MANAGING BLACK ROOT ROT

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The rise of black root rot in Australian cotton

Black root rot is an intractable soilborne disease that threatens the sustainability of Australian cotton farming. In this paper we describe the factors contributing to the spread of black root rot, the effects of black root rot on the maturity and yield of cotton, and prospects for its management and control.

Black root rot was first observed in Australian cotton in 1989 (Allen, 1990). Annual disease surveys have shown an exponential increase in the number of fields with black root rot in NSW (Figure 1) and the disease now occurs in all cotton growing regions of NSW except Menindee. Black root rot is also widespread in south west Queensland and the Darling Downs (J. Kochman, personal communication).

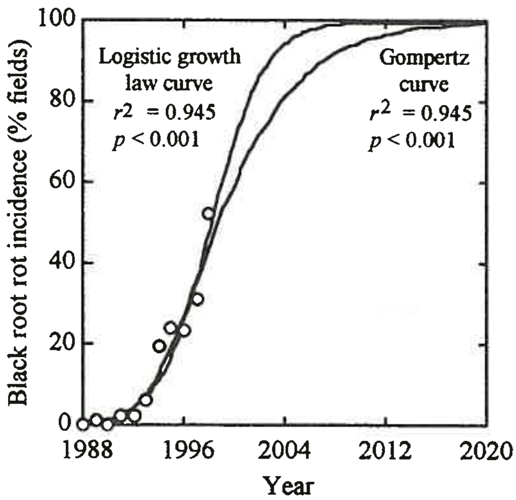

Figure 1. Historic and projected increase in the distribution of black root rot in irrigated cotton in NSW.

An understanding of the life cycle of the pathogen, *Thielaviopsis basicola* (Figure 2), is a key factor in explaining the increasing spread and severity of black root rot. *T. basicola* is a soilborne fungus that produces two types of spores; thick walled **chlamydospores** and thin-walled **endospores** (Figure 2). Both spore types can cause disease. The spores of *T. basicola* are primarily soilborne but may also occur internally with stem rot (Figure 2). Consequently, most spread of *T. basicola* is by movement of soil, carried either in moving water or on vehicles and machinery.

While machinery working in cotton fields can obviously carry infested soil, the potential for vehicles that only drive past fields on 'uncropped' roads may appear to be a lesser risk. However, when soil was collected from the wheel arches of 16 grower's vehicles parked at the Australian Cotton Research Institute (**ACRI**) in 1998, three of the 16 were carrying *T. basicola*. The observation of black root rot in self-sown cotton on 'uncropped' tail-ditch roads indicates that infested soil graded up from tail ditches is a source of spread.

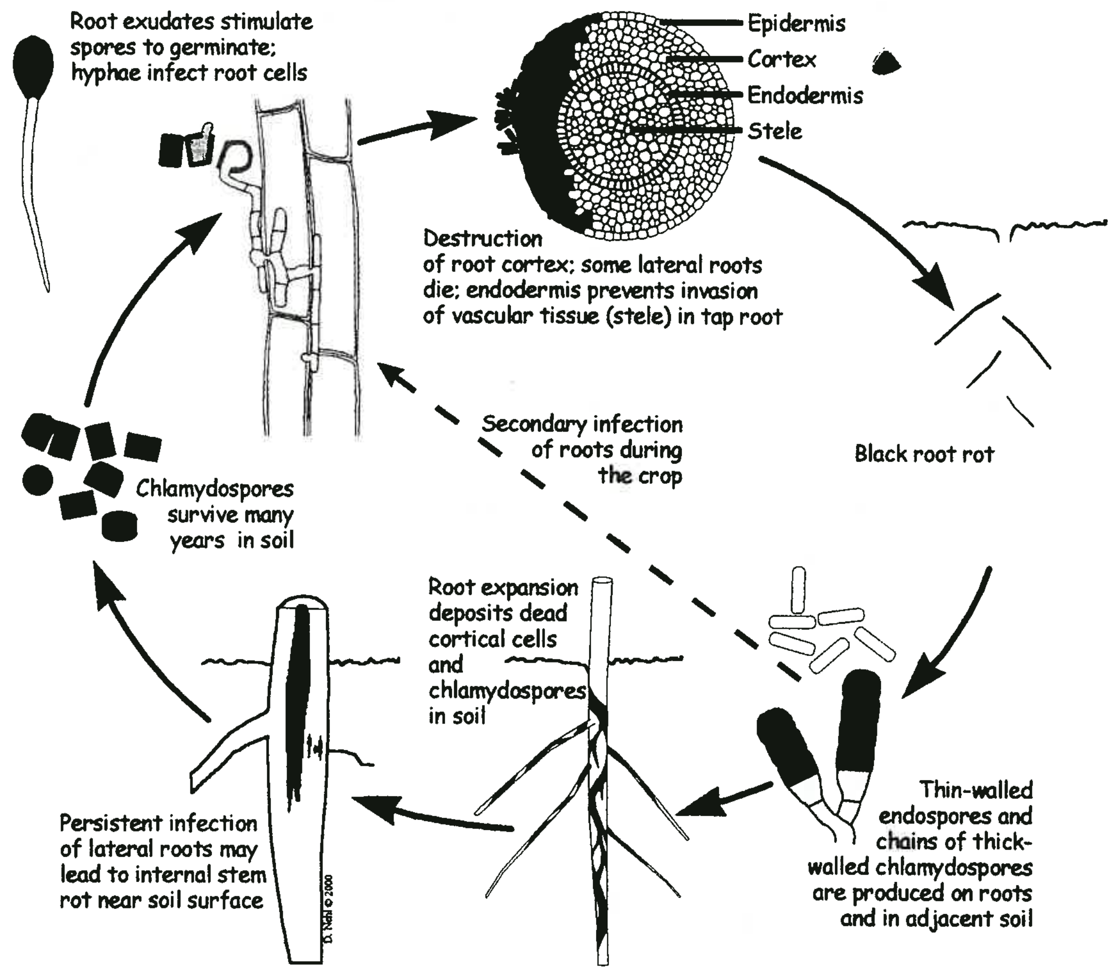

Figure 2. The life cycle of the black root rot fungus, *Thielaviopsis basicola*, in cotton.

In March 2000, we sampled tail water during irrigation of a field infested with *T. basicola*. Large quantities of spores were leaving the field suspended in the irrigation water (Table 1). The population density of *T. basicola* in mud washed from floating trash was lower on trash collected at the drop box (mostly dead flowers at the time) than on trash collected at the return channel (mostly old stalks). The latter sample was from a main return channel system and included trash from other fields, which may account for the lower population density. Although spores of *T. basicola* suspended in tail water appear to settle with increasing distance from cotton fields (Table 1), soil adhering to floating trash makes *T. basicola* very mobile in both irrigation and flood waters.

Table 1. Density of *Thielaviopsis basicola* exiting a field where black root rot occurs in cotton.

	In water		On floating trash	
	Drop box	Return channel	Drop box	Return channel
Million spores/megalitre	175	46	-	-
Spores/kg trash	-	-	11750	2671
Distance from field (m)	0	700	0	2000
Water flow	Fast	Medium	Fast	Very slow

While the mobility of *T. basicola* in water and soil contributes to its spread, the reproductive capacity of this fungus on cotton results in rapid increases in disease severity within fields. *T. basicola* cannot grow on dead organic matter in the and is, therefore, an obligate parasite soil (Hood and Shew, 1997). During periods when no susceptible host plants are available the fungus must survive as dormant spores (Figure 2). The thin-walled endospores are relatively short lived (up to seven months in soil). In contrast, the thick walled chlamydospores survive for many years in soil. *T. basicola* is able to produce enormous quantities of spores on the roots of cotton and in the adjacent soil. For example, three weeks after cotton was sown into soil with a low population of *T. basicola* (40 chlamydospores/g soil), almost 800,000 chlamydospores were produced for every gram of cotton root (Rothrock and Nehl, unpublished data). Consequently, repetitive cropping with cotton or a susceptible host deposits an ever-increasing number of spores in the soil.

In the Australian Cotton Cooperative Research Centre (Cotton CRC) farming systems trial at Warren the severity of black root rot was proportional to the number of cotton crops grown, irrespective of the number of fallows or rotations with cereals (Figure 3A). For example, the severity of black root rot when cotton was rotated with wheat, which is not a host for *T. basicola*, was half that in the continuous cotton treatment but still increased each time cotton was grown. This observation was confirmed in another long-term trial at ACRI where the severity of black root rot in continuos cotton was double that of cotton rotated with wheat every other year. Put simply, once *T. basicola* becomes established in a field, the number of cotton crops determines the severity of the disease.

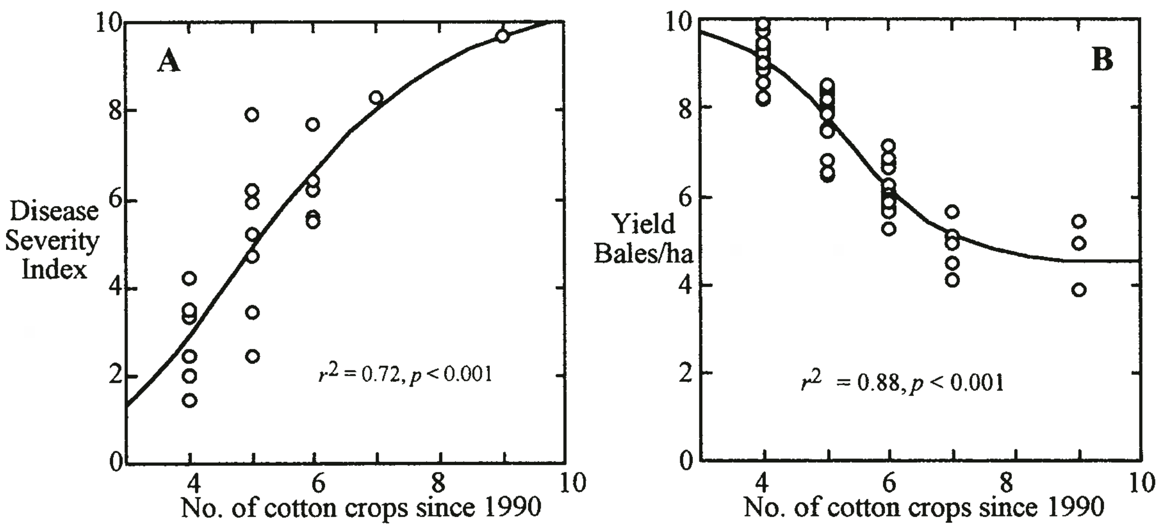

Figure 3. Increase in black root rot severity and decrease in cotton yield with repetitive cotton cropping in the CRC farming systems trial at Warren. Cotton was sown across the whole field in 1994, 1996 and 1998. Every other year the treatments were cotton, fallow, field pea, high input wheat, low input wheat or faba bean. In a seventh treatment the rotation was lablab, wheat and cotton for 1993, 1995 and 1997 respectively.

Conditions favouring black root rot

While the severity of black root rot is related to the density of *T. basicola* in the soil, the progress of disease in a given season will be affected by climatic conditions. The optimum range in soil temperature for development of black root rot is 16 to 20°C (Hillocks, 1992). However, infection will progress well at soil temperatures up to 25°C. Black root rot is also favoured by wet conditions, especially as wet weather usually coincides with a fall in temperature. The prolonged cool wet conditions during the first half of the 1999/00 season were very favourable for infection by *T. basicola*, and other soilborne pathogens.

Anecdotal observations indicate that the severity of black root rot varies with soil type, being more severe on medium clay soils than on very heavy clays or lighter soils. In a field at Goondiwindi the severity of black root rot was significantly correlated with a number of soil properties (Table 2). In a field near Narrabri, infection of cotton by *T. basicola* was also correlated significantly with a range of soil properties (data not presented). While the association of disease severity with certain soil properties confirms that soils may be conducive or suppressive to *T. basicola*, it does not prove a 'cause and effect'. Although the water holding capacity of soil increases with increasing clay content, the data do not show a strong association with black root rot. Infection of cotton by *T. basicola* at the Narrabri site was suppressed in very heavy clay soils, where the water holding capacity was greatest. The microbial diversity of the soil may be equally as important as its physical and chemical properties. This is the subject of a new Cotton CRC research project.

Table 2. Relationship between the severity of black root rot and soil properties, cotton growth and mycorrhizal development.

	Correlation coefficient	Probability
pH	0.75	<0.001
Electrical conductivity	0.71	0.001
Clay content	0.59	0.010
Organic matter	0.26	Not significant
Bicarbonate extractable P	0.30	Not significant
Exchangeable Ca	0.79	<0.001
Exchangeable K	0.71	0.001
Exchangeable Na percentage	-0.56	0.017
Shoot dry matter	-0.88	<0.001
Mycorrhizal colonisation (VAM)	-0.69	0.002

Symptoms and yield loss

The most obvious symptom of black root rot is stunted cotton growth during the early part of the season. The stunting is strongly correlated with black root rot severity (Table 2, Table 3). Diagnosis of black root rot requires examination of the roots. *T. basicola* causes characteristic blackening of the roots due to destruction of the root cortex (Figure 2). This damage reduces the capacity of the plant to absorb nutrients. Colonisation of roots by the beneficial fungi that form mycorrhizas (VAM) is also reduced by black root rot (Table 2).

T. basicola does not kill cotton seedlings; seedling death is associated with other seedling pathogens, namely *Rhizoctonia* and *Pythium*. Although some lateral roots may die, *T. basicola* does not usually enter the vascular tissue of cotton and the tap root survives (Figure 2). As the season becomes warmer, plants resume growth and the expanding roots slough off the dead tissue. Infection by *T. basicola* will occur throughout the season if conditions are cool. A proportion of older plants may develop an internal stem rot if black root rot is severe (Figure 2). This internal stem rot contributes further to the survival of *T. basicola* in the field and may enhance the spread of the fungus in floating trash.

Table 3. Decreased cotton growth and maturity caused by black root rot in a field near Wee Waa.

	T. basicola population density (spores/g soil)		Probability
	414	648	p =0.012
10 December 1999			
Disease severity index (0-10 scale)	0.6	6.1	p <0.001
Healthy lateral roots (No./plant)	9.0	1.0	p <0.001
Plant stand (plants/m)	12.7	11.1	p =0.019
Plant height (mm)	232	72	p <0.001
Shoot dry matter (g/plant)	5.0	0.6	p <0.001
25 January 2000			
Fruit development (bolls/m)	27	0.5	p <0.001

Quantification of the effect of black root rot on yield is difficult because replicated plots with and without the pathogen are difficult to generate. As an alternative we measured the effects of black root rot on cotton growth, maturity and yield using paired sites, with high and very high populations of *T. basicola* respectively (Table 3). Stand establishment was adequate in all plots, although it was slightly lower in the plots with severe black root rot. Black root rot was present throughout the field. The very high population of *T. basicola* was sufficient to delay fruit development and maturity by approximately three weeks, compared to areas of the field where the disease was not as severe (Table 3, Figure 4). The result was a 26% loss in yield.

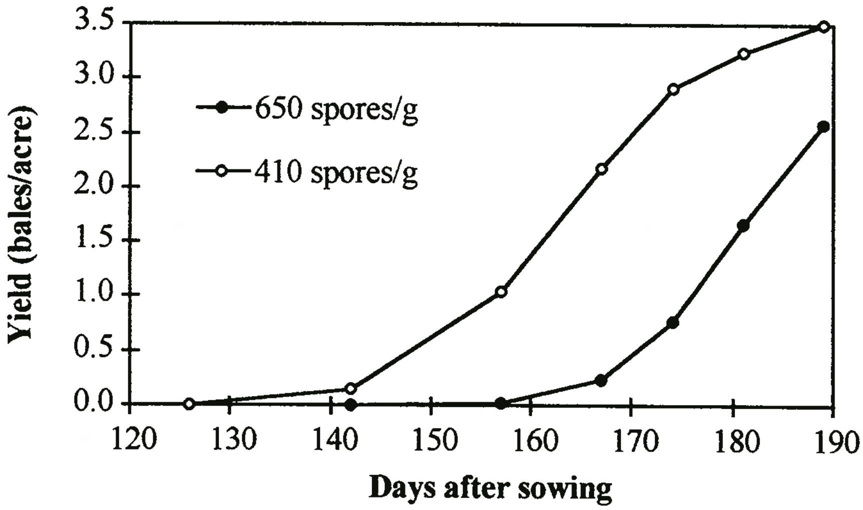

Figure 4. Delayed maturity and reduced yield of cotton caused by black root rot. Data is from replicated sites in a field near Wee Waa (see Table 4) with high (410) and very high (650) populations of *T. basicola* in the soil (see Table 4). Yield values were calculated from hand-picked seed cotton mass and adjusted to reflect the mechanically harvested yield for the whole field.

The yield loss at the Wee Waa site only occurred in those patches with a very high spore population. However, yield losses are potentially much higher. At a farm near Pilliga the grower estimated that black root rot caused a yield loss of 1.5 bales/acre across approximately 50 % of each of two fields in the 1999/00 crop. Although the severity of black root rot was not assessed early in the season, the Pilliga soil contained extremely high populations of *T. basicola*; 1200 to 1400 spores/g soil.

In the Cotton CRC farming systems trial at Warren, yield declined in proportion to the number of cotton crops, irrespective of rotation treatments (Figure 3B). This decline mirrored the increase in black root rot severity (Figure 3A). It is possible that other soil factors may have contributed to this yield decline but, so far, nothing other than black root rot severity has been shown to be correlated with the yield decline. Soil compaction was not related to the yield decline because compaction was worse in some of the rotation treatments than in the continuous cotton treatment (N. Hulugalle, personal communication). Similarly, measurement of soil compaction at the Wee Waa site was not correlated with the degree of stunting and yield loss (Nehl and Hulugalle, unpublished data).

Management options

Exclusion The true distribution of *T. basicola* is probably greater than that shown by the disease surveys (Figure 1) because it takes time for the fungus to increase to levels that cause noticeable symptoms in the crop. Nevertheless, there are still many farms and fields that do not yet have the disease. Exclusion is one of the most valuable controls for plant diseases. All growers should practice good farm hygiene to minimise the spread of black root rot between fields, farms and valleys.

Timing Planting should be timed to avoid the cool temperatures that favour black root rot, as well as other seedling diseases. While climatic averages suggest that mid-October should be warmer than late September, 'average' weather never occurs! In the 1999/00 season, crops sown in infested fields at the end of September were well established when cold weather arrived in mid-October. Although these crops were stunted with black root rot throughout October, they had passed the stage of being susceptible to *Rhizoctonia* and appeared to be better off than the crops sown later. Sowing at soil temperatures of 20°C is ideal but not practicable. The best option appears to be to sow early if conditions are suitable (16°C or more), particularly when there is a trend for rising soil temperatures, rather than falling. Replanting decisions should be made on the basis of stand loss, not the degree of stunting with black root rot.

Varieties All cotton cultivars in Australia appear to be equally susceptible to *T. basicola*. No sources of resistance have been identified in our field trials in Australia, nor those of pathologists in the USA. Transfer of resistance genes from wild species of cotton may be possible but offers no short term prospects. An alternative approach would be growing cultivars that may be managed for performance later in the season.

Rotations Rotation with cereals does not increase the population of *T. basicola*, but neither does it reduce it. Anecdotal evidence suggests that three consecutive years of wheat may be long enough for the population of *T. basicola* to decline. A field trial with one, two and three years of wheat has been established in the Macquarie valley. Many of the legumes currently used in rotation with cotton are hosts for *T. basicola* (see paper by Mondal et al., this proceedings) and should be avoided.

Biofumigation This method involves planting a 'green manure' crop that releases compounds that are toxic to pests or pathogens in the soil. Biofumigation offers a safe, self-generating method of distributing a natural fumigant throughout the soil profile. Vetch has been used successfully as a biofumigant for black root rot in cotton in the USA (Rothrock and Kirkpatrick, 1995) and has the added benefit of providing nitrogen to the following cotton crop (see paper by Rochester et al., this proceedings). We tested biofumigation for black root rot in a number of field trials over two seasons (Table 4). It must be stressed that the dry matter production in the biofumigant crop and the success of its incorporation will determine the effectiveness against *T. basicola*. Furthermore, the population of *T. basicola* can vary within plots and experiments, adding errors to the spore population data and masking treatment effects. Nevertheless, biofumigation appears to have potential to reduce the severity of black root rot (Table 4).

Table 4. Summary of results of biofumigation trials for control of black root rot in cotton.

Trial	Crop	Difference from control (%)			
		Disease severity	Spore numbers	Cotton growth	Maturity
Narrabri 98/99	Vetch	-61	-59	12 NS	ND
Narrabri 98/99	Indian mustard	-56	ND	-11 NS	ND
Moree 99/00	Indian mustard	-34	NS	26	26
Narrabri 99/00	Indian mustard	-31	-65	22	ND
Narrabri 99/00	Vetch	-23 NS	-10 NS	8 NS	ND
Walgett 99/00	Vetch	ND	-24	ND	ND
Warren 99/00	Indian mustard	-29	-21	47	26
Warren 99/00	Indian mustard	-70	-88	19	19
Warren 99/00	Vetch	-38	4NS	9NS	1 NS

NS = Not statistically significant. ND = Not determined

Fungicides The fungicide Baytan® (Bayer Australia Ltd) gives a degree of control of black root rot when used as a seed dressing on some occasions but not on others, and has a slight phytotoxic to cotton as well. Baytan is more effective when used as an in-furrow spray at planting. In two field trials Baytan reduced the severity of black root rot symptoms by at least half. However, in both trials, early season growth and crop maturity were not increased by this fungicide. Since Baytan did not reduce the development of mycorrhizas in cotton, its application in-furrow may also have involved phytotoxic effect. Further trials will examine various rates and methods of application of Baytan. Baytan is not registered for cotton and can only be used for trial purposes by NSW Agriculture.

Induced resistance All plants are equipped with defence systems that enable them to resist infection by most microorganisms. Plants respond differently to pathogens depending on the nature of their defences. Plant pathologists have recently investigated ways to activate these inherent disease resistance mechanisms by applying chemical inducers to the plant, in advance of the pathogen. We have conducted a number of experiments using Bion (a Novartis product containing benzothiadiazole) to induce resistance to black root rot in cotton. In several pot experiments, Bion reduced the severity of black root rot in cotton and legumes that are used in rotation with cotton (see paper by Mondal et al., this proceedings). Bion may potentially reduce both the severity of black root rot and the build-up of *T. basicola* in the soil, and will be evaluated further in field trials.

Summer flooding Flooding is used for control of soilborne diseases of cotton in parts of California. Growers there report that the severity of black root rot is reduced substantially in at least the next four cotton crops after flooding. Temperature is an important factor. Flooding is most effective during summer, requiring a minimum of 30 days with maximum air temperature at 30°C or more (O'Niell, 1997). In Australia, the population density of *T. basicola* was decreased dramatically by flooding a field for approximately 57 days, during February and March 2000 (Table 5). The flooding was effective over the range of depths and temperatures across the field. The cost effectiveness of the procedure will be calculated after yield is determined in the 2000/01 season. Summer flooding is a useful option for black root rot control but its use in Australia will be restricted by the availability of water.

Table 5 Decline in the population of *Thielaviopsis basicola* after summer flooding of a field at Merah North

	Sampling position	
	50 m from head ditch	50 m from tail ditch
Water depth (cm)	30	55
Soil temperature[A] maximum(°C)	26.2	25.6
Soil temperature[A] minimum(°C)	23.8	24.1
Population before (spores/g soil)	359 ±69	485 ±53
Population after (spores/g soil)	8 ±3	19 ±4
Population reduction	98%	96%

[A] 10 cm below the top of the bed.

Can we live with black root rot?

If black root rot were to continue spreading at the current rate (see logistic growth curve, Figure 1), then 95% of irrigated farms in NSW would have the disease by 2004. However, the rapid initial spread of the disease probably included some farms with soils that are more conducive to the disease. Black root rot may never become obvious on farms with soils that suppress it, or on rain-fed farms where the frequency of cotton cropping is low, or in hot dry regions. Hence, it seems likely that further spread of *T. basicola* may progress more slowly (Gompertz curve, Figure 1).

Yes, we can live with the delays in maturity caused by moderate levels of *T. basicola*, especially if the seasons are long and hot. At moderate levels, yield losses may only be experienced after prolonged cool weather, such as that experienced in the 1999/00 season. **No**, we can not live with the large yield losses that occur with severe infestation by *T. basicola*. Unless black root rot can be managed effectively, it clearly has the potential to cause chronic yield losses of sufficient magnitude to threaten the sustainability of cotton production. The best approach will be integrated management, utilising a range of techniques to reduce the severity of black root rot and to prevent it from becoming severe in the first instance.

Acknowledgments

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