Monitoring fruiting factors as a tool in insect management

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ABSTRACT

Assessing fruit load in conjunction with regular insect monitoring provides significant benefit when making insect management decisions. Growers and consultants have used a number of techniques to measure or estimate a crops fruit load. These include fruit retention and total fruit counts. A new technique used by Australian growers is called 'Fruiting Factor', (FF). Fruiting factors are determined by assessing the ratio of fruit per fruiting branch. The concept of fruiting factors was developed in response to comments from growers and consultants that monitoring first position fruit retention by itself was not providing an effective guide to crop performance. Particularly in situations where a combination of high early season fruit loss, excessive vegetative damage and tipping out has occurred. As first position retention didn't consider secondary fruit, it underestimated the ability of a crop to compensate for fruit loss and this could in turn cause unnecessary reductions in pest thresholds. To assess fruiting factors as a fruit load monitoring tool, data was collected from over 300 commercial irrigated cotton fields during the 1999/2000 and 2000/01 growing seasons. Yields averaged 8.75 bales/ha and 7.45 bales/ha respectively. Fruiting factors where shown to change throughout the growing season starting at less than 1.0, peaking above 1.5 and declining to 1.0 or less at the end of the season. To assist in insect and crop management one of the key periods for measuring fruiting factors is at flowering. A significant correlation (R^2=0.58) was determined between fruiting factors at flowering and yield. It is indicated that values between 1.1 and 1.3 will provide optimum yield potential. Values less than 0.8 (R^2=0.60) or greater than 1.5 (R^2=0.69) where correlated with reductions in yield. This was a clear indication that excessive fruit load at flowering can reduce crop yields. This can have implications for the management of transgenic Bt cottons where high fruit load are observed at flowering. Fruit counts alone at flowering proved less useful than fruiting factors, providing a linear relationship to yield (R^2=0.32). Fruit counts did not provide an indication of yield reductions for excessive fruit loads. Fruiting factors provided a better indication of yield potential compared to first position retention (R^2=0.28). While a significant relationship can be determined between final yield and fruiting factors for each year that data was collected (R^2=0.73 in 1999/2000 and R^2=0.53 in 2000/01) it should be used to assess the crops yield potential rather than predict final yield. Fruiting factors have been incorporated into new integrated pest management guidelines (IPM) developed by the Australian Cotton Cooperative Research Centre. This paper discusses the use of fruiting factors in monitoring a crop's fruit load to assist in insect pest management.

Introduction

In developing strategies for insect pest management, growers and consultants have demonstrated that adopting a more dynamic approach to insect thresholds is more important than using any predetermined threshold. In combining dynamic thresholds with the use of less disruptive insecticides and the conservation of beneficial insects growers have be able to improve farm profits (Mensah, 2002; Hoque, *et al.*, 2002).

When adopting a flexible approach to insect pest management it is important to monitor crop growth rates and fruit development to avoid excessive periods of crop damage. Acceptable damage levels will vary depending on yield expectations and climatic conditions, which will determine the seasonal length. Assessing fruit load in conjunction with regular insect monitoring, provides significant benefit when making insect management decisions. This is particularly valuable when a range of insect pests is present in the crop such as mirids and *Helicoverpa* spp.

Fruit load is obviously a key aspect in determining crop yield and maturity. The loss of fruit during squaring and early flowering is less critical to yield than fruit loss later in the season (Ungar *et al.*, 1987; Wilson *et al.*, 2003; Abaye and Herbert, 2002). Kennedy *et al.* (1986) showed that early fruit loss could increase yield, however excessive early fruit loss can delay final maturity (Jones *et al.*, 1996) and reduce yield (Abaye *et al.,* 2001). It is also known that holding too much fruit can reduce crop growth, cause premature cut out and thereby may reduce yield. Kerby *et al*. (2001) showed that high boll retention on the bottom five fruiting branches reduced total fruiting nodes and yield. There is a clear need for growers to assess crop fruit load throughout the season so that excessive fruit loss can be avoided and crops with high fruit load can be managed to prevent premature cutout.

Growers and consultants have used a number of techniques to measure or estimate a crops fruit load. These include fruit retention and total fruit counts. A new technique under investigation is called 'Fruiting Factors' (FF).

The concept of fruiting factors was developed in

1999 in response to comments from growers and consultants that monitoring first position fruit retention by itself was not providing an effective guide to crop performance particularly in situations where a combination of high early season fruit loss, excessive vegetative damage and terminal damage has occurred. In assessing pre-flowering fruit loss, integrated pest management (IPM) guidelines developed in Australia recommend to maintain first position retention between 50% and 60% (Mensah and Wilson, 1999). However, growers and consultants have reported that crops with pre-flowering first position retention levels less than 50% still reach there full yield potential. Wicks (2002), in assessing commercial field data, showed poor correlation between yield and first position retention. It was felt that because first position retention didn't consider secondary fruit, it underestimated the ability of a crop to compensate for fruit loss and this could in turn cause unnecessary reductions in pest thresholds. Crops that suffer high levels of early terminal damage and fruit loss are also difficult to assess for first position retention. In comparing first position retention from plants with and without terminal damage it has been found that if more that 30% of plants in a crop suffer early terminal damage, that retention data collected just from undamaged plants will over-estimate average first position retention for these fields (Gibb, 1999).

To overcome difficulties in monitoring retention growers can conduct total fruit counts. Fruit counts require conversion factors for varieties and growth stage before they can be used, and increase in proportion to yield expectations. Fruit counts do not provide a simple guide to assess fruit load irrespective of yield.

To assess the use of fruiting factors data was collected from commercial cotton fields in 1999/2000 and 2000/01 cotton seasons. This field data was used to validate results from controlled damage trials conducted in 2000/01 (Gibb *et al.*, 2002).

Fruit counts, retention and fruiting factors - What's the difference?

Total fruit counts are the most common fruit monitoring techniques used by growers. At the end of the season they provide growers with a basic tool to estimate final crop yield. Fruit counts are generally used at the end of the season but can be used throughout the year to give an indication that a crop will reach original yield targets.

Fruit retention and fruiting factors do not provide growers with an accurate estimate of final crop yield. They are used to provide a guide of yield potential, irrespective of final yield. That is, they consider a crop's fruiting capacity.

Fruiting factors provide an advantage over retention measurement in that they can be used in crops that have a number of vegetative stems that develop fruit. Plants with three or four large vegetative stems are commonly found in conventional crops in Australia as growers use higher early season thresholds to reduce insecticide use and preserve beneficial insects. Wilson *et al*. (2003) indicated that 100 percent removal of vegetative terminals during the pre-squaring period of growth does not affect yield.

First position retention is a useful tool up to flowering but its value declines after flowering. Retention monitoring also doesn't consider secondary fruit that can make significant contributes to yield particularly in situations of low first position retention. Fruiting factors provide an indication of the amount of fruit a plant is holding relative to its stage in vegetative growth (fruiting branches). Fruit counts by them selves cannot do this.

In assessing fruit shedding Jackson and Gerik (1990), showed a relationship between the ratio of boll load (BOLL) and carrying capacity (CA) and young-boll shedding. They concluded that estimating the ratio BOLL/CA could be used to index crop development or boll shedding fraction and aid crop management. Jackson *et al.* (1988) also assesses average fruiting sites per fruiting branch and found for a plant population of 12 plants/m (recommended plant population for irrigated cotton in Australia), that there would be between three and four fruiting sites produced per node. Fruiting factors are a measure of fruit load per fruiting branch and thereby an indication of BOLL/CA and is a practical extension of this early work.

Experimental procedure

Fruiting Factors – How to measure them?

Fruiting factors have been developed to consider both fruit counts and the number of fruiting branches. A crop's fruiting factor is determined by dividing the fruit count per meter by the number of fruiting branches per meter.

$$\text{Fruiting Factor} = \frac{\text{Total fruit count per meter}}{\text{Total number of fruiting branches per meter}}$$

The simplest way to estimate fruiting factors is to count all fruit and fruiting branches in a meter of row. This includes vegetative branches within that meter. It is recommended that at least three meters be monitored per field. To save time in monitoring the fruiting factor for fully irrigated crops it is recommended to only count first and second position fruit (squares and bolls), from the main stem and the first dominant vegetative branch. In irrigated crops this should account for 90% of the fruit that will be picked (Schulze and Tomkins 2002).

In assessing fruiting factors, data was collected over two years from commercial cotton fields in the

McIntyre Valley of south west Queensland. In 1999/2000, 151 fields were assessed and in 2000/01 165 fields were assessed. Fruiting factors where determined by counting all fruit and all fruiting branches in a one meter row from a minimum of three meters of row randomly selected per field. Fields were first assessed 50 to 60 days after planting (DAP), and then every seven to 10 days up to 110 to 130 days after planting. Data was collected from conventional and transgenic Bt cotton (INGARD®).

Data collected in 1999/2000 was grouped and averaged for fruiting factor values 0 to 2.0 in units of 0.1 for each of the sampling periods. This was used to determine changes in fruiting factor throughout the season. INGARD® and conventional crops were separated to determine if there were differences in fruiting pattern between the two crop types.

First flowering is a key period for assessing fruit load. An assessment at this time allows key crop management decisions to be made before the crop moves into boll development. Fruiting factor data at first flower (65 to 75 days after planting) were used to determine if assessments at this time could be correlated to yield. Individual field data was grouped and averaged for fruiting factors values 0 to 2.0 in units of 0.1. All data from conventional and INGARD® cotton were grouped together.

Data from 53 fields assessed in 1999/2000 was used to compare first position retention and fruiting factors at first flower to final yield. Total fruit counts per meter at flowering were compared to fruiting factors in 2000/2001.

Planting and defoliation dates were used to assess season length in 2000/2001. Season length was compared with fruiting factors at flowering.

Results

Changing fruit loads

Data collected from fields during the 1999/2000 season indicates that fruiting factors change throughout the life of the crop (Figure 1). During early squaring (55 to 65 DAP), values of 0.8 to 1.0 where observed. The fruiting factor then increases throughout flowering as the crop produces a large number of squares and flowers. Values peak at 100 to 110 DAP coinciding with peak squaring. Fruiting factors decline after peak squaring and as the crop matures. This decline coincides with the natural reduction in fruit numbers. Eventually, at maturity fruiting factors approach levels of 0.8 to 1.0, which represents the natural fruiting load that plants can carry through to harvest. This is consistent with fruit shedding reported by Jackson and Gerik (1990) and Heitholt (1993).

Figure 1 demonstrates that fruiting factors in INGARD® crops can be higher in the first half of the season compared with conventional crops. This is in line with higher levels of early fruit retention in INGARD® crops due to reduced *Helicoverpa* spp. damage compared with conventional crops. These higher levels of early fruit load result in fruiting factors peaking at 95 DAP which was 12 days earlier than conventional crops. This is consistent with work by Sadras (1996), who showed that the time it takes to reach peak fruit numbers per plant was delayed by 20 to 25 days after high early fruit loss. In comparing season length, the period between planting and defoliation, for Ingardâ and conventional crops in 2000/01, INGARD® crops were defoliated 7 days earlier than conventional crops, (158 days compared to 165 days) indicating that the earlier peak in fruit numbers did result in earlier cutout.

Fruiting factor and yield

A key period for measuring fruiting factors is at flowering. There was a significant correlation between fruiting factor and yield in both years ($P<0.01$). Figure 2 compares fruiting factors at flowering with final yield for the two years of data collection. Yields significantly varied between the two years averaging 8.75 bales/ha in 1999/2000 and 7.45 bales/ha in 2000/01. The difference in yield was due to seasonal conditions and not any major difference in insect or other pest damage. Although there was a difference in yield, the relationship between fruiting factor at flowering and yield was consistent reaching maximum yield at a similar fruiting factor. To collate the two years of data, yield from each year were divided by the average yield for that year. The combined data expressed as yield potential (%), that is final yield compared with average yield, ($R^2=0.57$; $P<0.01$). The yield potential for a given fruiting factor (FF) at flowering is expressed in equation [1].

$$\text{Yield potential } \% = -30.12 \times FF^2 + 79.52 \times FF + 50.49 \quad [1]$$

It was shown that yield values peaked at fruiting factors between 1.1 and 1.3. Values less than 0.8 or greater than 1.5 where shown to have a negative correlation ($P<0.01$), with yield, (R^2; 0.60 and R^2; 0.69 respectively). This confirmed that excessive levels of fruit load could cause a yield reduction and validates the relationship between fruiting factors and yield recorded from controlled experiments, (Gibb *et al.* 2002). The rate of yield decline for fruiting factors less than 0.8 was 2.5 times the rate of decline for values greater than 1.5.

In assessing fruiting factors across different growing region in Australia Gibb *et al*. (2002) reported that the general trend was for yields to decline for values less or greater than optimum, however, the degree of impact varied across the different regions. They reported the effects of fruiting factor on yields at Emerald (hotter, longer season region), Narrabri (warm season region), and in the Upper Namoi and Darling Downs (cooler shorter season regions). At Emerald there was no relationship between lower fruiting factors at flowering and yield. This demonstrates the capacity of crops to compensate for early season damage in those areas that have a longer season. In the cooler regions lower fruiting factors resulted in a higher rate of yield decline, reflecting the reduced capacity of these crops to compensate for early damage.

Crop maturity

The higher the fruiting factor the greater the number of fruit per fruiting branch. Once a crop has flowered the plant begins to assign assimilates (energy) to boll development over vegetative growth. When fruit load exceeds the plants ability to support effective boll development and additional vegetative growth, the crop begins to shut down or progress towards what is commonly called 'cut out'. This can be an advantage if we want an early maturing crop, however, premature cut out can reduce yield (Kerby *et al.*, 2001). Crops with fruiting factors greater than 1.5 at flowering illustrate this point.

The impact of increasing fruiting factors on crop maturity is shown in Figure 3. The data is based on the field data collected in 2000/2001 where maturity was assessed as the time taken from planting to defoliation. The results indicate that days to maturity is reduced as fruiting factors increase ($P<0.01$). This may help explain why crops with high fruit load have reduced yield, however, further data is needed on the impact of fruiting factors on total fruiting nodes and boll weight to explain the extent to which high fruiting factors can lead to reduced yield.

In recognizing that a crop with a high fruiting factor at flowering may progress to early cut out, monitoring fruiting factors may be used to priorities fields for irrigation and additional fertilizer if required. The aim would be to minimize any additional crop stress, for example water stress, on crops with high fruiting factors as any external stress may further reduce crop maturity and exacerbate yield loss.

Fruiting factors, retention and fruit counts

Fruiting factor and first position retention data collected at flowering was compared from 53 fields assessed in 1999/2000. First position retention ranged from 38% to 92% and fruiting factors 0.5 to 1.8. There was no correlation between fruiting factors and first position retention at harvest ($R^2=0.28$; ns), however, a significant correlation was found between fruiting factors and yield ($R^2=0.73$, $P<0.01$). The correlation between fruiting factors and yield was similar to that recorded from the field data collected in 1999/2000 and 2000/2001. Yield peaked at a fruiting factor of 1.3 and declined for values less that 1.0 and 1.5.

Total fruit counts per meter at flowering were compared to fruiting factors in 2000/2001. Total fruit counts showed a significant ($R^2=0.32$, $P=0.01$) linear relationship with yield. Fruit counts don't provide any indication of yield decline for high fruit numbers (greater than 200 fruit per meter). Fruiting factor data as (Figure 2) showed a significant ($R^2=0.53$, $P<0.01$), relationship with yield and indicted a yield decline for high fruit numbers per fruiting branch or BOLL/CA.

This data comparing fruiting factor, first position retention and fruit counts per meter shows that fruiting factors may provide an improved indicator of yield potential and the impact of high and low fruit load (BOLL/CA) at flowering.

Conclusion

Plant monitoring has always been an important component in the management of insect pests. Growers and consultants have recognized that cotton has a high capacity to compensate for early vegetative and fruit damage. With the aim of reducing insecticide costs without affecting yield or crop maturity it is important to have guidelines for the levels of damage that can be tolerated.

Through monitoring fruiting factors, insect thresholds can be managed in accordance with yield potential and maturity. Assessing fruiting factors at first flower can provide a useful guide to the yield potential of a crop. It can also indicate if insect thresholds need to be changed or if additional care needs to be taken in the timing of irrigations to avoid plant stress in crops with high fruit loads.

Table 1 details how fruiting factors can be used as a tool at flowering to assess crop fruit loads. The values shown in Table 1 provide a guide to interpreting fruiting factors and indicate values that will prevent any significant risk to crop yield or maturity.

IPM Guidelines published by the Australian Cotton Cooperative Research Centre (Cotton CRC), (Mensah and Wilson, 1999), highlight how monitoring fruit damage can assist in using dynamic thresholds. When using fruit retention and fruiting factors the objective is not to replace insect thresholds with damage thresholds. The objective is to use this information in conjunction with information on pest abundance to make more informed decisions regarding the need to control pests.

First position fruit retention and fruiting factors can best be used when making a decision of whether or not to control insects that are just under or over threshold limits. Alternatively, this monitoring can be used in situations where consistent, low, insect pressure is occurring. For example, there is no value in controlling a pest infestation that is just over threshold if the crop is fruiting well and some damage can be tolerated without effecting yield. Another example is where the combination of below threshold populations of *Helicoverpa* spp. and mirids can reduce fruit retention if present in a crop for an extended period. By monitoring fruit loss though measuring fruiting factors, a decision can be made if such populations are worth controlling.

Monitoring first position fruit retention is a technique that is best used early in the season during squaring and prior to or just after flowering. It is quicker than total fruit counts and can provide an early sign of insect damage. Fruiting factors can be used throughout the season and allow total fruit load to be monitored. Fruiting factor should be used when first position retention falls below recommended levels (i.e. 50% to 60%), to ensure excessive fruit loss has not occurred, or in situations where a crop is tipped out and retention is difficult to determine.

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***Table 1.** General guide to using fruiting factors at first flower.*

Fruiting factor at flowering	Impact on yield and maturity
Less than 0.8	High risk of yield decline and maturity delay. Particularly in cooler regions
1.1 to 1.3	Optimum for yield
More than 1.5	Risk of premature cut out and yield decline.

***Figure 1.** Change in fruiting factor throughout the season, conventional and Ingard® crops.*

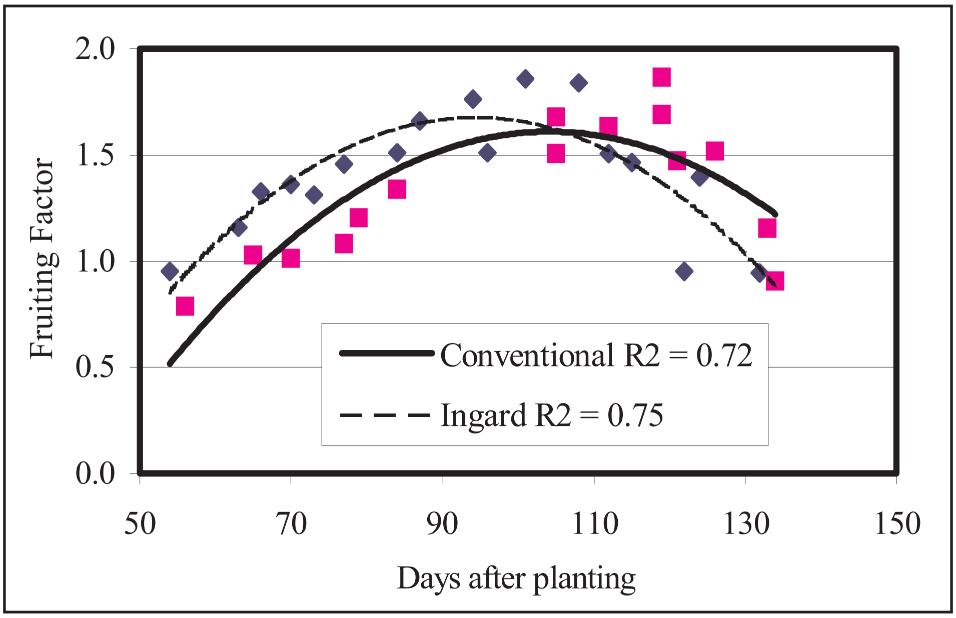
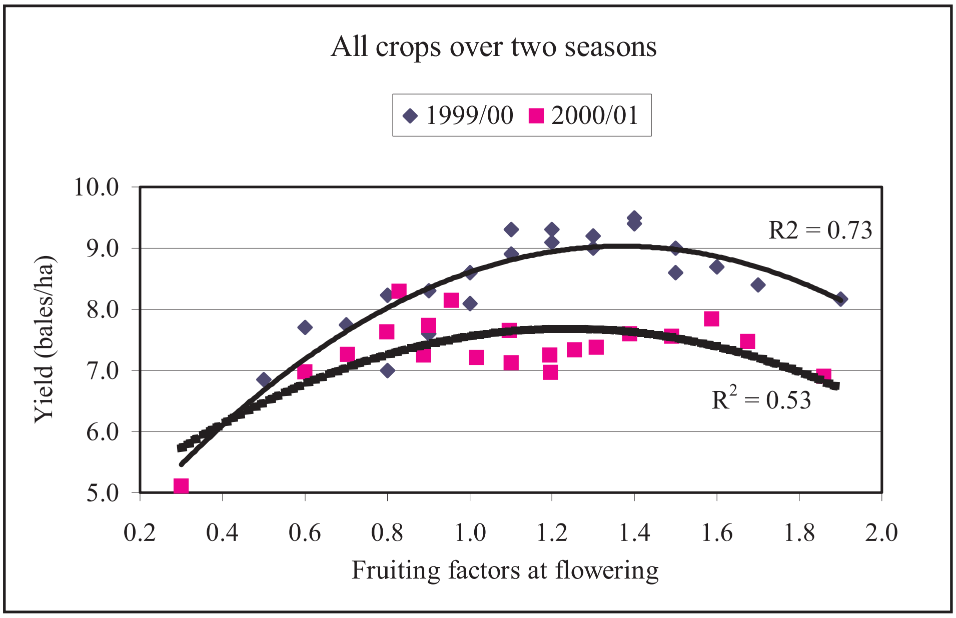


***Figure 2.** Fruiting factors at flowering and yield.*



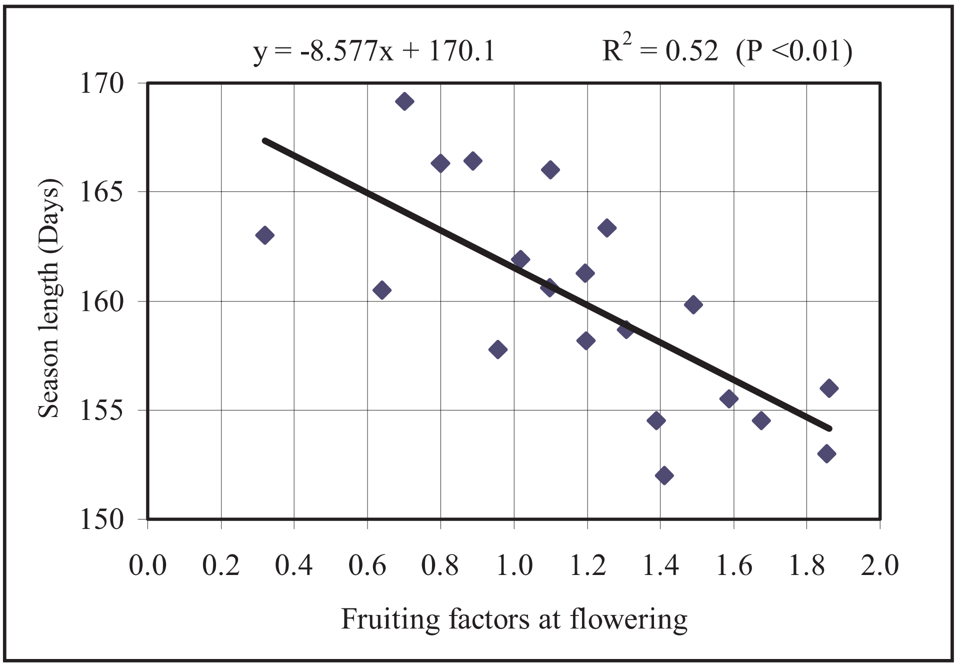


Figure 3. *Impact of increasing fruiting factors on crop maturity.*