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Plant Monitoring Techniques for Analyzing Yield Differentiation between Cotton Fields and Improving Crop Management

Yves Crozat[1] and Poonpipope Kasemsap[2]

ABSTRACT

Plant structure components related to variation in yield between 25 cotton fields were investigated in the cotton growing area of Chaibadan District, Lop Buri Province during 1994 and 1995. Survival of P1 fruits (first flower bud appeared on a sympodium) of the first-ten fruiting nodes together with the change in Height to Node Ratio (HNR) were relevant criteria for analyzing yield differentiation. In a second step their relevance was validated with yield data from 75 plots surveyed in 1993. It showed that monitoring the production and survival of P1 fruits, together with the changes in node number and height of the mainstem provided a meaningful appraisal of the origin and the cause of yield differentiation. From this type of monitoring, standards were generated with the aim of improving crop management through a better adjustment of inputs to actual plant structure.

Key words: cotton, plant monitoring, yield analysis, on-farm research

INTRODUCTION

It is a common fact to observe large variation in yield between farmers fields in a given agroecological environment. Surprisingly, analysis of the yield differentiation between farmer fields is rarely achieved although it should be a prerequisite for appropriate improvements in crop management (Sebillotte 1978; Byerlee *et al.*, 1991). Correlation study between technical components (such as fertilization, pesticide application) and the final yield provides generally a poor understanding of the causes of yield variation because it does not take into account interactions processes which affect the yield build-up (Sebillotte 1990). An alternative is to develop integrated approaches based on a monitoring of plant structure and yield build-up (Crozat and Chitapong, 1988, Leterme *et al.*, 1994). However, the indeterminate growth habit of cotton together with its unique plant structure require techniques of plant mapping that may become rapidly high-time consuming (Munro and Farbrother 1969; Kirby, 1994). Recently, simple techniques for monitoring changes in cotton growth have been developed and applied with success for adjusting crop management to plant structure (Hake *et al.*, 1994; Bourland *et al.*, 1994; Klein *et al.*, 1994 and Kirby and Hake, 1994). They were established for cultivars and plant structures of the american cotton-belt which differ much from these found in humid and sub-humid tropical conditions of Thailand. In this country, field-grown cotton plant

1 Annual Crop Department, CIRAD, DORAS Centre, Kasetsart University, Bangkok 10900, Thailand.
2 Department of Agronomy, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand.

exhibits excessive vegetative growth and a rather complex plant structure as a result of a long growing season and low plant population (< 20,000 plants. ha^{-1}). The aim of this study was to adapt these techniques of plant monitoring to Thai conditions for analyzing yield differentiation between cotton fields and for improving crop management.

MATERIALS AND METHODS

General design

In the cotton growing area of Chaibadan District, Lop Buri Province (Thailand), 20 and 15 farm plots (2,000 m^2 to 9,000 m^2) were chosen in 1994 and 1995, respectively. All plots were planted with the cultivars Sri Sumrong 60 (SSR 60). After emergence, a monitoring area of 4 rows × 10 m representative of the average plant stand was selected in each plot. Crop management was by farmer decisions. Soil samples (O-30 cm, 30-60 cm) were taken prior to planting for soil texture and chemical properties characterization.

Plant monitoring

Changes in plant structure were monitored throughout the growing season. Observations were carried out at weekly on the same 20 plants (4 groups of 5 consecutive plants/row). It consisted of a simplified plant monitoring (adapted from Kirby and Hake (1994)) and insect scouting. During plant monitoring the following data were recorded: plant height, node of the first mainstem sympodium, last mainstem node (defined as the uppermost node whose subtending leaf unfolded), last squaring node (defined as the uppermost sympodium whose subtending leaf of the first fruiting site -P1- unfolded), last flowering node (defined as the uppermost sympodium with white flower on P1 fruiting site) and % retention of P1 fruiting bodies. For insect scouting, Jassids (*Amrasca biguttula biguttula*) population and number *of Helicoverpa armigera* (Hbn.) eggs were recorded on the top-five unfolded leaves. The number of *H. armigera* larvae was counted on the whole plant.

Observations at harvest

Seed-cotton was harvested by hand (4 to 8 picking according to plots) on the whole observation area (4 rows × 10 m). Number of boll harvested as well as fresh and dry-weight of seed-cotton were measured after each picking. At final picking, 10 out of the 20 monitored plants were pulled-out. All fruiting sites of these plants were inspected in order to provide a comprehensive mapping of the yield structure. The seed-cotton yield of the whole farm plot was also recorded for economic study (not presented in this paper).

Steps of analysis

In a first step, variation in seed-cotton yield was analyzed according to the variation of components of plant structure recorded in the plots. Thus components whose variation was a determinant source of yield differentiation were identified as key criteria for plant monitoring. In a second step, their relevance for yield analysis was validated with another set of data from on-farm trials and agronomic surveys carried out in 1993 at Lop Buri and Kanjanaburi Provinces. Design of these trials and surveys has been reported by Castella (1995 and 1997). In total there were 75 plots for which plant mapping at harvest, yield components and seed-cotton yield were available. In a third step, standards for adjusting crop management to yield potential according to plant structure were generated from previous steps and growth patterns of plots displaying high yield.

RESULTS AND DISCUSSION

Relevant criteria of plant structure

Planting occurred mostly between June 15 to 30 (72 % of studied plots). Plant population averaged 1.9 plants.m^{-2} (± 0.4) in 1994 and 2.3 plants.m^{-2} (±0.6) in 1995. Over both years, average seed-cotton production was 2.36 t. ha^{-1}, but large variation existed between plots. Yield ranged from 1.5 to 3.4 t. ha $^{-1}$ in 1994 and from 1.1 to 3.5 t.ha^{-1} in 1995. Variation in boll number was the major determinant of seed-cotton yield (Figure 1). Conversely the average boll-size which varied little between plots and years, was poorly correlated with the yield ($r^2 < 0.12$). When considering bolls on mainstem only, mainstem-bolls.m^{-2} removed at least 80% of the variation in total boll observed each year (Figure 2). It indicated that bolls on vegetative branches were not a substantial source of differentiation in boll production, although their average contribution to total boll number were 15% and 26% in 1994 and 1995 respectively. Little variation between plots in their contribution explains this result. In addition bolls found on vegetative per unit area increased linearly with bolls on mainstem (r=0.74). High contribution of vegetative branches to boll production is a common feature of cotton crop grown at low plant population (Constable 1986, Munro1987).

Furthermore, bolls in first position (P1) on mainstem sympodia contributed for less than 30% to total boll production (29% in 1994 and 19.5% in 1995). However, P1-bolls.m^{-2} removed at least 79% of the variation in mainstem-bolls.m^{-2}(r =0.79 in 1994 and r = 0.82 in 1995). It suggested that P1 boll could be a fair indicator of yield differentiation between farmer plots. Thus, in both years, the retention rate of P1 fruits located on the first-ten sympodia along the mainstem was a relevant criterion for analyzing boll production (Figure 3). Considering a age-cohort approach of fruit appearance (Sequiera *et al.*, 1994), this result indicated that difference in boll number between plots occurred during the development of fruit co-appeared during the abscission-sensitive period of

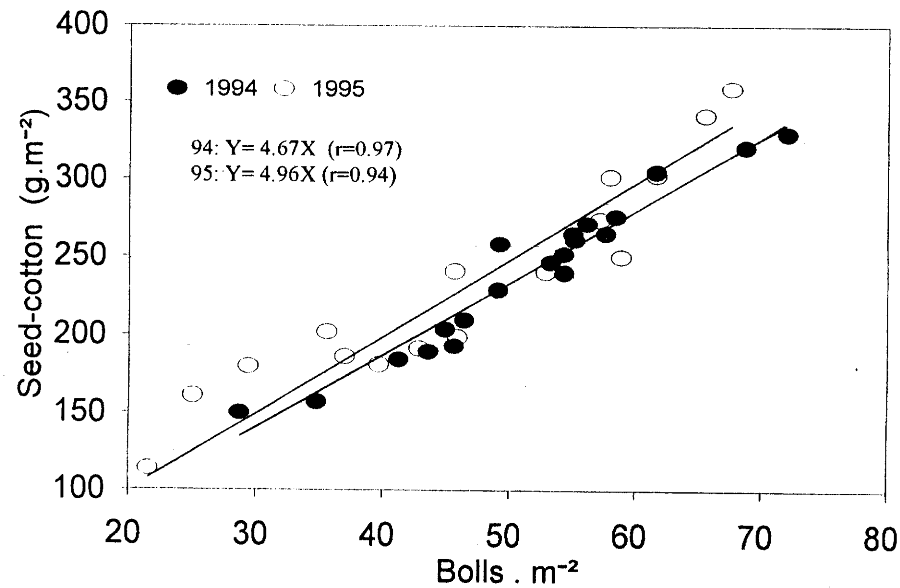

Figure 1 Seed - cotton yield (in g.m^{-2}) recorded in farmer's plot according to the number of bolls harvested.m^{-2}.

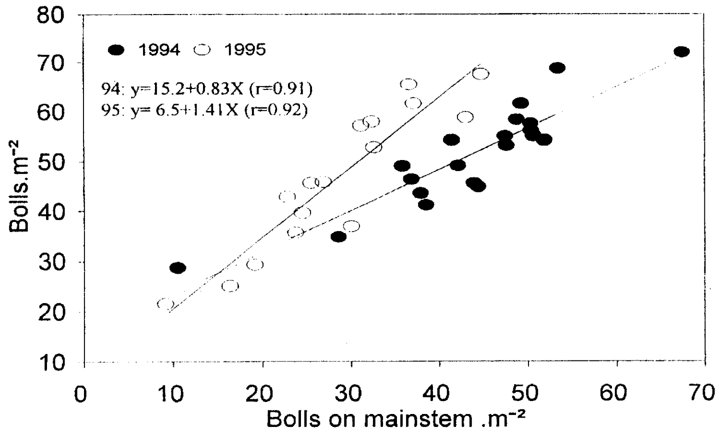

Figure 2 Relationship between the number of bolls.m^{-2} and the number of the bolls located on the mainstem.m^{-2}.

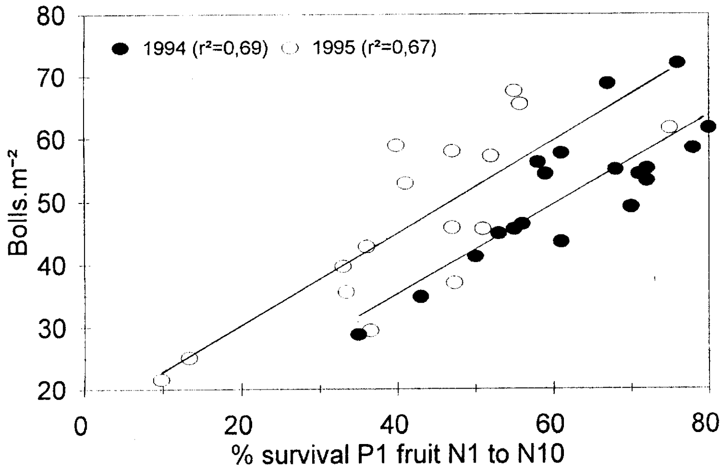

Figure 3 Relationship between the number of bolls.m^{-2} and survival rate of P1 friuting site of the first-ten fruiting branches.

fruits of the first-ten P1 fruiting sites. *Helicoverpa armigera* infestation during this period was the major cause of low retention rate (Crozat *et al.*, 1995 and Crozat *et al.* 1997). However, in plots with low (or no) *H. armigera* infestation (< 3 larvae. 20 pt.$^{-1}$) survival rate of fruits together with boll production increased with the change in Height to Node Ratio (HNR) between node 10 to 20 (Figure 4). According to Kirby and Hake (1994), change in HNR after node 10 is related to plant growth rate and photosynthesis capacity which in return determine the boll carrying capacity of the stand.

Validation step

The range of plant structure covered for the validation step was larger than that recorded in 1994 and 1995 Lop Buri (Table 1). Seed-cotton

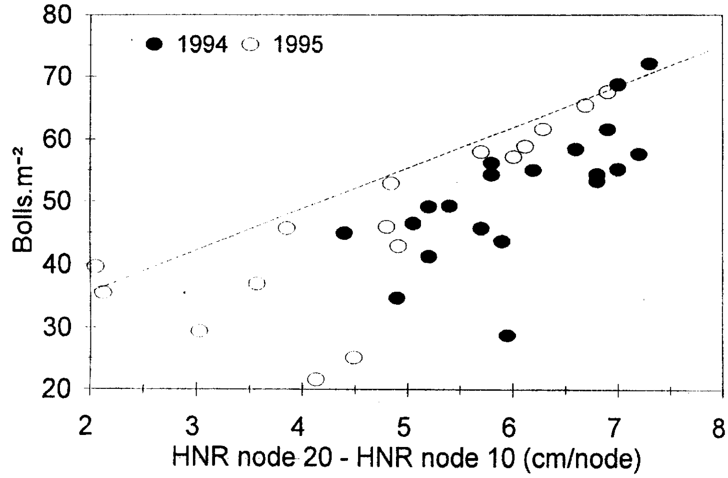

Figure 4 Boll production (Boll.m^{-2}) according to the change in internode length (Height to Node Ratio) between mainstem node 10 and 20.

yield varied from 0.1 to 3.8 t.ha^{-1}. It was the consequence of various pest management programs (such as no control and maximum control) together with planting dates (early June to mid-August) which were tested in the network of plots (Castella *et al.*, 1997). Seed-cotton yield was well correlated with boll-number whose variation was explained in a large extent by survival and distribution of P1 fruits (Table 1). Relationship observed between retention rate of the first-ten P1 fruits and boll number confirmed the determinant role of fruit survival on final yield. Fruit abscission was mainly caused by *H. armigeria* damage (Castella *et al.*, 1997). As a consequence, relationship between boll production and plant growth rate estimated by the change in internode length (HNR) was weak because abscission caused by bollworms probably masked physiological shedding caused by growth limitation. These results showed that monitoring technique of plant structure may be simplified to mainstem observations (plant height, node production) and a record of the production and survival of P1 fruits only, despite their low contribution to boll production. It is stated that P1 fruit survival pattern is a practical appraisal of the survival of other fruits born at the same time on other positions of the plant. Two observations support this statement : (i) in a cohort of iso-born fruits, although P1 fruits survive better than fruits from other positions (Kerby and Buxton, 1981; Constable, 1991, Crozat *et al.* 1997a) their changes in survival with time were found to follow similar trends (Crozat *et al.* 1997b); (ii) fruit abscission caused by *H. armigera* (which is a major cause of abscission in our conditions) have been reported to be fruit-age dependent rather than position dependent (Wilson and Gutierrez, 1990).

Generation of standards for crop management

Over all data (100 plots), a typology of cotton fruiting structure based on the survival of P1 fruits located on the first-ten fruiting nodes provided a rather accurate classification of seed-cotton yield observed (Table 2). It indicates that high yield may be achieved with an early boll setting and a high fruit retention of the first-half fruiting nodes. In case of poor retention rate of the five-first nodes (< 70%), compensation on upper nodes may exist

Table 1 Range in plant structure recorded at harvest in the 81 plots used for the validation step and determinant relationships identified for yield differentiation analysis.

Plant structure	Mean (min-max)
- plants.m^{-2}	1.7 (1 - 2.7)
- % bolls on veg.branches	36.6 (3 - 65)
- % bolls on P1	28.1 (8-48)
- fruiting nodes. mainstem $^{-1}$	18.4 (10-24)
- seed-cotton yield (t.ha^{-1})	0.8 (0.1- 3.8)
Relationship between plant structure components	**Linear regression (r)**
- Seed-cotton (g.m^{-2}) and Bolls.m^{-2}	y = 3.99 x (0.94)
- Bolls.m^{-2} and Bolls mainstem.m^{-2}	y = 0.92 + 1.21x (0.92)
- Bolls mainstem.m^{-2} and P1 Bolls.m^{-2}	y = 4.84 + 3.96x (0.73)
- Bolls.m^{-2} and % survival P1 fruits $_{\text{nodes 1-10}}$	y = 11.5 + 0.63x (0.64)
- Bolls.m^{-2} and HNR $_{90\text{days}}$-HNR $_{60\text{days}}$	(linear response of envelope curve as in Figure 4)

Table 2 Yielding probability according to boll retention rates of the first-ten P1 fruiting sites (100 fields, SSR 60, 3 years).

% survival of P1 fruits			Probability to reach a yield higher than: (t.ha^{-1})					
Fr. nodes 1 to 5	Fr. nodes 6 to 10	% plots	0.5	1	1.5	2	2.5	3
70	70	10	1	1	1	1	1	0.8
70	50-<70	16	1	1	1	0.9	0.75	0
70	<50	5	1	1	0.4	0	0	0
50-<70	70	8	1	1	1	0.75	0.5	0
50-<70	50-<70	12	1	1	0.7	0.5	0	0
50-<70	<50	8	1	0.7	0.4	0.1	0	0
<50	70	2	-	-	-	-	-	
<50	50-<70	7	1	1	0.2	0	0	0
<50	<50	18	0.8	0.2	0	0	0	0
0	<25	14	0.1	0	0	0	0	0

but in a limited extent since maximum yield never overpasses 2 $t.ha^{-1}$. Such a typology provide a framework for predicting potential yield according to the actual fruit retention rate of the crop and in return adjusting crop management to yield forecast, especially inputs level and plant protection.

High yielding plots (>3 $t.ha^{-1}$ in our conditions) displayed a similar change in HNR with mainstem nodes appearance (Figure 5). As proposed by Kirby and Hake (1994) this relationship may be used as a standard curve (an ideal change in plant structure) for assessing if a crop has a proper size for its physiological age. Crop with a change in HNR lower than the standard curve, especially between node 10 and 20, is likely to experience a growth limitation which will limit its boll carrying capacity. According to Figure 1, a carrying capacity of a minimum of 60 $bolls.m^{-2}$ should be targeted for achieving a final yield of at least 3 $t.ha^{-1}$. Change in HNR is also a key criteria for making decision for application of growth regulators such as Mepiquate Chloride (Constable, 1994). Application of Mepiquate Chloride on SSR60 cultivars is recommended when the change in internode length overpass 6 cm $node^{-1}$ (Crozat *et al.*, 1997c).

The change in the number of Nodes Above White Flower (NAWF) in high yielding plots was 9 at first flower and decreased steadily at the rate of 0.15 $node.day^{-1}$ (6.7 $day.node^{-1}$) as the flowering period continued (Figure 6). According to Oosterhuis *et al.*, (1993), the decrease in NAWF coincides with the decline in canopy photosynthesis and provides an indication whether the developing bolls or the upper canopy vegetative growth is the predominant sink. NAWF = 5, is generally considered as a critical value below which new fruits produced are likely to abscise in large number (Hake *et al.*, 1994; Bourland *et al.*, 1994; Klein *et al.*, 1994 and Kirby and Hake, 1994). A low NAWF in comparison with the standard pattern indicates an insufficient vegetative growth in comparison with fruit requirement, leading to an early stop of fruiting. At opposite, high NAWF indicates excessive vegetative growth (often due to fruit loss by insects), limiting fruiting and a delay in crop harvest.

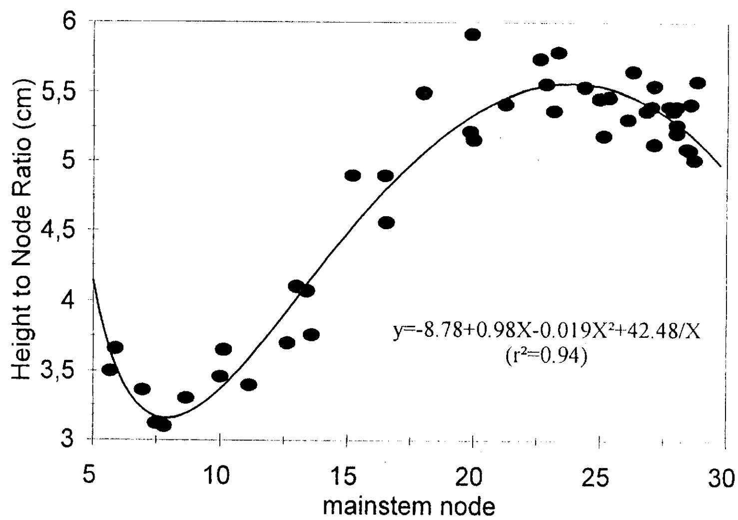

Figure 5 Change in the Height to Node Ratio with mainstem node appearance in high-yielding plots (>3$t.ha^{-1}$).

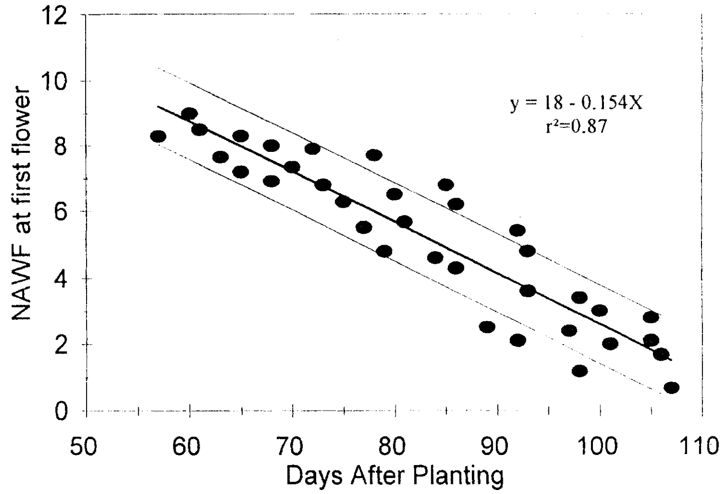

Figure 6 Decline in the number of Node Above White Flower (NAWF) recorded in high-yielding plots (>3t.ha^{-1}).

CONCLUSION

As expected, large variation in seed-cotton yield existed between farmer fields. This variation was related to the variation in boll number. Despite a complex plant fruiting structure found in farm fields, the production and survival of P1 fruits, together with the change in node number and height of the mainstem were meaningful appraisal of the origins and causes of the difference in boll number. As a consequence, these simple plant-monitoring techniques can serve as decision-taking tools for adjusting crop management according to actual yield potential.

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