI \tag{2}$$

Transpiration efficiency (TE) is defined here as the ratio of above ground biomass to the amount transpired water (T). There is generally a linear relationship between total biomass accumulation and cumulative transpiration (de Wit, 1958; Fischer and Turner, 1978; Tanner and Sinclair, 1983) which is especially robust during grain filling (de Wit, 1958; Nix, 1976; Passioura, 1976) and therefore TE is commonly constant for a given environment. If the unproductive loss of water through soil evaporation could be reduced then the WUE of the crop should increase, such that when all soil evaporation was prevented WUE should have the same value as TE.

i.e. $$WUE = TE \times T \,/\, Es + T \tag{3}$$

Manipulation of row spacing offers the possibility of changing the proportion of T:Es+T. Narrow rows with equidistant plants (NR) usually produce high LAI than a wide row (WR) crop of the same plant population density (Allen, 1974). When there is an adequate amount of soil water in the early growing season, higher radiation interception by NR could lead to high water use especially in the vegetative phase of the crop (Steiner, 1986). Bond *et al.*, (1958) measured greater depletion of soil water before anthesis in NR plots which under condition of low soil water availability, reduced grain yield. High population density and narrow rows which increased the water use from seedling to boot, produced an extremely critical water shortage during grain filling. Adams *et al.*, (1976 a, b) compared narrow rows with conventional 100 cm rows at similar plant population density and found that Es+T was not different while the NR increased the grain yield by about 25%. Blüm and Naveh (1976) compared regular rows (100 cm) with double rows and found that early plant competition in double rows reduced the water use prior to anthesis. Consequently the plants had access to more residual soil water during grain filling which resulted in a 20% higher grain yield.

In contrast Fukai and Foale (1988) could not find a difference in the temporal pattern of water use between 2 m double row and 1 m single row sorghum. The lack of water saving prior to boot stage compared to the work of Blum and Naveh (1976) was thought to be the consequence of higher soil evaporation in the 2 m double row sorghum. Steiner (1986) reported that Es+T in the vegetative period was high in the NR but the percentage of water available during grain filling was increased with frequent rainfall compared to a drier season. This also resulted in higher TDM and higher WUE in NR than in WR.

In an experiment conducted in south east Queensland in summer 1985/86 (Peries, 1989), sorghum was grown in wide (1 m) and narrow (0.33 m) rows with similar plant population density and variation was created in the amount of radiation intercepted. There was a high level of solar radiation ranging from 17.7 to 28.7 $MJ/m^2/day$ during the experiment but was a season of very low rainfall. The weekly evaporation remained higher than the rainfall throughout the period of the experiment. There was again no difference in water use between WR and NR. However, NR achieved a higher WUE (4.1 $g/m^2/mm$) than WR (3.0 $g/m^2/mm$) for the total crop duration and this difference was more pronounced during the early stages of crop growth.

The current study examined the possible reasons for the lack of a difference in water use between NR and WR and tested the hypothesis that higher WUE in NR compared to WR was the result of higher Es in wide rows.

MATERIALS AND METHODS

Site and climate

The experiments were carried out at the CSIRO Cooper field station (elevation 150 m, 27^0 33's; 152^0 20'E) Gatton, Queensland in the spring/summer season of 1987/88. The location had a sub tropical, subhumid environment with a mean annual rainfall of 779 mm (Powell, 1982). The summer was warm to hot with a maximum temperature of 28 to 33 C. The annual evaporation rate was almost double the annual rainfall. The soil at the site was deep, clay to clay loam in texture, changing to silty loam in bands below a depth of 80 cm. It was a black, self mulching cracking clay. This was the same site at which the summer 1985/86 experiment (Peries, 1989) was conducted.

Two experiments were conducted during the season. One was carried out under normal rainfed (R/fed) conditions. The other was conducted under rain-out shelters (ROS) (Foale *et al.*, 1979) and received no rainfall or irrigation from seedling emergence to maturity. Seeds of *cv* Pride were sown on 22 October 1987 with two row spacings (1 m; 0.33 m) using a tractor mounted 4-row seeder (Nodet - suction plate type). One week after emergence seedlings were thinned to the required plant population density (10/m^2). Plots were 12 m x 8 m in the R/fed experiment whereas it was 5.5 m x 3.6 m in the ROS experiment. Treatments were replicated four times in a Randomized Complete Block design.

Four harvests (H1-H4) were carried out for the determination of TDM. The first was at 34 DAS and the second harvest at 48 DAS was around flag leaf stage in both experiments though it became clear that the ROS plants were developing more rapidly. H3 (anthesis) and H4 (maturity) under ROS was done at 57 and 92 DAS compared to 61 and 106 DAS respectively in the rainfed experiment. The harvest area was confined to 1 m^2 in the ROS experiment whereas it was 2 m^2 in the rainfed experiment.

Radiation Interception

A linear probe of 1 m length was used to measure photosynthetically active radiation (PAR) intercepted by the canopy several times between 25 and 80 DAS. One reading at the top of the canopy and the average of 10 readings at the bottom of the canopy were used to calculate the percentage of PAR intercepted.

Soil water

An aluminium access tube of 2 m length was installed (in a vertical position with 0.1 m protruding) near the centre of each plot, mid way between the two rows. It provided access for the neutron moisture meter (NMM) (USA DOT 7A TYPE A) for measurement of the temporal pattern of water use. Readings were taken at 20 cm intervals from 30 cm depth down to 170 cm. Water content of the top 20 cm of the soil was determined by gravimetric sampling. The readings were taken at 26, 43, 57 and 92 DAS in the ROS experiment and at 26, 43, 57, 92 and 106 DAS in the rainfed experiment.

Soil evaporation

Minilysimeters were designed for the measurement of soil evaporation by borrowing some of the features of the design used by Boast and Robertson (1982) and Shawcroft and Gardner (1983). Soil evaporation was measured at 5, 10, 14, 20, 26, 28, 32, 39, 46, 60, 62, 70 and 80 DAS in the ROS experiment and at 5, 10, 39, 46, 52, 55, 70 and 80 DAS in the rainfed experiment. Six lysimeters were installed in each plot at each measurement. In NR they were randomly installed, while in WR they were placed in two sets of three. The three lysimeters were placed in line, equally spaced across the 1 m space between the rows. Measurements were made for 24 hour periods from 9 am to 9 am. The water loss by soil evaporation was measured by the difference in weight of the lysimeters, at the 2 measurement occasions.

Soil and leaf temperature

An infra-red thermometer (Everest - 100; view angle 3) was used several times during the experiment (43, 48, 56, 62 and 68 DAS) to measure the temperature of the canopy and the soil surface around mid-day. In WR, six measurements per plot were made across the interrow, at regular intervals (approx. 10 cm) covering both sun-lit and shaded areas. The infra-red gun was directed vertically down at the area where the temperature was to be measured. Under the NR canopy where the sun-lit and shaded areas were mixed, 6 readings were taken at random. For measurements of leaf temperature, the infra-red gun was directed at the canopy at an angle of about 45^0 from the horizontal, a few centimeters above the leaf. The measurement was made on one of the upper (2nd or 3rd) leaves.

RESULTS

Weather

Details of weather conditions during the experiment are shown in Figure 1. The daily mean solar radiation ranged from 14.1 $MJ/m^2/day$ to 25.0 $MJ/m^2/day$. Weekly mean maximum temperature ranged from 24 C to 33 C. The early part of the season was cooler and the minimum temperature ranged from 15 at this time to 21 during the later stages of growth. There was a total of 338 mm of rainfall during the experiment. The period upto 39 DAS was fairly dry. There was a heavy rainfall event of over 100 mm at 39 DAS. Between then and physiological maturity of the crop, there were a few, heavy rainfall events. The weekly pan evaporation higher than the weekly rainfall at all times at 6 and 11 weeks from sowing, when there was heavy rain. Weekly pan evaporation ranged from 34 mm at 3 weeks from sowing to 68 mm at 5 weeks from sowing. The total pan evaporation for the duration of the experiments was 509 mm.

Soil water deficit

Temporal change in SWD down to 180 cm in the profile for the two experiments between 26 DAS and physiological maturity are shown in Figure 2. The deficit was approximately 270 mm when all layers down to 180 cm were at the water potential of wilting point (WP). Following heavy rain at 39 DAS the SWD was small at 43 DAS and then increased gradually up to maturity in the R/fed experiment. There was a trend to higher deficit in WR but the difference was significant only at 92 DAS. Under the ROS, the deficit was around 100 mm with no difference between treatments at 26 DAS. This deficit gradually increased with no significant treatment difference at any stage measurement. At maturity the deficit was 270 mm or more in both NR and WR.

Dry matter production

The pattern of DM production in the two experiments are shown in Figure 3. In the R/fed experiment TDm yield in NR was significantly higher than WR at H2. This difference was maintained upto maturity

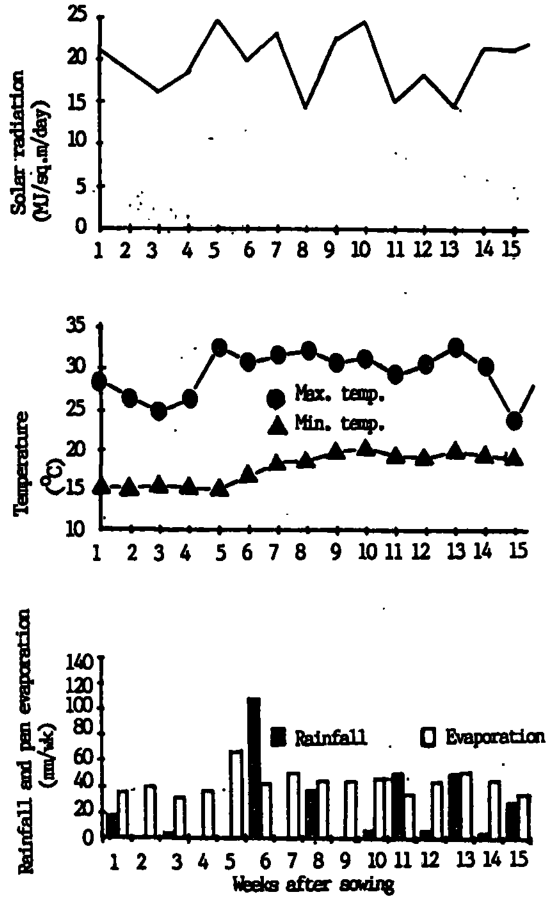

Fig. 1. Weather conditions during the spring/summer experiment of 1987/88 in south east Queensland, Australia.

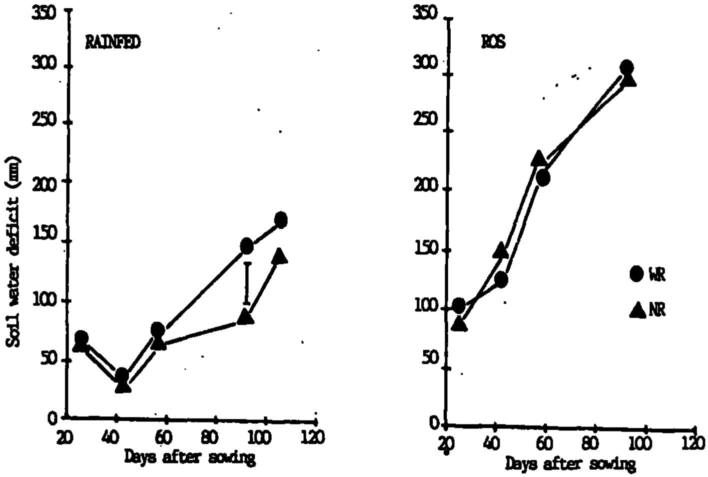

Fig. 2. Temporal change in soil water deficit under the different row spacings in the two experiments of 1987/88. Vertical bars indicate lsd at P 0.05.

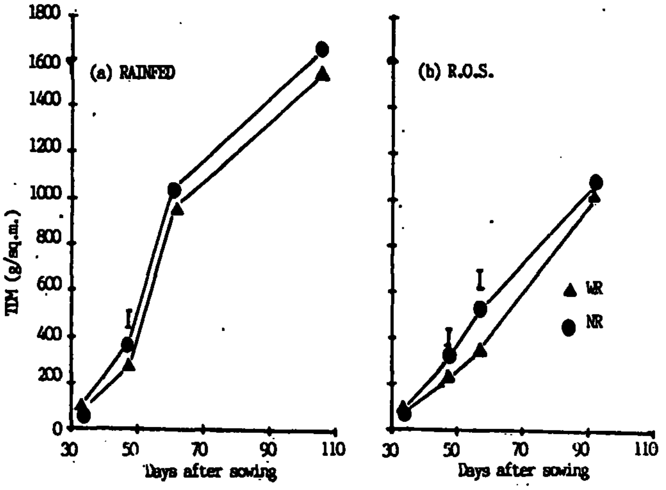

Fig. 3. Temporal change in total dry matter production under the two row spacings in the two experiments of 1987/88. Vertical bars indicate lsd at P 0.05.

(H5) but was small and not significant at later harvests. Similarly under the ROS, the TDM yield was significantly higher in NR than in WR at H2. The difference was maintained upto maturity of the crop, although small in magnitude.

Grain yield and its components

The grain yield and its components for the two experiments are presented in Table 1. In the R/fed experiment there was no significant treatment effect on grain yield. Under the ROS the grain yield was similar between the two treatments and also much lower than in the R/fed experiment.

Radiation Interception

The pattern of radiation interception in the two experiments between 25 and 80 DAS is shown in Figure 4. In the R/fed experiment, there was a high level of radiation interception than in the ROS experiment. In both experiments NR intercepted about 20% more radiation than WR on occasions later than 34 DAS.

Water use and water use efficiency

Values of evapotranspiration (Es + T) and soil evaporation (Es) for different periods during the experiments are summarised in Table 2. Water use between treatments for any comparable period was not significantly different in either of the experiments. There was however a trend to higher Es in WR than in NR in the R/fed experiment. During early crop growth WUE was higher than in NR than in WR in both experiments.

Soil and leaf temperature

Table 3 shows differences in leaf and soil surface temperature between NR and WR in the R/fed and ROS experiments. In the R/fed experiment, the soil temperature differences between WR and NR was significant only at 48 DAS. Leaf temperature was similar between the

Table 1. Treatment effect on yield and yield components of sorghum (spring/summer 1987/88).

Treatment	TDM (g/m^2)	Grain yield (g/m^2)	HI (%)
RAINFED			
WR (1 m)	1549	754	49
NR (0.33 m)	1661	758	46
1sd ($P<0.05$)	ns	ns	3
ROS			
WR (1 m)	1030	555	54
NR (0.33 m)	1089	573	53
1sd ($P<0.05$)	ns	ns	ns

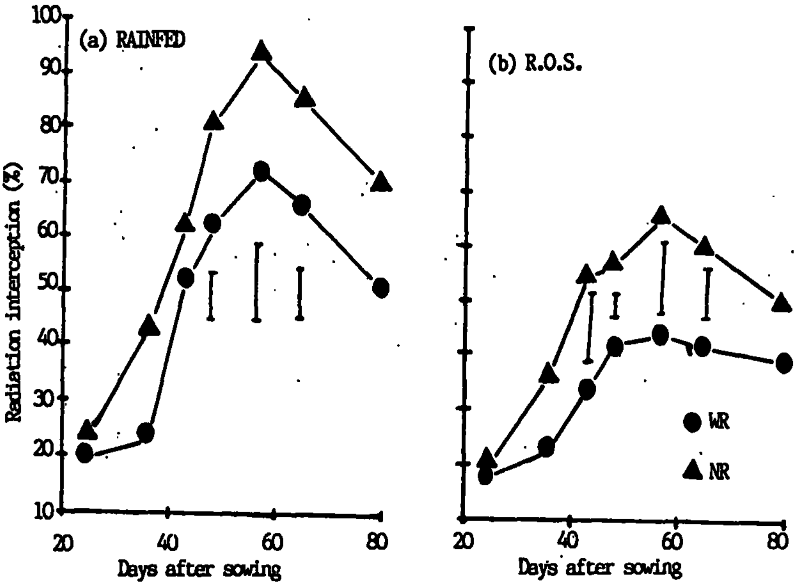

Fig. 4. Pattern of radiation interception by the two row spacings in the two experiments of 1987/88. Vertical bars indicate lsd at 0.05.

Table 2. Treatment response to water use (Es+T) and water use efficiency (WUE) in the spring/summer 1987/88 experiments.

Treatment	WUE (g/m^2/mm)			Water use Es+T (mm)	Soil Es (mm)		Es:Es+T (%)
	(H1-H2)	(H1-H3)	(H1-H4)	(H1-H4)	(H1-H2)	(H1-H4)	(H1-H4)
<u>RAINFED</u>							
WR	2.8 (5.5)	6.0	4.0 (6.0)	409	34.6	136	42.4
NR	3.8 (6.4)	6.9	4.6 (6.9)	383	27.8	116	40.4
lsd (P<0.05)	0.8	ns	0.3	ns	na	na	na
<u>ROS</u>							
WR	3.1 (3.9)	2.8	4.8 (5.4)	213	10.0	25.0	29.5
NR	3.4 (4.0)	4.1	5.8 (6.8)	204	10.0	25.0	30.6
lsd (P<0.05)	ns	0.1	ns	ns	na	na	na

na = not analysed. Estimated values of Transpiration efficiency (TE) are given in brackets.

Table 3. Effect of row spacing on leaf and soil temperature (C) under two different water regimes (R/fed on ROS). Each value is the mean of six readings.

	Days after sowing					Days after sowing				
	43	48	56	62	68	43	48	56	62	68
	Leaf temperature (C)					Soil temperature (C)				
RAINFED										
WR (1 m)	26	29	32	24	27	29	53^{a}	55	27	31
NR (0.33 m)	26	30	31	24	27	29	36^{b}	55	25	28
<u>ROS</u>										
WR (1 m)	30	33	34	24	27	46^{a}	67^{a}	66	31	36^{a}
NR (0.33 m)	29	31	34	24	28	42^{b}	58^{b}	64	28	32^{b}

Note: Only values followed by different letters are significantly different at $P<0.05$.

treatments. Under the ROS, the soil temperature in WR was higher than NR at all measurements and the difference was significant at 43, 48 and 68 DAS. The leaf temperature difference was small and not significant, but slightly higher in WR than in NR at 43 and 48 DAS. Both leaf and soil temperatures were high in the ROS experiment at all times than in the R/fed except for leaf temperature at 62 and 68 DAS. The period during which treatment differences in soil temperature occurred in the ROS (43 – 68 DAS) also coincided partly with the period (48 – 57 DAS) when NR showed a higher TE than WR.

DISCUSSION

Despite a higher level of radiation interception by NR (mean 70%) compared to WR (mean 50%) there was no corresponding difference in water use, between H1 and H4. Higher interception of solar radiation resulted in significantly high TDM production, which led to a higher WUE. Grimes and Musick (1960) and Kanemasu and Arkin (1974) have also found that NR sorghum crops produced higher DM and grain yield for a given level Es + T under subhumid conditions. Even though the difference in midday interception between NR and WR was large in this experiment (70% *vs* 50%), on a diurnal basis this difference may not have been large enough (Charles – Edwards and Lawn, 1984) for a difference in Es + T to be expected.

The lower WUE in WR compared to NR was thought to be associated mainly with a higher level of Es in WR. In the rainfed experiment, the estimated total Es in NR (116 mm) was lower than WR (113 mm) from H1 to H4. The WUE was higher in NR (4.6g/m^2/mm) than in WR (4.0 g/m^2/mm). However, when the Es component was separated, a difference in WUE still remained, indicating that transpiration efficiencies (TE) during this period may have been different between these treatments.

TE values indicate that Es alone is not sufficient to explain the difference in WUE between NR and WR. From H1 – H2 in the R/fed experiment there was a large significant difference in WUE between NR (3.8 g/m^2/mm) and WR (2.8 g/m^2/mm) which was associated with a high level of Es following heavy rainfall. When Es was separated in the H1 to H2 period, this difference was small, indicating that Es was a major factor for lower WUE in WR during that period.

In the ROS experiment where there was no water input, the higher WUE in NR (4.0 $g/m^2/mm$) than in WR (2.3 $g/m^2/mm$) between H1 and H3 was associated with similar Es in the two treatments. This suggests that a difference in TE may have existed between NR and WR during this period. When the surface soil remained dry, Es was not an important factor determining the WUE in the ROS experiment, but was important when soil underwent a number of re-wetting events (Ritchie, 1972).

In both experiments NR developed a large canopy than WR early in their growth. The planting geometry and the pattern of tiller development in NR resulted in a more closed canopy which offered greater resistance to wind movement than when plants were spaced 1 m apart. In the current experiment it is possible that more rapid wind movement though the 1 m row canopy, resulting in greater mixing of air between the canopy boundary layer and the bulk atmosphere, increased the vapour pressure deficit (VPD) around plants. This possibly resulted in lowering the TE in WR. Graser (1985) found greater mixing of air in WR (1.5 m) compared to NR (0.75 m) and the WR also had slightly higher water use. Rapid wind movement can increase the VPD around the plants even when soil was not dry through rapid mixing of "canopy" air with the air above the crop.

Striking differences between treatments in surface soil temperature were observed only under the ROS. The higher soil temperature in WR was quite consistent over the period during which measurements were made. During this period WR was using water less efficiently than NR. It is possible that a higher soil temperature could cause an increase in the VPD around the plants due to advective heat transfer from soil to both the air layer in the canopy and to the leaves. This would lower TE. Hanks. *et al*., (1971) found advective heat transfer occurring when the soil temp was 20 C higher than the leaf temperature. Our data suggests that a similar mechanism may have been in operation during this experiment. Ritchie (1972, 1983) has termed this the localised "clothesline effect" where hot air originating between plant rows become a significant source of energy in driving plant transpiration. Ritchie (1983) has used several sets of data (Ritchie and Burnett, 1971; Adams *et al*., 1976b) to stress the importance of this effect, especially when there is incomplete canopy cover. Kanemasu and Arkin (1974) have also shown that water use could be 10% higher in WR than in NR due to this effect. It would therefore appear, that when soil surface remains dry, advective heat transfer is the dominant factor lowering WUE in WR plants. In the rainfed experiments the supposed greater mixing of air in WR associated with wind movement appeared to have contributing to lower WUE, even when soil was not dry. This would be supplemented by the effect of advective heat transfer in relatively dry periods.

CONCLUSIONS

Despite the difference in the amount of radiation intercepted by the canopy during early crop growth, no saving of water was possible and under favourable environmental conditions narrow rows achieved a higher WUE than wide rows, particularly during the early part of crop growth.

Higher soil evaporation under the wide row canopy was only partly responsible for its lower WUE, even when the soil surface was frequently wet. Under dry surface conditions, the transpiration efficiency of the wide row plants appeared to be lower than that of narrow rows. The opportunities for increased WUE through reduced soil evaporation, therefore appeared to be low.

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