PROJECT REPORT No. OS 64

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by

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Contents

Abstract

Previous research, funded by HGCA and Defra, has shown that oilseed rape green canopies can be too large, leading to poor utilisation of light and reduced yields. This may be due to early establishment, plentiful nitrogen availability and mild winter conditions.

This project aimed to identify crops requiring remediation to attain optimum size during pod filling and the most effective methods of achieving it. The triazole fungicides tebuconazole (Folicur) and metconazole (Caramba) have plant-growth-regulating activity due to their inhibition of gibberellin synthesis. Another previously investigated technique is mowing the crop in late winter. A series of experiments investigated optimum timing of the PGR chemicals, and use of mowing, in relation to canopy size and variety of oilseed rape. Crops of the conventional variety Apex and the hybrid Pronto were grown at ADAS Rosemaund and ADAS High Mowthorpe in 1999, 2000 and 2001.

In 1999, the effect of timing (March-May), dose and mixture of the PGR chemicals with chlormequat on growth and yield was studied. The chemicals significantly reduced crop height and lodging when applied at stem extension (GS 2) in March. Later applications (up to early May) at green bud – early flowering (GS 3 – 5) increased yield by up to 0.6 t ha^{-1}.

Subsequent trials in 2000 and 2001 compared the effect of early (March, *greatest height and lodging effects previously*) and late applications (potentially more beneficial for yield) on crops of different canopy sizes. A range of canopy sizes resulted from the two sowing dates (early September/early October) and two seed rates (120 and 60 seeds m^{-2}). At both sites, yield improvements were produced most consistently from spraying the largest crops (early-sown, high seed rates) with PGRs, with GAIs > 0.5-1 in March or 1.5-2 in April. Spraying small crops could result in small yield losses. Benefits were possible from both March and April full rate sprays, but the April sprays were generally more consistent and gave greater yield benefits (up to 1 t ha^{-1}). Yield enhancements greater than about 0.2 t ha^{-1} were needed for an economic return.

Growth analysis data was used to derive a relationship between crop fresh weight (FW) and green area index (GAI = 0.8*(FW in kg)), which can be used to identify the crops most suitable for remediation. Yield benefits were generally due to increased numbers of seeds per square metre and increased thousand seed weight. This could be due to enhanced assimilate supply and seed survival, better light interception and partitioning and better combine harvest seed recovery.

Mowing was attempted in all years but was not possible in 1999 and 2001 due to soil conditions. In 2000 mowing generally caused small yield decreases, since the canopies being mown were not excessive to start with.

Summary

Introduction

Oilseed rape (*Brassica napus*, L.) is the third most important combinable crop in the United Kingdom, with up to 0.5 Mha grown each year in the late 1990s (Defra, 2002). To maintain margins in the current economic climate, growers need to increase yields and/or reduce the unit costs of production. HGCA and Defra statistics show that the UK mean rapeseed yield has improved little since 1979 (Sylvester-Bradley *et al.*, 2002). The mean yield for 1979-2001, 2.97 t ha^{-1}, falls well short of the 7.56 t ha^{-1} proposed as the theoretical maximum by Daniels and Scarisbrick (1983). Inconsistency in yield is also a major problem recognised by growers, with a range of yields of 2 – 5 t ha^{-1} reported around the 3 t ha^{-1} mean. To improve profitability of oilseed rape production, then higher yields which are obtainable under UK conditions, must be achieved more consistently by more producers.

Previous research into 'canopy management' of winter oilseed rape (Lunn *et al.*, 2001), presented in HGCA Project Report OS49, has shown that large crops usually do not give the highest yields. This is because a green area index of about 3 – 4 units just prior to flowering is sufficient to intercept about 90-95% of the incident solar radiation. This consequently provides enough assimilate to provide sufficient flowers to produce the correct number of pods, which ultimately determines yield. Excessively dense crops (due to high plant populations and over-production of leaf and pods) do not intercept significantly greater amounts of light and produce too many flowers, which themselves reflect and absorb light (Mendham *et al.*, 1981; Fray *et al.* 1996). Production of too many flowers leads to production of more pods than necessary and also wastes resources on unfertilised flowers and aborted pods. The excess floral parts can form a reservoir of inoculum for the stem rot fungus *Sclerotinia sclerotiorum*. Dense and tall crops are also prone to lodging during flowering, which can lead to severe yield losses. Yield of oilseed rape is almost wholly determined by pod and branch photosynthesis during pod filling, since leaves fall off soon after flowering and there is little retranslocation of previously stored stem reserves (Stafford, 1996), unlike wheat where up to 30% of yield can come from remobilised soluble stem carbohydrate (Foulkes *et al.*, 1997). Our research has shown that above an optimum number of pods (about 6,000 m^{-2}), there is no significant increase in yield since the average number of seeds retained per pod declines rapidly with increases in pod density.

Consequently, similar or better yields can be obtained from sparser oilseed rape canopies, which have less foliage and fewer pods. Such canopies require lower inputs of seed and nitrogen to grow and may have lower requirements for fungicides due to smaller surface area and a less favourable microclimate for fungal growth. Canopy management work (Lunn *et al.*, 2001) has identified agronomic strategies for growing smaller canopies, including reduction in seed rates, later sowing dates and careful control of N fertilisation, taking account of soil mineral nitrogen. Current commercial practice tends to produce large and dense canopies in the spring, since relatively high seed rates are used due to fears of poor establishment and earlier sowing dates have been favoured to avoid clashes with cereal drilling. Strategies for growing smaller crops may not be applicable in certain systems or there may be resistance to their use, due to the perceived benefits of lush canopies for over winter survival, weed and pest (pigeon and slug) control.

Consequently, an alternative strategy is to establish a relatively large over winter canopy with its attendant agronomic benefits and then to take remedial action in the spring to return the canopy to the optimal size. Two strategies are possible. Certain triazole fungicides, used for control of light leaf spot (*Pyrenopeziza brassicae*), phoma leaf spot and canker (*Phoma lingam*), alternaria (*Alternaria brassicae*) and sclerotinia stem rot (*Sclerotinia sclerotiorum*) also have plant growth-regulating (PGR) activity, due to anti-gibberellin effects. Additionally, mowing in late winter (January/February) can remove excess leaf material and has been shown by past research to give some yield benefits (Spink, 1992).

The aim of this research was to assess the optimum timing and dosage of the range of PGR-active chemicals available (Appendix I) and to assess the interaction of PGR activity and mowing with crop size (Appendix II). The final objective of the research was to define a method for identifying which crops would benefit from remedial action to alter canopy size (Appendix III). Although it was originally intended to include mowing in February as a treatment throughout the work, weather conditions prevented this treatment in 1999 and 2001. Mowing results from 2000 are discussed in Appendix II and in 2001 this treatment was replaced with half-rate applications of the PGRs. Throughout the work the conventional variety Apex and the restored hybrid Pronto were used, to determine if hybrids, which reputedly have more vigorous growth, might respond to PGR applications more favourably than conventional varieties.

Materials and Methods

Crops of the varieties Apex and Pronto were grown at ADAS Rosemaund and High Mowthorpe. In 1999, plots were cut out of commercial crops grown at standard seed rates (120 and 70 seeds m^{-2} respectively), managed by conventional agronomy. Fungicides with no known PGR activity were applied to control disease, so the yield differences observed should be due to the PGR activity of the chemical treatments. Different doses, timings and mixtures of PGR chemicals (Folicur, Caramba and chlormequat) were applied from March to May. Height was measured with a measuring pole at 5–10 random locations per plot. At intervals throughout the growing season, from February to immediately pre-harvest, all the above-ground material was harvested from 1.0 m^2 quadrats and was returned to the laboratory for growth analysis. Plant numbers were counted and the plants were divided into stem, leaf, pod and seed fractions as appropriate. The fresh and dry weight of each fraction and the green area index was recorded. Yield was determined at combine harvest and thousand seed weight was recorded, to allow analysis of components of yield (thousand grain weight, seeds per pod and pod and seed numbers per square metre).

In 2000 and 2001, different crop sizes of Apex and Pronto were established, with early (early September) and late (late September/early October) sowing dates and high (120 seeds m^{-2}) and low (60 seeds m^{-2}) seed rates at both Rosemaund and High Mowthorpe. Crop development and PGR effects were assessed by height and growth analysis as described previously. Two timings of PGR application were compared: these were in March and in April. In 2000, mowing to remove approximately 70% and 35% of leaf material in January/February was also studied. However, this was not possible in 2001 due to weather conditions and mowing treatments were replaced by half rate sprays of Folicur and Caramba in March. Finally, growth analysis data was used to assess the usefulness of crop knowledge, visual observation, height and fresh and dry mass for assessment of crop suitability for spraying.

Results and Discussion

Chemical type, timing and dose (RM and HM, 1999)

At Rosemaund, untreated yields were only average with control yields of about 3.7 t ha^{-1} for both Apex and Pronto (Table 1). Tebuconazole (Folicur) application to Apex, resulted in significant yield increases of 0.45 – 0.6 t ha^{-1} from early April to early May applications. There was no significant increases in yield with Apex for any application of either the metconazole (Caramba) or chlormequat (or a combination of the two). The cultivar Pronto showed significant yield responses (0.39 – 0.46 t ha^{-1}) from metconazole application in mid April to early May and to tebuconazole from early April to mid May and also responded positively to half rate chlormequat.

Control yield at High Mowthorpe were similar to those at Rosemaund at 3.7 and 3.9 t/ha for Apex and Pronto respectively (Table 2). Due to poor weather conditions at High Mowthorpe, sprays in early March could not be applied. Positive yield responses were found for the cultivar Apex from a range of full rate and two split applications of tebuconazole or metconazole applied from late April to mid May. Chlormequat and mixes of the triazoles with chlormequat also gave positive yield benefits for Apex. However, there were fewer benefits from spraying Pronto with triazoles, with the largest yield increases found in mid April.

PGR treatments reduced crop size by about 5 –10 cm (data not shown – see Appendix I) and also significantly reduced lodging (Appendix I), with the greatest reductions corresponding to application in late March/early April (stem extension). However, these changes in crop morphology were not related to the yield increases.

Table 1: Effect of spray application on yield, 1999 – Rosemaund. (see Appendix I for full explanation of spray timing codes).

Spray Timing	**Product**	**Cultivar**	
		Apex	**Pronto**
Untreated		3.66	3.72
Early March	Folicur	3.68	3.62
Early March	Caramba	3.34	3.42
Mid March	Folicur	3.66	3.55
Mid March	Caramba	3.72	3.73
Early April	Folicur	4.25	4.20
Early April	Caramba	3.91	3.72
Mid April	Folicur	4.18	4.03
Mid April	Caramba	3.94	4.13
Early May	Folicur	4.11	4.19
Early May	Caramba	3.72	4.12
Mid March/Mid April	Folicur	4.16	4.28
Mid March/Mid April	Caramba	3.91	4.18
Mid March – half rate	Folicur	3.61	3.78
Mid March – half rate	Caramba	3.62	3.93
Mid March – half rate + half rate Chlormequat	Folicur	3.72	4.05
Mid March – half rate + half rate Chlormequat	Caramba	3.35	3.71
Mid March – half rate Chlormequat	Folicur	3.55	4.07
Mid March – full rate Chlormequat	Folicur	3.86	3.64
SED (df)		0.162	0.173
LSD (5%)		0.32	0.346

Table 2: Effect of spray application on yield, 1999 – High Mowthorpe. (See Appendix I for full explanation of spray timing codes).

Spray Timing	**Product**	**Cultivar**	
		Apex	**Pronto**
Untreated		3.69	3.86
Mid April	Folicur	3.97	3.95
Mid April	Caramba	3.89	3.75
Late April	Folicur	4.14	4.00
Late April	Caramba	4.13	3.95
Mid May	Folicur	3.81	3.52
Mid May	Caramba	3.82	3.63
Mid April/Late April	Folicur	4.08	4.11
Mid April/Late April	Caramba	4.17	4.37
Mid April/Mid May	Folicur	3.93	3.91
Mid April/Mid May	Caramba	4.14	4.02
Late April/Mid May	Folicur	3.85	3.87
Late April/Mid May	Caramba	4.23	3.85
Mid April Half rate	Folicur	4.05	4.04
Mid April Half rate	Caramba	4.10	4.03
Mid April Half rate + half rate Chlormequat	Folicur	4.07	4.25
Mid April Half rate + half rate Chlormequat	Caramba	3.98	3.79
Mid April Half rate Chlormequat		3.59	3.77
Mid April Full rate Chlormequat		3.94	3.86
SED (df)		0.101	0.162
LSD (5%)		0.202	0.324

Due to inherent variability within the crop growth analysis revealed no significant differences (*P*>0.1-0.5) in pod numbers or seed numbers per square metre, seeds per pod, thousand grain weight, harvest index, combine harvest recovery or fractional light interception (data not shown). Identification of the physiological mechanisms by which the growth regulators were improving yield was therefore not possible. The absence of any correlation between yield response and either crop height or lodging indicates that some structural effect perhaps influencing resource capture or resource use efficiency is most likely.

In subsequent work the influence of crop size on response to PGR treatment was to be investigated, it was not possible, therefore, to continue with the wide range of timings and chemical combinations. The data indicated yield benefits associated with later sprayings in April and early May with potential yield deficits caused by spraying in March. However, for disease control optimum spray timings are often earlier, in February or March, and there was the possibility that in larger crops these earlier timings may be beneficial. Therefore, it was decided to compare these two spray timings (with full rate applications of the chemicals), and mechanical defoliation on crops of varying canopy size. In the final year of the study defoliation was not possible due to wet soil conditions these were therefore replaced with half rate applications. Studies of the effects of chlormequat were discontinued as its approval for application to oilseed rape was not to be renewed, and its use would cease.

Interaction of canopy size and chemical application or mowing (RM and HM, 2000 and 2001).

Growth analyses of control crops revealed that seed rate rarely caused any significant difference in gross crop parameters such as height, dry matter or green area index. However, sowing date did cause significant differences in crop properties. Particularly early in the season later-sown crops were usually shorter and with significantly smaller green area indices and dry matters than the earlier crops, these effects diminished as the season progressed as the late sown crops caught up. Effects of the PGRs on crop height and lodging were less evident in 2000. Although crop height was affected immediately post-application, the crops were able to catch up so that by harvest there was usually no significant difference in height. Also, in 2000 there was very little lodging, so significant effects of the PGRs could not be further demonstrated. However, in 2001 height and lodging reduction were again evident, particularly in crops of Apex grown at ADAS Rosemaund (see Appendix II).

Due to the inherently high degree of variability in the crop, it was difficult to demonstrate statistically significant yield differences due to treatment in many instances. At Rosemaund in 2000, there were no significant effects on yield of any of the treatments on Apex or Pronto, due to large LSDs of around 0.6 t ha^{-1}. At High Mowthorpe, the LSDs were lower (around 0.2 t ha^{-1}) and significant benefits were found with spraying the larger (early sown, high seed rate) crops of both Apex and Pronto with both chemicals in March and April. Mowing tended to have a variable effect, with 70% mowing significantly reducing yield and 30% mowing had less severe, though inconsistent, effects. The size of the yield response from PGR spraying tended to increase with increased canopy (GAI) at application. Data for High Mowthorpe in 2001 is shown in Table 3 as an example: results for other site x season combinations were similar. Due to the large SEDs, the only significant enhancement in yield came from spraying the largest (early-sown, high seed rate) crops of Apex with Folicur or Caramba in March or April. Half-rate PGR application generally produced less benefit than full rate application. The benefit of PGR application for yield appeared to be associated with crop size, with yield enhancement obtainable from spraying large crops whereas spraying of small crops could produce yield deficits. In many cases there was a good linear relationship between the crop canopy size at spraying and yield difference from control (Figure 1, High Mowthorpe 2001 Apex as an example). However, in other instances particularly where only small differences in canopy size had been generated this relationship was not apparent (Appendix II).

Analysis of yield components and growth analysis data showed that enhanced yield was most commonly associated with increased numbers of seeds per square metre (Figure 2), although sometimes enhanced thousand seed weight contributed to yield increases. The yield differences were not realised through increased pod number per unit area, but the increased seed number per unit area being apparently due to increased numbers of seeds per pod. Overall, there was more evidence to support the hypothesis that the PGR effect was due to changes in canopy structure and light interception causing better assimilate supply and seed survival during the critical post-flowering phases. No firm evidence was found to support the hypothesis of better combine harvest seed recovery, although this potential mechanism cannot be fully ruled out.

Table 3: Effect of spray application on yield, ADAS High Mowthorpe 2001.

Treatment	**Apex**				**Pronto**			
	Early		**Late**		**Early**		**Late**	
	120	**60**	**120**	**60**	**120**	**60**	**120**	**60**
Control	2.84	2.93	2.91	3.01	3.50	3.33	3.13	3.22
Full rate Folicur March	3.48	3.35	3.02	2.30	3.16	3.77	3.64	3.77
Full rate Caramba March	3.50	3.30	2.70	2.65	3.29	3.11	3.62	3.61
Full rate Folicur April	3.50	3.01	2.96	2.73	3.90	3.54	3.60	2.94
Full rate Caramba April	3.58	3.29	2.99	2.65	3.41	3.35	3.32	3.30
Half rate Folicur March	3.15	3.37	2.93	2.98	3.50	3.52	3.29	2.89
Half rate Caramba March	3.06	3.07	2.75	2.62	3.19	3.38	3.01	2.74
SED (df)	Sow date x seed rate x variety x treatment (160 df) = 0.302							
LSD (5%)	Sow date x seed rate x variety x treatment (160 df) = 0.603							

Figure 1: Relationship between canopy size at spraying and yield benefit, ADAS High Mowthorpe Apex, 2001

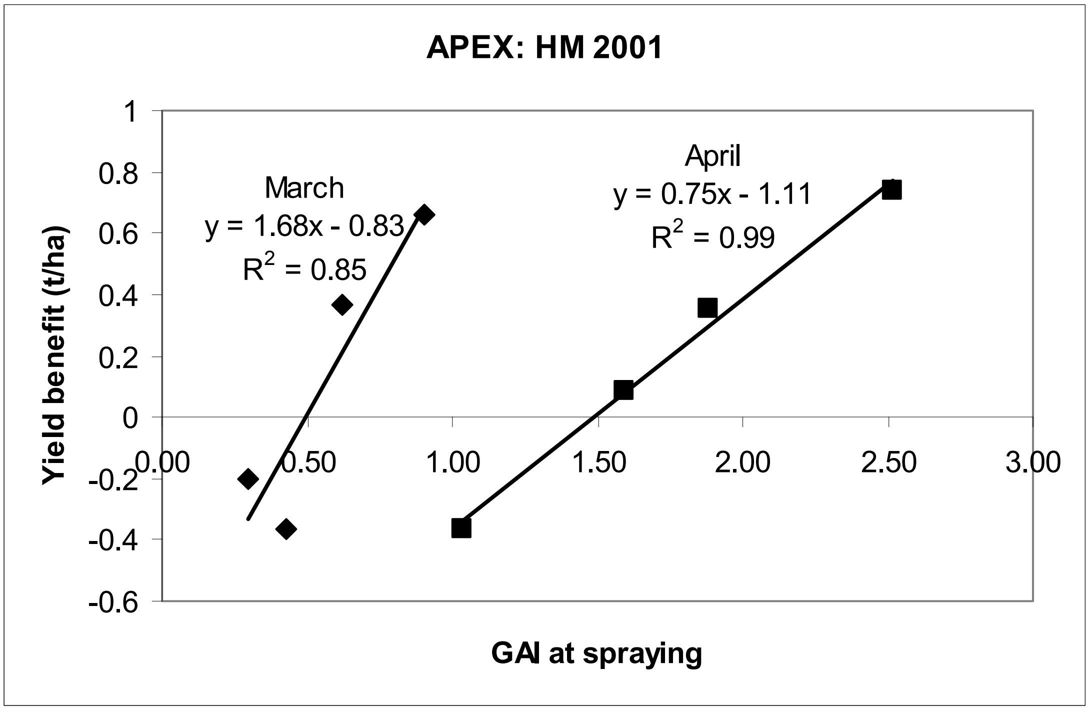
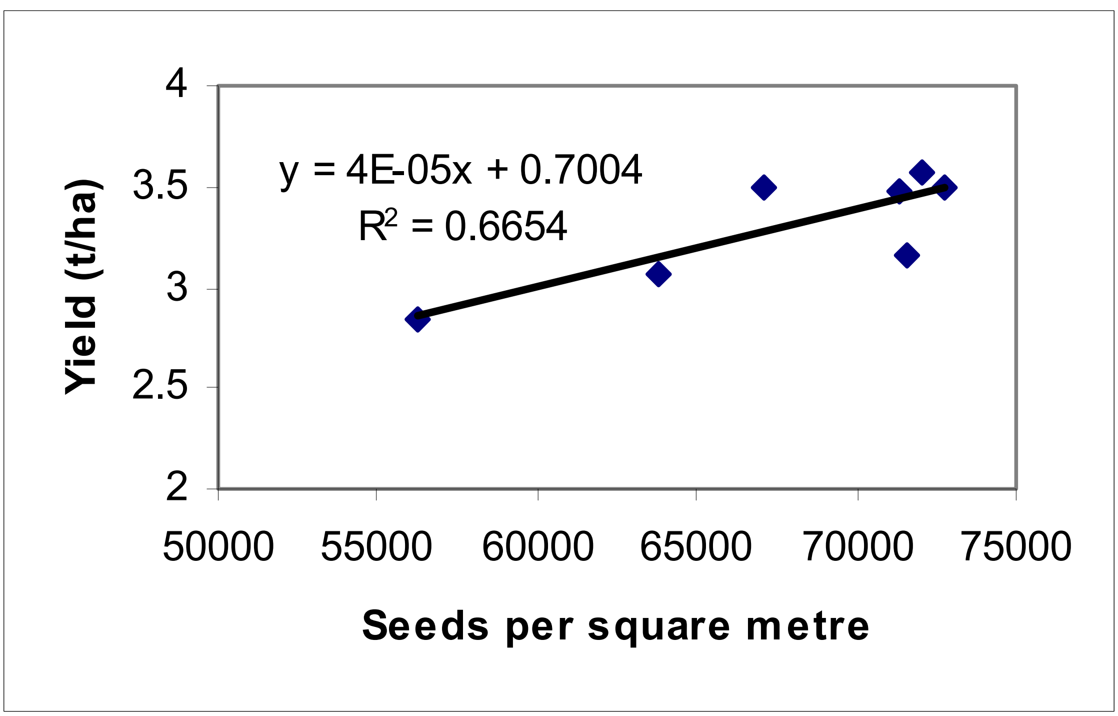


Figure 2: Relationship between seed numbers per square metre and yield, ADAS High Mowthorpe, Apex , 2001.

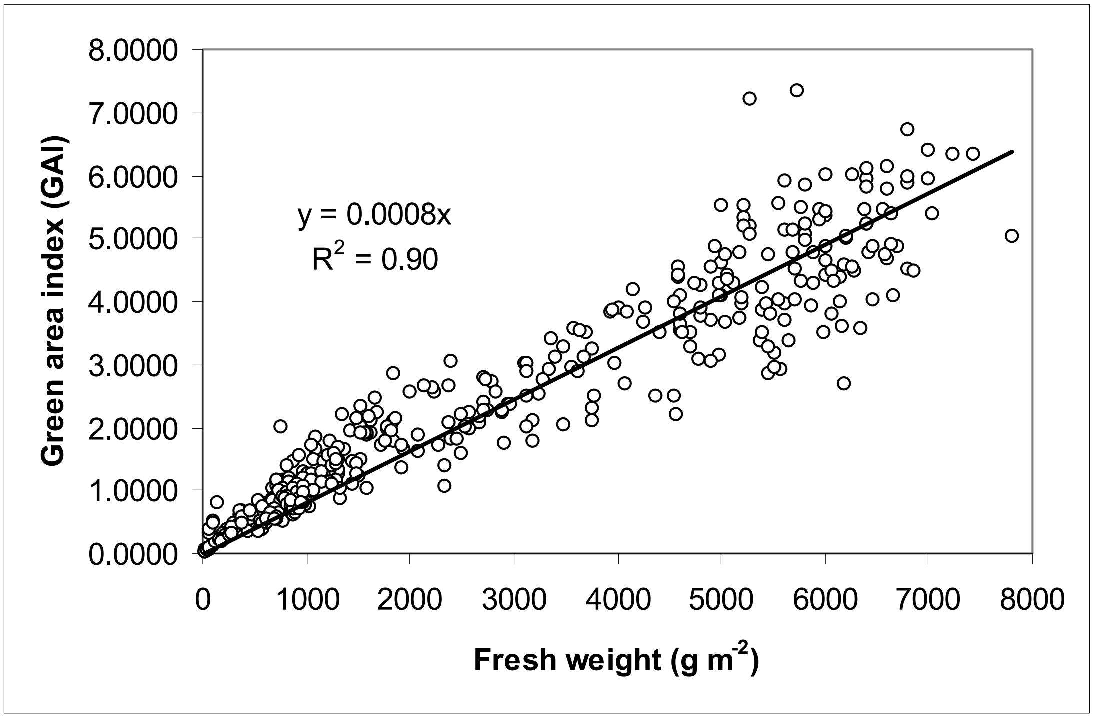


From the results described above it is evident that some crops are not suitable for remediation. Throughout the work, the smaller (<GAI 0.5 in March, < GAI 1 in April) crops suffered yield deficits when PGRs were applied, whereas larger crops (GAI > 1 in March or > 2 in April) usually, although not always, benefited from PGR application. Thus it is important that the use of PGRs should be avoided on small crops.

Identification of crops suitable for remediation

The results described above indicate that caution is needed with PGR use. Due to the combined fungicidal and PGR activity of Folicur and Caramba, some compromise may be needed in their use. The main timings for effective fungicidal control of phoma and light leaf spot are in October/November and February. Only very forward crops are likely to benefit from PGR activity of Folicur and Caramba at this timing and it may be better to use non-PGR fungicides on smaller crops. The PGR activity of the fungicides appears to boost yield of larger crops at later timings in March and April, where there may be some useful further control of light leaf spot, alternaria, and sclerotinia. Thus it is important to identify crop size suitable for remediation at the decision point. Investigation of a range of possible methods to identify responsive crops including; visual observation/crop knowledge, crop height and crop fresh and dry mass, identified a good relationship between crop fresh mass per square metre and green area index (Figure 3), given by the relationship GAI = 0.0008*(FW in g/m^2), or GAI = 0.8*(FW in kg/m^2). Thus a crop with more than 1.25 kg m^{-2} plant material in March would be suitable for PGR application, as would one with more than 2.5 kg m^{-2} plant material in April.

Figure 3: Relationship between crop fresh weight and green area index of oilseed rape



Conclusion

The work described above has shown that the PGR activity of the fungicides Folicur (tebuconazole) and Caramba (metconazole) can be used to reduce plant height and lodging over a range of sites and seasons and in 2 contrasting cultivars, Apex and Pronto. The cultivar Pronto (a restored hybrid) did not appear to be more responsive orhave any greater requirement for remediation. The optimum growth stage for height and lodging reduction was around stem extension in late March and early April, although the effects were variable and significant differences were not always seen.

The PGRs could also give yield benefits, although these generally appeared to come from later application than those that gave the greatest height reduction and lodging control: early applications to small crops could result in yield reduction. As with height and lodging reduction, the PGR effect on yield was somewhat variable. However, in general greater benefits were associated with spraying larger canopies, and yield increases (up to 1 t ha^{-1}) far outweighing the cost of application, could be realised. Thus the PGR activity of these triazole fungicides offers a useful mechanism of increasing the productivity of large oilseed rape canopies. However, to avoid economic loss from remediation of small canopies (i.e. cost of application plus resultant yield loss), spraying of inappropriate canopy sizes should be avoided where possible. Estimation of canopy GAI from the fresh plant biomass in a square metre area offers an inexpensive and reliable method of discriminating between crops.

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APPENDIX I:

Effects of chemical type, timing, dose/mixture and target variety on growth regulation and yield responses

1. Introduction

There have been numerous previous studies of the effects of various chemical plant growth regulators (PGRs) on oilseed rape, but these have usually been inconclusive. Scarisbrick and Daniels (1986) summarised studies of chlormequat, mefluidide, mepiquat chloride, 'R201', terpal (mepiquat chloride + ethephon), paclobutrazol, triapenthenol UK140 and cerone (ethephon), but made no firm conclusions other than that the response to PGRs was 'very variable' and inconsistent. Reductions in height and changes in canopy structure were often found and increases of yield up to about 118% of controls were possible. However, the yield changes were usually non-significant and yield reductions were also sometimes caused by PGRs.

The quaternary ammonium retardants ('onium' compounds), chlormequat and mepiquat chloride, block enzymes in the gibberellic acid synthetic pathway before the precursor *ent*-kaurene (Rademacher, 2000). These chemicals have shown the least consistent effects on oilseed rape (Bowerman, 1984) and are no longer approved for application to the crop, although they may still be applied to cereals. Approval for application of chlormequat to oilseed rape was withdrawn in 2000. Triazole fungicides (which include a nitrogen-containing heterocyclic group in their structure) inhibit sterol synthesis in fungal cell walls, which leads to their fungicidal activity. They also inhibit monooxygenase enzymes which catalyse the conversion of *ent*-kaurene to *ent*-kaurenoic acid (Rademacher, 2000) and consequently lead to reduced levels of gibberellic acids, the plant hormones controlling cell elongation (Hedden *et al.*, 1989). Changes in canopy structure, increased frost tolerance, increased lodging resistance and greater synchrony of pod maturity were found with the experimental triazoles triapenthenol and BAS111..W (Child *et al.* 1987), although these failed to attain approval as PGRs on oilseed rape. Stafford (1996) reported effects of the imidazole derivative fungicide prochloraz in one year out of three, causing a yield increase of about 16%. The yield increase appeared to be due to an increase in crop green area and light interception, with a slight increase in the number of pods, the number of seeds per pod and delayed senescence. The effect was not attributed to fungicidal activity. However, the effects were not replicated in subsequent trials when negative or inconclusive yield responses were found. In 1996, Stokes and Spink tested a range of chemicals including Folicur (tebuconazole, fungicide), Sportak 45 (prochloraz, fungicide), New 5C Cycocel (chlormequat/choline chloride, PGR), Moddus (trinexapac-ethyl, PGR), Opus (epoxyconazole, fungicide) and Cerone (ethephon, 2-chloroethyl phosphoric acid, PGR). In this study, only limited effects of the fungicide Folicur were found. Significant effects were found only in hand-harvested quadrat samples where greater yield was produced in early Folicur-treated plots due to more pods per square metre and more seeds per pod. Combine-harvested samples showed no significant yield differences.

Strong growth-retardant effects of the triazole fungicides Folicur (tebuconazole) and Caramba (metconazole) have been recognised, although they are approved for use as fungicides on oilseed rape and not currently specifically as PGRs. Consequently these two chemicals as well as chlormequat were chosen for initial study in this set of experiments. Chlormequat was chosen as the only specific PGR product still approved for use on OSR at the start of the research, although approval was withdrawn in 2000. It was considered that the variation in crop response to various PGRs noted in previous research could be related to differences in developmental stage and crop size at time of application, so a series of different timings were studied with these chemicals.

2. Materials and Methods

Commercial crops were drilled at ADAS High Mowthorpe (Wold Soil Series) and ADAS Rosemaund (Bromyard Soil Series) on 27/08/98 and 11/09/98 respectively. The conventional in-bred variety Apex and the restored hybrid Pronto were sown at ADAS High Mowthorpe at 120 and 70 seeds m^{-2} respectively. Due to poor establishment, Apex was re-drilled on 10/09/98. At ADAS Rosemaund, both varieties were sown at 5.5kg ha^{-1}, also giving seed rates of approximately 120 and 70 (67) seeds m^{-2} for Apex and Pronto (with thousand seed weights of 47 and 8.0g respectively). The seed dressing was Roural + Thiram (Apex) or Urtavax (Pronto) at both sites.

2.1. Husbandry

Molluscides were applied regularly throughout establishment, and weeds were controlled using the standard farm husbandry at each site.

The crops were monitored for pest infestation but at both sites pest incidence was very low and no insecticide was applied. Diseases were controlled prophylactically using Punch C, Plover and Compass

Fertiliser applications were made appropriate to the soil and site. At ADAS High Mowthorpe the crop received 190Kg / ha^{-1}N (30:80:80 split on 10/11/98, 22/02/99 and 25/03/99 respectively). At ADAS Rosemaund the crop received 282Kg / ha^{-1}N (43:100:35:104 split on 16/10/98, 10/02/99, 17/03/99 and 24/03/99, with 66Kg / ha^{-1}P and 99Kg / ha^{-1}K (09/99/98) and 111Kg / ha^{-1}S (10/02/99).

2.2. Treatments

The PGA treatments, date of application and crop growth stage are listed on Table 1. Due to sustained adverse weather conditions at ADAS High Mowthorpe the early spray applications were not possible and the spray treatments were revised as shown in Table 1.

At both sites the extremely wet winter and spring caused the intended February mowing treatment to be impractical and these plots were left untreated as additional controls.

Table 1.1a: 1999 Experimental treatments - Rosemaund.

Product and rate at Rosemaund	**Date**	**Growth Stage**
Untreated	-	-
Folicur 1.0 l/ha	5/3/99	9 leaves
Metconazole 1.2 l/ha	5/3/99	9 leaves
Folicur 1.0 l/ha	18/3/99	Early green bud
Metconazole 1.2 l/ha	18/3/99	Early green bud
Folicur 1.0 l/ha	1/4/99	Late green bud
Metconazole 1.2 l/ha	1/4/99	Late green bud
Folicur 1.0 l/ha	19/4/99	Mid flower
Metconazole 1.2 l/ha	19/4/99	Mid flower
Folicur 1.0 l/ha	5/5/99	Early pod set
Metconazole 1.2 l/ha	5/5/99	Early pod set
Folicur 0.5 l/ha	18/3/99	Early green bud
Metconazole 0.6 l/ha	18/3/99	Early green bud
Folicur 0.5 l/ha + New 5C Cycocel 1.5 l/ha	18/3/99	Early green bud
Metconazole 0.6 l/ha + New 5C Cycocel 1.5 l/ha	18/3/99	Early green bud
New 5C Cycocel 1.5 l/ha	18/3/99	Early green bud
New 5C Cycocel 3.0 l/ha	18/3/99	Early green bud
Folicur fb. Folicur 1.0 l/ha	18/3/99 +19/4/99	Early green bud and Mid flower
Metconazole fb. Metconazole 1.2 l/ha	18/3/99 +19/4/99	Early green bud and Mid flower

Table 1.1b: 1999 Experimental treatments – High Mowthorpe.

Product and rate	**Date**
Untreated	-
Folicur 1.0 l/ha	28/4/99
Metconazole 1.2 l/ha	28/4/99
Folicur 1.0 l/ha	28/4/99 + 15/5/99
Metconazole 1.2 l/ha	28/4/99 + 15/4/99
Folicur 1.0 l/ha	16/4/99
Metconazole 1.2 l/ha	16/4/99
Folicur 1.0 l/ha	28/4/99
Metconazole 1.2 l/ha	28/4/99
Folicur 1.0 l/ha	15/4/99
Metconazole 1.2 l/ha	15/4/99
Folicur 0.5 l/ha	16/4/99
Metconazole 0.6 l/ha	16/4/99
Folicur 0.5 l/ha + New 5C Cycocel 1.5 l/ha	16/4/99
Metconazole 0.6 l/ha + New 5C Cycocel 1.5 l/ha	16/4/99
New 5C Cycocel 1.5 l/ha	16/4/99
New 5C Cycocel 3.0 l/ha	16/4/99
Folicur fb. Folicur 1.0 l/ha	16/4/99 + 28/4/99
Metconazole fb. Metconazole 1.2 l/ha	16/4/99 + 28/4/99
Folicur fb. Folicur 1.0 l/ha	16/4/99 + 15/5/99
Metconazole fb. Metconazole 1.2 l/ha	16/4/99 + 15/5/99

2.2. Growth analysis

At each early biomass sampling, samples were taken only from unsprayed (equivalent to control) treatments, as shown in Table 1.2. The growth stage of the crop was recorded according to the scale devised by Sylvester-Bradley (1989). Actual controls were not sampled for growth analysis until the pre-harvest analysis. At the sixth (pre-harvest) biomass sampling, a sub-set of treated samples was taken for growth analysis (Table 1.2). This subset was chosen on the basis of perceived differences in crop remediation. At Mowthorpe, fewer assessments were made pre-spraying due to weather conditions causing fewer spray opportunities.

Table 1.2: Samples taken for growth assessment

Biomass sample	Growth stage and date (RM)	Date (HM)	Treatments sampled	
			Rosemaund	Mowthorpe
1	9 leaves (05/03)		3,4	
2	Early green bud (18/03)		5,6	
3	Late green bud (01/04)	19/04	7,8	7,8
4	Mid flower (19/04)	28/04	9,10	9,10,19,20
5	Early pod set (05/05)	15/05	11,12	11,12,21,22
6	Pre-harvest		1,5,6,9,10,13, 14,15,16,17	1,7,8,11,12,13,14,15, 16,17

For selected treatments at each sampling, crop height was recorded within the area from which the biomass sample was to be taken. Pre-flowering, a metre rule was used to measure from the ground level to within 1 cm of the top of the crop at five locations. Post-flowering, using a suitably graduated measuring stick, the height from the ground to the bottom of the pod layer and the overall height of the canopy was measured to within 1 cm at five locations.

Light interception measurements (ADAS Rosemaund only) were also taken at each sample point within the area for biomass sampling and in the rest of the plot. Pre-flowering, using two ceptometers (Delta-T Systems), five concomitant readings of photosynthetically active radiation (µmol photons m^{-2} s^{-1} in the 400-700 nm wavelength band) were taken for incident (one ceptometer above the crop) and transmitted radiation (one ceptometer at ground level) and reflected radiation (one ceptometer inverted). Post-flowering, two ceptometers were used to take five concomitant readings for incident and transmitted light at the base of the pod layer (95% of pods above ceptometer) and reflected (one ceptometer inverted above the crop). The fractional light interception of the whole crop or pods was calculated as F = 1 – (transmitted radiation/incident radiation). This value was adjusted for the fraction of reflected light, F_R which was calculated as reflected radiation (inverted above crop)/incident radiation. Thus the amount of light absorbed by the whole crop or pods was calculated as $F_A = F - F_R$.

At each sample point, all the above-ground material was removed from a 1.0 m^2 quadrat with secateurs or sharp serrated knives. On each occasion, at least 0.5 m was left between sample areas and samples were taken at least 1 m from the ends and edges of plots and tramlines. The material was placed as quickly as possible into a plastic bag, with the stems oriented to the bottom of the bag to avoid contamination with soil. Samples were then stored in a cold room at 6°C for up to 2 days.

Generally, the samples were free of soil, but when necessary they were washed under a running tap and blotted dry with paper towels to remove excess water. For pre-flowering analyses, the whole sample was weighed fresh and plants were counted by sorting into ten piles. For two piles (SS1) the fresh weight was recorded; if it was not 20%, two other piles were sampled. The remaining eight piles (SS2 = 80%) were dried at 80°C for 48 hours and the dry weight was later recorded. The SS1 sample was divided into leaf and stem material and the projected areas of each were measured. The SS1 fractions were then dried for 48 hours at 80°C and the dry weight was determined as for SS2.

For post-flowering analysis, the total fresh weight was determined and the number of plants counted. The material was spread into four piles and plants were selected from the piles to give two subsamples, each of about 15% of the total fresh weight. One subsample (SS2) was dried at 80°C for 48 hours and the dry weight was later recorded. For the other sample (SS1) the plants were split into two layers, pod (containing at least 95% of pods) and stem. The depth and weight of each layer was recorded. For each layer the green leaves, non-green leaves, flowers, buds, pods and stems were separated into trays and the fresh weight of each fraction was determined. The number of flowers, buds and pods in each layer was counted and the projected area of all green SS1 fractions was recorded. The samples were then dried at 80°C for 48 hours and the dry weights were determined.

At the pre-harvest sample point, the number of plants in each sample was counted. All the seed was threshed out and haulm and seed plus pod wall was separated. The total fresh weight of haulm was recorded and a sub-sample of 150-200 g was removed for dry weight analysis. The seeds and pod halves were separated by sieving. The total fresh weight of seeds was recorded and 1000 seeds were accurately counted and weighed. The total fresh weight of pod halves was recorded and a sub-sample of 50 g was taken and the number of pod halves counted. The haulm, seed and pod wall subsamples were then dried for 48 hours at 80°C and the dry weight was determined.

2.3. Harvest

Plots were harvested with a Sampo 2025 air-assisted plot combine at High Mowthorpe on 29-31 July 1990 and at Rosemaund on 27 and 28/7/99.

3. Results and Discussion

3.1. Effects of PGRs, timing, dose and target variety on crop height and lodging.

3.1.1. Control (Unsprayed) Crop Development

Table 1.3 shows the plant population and emergence data recorded in April at the first biomass assessment for High Mowthorpe (the fourth for Rosemaund). There was a significant (P=0.003) difference in plant population due to site, with greater populations at High Mowthorpe. There was also a significant difference in plant population due to cultivar (P<0.001). As expected, plant populations were smaller in Pronto than Apex due to the lower seed rates used with the hybrid. There was a significant difference in percentage establishment (P<0.001) due to site, with better establishment at High Mowthorpe. There was no cultivar effect on percentage establishment, or site x cultivar interaction, with percentage establishment in the range 60-80%. Hybrids are reputed to have 'hybrid vigour' and so more successful emergence and establishment could be expected from Pronto, but there was no evidence of significantly greater success of hybrid establishment at either site. Growth analysis data for the control (unsprayed) plots of Apex and Pronto grown at ADAS Rosemaund and ADAS High Mowthorpe are shown in Figures 1.2. – 1.4. Figure 1.2. shows development of crop height. At Rosemaund, before April there was no significant difference in height between the restored hybrid Pronto and the conventional variety Apex. At High Mowthorpe, early growth analysis records were not taken due to adverse weather conditions. After April, crops of Pronto at both Rosemaund and Mowthorpe were taller than those of Apex, with a more marked difference at Mowthorpe (where Apex was later-sown than Pronto due to poor establishment of the first sowing). At the final analysis point, Pronto crops were about 10 cm taller than Apex at Rosemaund and about 35 cm taller at Mowthorpe. Figure 1.3. shows the development of green area index (GAI). At Rosemaund, before April, GAI of Pronto was significantly smaller than that of Apex, due to the lower plant populations. After April, GAI of Apex and Pronto were not significantly different, indicating development of greater green area per plant of the hybrid. At Mowthorpe, GAI of Pronto was significantly smaller than that of Apex, despite the later sowing of that cultivar. All crops reached a similar maximum GAI of about 5.50, apart from

Table 1.3. Plant populations and percentage emergence (analysis of angular transformed data of percentage establishment, untransformed data in brackets)

Site	Variety	Plant population	Percentage establishment
Rosemaund	Apex	72	51.1 (60.2)
	Pronto	41	49.7 (60.6)
	Site mean	56	50.4 (60.4)
High Mowthorpe	Apex	86	59.4 (71.7)
	Pronto	56	63.8 (80.2)
	Site mean	71	61.6 (75.9)

df = 31, SED_{pop} (site, cultivar, site.cultivar) = 4.42, 4.42, 6.25, SED_{estab} (site, cultivar, site.cultivar) = 2.79, 2.79, 3.95.

Figure 1.1: Development of crop height (cm), control crops 1999 (error bars show SEMs)

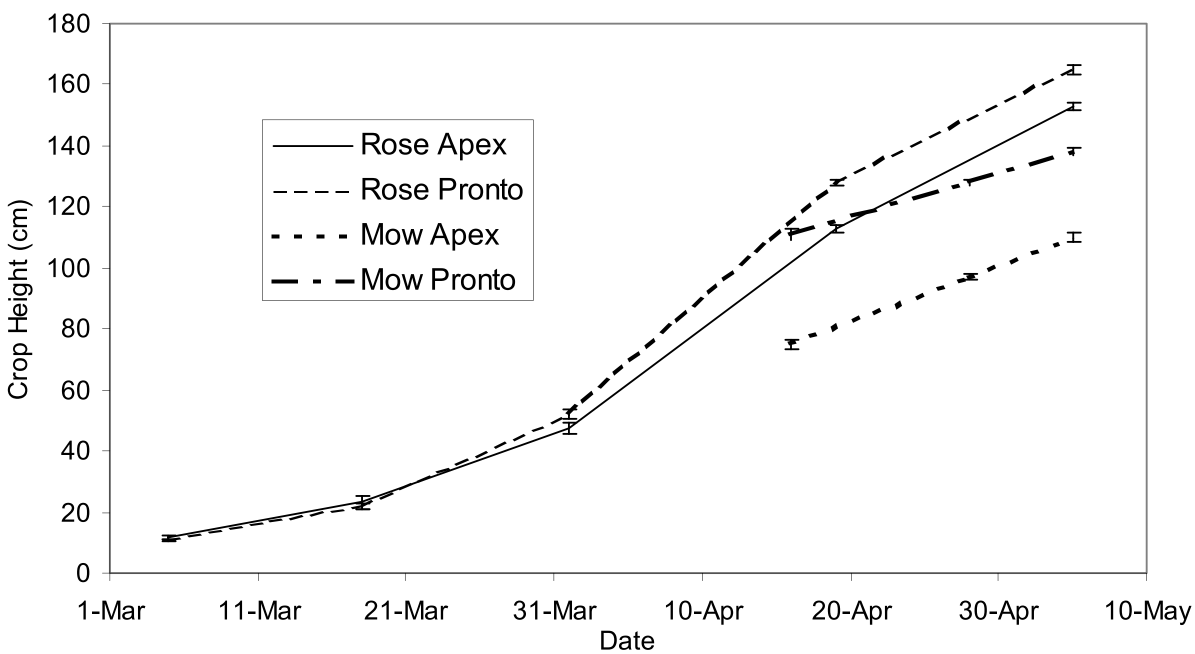


Figure 1.2. Development of green area index control crops 1999 (error bars show SEMs)

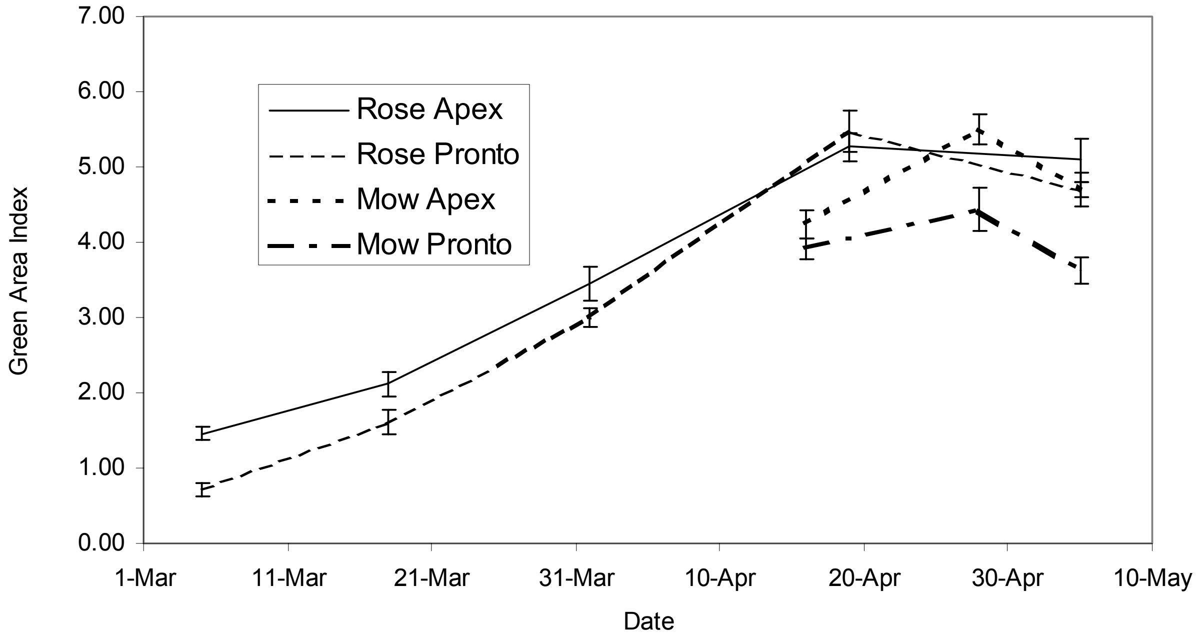
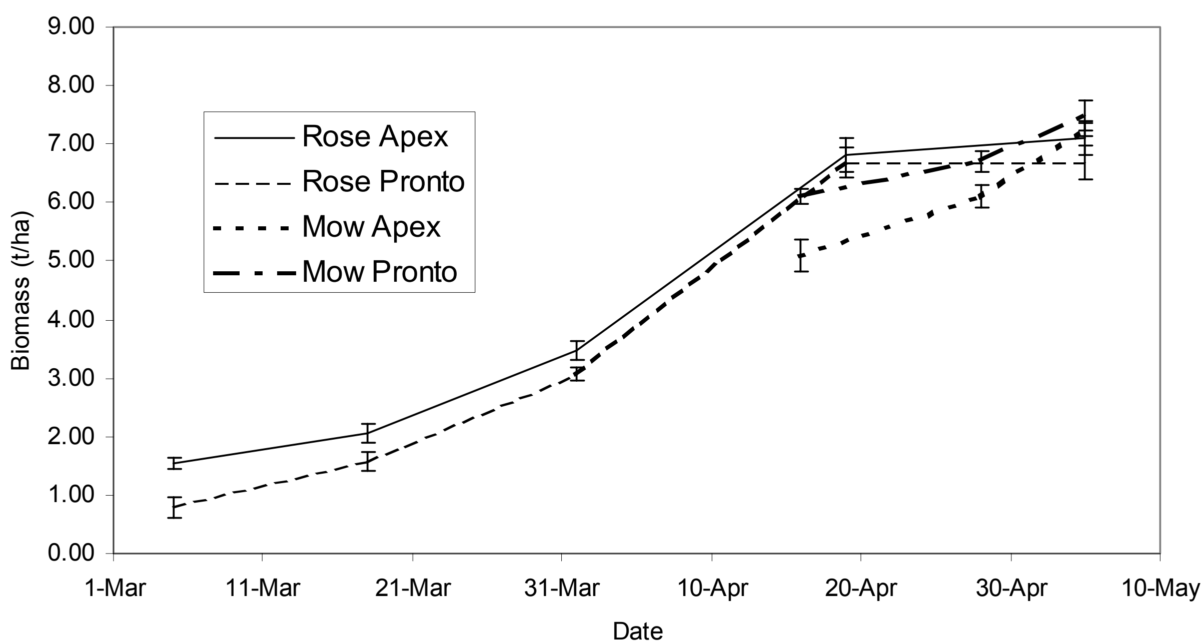


Figure 1.3. Development of biomass, control crops 1999 (error bars show SEMs)



Pronto at High Mowthorpe where GAI was around 4.25. Total crop biomass development (Figure 1.4) was similar to that of GAI at Rosemaund, with biomass of Pronto significantly smaller than that of Apex before April, but not significantly different afterwards (indicating greater biomass per plant of the hybrid). At Mowthorpe, however, biomass of Apex was initially smaller than that of Pronto, despite Apex's greater green area and plant population. However, at the final growth analysis sampling in May, the biomass of all crops was similar at around 7 t ha^{-1} dry matter. One of the initial hypotheses of this work was that more vigorous hybrid Pronto might lead to larger crops, which could therefore benefit more from PGR spraying. However, there was no evidence of significantly greater hybrid *crop* size in this experiment, which may be explained by the lower seed rates and populations. Individual hybrid plants were larger than those in the in-bred crops (Figure 1.5 and 1.6). Figure 1.5. shows green area per plant and Figure 1.6 shows biomass per plant. Individual plants of Pronto had greater green areas than Apex at both sites, although the difference was most marked at Rosemaund. Individual plants of Pronto had much greater green areas at Rosemaund than at Mowthorpe, whereas green areas of Apex at both sites were similar. However, these effects cannot be deconvoluted from the effects of compensatory growth due to plant population and therefore cannot be attributed conclusively to hybrid vigour. Having said this, the difference in the plant sizes composing the hybrid and in-bred crops could theoretically affect the responsivity to PGR chemicals.

Figure 1.5. Development of green area per plant, control crops 1999 (error bars show SEMs)

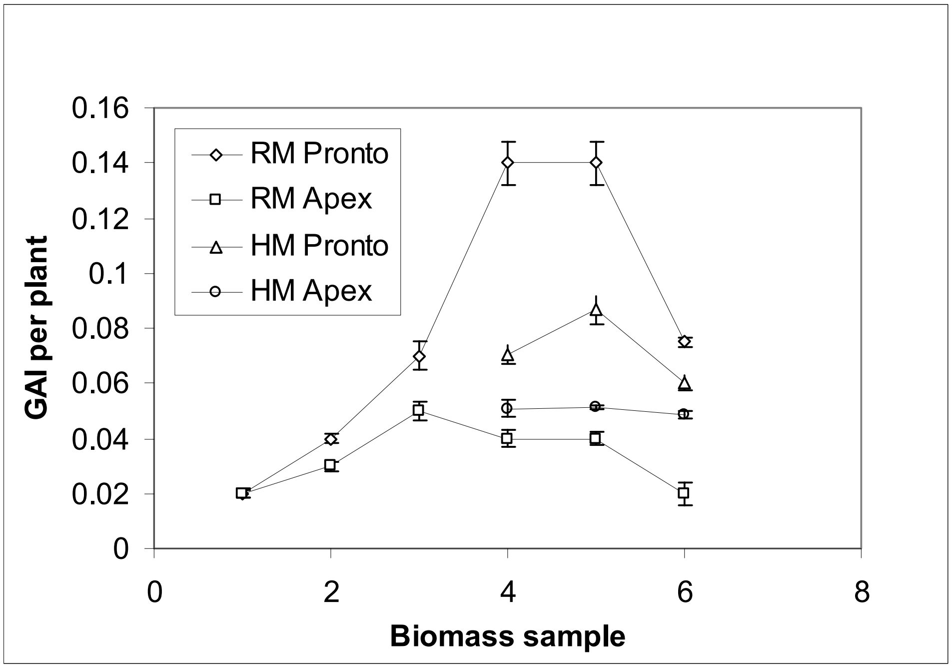
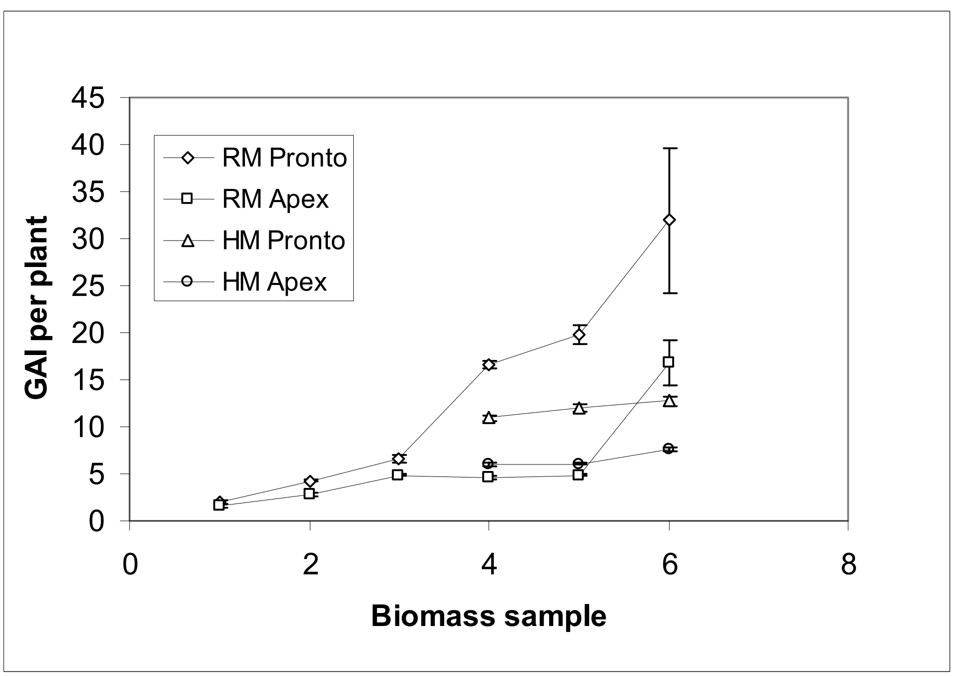


Figure 1.6. Development of dry matter per plant, control crops 1999 (error bars show SEMs)



3.1.2. Effects of PGRs on crop height

The greatest differences in crop height were seen in the weeks directly after PGR application (D. Turley and A. Wade, pers. comms.) when sprayed crop growth was immediately retarded. However, as re-growth commenced, the differences between controls and sprayed treatments diminished. As spray applications occurred at different times and frequent early height measurements of sprayed treatments were not taken, direct comparisons of the effects of all treatments on crop height could only be made with final biomass sample (May) and the pre-harvest height measurements (June). Due to re-growth after spraying, effects on height were generally small and only the pre-harvest data is presented. Overall, the effect of PGRs on the height of Apex was significant (P<0.001) at Mowthorpe and Rosemaund, for Pronto significant (P<0.001) at Rosemaund and non-significant (P=0.44) at Mowthorpe. At the pre-harvest assessment, the maximum height reduction was 19.4 cm, gained from half rate application of Folicur and chlormequat to Apex in mid March at Rosemaund. In many cases, height reductions were not significant. The pre-harvest crop heights are summarised in Table 1.4. The effect of PGRs on crop height was variable, with only 43% of applications resulting in significantly reduced crop height. Application of full rate chlormequat resulted in no significant height reduction, and of half-rate chlormequat a height reduction in only two cases (both Apex at Mowthorpe). The greatest height reductions appeared to come most consistently from early application (Mid March at Rosemaund and Mid April at Mowthorpe), at about the time of stem extension/green bud (GS 2-3), with most consistent decreases occurring with the half-rate application of either tebuconazole or metconazole mixed with chlormequat. The half rate triazole application alone was less consistent, but a programme of two applications of triazole was effective at height reduction. However, for Pronto grown at High Mowthorpe, none of the spray programmes caused a significant decrease in crop height.

Table 1.4: Effects of PGR application on pre-harvest crop height (cm) – Rosemaund.

Spray Timing	**Product**	**Cultivar**	
		Apex	**Pronto**
Untreated		164.9	178.3
Early March	Folicur	162.0	172.5
Early March	Caramba	157.0	173.5
Mid March	Folicur	153.0	173.5
Mid March	Caramba	153.5	169.0
Early April	Folicur	164.5	167.5
Early April	Caramba	157.5	175.0
Mid April	Folicur	164.3	176.8
Mid April	Caramba	161.5	175.8
Early May	Folicur	162.5	165.5
Early May	Caramba	166.5	176.5
Mid March/Mid April	Folicur	158.5	171.5
Mid March/Mid April	Caramba	150.0	167.0
Mid March – Half rate	Folicur	158.5	178.0
Mid March – Half rate	Caramba	158.0	168.0
Mid March – Half rate - Half rate Chlormequat	Folicur	145.5	169.0
Mid March - Half rate – Half rate Chlormequat	Caramba	149.5	172.5
Mid March – Half rate Chlormequat		163.0	179.0
Mid March – Full rate Chlormequat		169.5	180.5
SED (df)		4.09	2.80
LSD (df)		8.36	5.70

Table 1.5: Effects of PGR application on pre-harvest crop height (cm) – High Mowthorpe.

Spray Timing	**Product**	**Cultivar**	
		Apex	**Pronto**
Untreated		154.0	152.1
Mid April	Folicur	146.3	153.8
Mid April	Caramba	146.6	152.7
Late April	Folicur	152.2	152.2
Late April	Caramba	149.4	150.0
Mid May	Folicur	151.6	152.0
Mid May	Caramba	149.2	150.7
Mid April/Late April	Folicur	150.1	150.1
Mid April/Late April	Caramba	147.5	153.3
Mid April/Mid May	Folicur	146.2	157.3
Mid April/Mid May	Caramba	153.0	153.5
Late April/Mid May	Folicur	148.3	156.2
Late April/Mid May	Caramba	152.3	150.3
Mid April – Half rate	Folicur	157.8	152.6
Mid April – Half rate	Caramba	151.3	151.8
Mid April – Half rate + Half rate Chlormequat	Folicur	142.8	154.1
Mid April – Half rate + Half rate Chlormequat	Caramba	140.0	152.2
Mid April – Half rate Chlormequat		147.1	151.3
Mid April – Full rate Chlormequat		149.5	153.8
SED (df)		2.68	2.65
LSD (5%)		5.49	5.42

3.1.3. Effects of PGRs on lodging

At ADAS Rosemaund, applications of Folicur to Apex resulted in significant ($P<0.001$) reductions in lodging except for the early May spraying (Table 1.5a). Full rate chlormequat in mid March significantly reduced lodging, but not as much as the fungicide sprays did. Half rate chlormequat application did not significantly reduce lodging of Apex. Applications of Caramba showed exactly the same pattern. Applications of Folicur to Pronto also significantly (*P*<0.001) reduced lodging. Again many applications significantly reduced lodging, except the mid April and early May sprays. The mid March full rate, half rate and half-rate plus chlormequat applications were nearly statistically significant. However, for Pronto sprayed with Caramba, only the early March full rate, and mid March half rate applications significantly reduced lodging.

At High Mowthorpe, there was a significant effect of spraying on lodging in both Apex (*P*<0.001) and Pronto (*P*=0.004) (Table 1.5b). For Apex, all the Folicur timings significantly reduced percentage lodging except the half rate application in mid April. However, the half rate application with half rate chlormequat, and full rate chlormequat applied in mid April did significantly reduce lodging. An application of half-rate chlormequat did not reduce lodging significantly, although it was numerically lower than the control in this treatment. For Pronto sprayed with Folicur, only the half rate application mixed with half rate chlormequat in mid April significantly reduced lodging. The situation with Caramba (metconazole) sprays at High Mowthorpe was similar. On Apex, all but the mid May application significantly reduced lodging. However, for Pronto, only the mid April full and half rate applications significantly reduced percentage lodging

Thus spraying with Folicur and Caramba both reduced the percentage lodging at ADAS Rosemaund, as did some of the other combinations of chemicals. The greatest reductions came from spraying in March to Mid April at around the time of stem extension (GS 2), with fewer effects on lodging reduction found with later sprays. The effects of the two chemicals appeared to be similar.

Table 1.5a Effects of PGR application on percentage lodging – Rosemaund.

Spray Timing	**Product**	**Cultivar**	
		Apex	**Pronto**
Untreated		64.0	18.5
Early March	Folicur	34.5	5.50
Early March	Caramba	29.5	2.0
Mid March	Folicur	9.0	7.5
Mid March	Caramba	9.5	7.7
Early April	Folicur	8.0	0.2
Early April	Caramba	6.0	1.0
Mid April	Folicur	13.7	16.8
Mid April	Caramba	30.6	12.0
Early May	Folicur	46.2	23.0
Early May	Caramba	70.5	29.0
Mid March/Mid April	Folicur	3.7	1.2
Mid March/Mid April	Caramba	3.0	0.2
Mid March – half rate	Folicur	20.5	2.0
Mid March – half rate	Caramba	18.8	7.5
Mid March – half rate + half rate Chlormequat	Folicur	8.7	5.2
Mid March – half rate + half rate Chlormequat	Caramba	10.2	8.5
Mid March - half rate Chlormequat		62.5	8.8
Mid March – full rate Chlormequat		36.2	21.5
SED (df)		6.60	5.90
LSD (5%)		13.10	11.80

Table 1.5b Effects of PGR application on percentage lodging – High Mowthorpe

Spray Timing	**Product**	**Cultivar**	
		Apex	**Pronto**
Untreated		38.7	31.0
Mid April	Folicur	5.0	36.2
Mid April	Caramba	2.5	14.0
Late April	Folicur	11.3	29.9
Late April	Caramba	10.0	46.2
Mid March	Folicur	12.5	41.2
Mid March	Caramba	26.3	56.2
Mid April / Late April	Folicur	3.7	30.0
Mid April / Late April	Caramba	0.0	26.2
Mid April / Mid May	Folicur	8.7	43.7
Mid April / Mid May	Caramba	0.0	27.5
Late April / Mid May	Folicur	15.0	48.7
Late April / Mid May	Caramba	3.7	43.7
Mid April – half rate	Folicur	20.0	22.5
Mid April – half rate	Caramba	11.2	22.5
Mid April – half rate + half rate Chlormequat	Folicur	0.0	13.7
Mid April – half rate + half rate Chlormequat	Caramba	0.0	16.2
Mid April - half rate Chlormequat		28.8	25.0
Mid April – full rate Chlormequat		7.5	17.5
SED (df)		10.49	7.80
LSD (5%)		20.89	15.54

3.2. Effects of PGR application on combine harvest yield

The effects of the PGR fungicide sprays on combine-harvested yield are shown in Table 1.6. The effects of PGRs on yield were significant (*P*<0.05) for both varieties at both sites. Sprays resulted in significant changes (including one significant yield decrease) in yield in 37% of the 76 possible treatment combinations. The maximum yield benefit was 0.59 t ha^{-1} at Rosemaund and 0.54 t ha^{-1} at High Mowthorpe. Folicur caused a significant yield increase in 47% of combinations and a decrease in 3%.

Caramba caused a significant yield increase in 34% of its possible combinations and chlormequat in only 12.5%. The yield increases were not directly related to effects on crop height or percentage lodging.

Nix (2002) gives a cost of between £10-£20 ha^{-1} for tebuconazole application, according to different application rate. Assuming the higher value for a full rate application, and a current price for oilseed rape of £130 t^{-1}, at least an extra 0.153 t ha^{-1} of extra yield would be required from the tebuconazole spray to break even. This emphasises the importance of identifying crops that will benefit from PGR spray applications.

Table 1.6: Effects of PGR treatments on yield - Rosemaund.

Spray Timing	**Product**	**Cultivar**	
		Apex	**Pronto**
Untreated		3.66	3.72
Early March	Folicur	3.68	3.62
Early March	Caramba	3.34	3.42
Mid March	Folicur	3.66	3.55
Mid March	Caramba	3.72	3.73
Early April	Folicur	4.25	4.20
Early April	Caramba	3.91	3.72
Mid April	Folicur	4.18	4.03
Mid April	Caramba	3.94	4.13
Early May	Folicur	4.11	4.19
Early May	Caramba	3.72	4.12
Mid March/Mid April	Folicur	4.16	4.28
Mid March/Mid April	Caramba	3.91	4.18
Mid March – half rate	Folicur	3.61	3.78
Mid March – half rate	Caramba	3.62	3.93
Mid March – half rate + half rate Chlormequat	Folicur	3.72	4.05
Mid March – half rate + half rate Chlormequat	Caramba	3.35	3.71
Mid March - half rate Chlormequat		3.55	4.07
Mid March – full rate Chlormequat		3.86	3.64
SED (df)		0.162	0.173
LSD (5%)		0.324	0.346

Table 1.7: Effects of PGR treatments on yield – High Mowthorpe.

Spray Timing	**Product**	**Cultivar**	
		Apex	**Pronto**
Untreated		3.69	3.86
Mid April	Folicur	3.97	3.95
Mid April	Caramba	3.89	3.75
Late April	Folicur	4.14	4.00
Late April	Caramba	4.13	3.95
Mid May	Folicur	3.81	3.52
Mid May	Caramba	3.82	3.63
Mid April/Late April	Folicur	4.08	4.11
Mid April/Late April	Caramba	4.17	4.37
Mid April/Mid May	Folicur	3.93	3.91
Mid April/Mid May	Caramba	4.14	4.02
Late April/Mid May	Folicur	3.85	3.87
Late April/Mid May	Caramba	4.23	3.85
Mid April – Half rate	Folicur	4.05	4.04
Mid April – Half rate	Caramba	4.10	4.03
Mid April – Half rate - Half rate Chlormequat	Folicur	4.07	4.25
Mid April – Half rate – Half rate Chlormequat	Caramba	3.98	3.79
Mid April– Half rate Chlormequat		3.59	3.77
Mid April – Full rate Chlormequat		3.94	3.86
SED (df)		0.101	0.162
LSD (5%)		0.202	0.324

3.3. Effects of PGR on yield components (pre-harvest growth analysis)

Pre-harvest growth analyses and analyses of yield components were completed to allow the mechanism of yield improvement due to PGR activity to be assessed. Due to the highly labour intensive nature of the growth analyses, a sub-set of treatments was chosen for pre-harvest analysis (Table 1.2) based on the greatest height differences observed post-spraying, which were considered likely to have the greatest effect on yield. Treatments 1, 5, 6, 9, 10, 15, 16 and 17 were analysed at ADAS Rosemaund and treatments 1, 7, 8, 11,1 2, 13, 14, 15, 16, 17 were analysed at High Mowthorpe (analysed treatments are identified on Table 1.6 by light blue shading).

A number of hypotheses may be forwarded to explain the yield differences resulting from PGR application. One hypothesis is that there is an optimum canopy size for light interception in oilseed rape and that retardation of canopy growth with plant growth regulators could lead to sprayed crops achieving the optimum canopy size, with excess growth of unsprayed crops causing yield limitation (Lunn *et al.*, 2001). Another hypothesis is that the shortening of the crop can lead to a more open pod canopy, which allows more efficient light interception by the first-formed basal pods. This may lead to retention of more seeds per pod and more seeds per square metre, hence greater yield. The result of more seeds per square metre could also be achieved by formation of more pods per square metre, although greater pod densities tend to reduce the number of seeds retained per pod. Another mechanism of yield improvement could be greater combine recovery of seed (Child). A large amount of seed is lost by premature pod shatter, and PGRs could alter the propensity for seed shedding by delaying maturity/altering pod structure *etc.* These hypotheses were assessed by growth analyses and analysis of light interception measurements made by ceptometry. However, light interception measurements were not made at ADAS High Mowthorpe in 1999. The data from ADAS Rosemaund showed no significant difference (P>0.5) in fractional light interception by the pod layer or whole crop, reflection of incident light, or in the fraction of light absorbed by the canopy for either cultivar studied (data not shown).

Unfortunately, at ADAS Rosemaund the treatments selected for growth analysis did not correlate well with the greatest yield differences. Only treatment 9 (Folicur mid April, on Apex) and 10 (Metconazole mid April, on Pronto) resulted in any significant yield differences from control plots. Analysis of variance (data not shown) did not reveal any significant differences between pod or seed numbers per square metre, seed numbers per pod, harvest index or estimates of shed seed (P>0.5), since there was a large degree of variation between replicates and thus standard errors were large.

The situation at ADAS High Mowthorpe for the cultivar Pronto was similar. There were few significant yield effects and these treatments did not correlate with those chosen for growth analysis, which showed no significant differences or patterns between yield components to explain the PGR effect. However, for Apex at High Mowthorpe, there was better correlation between the treatments chosen for growth analysis and yield differences caused by spraying. This data is therefore presented.

Peak green area index (achieved around full flowering in late April/early May), to assess the effect of PGR application on attainment of crop size, could not be assessed as only unsprayed treatments were analysed in early growth analyses, although untreated controls reached GAIs of about 4-5 (see previous section). Sprayed treatments were analysed post-flowering when leaves had started to senesce and canopy sizes were thus smaller than the peak values. However, green areas of the stem and pod layers and the whole crop were assessed at this timing. Figure 1.X shows the green area index at the pre-harvest sample: there was no significant difference in total GAI (P=0.223), which ranged from 2.60 – 3.22, nor in the GAIs of the pod or stem layer analysed separately (P=0.107 and P=0.426)

Analysis of yield component data pre-harvest was also not significant. There was no significant effect (P=0.554) of PGR spraying on numbers of pods per square metre. One treatment (sprayed with Folicur in mid April and mid May) had numerically greater numbers of pods per square metre, but there was no discernible pattern in pod numbers in the plots that yielded significantly more than the controls. There was no significant difference (P=0.324) in the number of aborted pods between post-flowering and pre-harvest analyses, when about 6,500 pods per square metre (30%) were lost on average. There was also no significant difference or discernible pattern (data not shown) for seed numbers per square metre (P=0.703, control value 83,370), or seeds per pod (P=0.562, control value 11.08). There was no significant difference (P=0.348, control value 36.4%) in harvest index or the weight of shed seed (P=0.838, control value 0.65 t ha^{-1}), calculated from the difference between the weights of hand-harvested seed in the pre-harvest sample and combine harvested seed. The percentage of the seed in pre-harvest grab samples recovered by the combine harvester also did not vary significantly (P=0.809, control value 84%).

4. Conclusion

These experiments verify the expected effects of PGR application on crop growth, with small reductions in crop height at harvest in some cases and reduction in percentage lodging. Increases in yield were also found, with greater benefits appearing to come with later sprays (green to yellow bud growth stage) than those associated with reduction in height and lodging (stem extension in early March). Indeed, there was no relationship between lodging, crop height and yield. However, effects on height and lodging and yield increases were observed in fewer than 50% of applications. No supporting evidence could be found to decide between any of the alternative hypotheses for the mechanism of yield improvement by PGR activity. The currently approved PGR chlormequat appeared to have little benefit, and since approval was withdrawn in 2000, this was not studied further. Due to the indication of the benefit of later timings for yield (later than the optimum timing in February/March for spring disease control), in the subsequent work studying the effects of PGR application to different crop sizes, both early (March) and late (April) timings were studied.

- The earlier applications (stem extension in early March) gave the better control of lodging.
- PGA application increased yield with the largest resulting from later applications (green to yellow bud growth stage).

5. References

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APPENDIX II: Effect of canopy size on yield response to remediation

1. Introduction

As summarised in Appendix I, application to oilseed rape of a range of chemicals with reputed growth-regulatory activity has lead to very inconsistent results, especially on yield. Although height and lodging have often been restricted by PGR application (as shown in Appendix I), effects on yield have been very variable. In 1999, the yield benefits were not correlated with reductions in height or lodging. Also, although yield increases due to PGR activity are possible, no change or yield decreases were also observed in 1999.

Consideration of 'canopy management' principles (Lunn *et al.*, 2001) has lead to the hypothesis that effects of PGRs on yield may be associated with the size of the crops pod canopy that would have been achieved, had the crop not been sprayed. Spraying a crop which would otherwise produce a moderate or small canopy, could lead to 'over-remediation' and failure to reach the optimum canopy size for yield formation, resulting in yield loss. Spraying a crop which otherwise would produce an excessively large canopy, could remediate its growth sufficiently so that it reaches the optimum size for yield formation, resulting in a yield benefit. it was further hypothesised that canopy size of the crop in March or April at the time of spraying would be a good indicator of eventual canopy size. This hypothesis was tested in the next phase of this work in 1999/2000 and 2000/2001 field trials. Accurate identification of crops likely to be responsive to PGRs according to their canopy size would be useful to producers in order to target application of PGRs only to responsive crops.

2. Materials and Methods

At both sites and in both years, weeds and insect pests were controlled using standard farm inputs of agrochemicals. Slugs were controlled using slug pellets at drilling and as necessary afterwards to ensure good establishment. all crops were kept free of disease through the use of non-pgr fungicides (primarily Punch C and Plover) according to need.

2.1. Husbandry – 1999/2000

Trial areas of Apex and Pronto were drilled at ADAS Rosemaund on a silty clay loam soil (Bromyard series) at seed rates of 120 seeds m^{-2} (high) and 60 seeds m^{-2} (low). The early sowing dates for Pronto and Apex were 2/9/99 and 3/9/99 respectively and the late sowing date was 6/10/99. The 'early' sowing date was actually close to the optimum for oilseed rape, with much commercial practice now leading to sowing in August. At High Mowthorpe, the same seed rates were drilled into a shallow silt clay loam overlying chalk (Wold series) on 17/8/00 and 12/9/00.

Fertiliser was applied at ADAS Rosemaund as 117 kg ha^{-1} N on 7/3/00, 70 kg ha^{-1} N on 28/3/00 and 26 kg ha^{-1} S on 7/3/00. At High Mowthorpe, N fertiliser was split into applications of 30, 120 and 65 kg ha^{-1} and 70 kg ha^{-1} S was applied.

Early sowing date trials at ADAS Rosemaund were harvested on 5/8/00 and the late sowing date on 21-22/8/00. At High Mowthorpe, crops were swathed on 1/8/00 and harvested on 17/8/00.

2.1.1. Treatments – 1999/2000

At ADAS Rosemaund, crops were mown to remove approximately 70% and 35% of foliage on 28/1/00. Full rate sprays (1.0 l ha^{-1} Folicur and 1.2 l ha^{-1} Caramba) were applied on 15/3/00 ('mid March') and 10/4/00 ('mid April'), with growth analyses taken subsequently. At High Mowthorpe, a non-flailing mower was used to remove excess crop material on 13/3/00 (mowing treatment was delayed from January/February due to limited over winter growth). At High Mowthorpe, sprays were applied on 17 March ('mid March') and 19 April ('mid April').

2.2. Husbandry 2000/2001

Trial areas of Apex and Pronto were drilled at ADAS Rosemaund on a silty clay loam soil (Bromyard series) at seed rates of 120 seeds m^{-2} (high) and 60 seeds m^{-2} (low).

The early and late sowing dates for Pronto and Apex were 6/9/00 and 30/9/00 respectively

Fertiliser was applied at ADAS Rosemaund as 41.4 kg ha^{-1} N on 22/9/00, 62.3 kg ha^{-1} N on 27/2/01 and 105.7 kg ha^{-1} on 2/4/01. 69.2 kg ha^{-1} S was added on 27/2/01. At High Mowthorpe, N fertiliser was split into applications of 65 and 145 kg ha^{-1} and 87 kg ha^{-1} S, 48 kg ha^{-1} P and 43 kg ha^{-1} K were also applied.

Rosemaund trials were harvested on15-16/8/01. At High Mowthorpe, early and late-sown crops were harvested on 7 and 16/8/2000 respectively

2.2.1. Treatments - 2000/2001

In 2000/2001, weather condtions in January and February prevented mowing, so these treatments were replaced by half rate spray applications (0.5 l ha^{-1} Folicur and 0.6 l ha^{-1} Caramba) at the March spray date. Full rate sprays (1.0 l ha^{-1} Folicur and 1.2 l ha^{-1} Caramba) were applied on 19/3/00 ('mid March') and 11/4/00 ('mid April') at ADAS Rosemaund, with growth analyses taken subsequently. At High Mowthorpe, full and half rate metconazole sprays were applied on 30 March ('mid March'), then wind delayed further spray application of tebuconazole until 12 April. The late sprays were applied on 25 April ('mid April').

2.3. Growth Analysis

Growth analyses and light measurements were completed as described in the Materials and Methods section of Appendix I. The controls of all crop types were analysed; only the treatments of the largest crop type (early-sown, high seed-rate) were analysed.

2.4. Statistical analysis

All statistical analyses were carried out with Genstat 5 software for Microsoft Windows. Before the post-flowering and pre-harvest analyses, Analysis of Variance (ANOVA) of the control plots was possible in a balanced design. For post-flowering and pre-harvest growth analysis, all control plots and the treated plots from the early-sown, high seed rate (E120) treatment were analysed. These had to be separated into separate data structures (controls and E120 samples only) for analysis in balanced design. Harvest measurements of yield, thousand seed weight etc. were done on all samples and were included in a balanced ANOVA. Due to the high numbers of zero lodging values skewing the analysis, a value of 0.5 was added to the zero values and all values were natural log transformed before ANOVA, to ensure normality of the data.

3. Results

3.1. 2000

3.1.1. Control crop development

3.1.1.1. ADAS Rosemaund

Establishment was most successful in the early-sown low seed rate crops, at about 80% of seeds sown. Establishment was less successful in the early-sown high seed rate and the late-sown crops, where it was around 42-55%. Seed rate had little effect on most crop parameters, with the major effects observed due to sowing date, with later development of late-sown crops. Crop height (Figure 2.1) showed a similar pattern between Apex and Pronto. Seed rate caused no significant difference, but early-sown crops initiated stem extension sooner: in April they were about four times taller than late-sown crops. However, by the post-flowering and pre-harvest assessments in May, there was no significant difference between crops, except those of Pronto were slightly shorter. Again, as in 1999, no evidence was found for greater ‘hybrid vigour’ requiring more remediation; emergence of Pronto was poorer than Apex and GAI, biomass and height of Pronto were all very similar (numerically slightly smaller) than Apex. There was little significant difference in green area index (GAI) due to seed rate (Figure 2.2). For the early-sown Apex crops, the high seed rate crops had slightly greater green area in early development, but by April GAI was not significantly different, at around GAI 4. For the late-sown Apex crops, seed rate had no significant effect throughout development. Expansion of green area occurred later than in the early-sown crops and by May, the late-sown crops reached GAIs of only about 2. For early-sown Pronto, GAIs early in the season were similar, but in April the GAI of the high seed rate crop was much larger than that of the low seed rate crop. However, by May the GAIs were again similar, but smaller than those of Apex at about GAI 3. The late-sown Pronto crops showed a similar pattern to late sown Apex: there was no significant effect of seed rate on GAI and post-flowering GAI was about 2. Crop biomass increased steadily throughout the season (Figure 2.3). For Apex, seed rate did not significantly affect biomass accumulation. For the early sown crops, considerable biomass (~ 2 t ha^{-1}) had accumulated by February, and by May crop biomass was about 10 t ha^{-1}. In the late-sown crops, biomass accumulation was much later, with less than 0.5 t ha^{-1} in March. However, post March the rate of increase in biomass was greater in late-sown than early-sown crops, so a similar (although numerically slightly lower) level of biomass was accumulated by late compared to early sown crops. The Pronto crops showed a similar pattern, although the high seed rate early sown crop had greater biomass earlier in the season. However, by the end of the season there was no significant difference in biomass accumulated (8-9 t ha^{-1}), which was slightly lower than that of Apex.

Figure 2.1: Control crop heights, Rosemaund 2000.

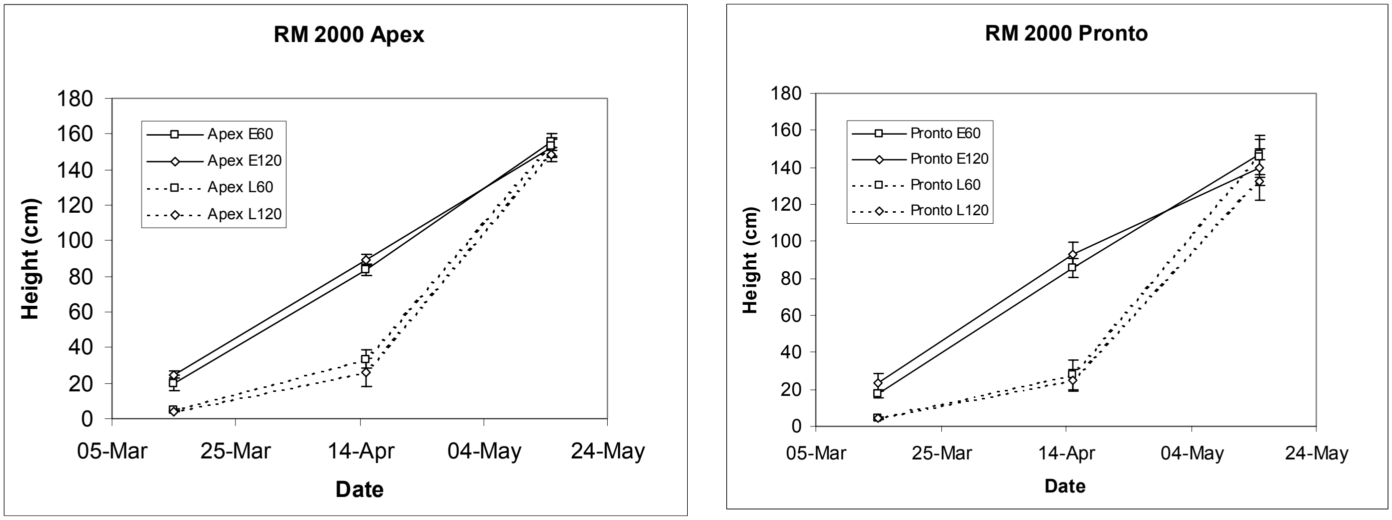


Figure 2.2: Control crop green area index, Rosemaund 2000

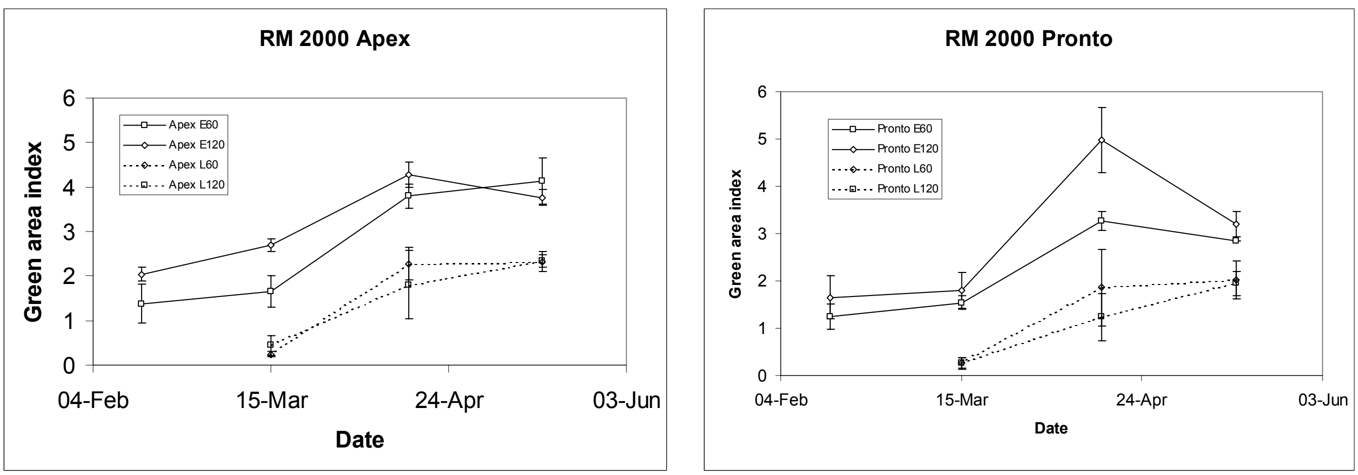
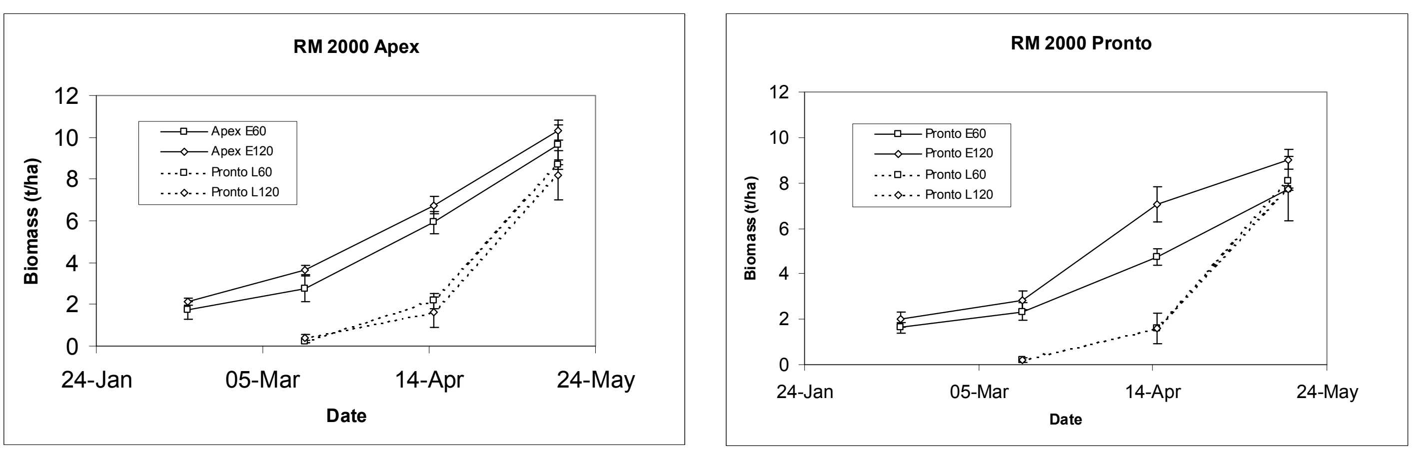


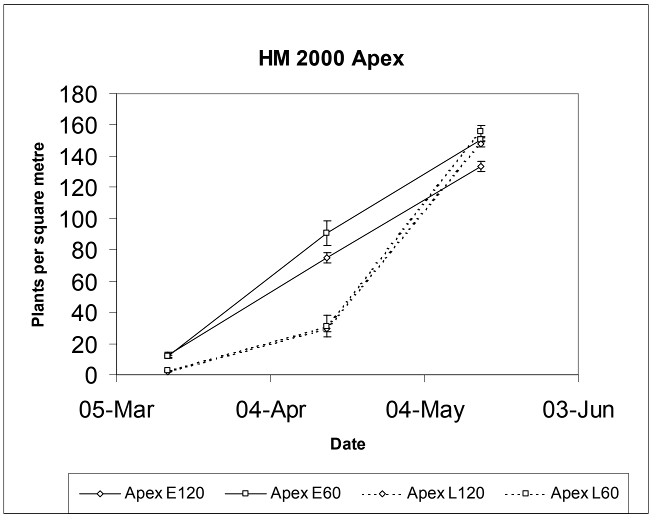
Figure 2.3: Control crop biomass, Rosemaund 2000.



3.1.1.2. High Mowthorpe

Patterns of growth and development at High Mowthorpe were similar to those at ADAS Rosemaund (Figures 2.4 – 2.6). Height showed exactly the same pattern, with no effect of seed rate but with late-sown crops significantly shorter in April. By May, however, late-sown crops had reached similar heights to the early-sown crops, reaching heights of 150-160 cm, values very similar to those recorded at Rosemaund. Green area index showed a similar pattern with Apex, with later-sown crops having significantly smaller GAIs than early-sown crops in April. However, for Pronto, the early-sown high seed rate crop had the largest GAI, but the other three crops had very similar GAIs and did not differ significantly. By the May sample, all crops at Mowthorpe had similar GAIs (~ 3), in contrast to Rosemaund, where GAIs of early-sown and late-sown crops were significantly different (~ 4 and ~ 2 respectively). The pattern of biomass accumulation at High Mowthorpe was similar to that at Rosemaund, with delayed accumulation in the late-sown crops followed by more rapid accumulation compared to early-sown crops from April to May. By May, biomass did not differ significantly between crops and for most was similar to the 9-10 t ha-1 accumulated at ADAS Rosemaund. However, early-sown crops of Pronto did surprisingly show numerically lower biomass than the late-sown Pronto crops.

Figure 2.4: Control crop height, High Mowthorpe 2000.



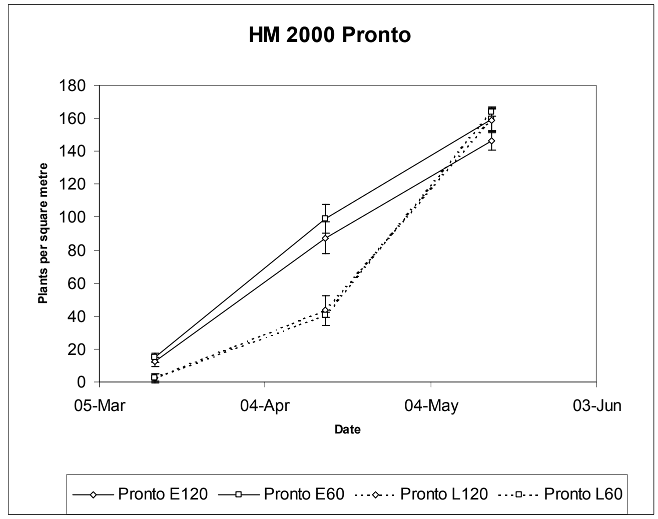
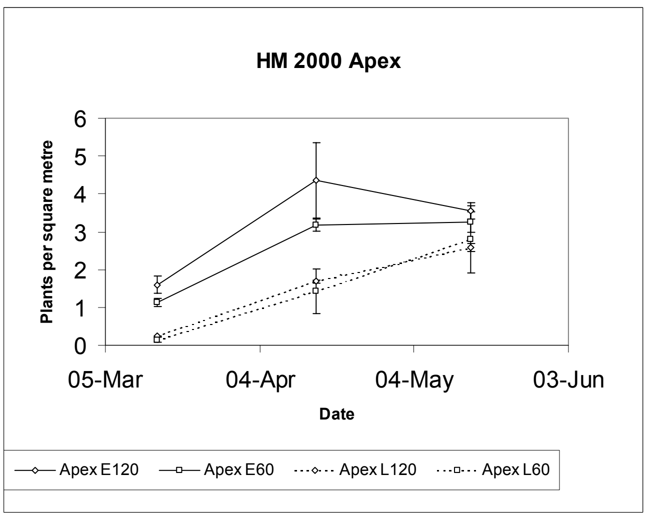


Figure 2.5: Control crop green area index, High Mowthorpe 2000



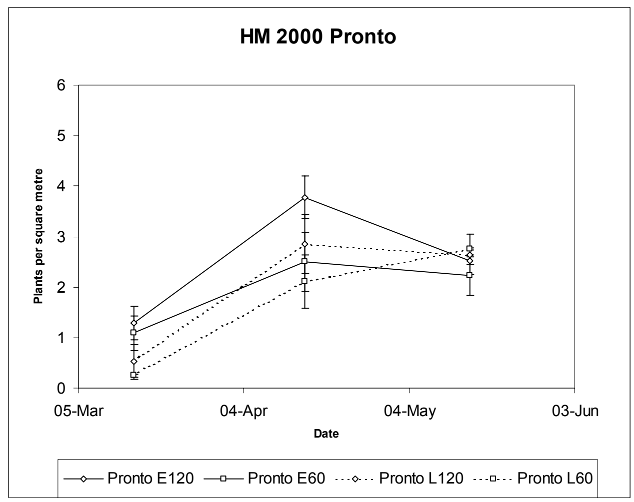
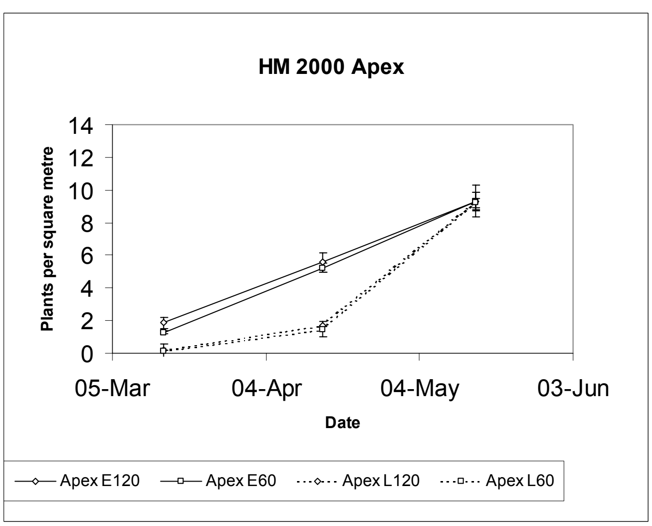
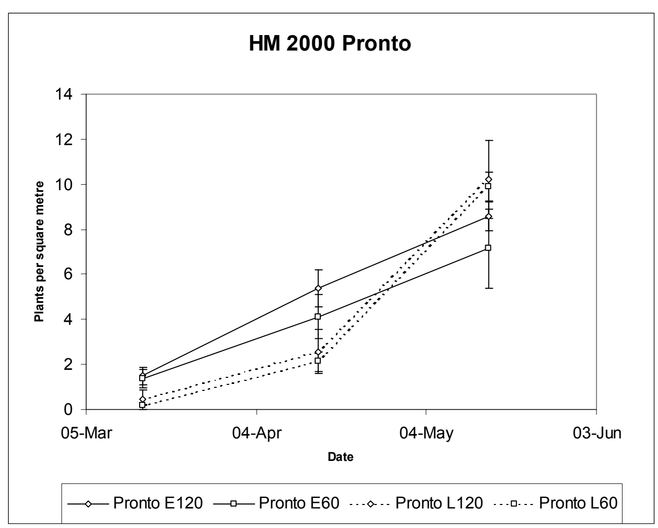


Figure 2.6: Control crop biomass, High Mowthorpe 2000.





3.1.2. Height and lodging

Assessments of crop height and lodging were taken at harvest on all plots.

At ADAS Rosemaund, there was a nearly significant (P=0.055) effect of variety, with generally taller crops of Pronto than Apex. These measurements averaged across all treatments contrast with the earlier measurements on controls only which indicated that Apex was slightly taller than pronto, perhaps indicating that the PGR treatements shortened Apex slightly more than Pronto. However, there was no significant effect of treatment (P=0.322) and no variety x treatment interaction (P=0.468), due in part to variation between replicate plots. Numerically, all the treated Apex crops were shorter than the control, but for Pronto, all treatments were taller than the controls.

At ADAS High Mowthorpe, there was no significant variety effect (P=0.09), but there were significant differences (P<0.001) in pre-harvest height between treatments, but with no variety x treatment effect (P=0.572). However, for Apex all the significant differences caused by PGR sprays (Table 2.1), were due to increases in crop height. For Pronto, the two crops sprayed in April were significantly taller than the unsprayed control, and only the 70% mowing treatment was significantly shorter.

Table 2.1: Pre-harvest height, treated early-sown high seed rate crops, 2000.

Treatment	**Rosemaund**		**High Mowthorpe**	
	Apex	Pronto	Apex	Pronto
Untreated	152.1	139.6	100.9	98.5
March – Full rate Folicur	153.8	156.8	113.5	103.3
March – Full rate Caramba	130.6	154.1	113.5	104.2
April – Full rate Folicur	146.8	158.2	118.0	108.3
April – Full rate Caramba	144.1	160.6	124.9	124.8
Feb – Mown 70%	137.0	151.2	102.5	92.6
Feb – Mown 35%	133.8	140.3	97.0	104.0
SED (26 df)	11.81		2.80	
LSD (5%)	24.30		5.76	

Table 2.2 shows that there was very little lodging at ADAS Rosemaund in 2000 compared to 1999 (Appendix 1). The high numbers of zero values skewed the analysis and made the conventional analysis of percentage values by angular transformation invalid. To achieve normality, zero values were converted to 0.5 and ANOVA was performed after natural log transformation. This produced approximately normally distributed residuals.

This showed a significant difference between varieties, with more lodging in Pronto than Apex. As the ANOVA could not be completed on the whole sowing date x seed rate x variety x treatment hierarchy, the two varieties were analysed separately. However, there were no significant effects (*P*>0.05) of sowing date, seed rate or PGR/mowing treatment.

Table 2.2: Percentage lodging, ADAS Rosemaund 2000. Transformed data in brackets to which statistics apply.

Treatment	**Apex**				**Pronto**			
	Early		**Late**		**Early**		**Late**	
	120	**60**	**120**	**60**	**120**	**60**	**120**	**60**
Control	0.0 (-0.69)	5.0 (0.44)	7.3 (1.32)	3.7 (0.34)	31.7 (2.21)	0.0 (-0.69)	7.3 (0.57)	4.0 (0.92)
FR Folicur March	0.0 (-0.69)	0.0 (-0.69)	0.0 (-0.69)	1.0 (-0.10)	0.0 (-0.69)	0.0 (-0.69)	3.0 (0.77)	5.0 (1.07)
FR Caramba March	0.0 (-0.69)	0.0 (-0.69)	1.0 (-0.10)	1.7 (0.07)	0.3 (-0.46)	0.0 (-0.69)	6.7 (0.54)	5.7 (1.13)
FR Folicur April	0.0 (-0.69)	0.0 (-0.69)	2.3 (0.54)	2.3 (0.54)	20.0 (0.90)	0.0 (-0.69)	1.0 (-0.10)	6.0 (0.50)
FR Folicur April	0.0 (-0.69)	0.0 (-0.69)	0.0 (-0.69)	2.0 (0.14)	1.7 (0.07)	0.0 (-0.69)	4.0 (0.77)	7.7 (1.27)
30% Mowing February	0.3 (-0.46)	0.0 (-0.69)	1.7 (0.14)	2.0 (0.14)	0.0 (-0.69)	0.0 (-0.69)	10.0 (1.38)	1.3 (0.00)
70% Mowing February	0.0 (-0.69)	1.3 (0.00)	4.7 (0.37)	4.0 (0.37)	1.7 (0.07)	0.0 (-0.69)	7.7 (1.13)	9.0 (1.07)
SED (54 df)	0.091				1.14			
LSD (5%)	2.070				2.74			

Table 2.3 shows the lodging data for High Mowthorpe. Similarly to Rosemaund, there was little lodging at Mowthorpe in 2000 compared to 1999. Seed rate had a significant effect for Apex (*P*<0.001) and Pronto (*P*=0.019) as lodging was only observed in a few early-sown high seed rate crops; sowing date was however, not significant (*P*>0.1). Treatment had a significant effect (*P*=0.012) on lodging (due to the low levels in the PGR-sprayed plots of early-sown high seed rate crops). However, the lodging in mown plots of the early-sown high seed rate crops was similar to the control, and lodging in other crops was negligible. For Pronto, the effect of PGR treatment or mowing was just non-significant (*P*=0.094).

Due to the low levels of lodging in 2000, no further firm evidence for the reduction in lodging caused by PGR application in 1999 can be given from 2000 results.

Table 2.3: Percentage lodging (ADAS High Mowthorpe) Transformed data in brackets to which the statistics apply.

Treatment	**Apex**				**Pronto**			
	Early		**Late**		**Early**		**Late**	
	120	**60**	**120**	**60**	**120**	**60**	**120**	**60**
Control	31.7 (1.78)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	6.67 (-0.54)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)
FR Folicur March	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)
FR Caramba March	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	1.67 (-1.00)	0.0 (-2.30)	0.0 (-2.30)
FR Folicur April	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)
FR Caramba April	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)
30% Mowing February	25.0 (1.39)	0.0 (-2.30)	1.7 (-1.00)	0.0 (-2.30)	33.33 (1.84)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)
70% Mowing February	33.3 (1.83)	0.0 (-2.30)	11.7 (-0.35)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)	0.0 (-2.30)
SED (54 df)	1.14				0.783			
LSD (5%)	2.307				1.570			

3.1.3.Yield

3.1.3.1. ADAS Rosemaund

Table 2.4 shows the yields at ADAS Rosemaund in 2000. There was no significant effect of sowing date (*P*=0.116), variety (*P*=0.43) or treatment (*P*=0.147), although seed rate was significant (*P*=0.002), with higher yields in the higher seed rate on average (3.37 compared to 3.18 t ha^{-1}, LSD (5%) = 0.121). Only the treatment with FR Caramba applied to the late-sown high seed rate Apex crop in March caused a yield difference greater than the 5% LSD (a decrease of 0.668 t ha^{-1}). For Apex, only 12.5% of the treatments caused numerical yield increases, whereas for Pronto, 58.3% of the treatments caused numerical yield increases. All mowing treatments of Apex caused numerical yield decreases; for Pronto, 50% caused numerical yield increase and 50% decrease.

Table 2.4: Yield at ADAS Rosemaund 2000

Treatment	**Apex**				**Pronto**			
	Early		**Late**		**Early**		**Late**	
	120	**60**	**120**	**60**	**120**	**60**	**120**	**60**
Control	4.01	4.09	3.04	2.76	3.58	3.63	3.05	2.64
March - Full rate Folicur	4.09	3.80	2.98	2.63	4.13	3.74	2.83	2.36
March – Full rate Caramba	3.78	3.87	2.37	2.68	3.99	3.93	2.79	2.49
April – Full rate Folicur	4.13	3.86	2.93	2.35	4.09	3.81	3.58	2.79
April – Full rate Caramba	3.70	3.94	3.19	2.36	3.96	4.06	2.60	2.37
February – 70% Mowing	3.52	3.79	2.61	2.61	3.65	3.34	3.22	2.88
February – 35% Mowing	3.46	3.24	2.71	2.65	3.55	3.37	2.94	3.12
SED (df)	Sow date x seed rate x variety x treatment (6.5) = 0.563, in the same level of sow x seed rate x variety (133 df) = 0.323.							
LSD (5%)	Sow date x seed rate x variety x treatment (6.5) = 1.356, in the same level of sow x seed rate x variety (133df) = 0.639							

3.1.3.2. High Mowthorpe

Yield results for High Mowthorpe are shown in Table 2.5. There was no significant effect of sowing date (*P*=0.212), but seed rate, variety and treatment were all significant (*P*<0.001). On average the high seed rates yielded more than the low (3.92 cf 3.65, 5% LSD 0.087) and Pronto yielded more than Apex (3.94 cf. 3.63, 5% LSD 0.087). Full rate Folicur in March, full rate Folicur and Caramba in April significantly increased yield, these effects were due mainly to large increases when applied to early sown high seed rate plots. On average the 70% mowing treatment significantly decreased yield.

However, overall there was a greater response to PGR treatment at Mowthorpe than Rosemaund, with 50% of treated Apex crops and 75% of treated Pronto crops resulting in numerical increases in yield. The yield changes were not associated with height and lodging reduction.

Table 2.5. Yield at ADAS High Mowthorpe, 2000

Treatment	**Apex**				**Pronto**			
	Early		**Late**		**Early**		**Late**	
	120	**60**	**120**	**60**	**120**	**60**	**120**	**60**
Control	3.61	3.49	3.71	3.51	4.12	3.85	3.77	3.62
March - Full rate Folicur	4.16	3.77	3.94	3.53	4.53	3.99	3.89	3.63
March – Full rate Caramba	3.60	3.62	3.75	3.45	4.68	4.15	3.88	3.58
April – Full rate Folicur	3.91	3.87	3.77	3.38	4.28	4.17	3.90	3.72
April – Full rate Folicur	3.95	3.92	3.78	3.46	4.57	4.30	4.10	3.74
February – 30% Mowing	3.50	3.37	3.36	3.29	4.09	3.47	3.81	3.40
February – 70% Mowing	3.54	3.46	3.70	3.21	4.04	3.85	3.76	3.52
SED (df)	Sow date x seed rate x variety x treatment (21 df) = 0.287, in the same level of sow x seed rate x variety (161 df) = 0.232							
LSD (5%)	Sow date x seed rate x variety x treatment (21 df) = 0.597, in the same level of sow x seed rate x variety (161 df) = 0.459							

3.1.4. Relationship between GAI and yield benefit

3.1.4.1. ADAS Rosemaund

The relationship between crop size (canopy green area index) at spraying and the yield benefit over unsprayed control plots is shown in Figures 2.7-2.10. For Apex sprayed with Folicur at Rosemaund, there were few yield increases (maximum 0.118 t ha^{-1}), although there were weak associations with canopy size at spraying and yield difference from control in both March and April, with smaller canopies experiencing greater yield loss and *vice versa* (Figure 2.7). Yield losses from spraying in March were less than in April, presumably because the March-sprayed canopies had longer to recover from ‘over-remediation’. For Apex sprayed with Caramba at Rosemaund, there was little yield benefit (maximum 0.154 t ha^{-1}) and no significant relationship between crop size at spraying and yield difference from control (Figure 2.8). At current prices, yield benefits of above 0.153 t ha^{-1}would be needed to outweigh the cost of the spray and application.

For Pronto at Rosemaund sprayed with Folicur, there was a strong, positive, linear association between canopy size at spraying in March and yield difference from control. Canopies with GAIs < 0.5 (also at earlier growth stages than larger crops) suffered yield penalties up to about 0.3 t ha^{-1}. Canopies with GAIs of 1.5-2 at spraying in March gave a yield benefit of 0.1-0.5 t ha^{-1} (Figure 2.7). There was no such linear correlation with spraying of Pronto in April, when all canopies were > GAI 1, and all sprayed crops gave yield benefits of 0.1 – 0.5 t ha^{-1}. For Pronto at Rosemaund sprayed with Caramba (Figure 2.8), there were strong, positive, linear correlations between canopy size at spraying and yield difference from control for both March and April spraying. In March, canopies with GAI < 0.5 gave yield deficits of 0.2 t ha^{-1}, and canopies > GAI 1.5 gave a benefit of around 0.4 t ha^{-1}. In April, similar yield benefits and deficits were gained from canopies of GAI < 2 and > 3 respectively.

Figure 2.7: Effect of Folicur at ADAS Rosemaund, 2000.

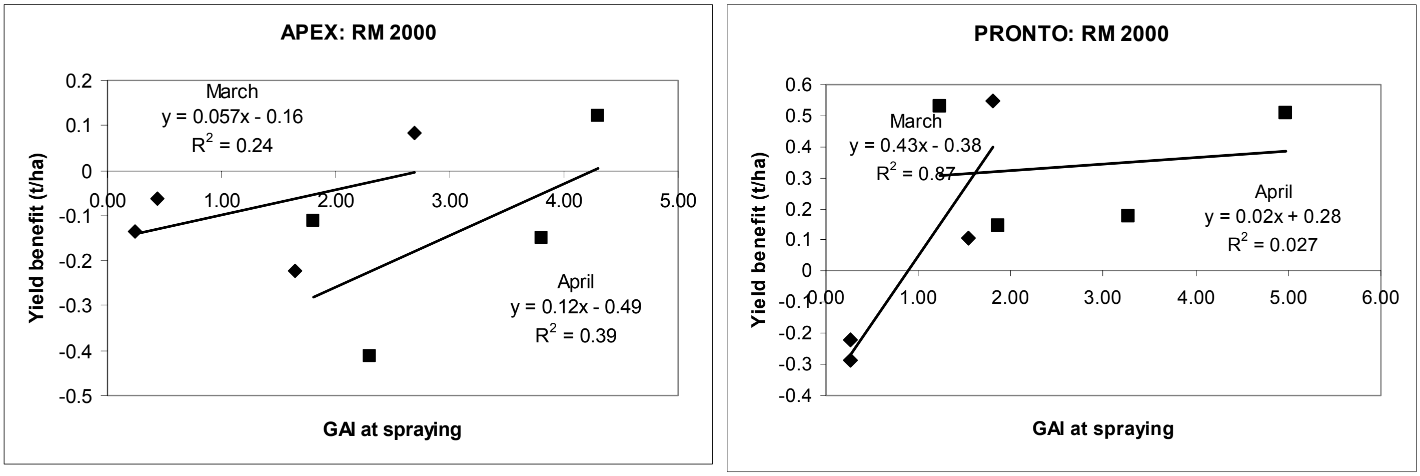


Figure 2.8: Effect of Caramba at ADAS Rosemaund 2000.

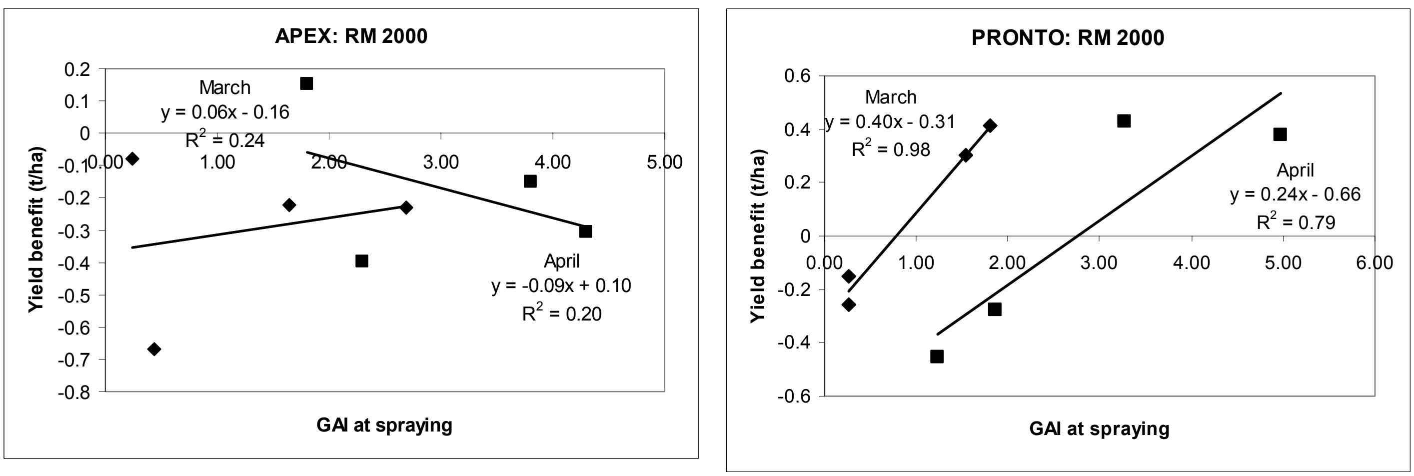
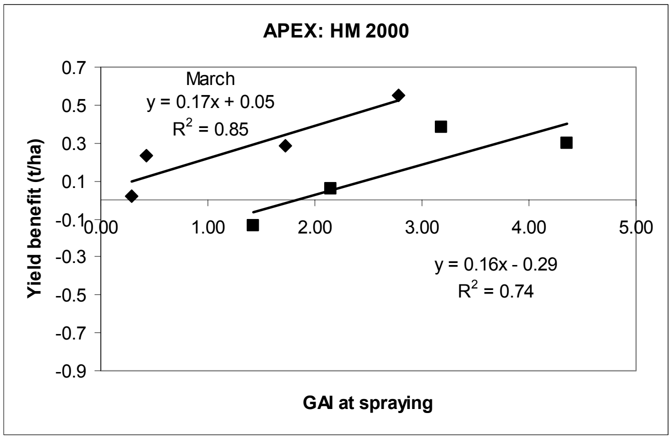


Figure 2.9: Effect of Folicur at High Mowthorpe, 2000.



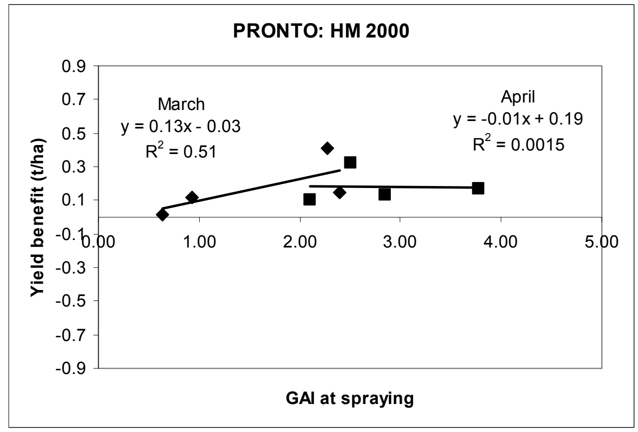
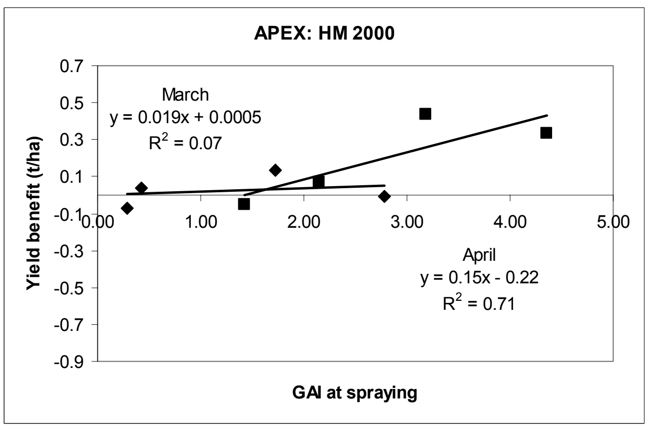
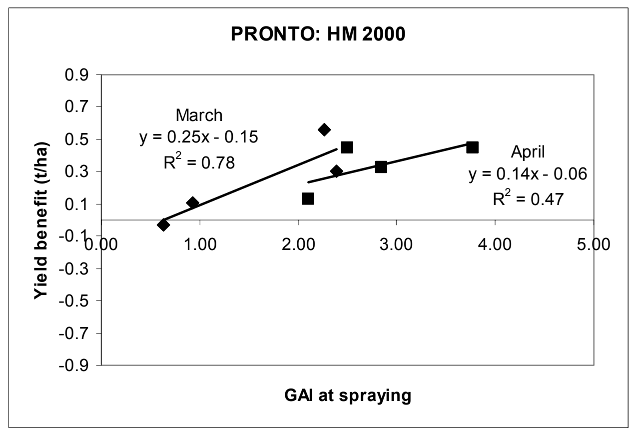


Figure 2.10: Effect of Caramba at High Mowthorpe 2000.





3.1.4.2. High Mowthorpe

At High Mowthorpe, Apex sprayed with Folicur gave positive linear correlations between yield difference and GAI at spraying in both March and April (Figure 2.9). In March, canopies < 0.5 GAI gave little response, while canopies > 1.5 yielded 0.3-0.6 t ha^{-1} more than controls. For April spraying, canopies < GAI 2.5 gave no response, while those with GAI > 3 yielded about 0.3 t ha^{-1} more. Spraying Apex with Caramba in March did not produce such a correlation (Figure 2.10): yield of sprayed plots did not differ from controls. However, in April, canopies < 2.5 did not respond whilst those > 3 yielded up to about 0.5 t ha^{-1} more than controls.

For Pronto, spraying with Folicur in March produced up to about 0.4 t ha^{-1} for canopies of GAI > 2, with no response at GAI < 1. For April spraying, there was no effect of canopy size, with all sprayed plots yielding 0.1-0.25 t ha^{-1} extra (Figure 2.9). For Pronto sprayed with Caramba, there were linear correlations between yield benefit and GAI at spraying in both March and April (Figure 2.10). Canopies > 1.5 in March yielded 0.3-0.6 t ha^{-1} extra, but with GAIs< 1 there was no response. In April, GAIs > 2 yielded 0.1-0.3 t ha^{-1} more.

3.1.5. Mechanism of PGR action (effects on yield components and growth analysis parameters)

Due to the time-consuming and intensive nature of growth analysis of oilseed rape, only the early-sown high seed rate crops were studied, in an attempt to elucidate the mechanism of PGR action.

3.1.5.1. ADAS Rosemaund.

As shown in Table 2.4, sprays on Apex at Rosemaund 2000 produced no significant differences in yield; LSDs were large because of a high degree of variability between replicates. However, spraying with Folicur in March or April produced a numerical increase of 0.08 – 0.12 t ha^{-1}. Spraying with Caramba or mowing resulted in numerical yield decreases of 0.2 – 0.54 t ha^{-1}.

Potential pod numbers per square metre (set pods + flowers + buds) did not differ significantly (*P*>0.1). However, potential pod numbers were close to the grand mean of 23,000 m^{-2} in most cases, except for the mown treatments, which were numerically substantially lower, about 18,000 m^{-2} (Figure 2.11). The final number of pods in the harvest sample around 5,900 m^{-2} (Figure 2.11) also did not differ significantly (*P*>0.1). Pod abortion or failure of pod set was very high, with only around 33% of potential pod sites remaining as fertile pods at harvest there was, however, no significant difference in the degree of 'pod abortion' between treatments. There was no significant difference in the number of seeds per square metre (Figure 2.12) or in the number of seeds per pod (Figure 2.13) (both *P*>0.1). There was a significant (*P*<0.001) effect of treatment on harvest thousand seed weight. Treatments did not differ significantly from controls, but mowing treatments had significantly smaller TSW values than the April spray treatments (Figure 2.14).

Figure 2.11: Potential and final pod numbers, Apex RM 2000

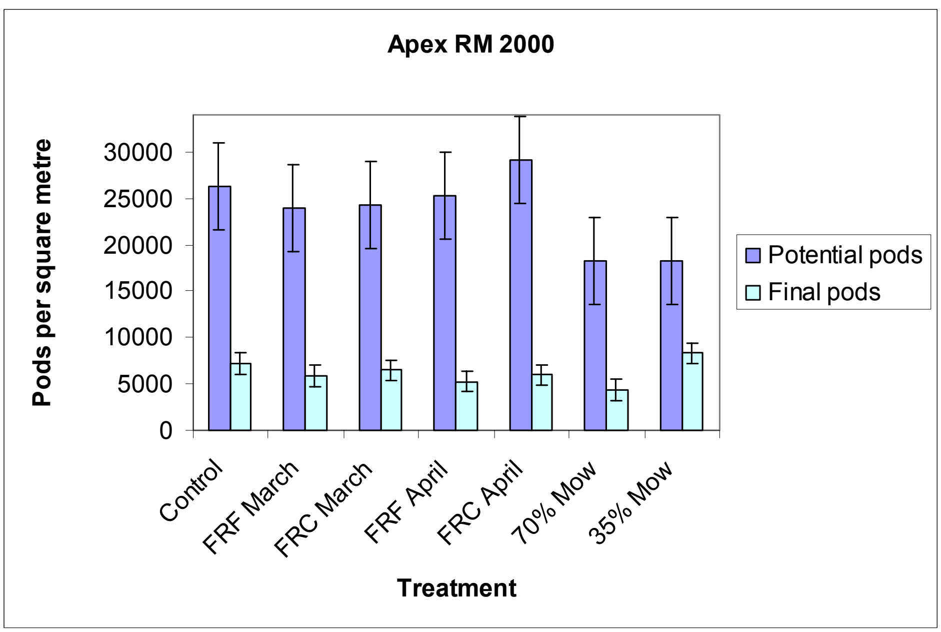


Figure 2.12: Numbers of seeds per square metre, Apex RM 2000.

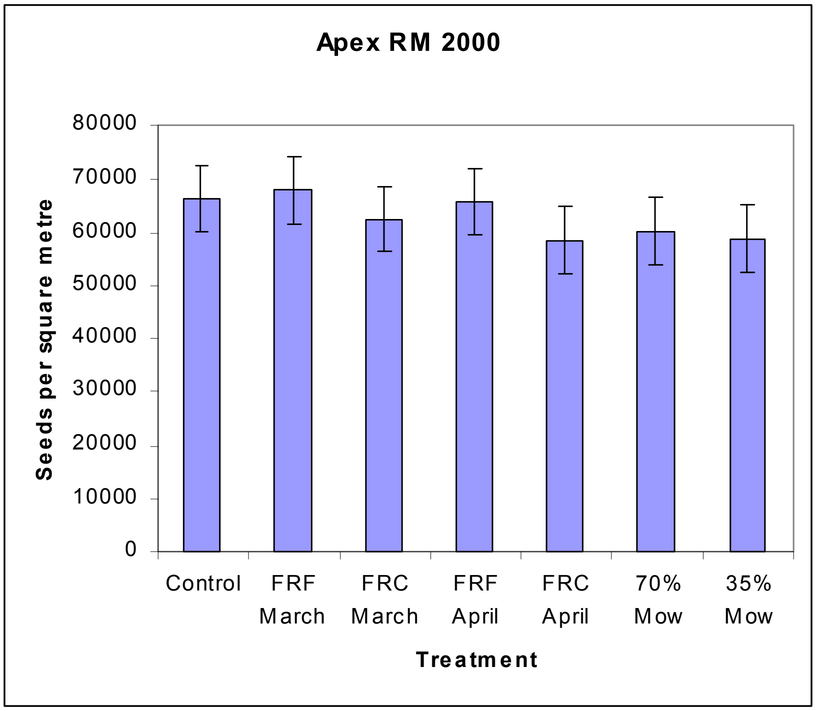


Figure 2.13: Numbers of seeds per pod, Apex RM 2000

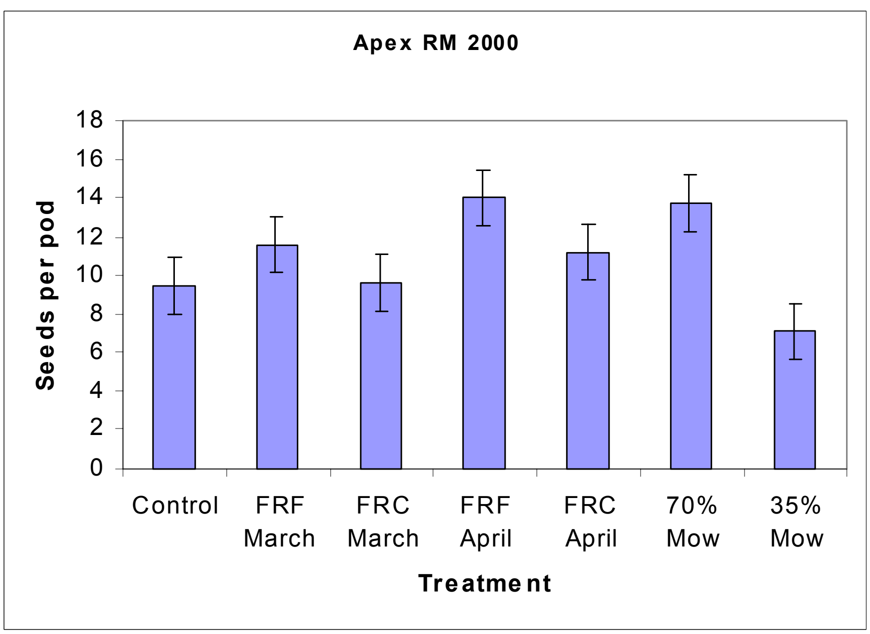
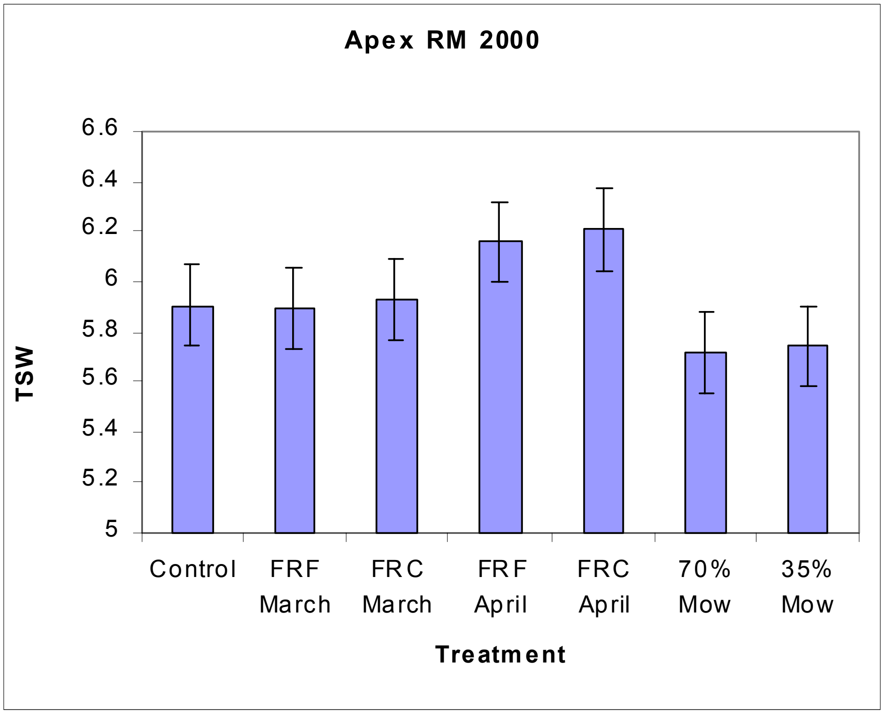
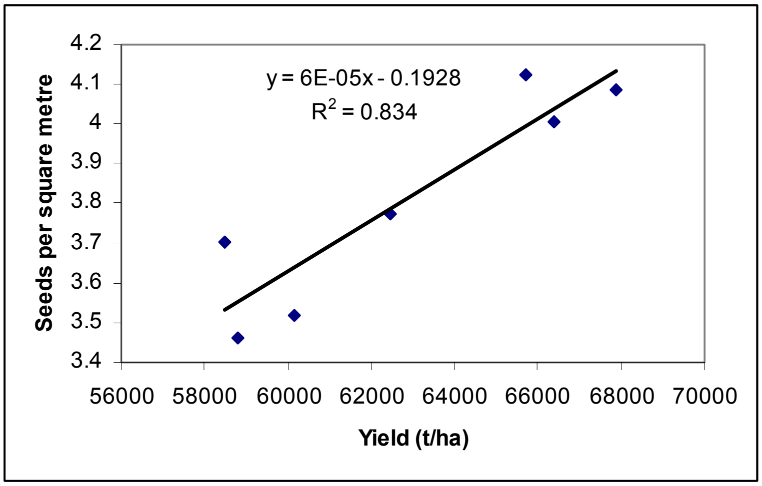


Figure 2.14: Thousand seed weight, Apex RM 2000.



Due to the lack of significance according to analysis of variance of most of the components of yield, the causes of yield differences were further assessed by regression analysis, plotting the various characters against yield. Final pod numbers did not account for the variation in yield of Apex at RM in 2000. Numbers of seeds per pod and thousand seed weight showed slight correlation with final yield, but did not account for much of the variance (data not shown). However, there was a strong correlation between the number of seeds per square metre and yield, with the highest yield produced from greater numbers of seeds per square metre (Figure 2.15). This relationship accounted for most of the variance in yield.

Figure 2.15: Relationship of seed numbers per square metre to yield, Apex RM 2000.



Several alternate hypotheses can be forwarded to explain the variation in seed numbers. Differences in canopy structure, due to PGRs, could lead to enhanced light interception and better assimilate partitioning, potentially leading to better assimilate supply and consequently pod and seed survival during the critical phase determining seed numbers immediately post-flowering. Alternatively, delayed senescence, altered pod characteristics or altered canopy structure could lead to better recovery of seeds during combine harvesting. Growth analysis data was assessed to see if evidence could be found to support one or other of these hypotheses.

At the pre-harvest growth analysis, remediation treatment had a nearly significant (P=0.056) effect on total crop dry matter and a significant (P=0.047) effect on pod layer total dry matter and on pod dry matter all were reduced by spraying with Caramba or by mowing (Figure 2.16). Total crop total dry matter was closely associated with yield (Figure 2.17), with reduction in total dry matter due to remediation associated with reduction in yield. Pod green area index showed a similar effect, with lower GAI in the remediation treatments (Figure 2.18), indicating that Apex (which was only very slightly above optimum GAI without treatment) was 'over-remediated' by Caramba or mowing in this case. Pod numbers did not vary significantly. Although this indicated that over-remediation may have limited assimilate supply and thus limited seed numbers per square metre, assessment of light interception data showed no significant differences in light absorption by the different canopies (P>0.1). An attempt was made to assess the second hypothesis, concerning seed recovery at combine harvest, but no significant differences (P>0.1) were found in estimates of losses, between pre-harvest and harvest.

Figure 2.16: Variation in total crop and pod layer dry matter

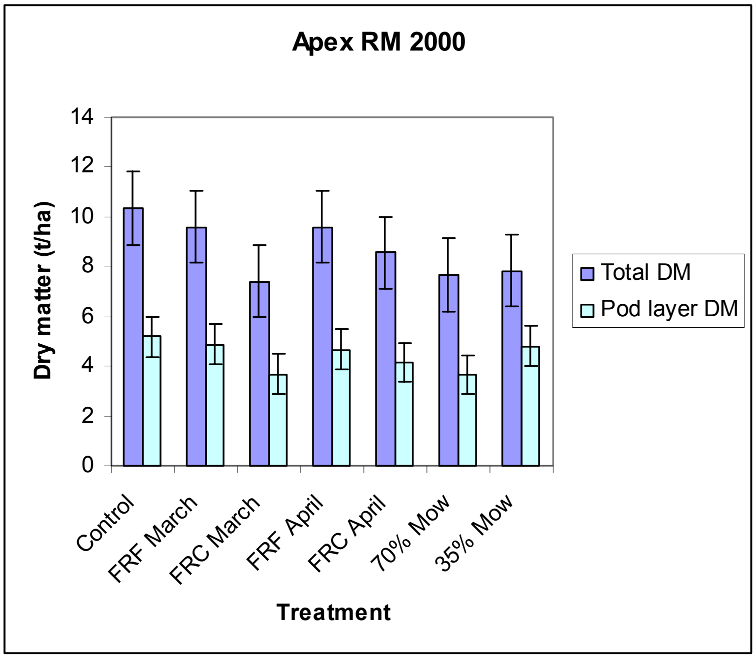
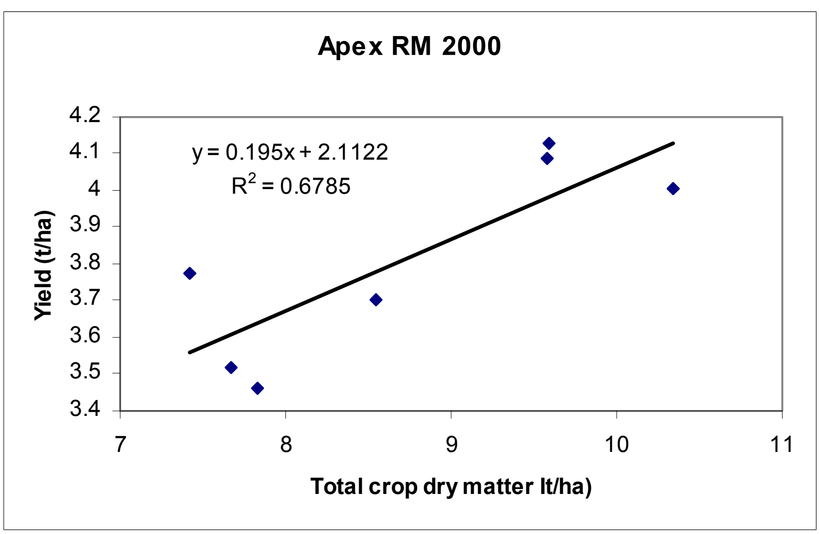
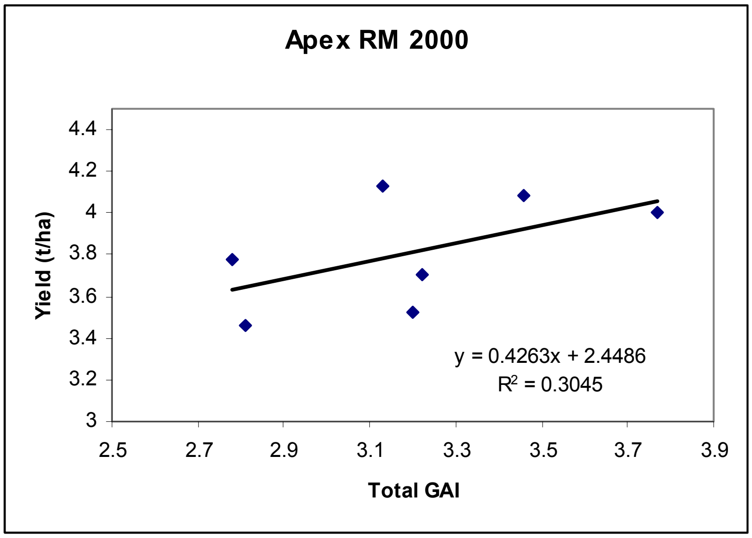


Figure 2.17: Relationship between total crop dry matter and yield.



A weak relationship was also seen between crop total green area index post-flowering and yield (Figure 2.18)

Figure 2.18: Relationship between total crop GAI and yield, Apex RM 2000.



For Pronto at RM 2000, only the Folicur treatment in March produced a significantly enhanced yield; however, the other spray treatments produced numerical increases in yield. Whilst the 70% mowing treatment hardly affected yield, 35% mowing treatment produced a numerical decrease in yield. Similarly to Apex, therewere no statistically significant differences between yield components (data not shown). Also similarly to Apex, the difference in yield for Pronto was largely explained by the numbers of seeds per square metre by regression analysis (Figure 2.19).

Figure 2.19: Relationship between yield and seed numbers per square metre, Pronto RM 2000.

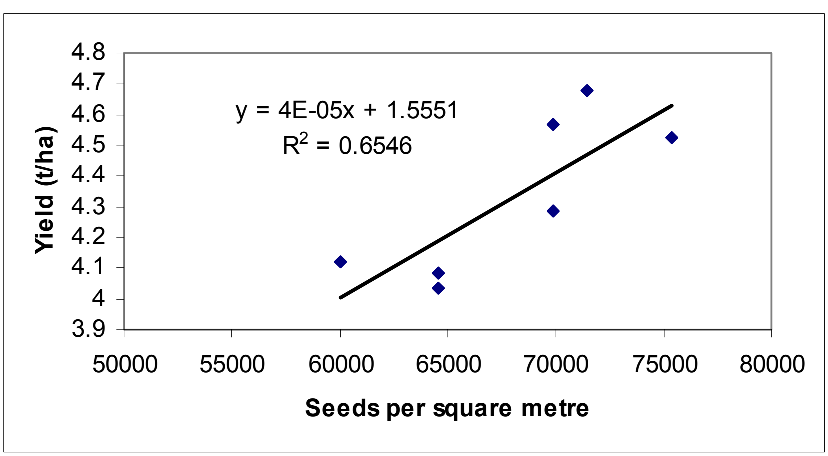
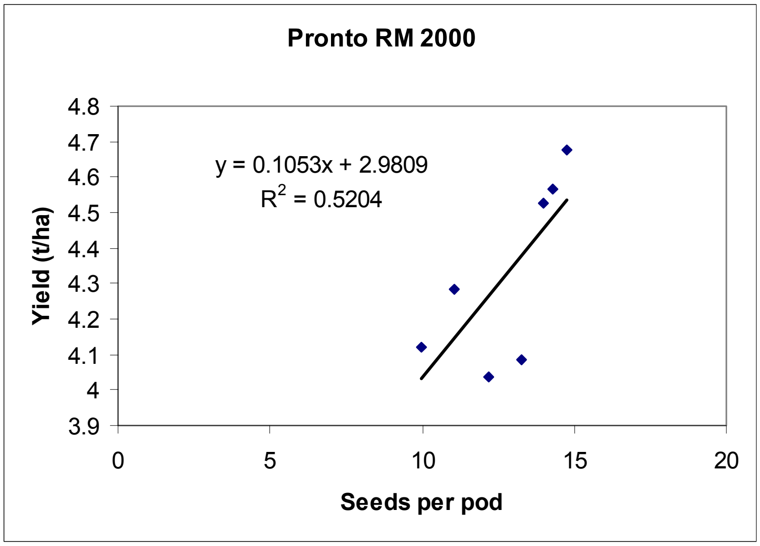


Figure 2.20: Relationship of seed numbers per pod to yield, Pronto RM 2000.



The increased numbers of seeds per square metre were due to increased numbers of seeds per pod (Figure 2.20). Differences in yield and seed numbers were not related to the number of pods, and there was no significant variation in thousand seed weight. Again, light interception measurements showed no significant differences between treatments (*P*>0.1, data not shown). Unlike for Apex, the additional yield could not be associated with changes in crop dry mass, pod layer dry mass, pod green area or pod layer total green area which did not vary significantly (data not shown).

3.1.5.2. ADAS High Mowthorpe

Analysis of variance of yield components again showed few significant differences. The only significant differences were due to cultivar rather than to treatment. Apex had more pods per square metre than Pronto at harvest (*P*<0.01), but fewer seeds per square metre and fewer seeds per pod (*P*<0.05, data not shown). For Apex at High Mowthorpe, only spraying with full rate Folicur in March significantly enhanced yield, although the April sprays resulted in numerical increases in yield. As for Rosemaund, the yield differences due to spray treatment were best explained by increased numbers of seeds per square metre, for both Apex (Figure 2.21) and Pronto (Figure 2.22). Thousand seed weight also contributed to a small extent for Apex, although the relationship between seed numbers per pod and yield was not significant.

For Pronto, the opposite was found, with a stronger relationship between seeds per pod and yield and a weaker effect of thousand seed weight.

Figure 2.21: Relationship between seed numbers per square metre and yield, Apex HM 2000

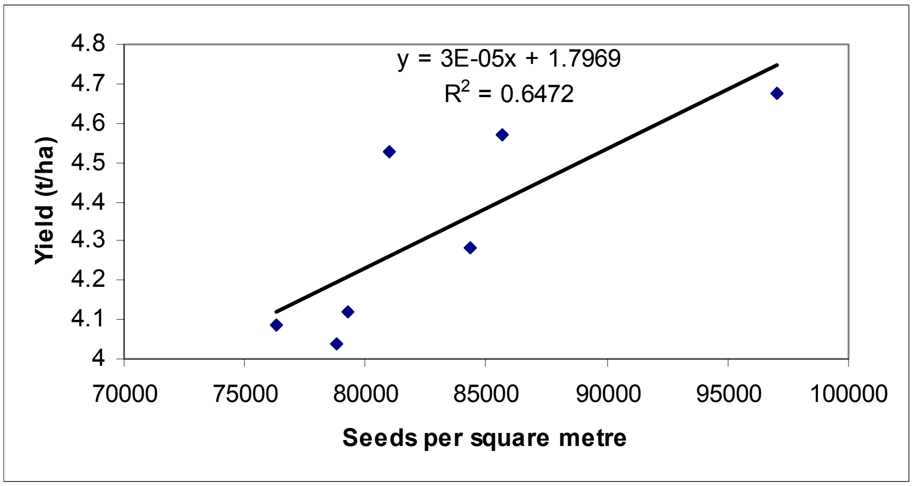
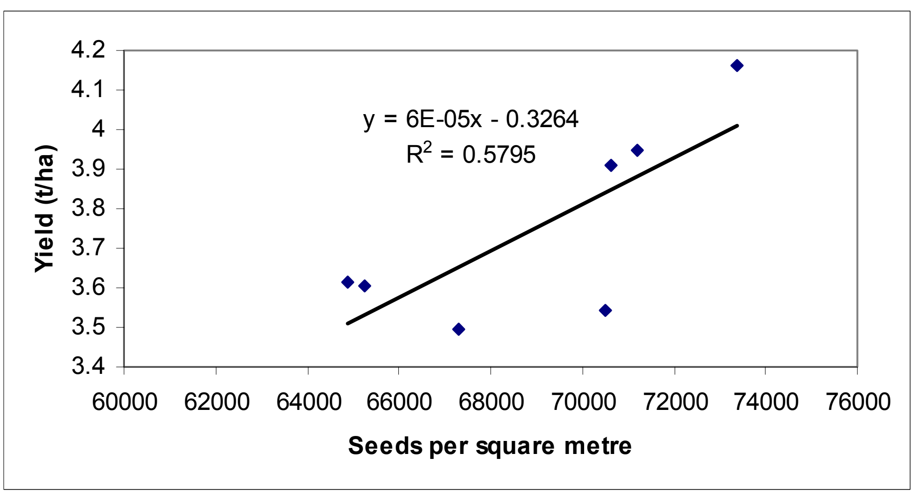


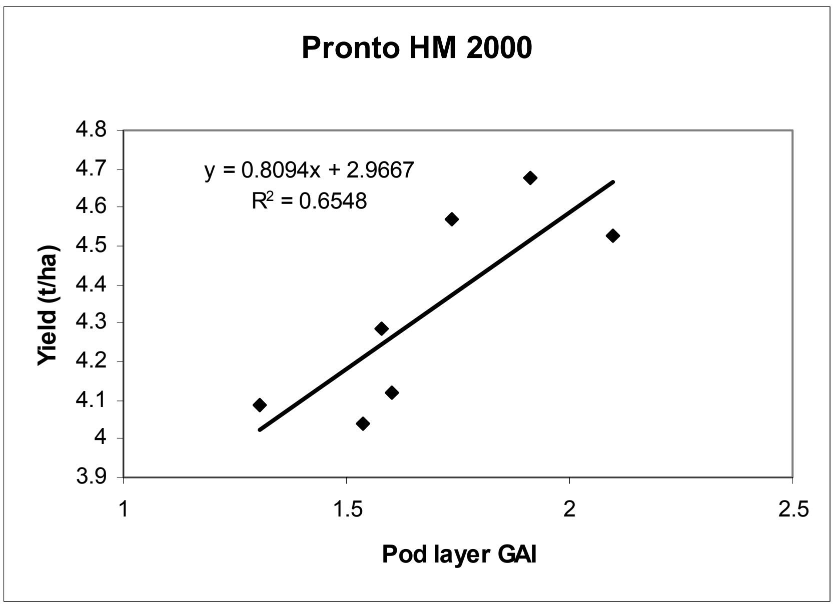
Figure 2.22: Relationship between seed numbers per square metre and yield, Pronto HM 2000



As was found at ADAS Rosemaund, light interception data showed no significant treatment differences and no evidence could be found for differences in seed recovery. Unlike the situation at ADAS Rosemaund, the high yields at High

Mowthorpe could not be significantly associated with crop or pod layer dry matter, although there was a similar numerical trend. However, for Pronto, there were close associations between a number of components of green area and greater yields (Figure 2.23). For Pronto at High Mowthorpe, no such relationships could be found as the data was more variable (data not shown).

Figure 2.23: Relationship between pod layer total green area (post-flowering sample) and yield, Apex HM 2000.



3.2. 2001

3.2.1. Control crop development

3.2.1.1. ADAS Rosemaund

Final crop height, its development through the season and treatment effects were very similar to the previous year (Figure 2.24). Green area index was not significantly affected by seed rate in either cultivar, with similar green area indices from high and low seed rates at both sowing dates, although there were numerically higher GAIs from the high seed rate of Apex (Figure 2.25). The late-sown crops of both cultivars displayed very delayed development of GAI compared to the early-sown crops (and the previous year), with GAIs <1 in April compared to GAIs > 2 in early sown crops. However, After April, GAI increased rapidly in the late-sown crops to produce maximum canopy sizes only slightly smaller than early sown crops. Canopy size in Pronto was numerically smaller than those of Apexalthough the size of both cultivars was less than the optimum value of 3. The canopies were smaller than those achieved at Rosemaund in 2000, and smaller than those produced at High Mowthorpe.

As with GAI, seed rate had no significant effect at either sowing date, with either cultivar on biomass accumulation (Figure 2.26). However, sowing date had a significant effect with much lower biomass accumulated up until april, in the late-sown crops of both Pronto and Apex. After April, biomass accumulatedat the same rate in the late-sown and early-sown crops, so the difference was preserved. Biomass accumulation was slightly lower in Pronto than in Apex. The early-sown crops produced similar biomass to that produced in 2000 and to High Mowthorpe in this year, but the late-sown crops produced markedly less biomass.

Figure 2.24: Control crop height, ADAS Rosemaund, 2001

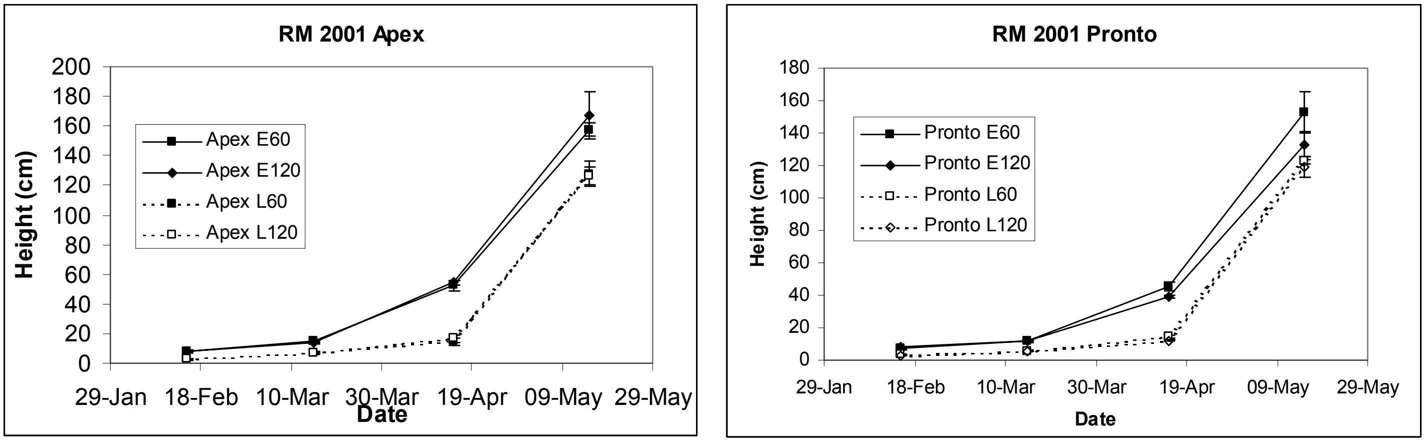


Figure 2.25: Control crop green area index, ADAS Rosemaund, 2001

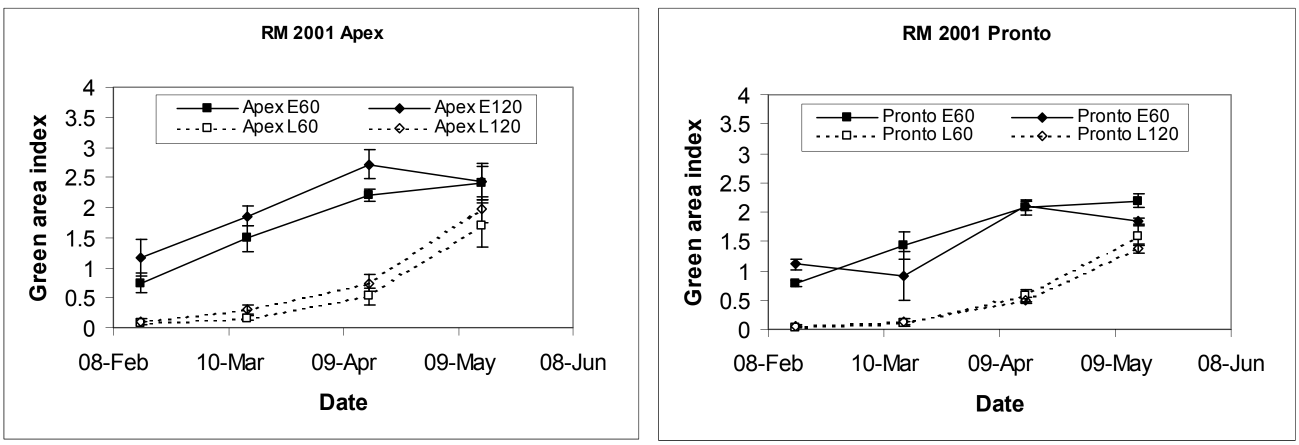
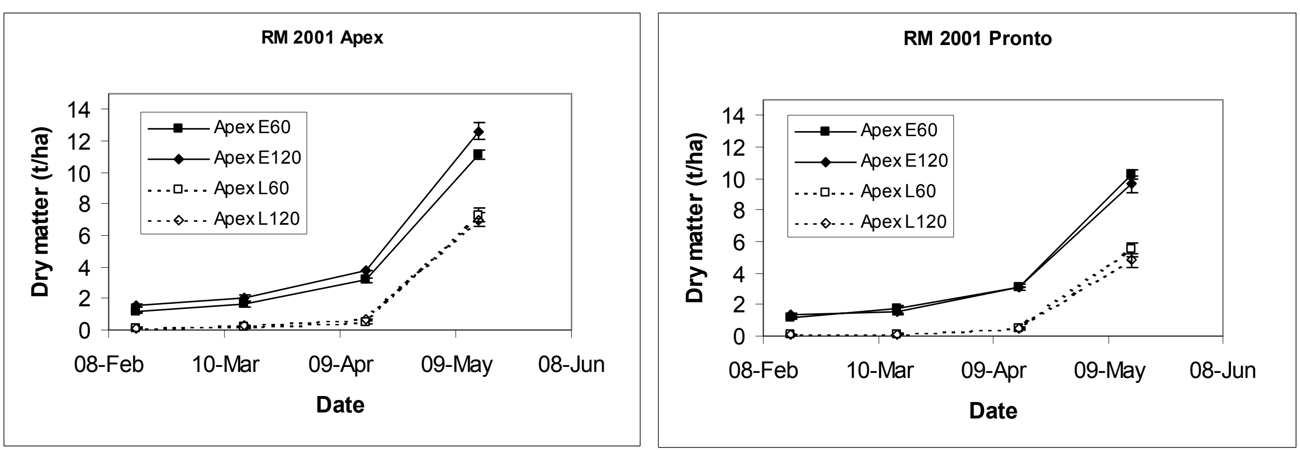


Figure 2.26: Control crop Biomass, ADAS Rosemaund 2001



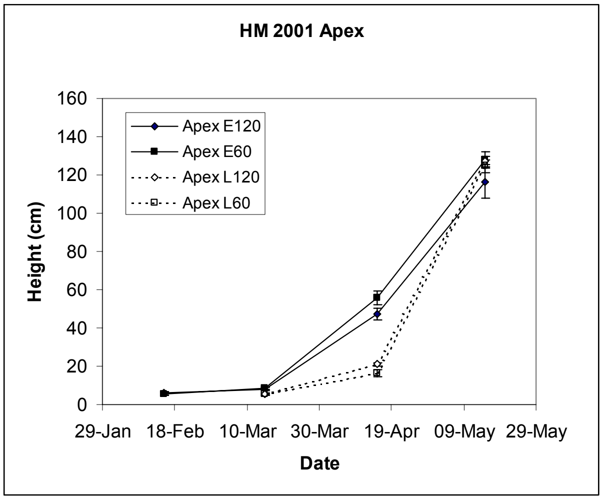
3.2.1.2. ADAS High Mowthorpe

Early-sown crops of Apex, were significantly taller than late-sown crops at the April sample point, there was no significant difference due to seed rate (Figure 2.27 (a)).By the post-flowering sample point there was no significant difference in height, with late-sown crops gaining similar height to the early-sown crops due to more rapid height increase post-April. The Pronto crops (Figure 2.27 (b)) showed exactly the same pattern as Apex, but by May were about 10 cm taller.

Green area index showed a similar pattern of development to crop height (Figure 2.28), although some effects of seed rate were apparent. In April, green area indices of the early-sown crops were greater than for the late-sown crops in both Apex and Pronto. In Apex, the high and low seed rate crops from the early sowing did not have significantly different GAIs, but for Pronto, the high seed rate had a greater GAI. For the late-sown-crops, high seed rates of both Apex and Pronto gave greater GAIs in April. However, after April, the late-sown low seed rate crops of both Apex and Pronto showed the most rapid increase in GAI and by May had numerically the greatest GAI, although there were no significant differences between treatments. Canopy size of both Apex and Pronto covered a similar range, from 2 – 3.5 GAI.

Biomass accumulated through the season in a very similar way height (Figure 2.29), with no effect of seed rate but with late-sown crops of both cultivars showing significantly less biomass accumulated by April. However, after the April sample point, biomass accumulation was more rapid in the late-sown crops than the early-sown crops, leading to similar amount of biomass post-flowering. Pronto crops had produced greater biomass than Apex by May (10.7 cf 8.9 t ha^{-1} on average).

Figure 2.27: Control crop height, ADAS High Mowthorpe 2001



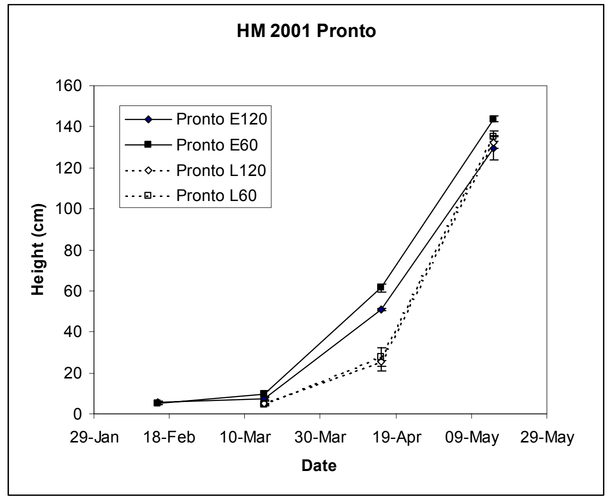
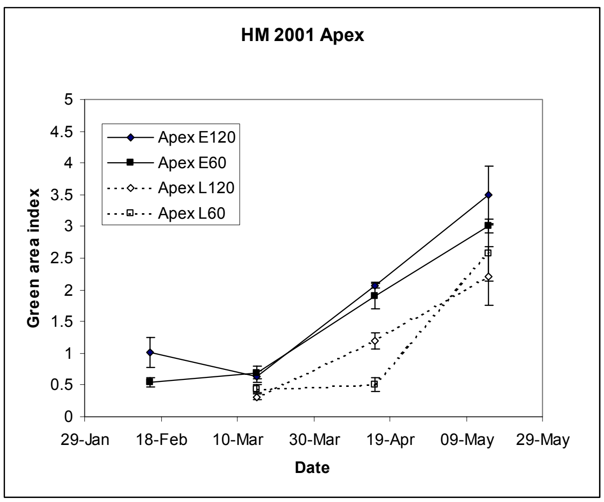


Figure 2.28: Control crop green area index, ADAS High Mowthorpe 2001



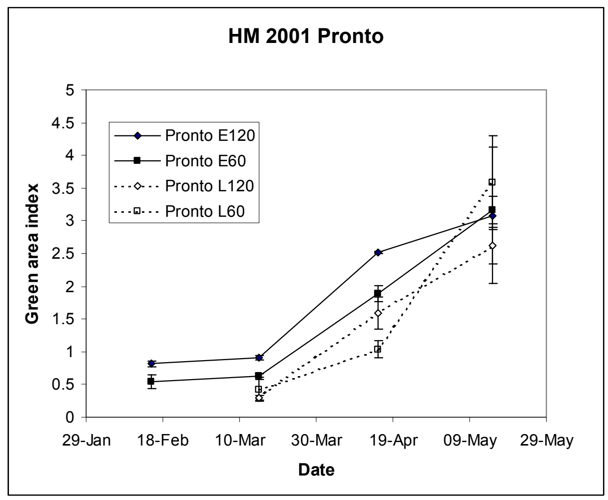
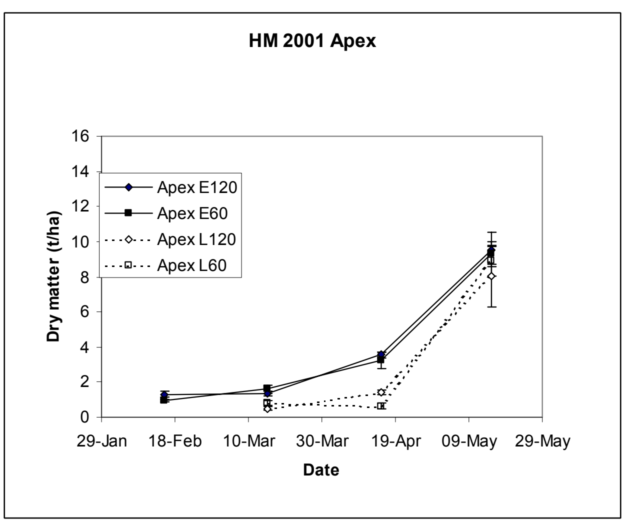
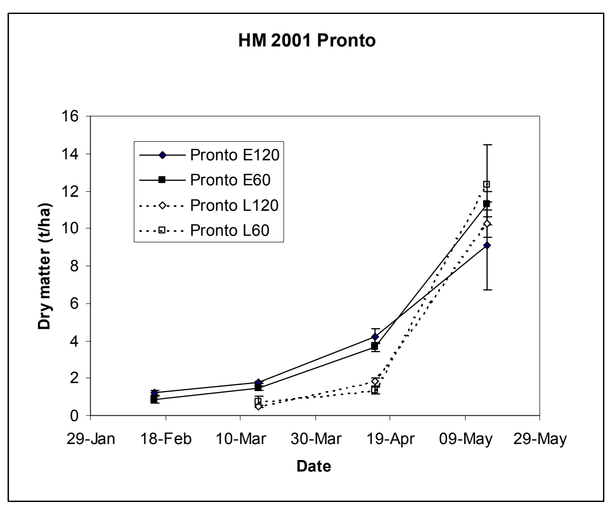


Figure 2.29: Control crop biomass, ADAS High Mowthorpe 2001





3.2.2. Height and lodging

3.2.2.1. ADAS Rosemaund

There was a significant (*P*<0.001) effect of variety, with Apex crops taller than Pronto (146.9 cf 134.3 cm. SED 2.33). There were no significant treatment effects (*P*=0.588) or a variety x treatment interaction (*P*=0.236). However, most treatments resulted in small numerical reductions in height of between 3.5 – 11.9 cm (2.5 – 7.8%) (Table 2.6).

Due to the large number of treatments with no lodging, the data was transformed as in the previous year (see section 2.4), the transformed data are presented in brackets in table 2.7. Lodging was greater in Apex than Pronto, with 93.7% lodging in the early sown high seed rate control tretment of Apex compared to 27.5% for the same Pronto treatment. Lodging was least sever in late sown low seed rate treatments and intermediate in early sown low seed rate and late sown high seed rate plots. The greatest reductions in lodging were achieved by full rate applications of Folicur or Caramba in April. Full rate applications in March were less effective and half rates in March had little effect.

3.2.1.2. ADAS High Mowthorpe

At High Mowthorpe, there was again a significant (*P*<0.001) effect of variety, except here Pronto crops were taller than Apex crops (124.4 cf 108.8 cm). Again there was no significant treatment effect (*P*=0.124) or treatment x variety interaction (*P*=0.936). As at Rosemaund, however, most of the treatments resulted in numerical decreases in height of 4.2 – 15-0 cm (max 3.6 – 12.9%) (table 2.6). In contrast to Rosemaund no lodging occurred at High Mowthorpe in 2001.

Table 2.6: Height measurements taken at the post-flowering growth analysis, May 2001.

Treatment	Rosemaund		High Mowthorpe	
	Apex	Pronto	Apex	Pronto
Untreated	153.2	138.9	116.1	129.7
March – Full rate Folicur	143.6	135.4	108.9	125.5
March – Full rate Caramba	145.9	129.2	105.9	119.7
April – Full rate Folicur	145.1	137.7	101.1	122.9
April – Full rate Caramba	149.7	129.7	99.9	120.7
March – Half rate Folicur	149.2	128.4	118.9	130.3
March – Half rate Caramba	141.3	140.7	110.7	121.9
SED (26 df)	6.17		8.02	
LSD (5%)	12.69		16.49	

Table 2.7: Lodging at ADAS Rosemaund, 2001. Transformed data in brackets to which the statistics apply.

Treatment	Apex				Pronto			
	Early		Late		Early		Late	
	120	60	120	60	120	60	120	60
Control	93.7 (4.533)	52.8 (2.378)	52.5 (3.008)	27.5 (2.159)	27.5 (2.103)	11.2 (1.181)	0.0 (-0.693)	1.2 (-0.118)
FR Folicur March	62.5 (3.938)	5.0 (0.733)	25.0 (1.441)	3.7 (0.157)	21.2 (2.577)	7.5 (0.978)	2.5 (0.056)	3.7 (0.631)
FR Caramba March	67.5 (4.152)	7.5 (1.380)	17.5 (0.542)	2.5 (0.458)	10.0 (1.727)	11.3 (1.655)	6.2 (0.285)	3.7 (0.157)
FR Folicur April	42.5 (2.733)	5.0 (0.805)	0.0 (-0.693)	0.0 (-0.693)	5.0 (0.733)	3.8 (0.157)	0.0 (-0.693)	2.5 (0.056)
FR Caramba April	32.5 (1.727)	5.0 (0.733)	0.0 (-0.693)	0.0 (-0.693)	1.2 (-0.118)	8.7 (1.583)	0.0 (-0.693)	0.0 (-0.693)
HR Folicur March	87.5 (4.468)	32.5 (1.739)	20.0 (1.374)	21.2 (0.591)	28.8 (2.450)	5.0 (0.733)	0.0 (-0.693)	0.0 (-0.693)
HR Caramba March	82.5 (4.398)	11.3 (1.711)	3.8 (0.631)	1.2 (-0.118)	41.2 (2.575)	10.0 (1.655)	0.0 (-0.693)	1.2 (-0.118)
SED	Sow date x variety x seedrate x treatment =1.12 (df 34.3), 0.972 (161 df) in the same level of TOS x variety x seedrate							
LSD (5%)	Sow date x variety x seedrate x treatment =2.284 (df 34.3), 1.9202 (161 df) in the same level of TOS x variety x seedrate							

3.2.3. Yield

3.2.3.1. ADAS Rosemaund

The difficult autumn and winter growing conditions were reflected at Rosemaund in 2001 in the performance of the later sowing date with significantly lower (*P*=0.004) yields averaging 1.52 cf. 3.56t/ha in the early sowing (Table 2.8). There was also a significant effect of variety (*P*<0.001), with higher yields from Apex (2.77 cf 2.31, SED 0.05), however, there were no significant effects of seed rate. PGR treatment effects were significant (*P*=0.008), but the only significant yield increases resulted from spraying early-sown high seed rate crops. The greatest yield increases (upto >1t/ha) came from the April applications which had given the biggest reductions in lodging, however, there was also a significant increase due to half rate Folicur applied in March which had given no reduction in lodging. PGR treatments generally resulted in yield decreases on late sown (particularly at low seed rate) plots with reductions of upto 0.6 t/ha. However, 43.8% of the combinations gave numerical yield increases compared to controls of greater than 0.1 t ha^{-1}.

Table 2.8. ADAS Rosemaund yield, 2001.

Treatment	Apex				Pronto			
	Early		Late		Early		Late	
	120	60	120	60	120	60	120	60
Control	2.71	3.17	1.42	1.41	3.31	3.81	1.92	1.84
Full rate Folicur March	3.40	3.10	1.48	1.18	3.63	4.07	2.30	1.75
Full rate Caramba March	3.15	3.12	1.31	1.35	3.76	3.11	1.88	1.55
Full rate Folicur April	3.79	3.43	1.58	1.20	4.14	4.11	1.87	1.61
Full rate Caramba April	3.44	3.41	1.29	1.20	3.81	3.35	1.53	1.83
Half rate Folicur March	3.36	3.26	1.40	1.19	3.84	3.79	1.70	1.48
Half rate Caramba March	3.19	3.42	1.42	1.32	3.20	3.38	1.83	1.22
SED	Sow date x seed rate x variety x treatment (13 df) = 0.356, in the same level of sow date x seed rate x variety (161 df) = 0.262							
LSD (5%)	Sow date x seed rate x variety x treatment (13 df) = 0.770, in the same level of sow date x seed rate x variety (161 df) =0.517							

3.2.3.2. ADAS High Mowthorpe

As at Rosemaund sowing date had a significant (*P*<0.001) effect on yield although the penalty for late sowing was relatively small , with early-sown crops outyielding late-sown crops on average (3.33 t ha^{-1} cf 3.06 t ha^{-1} SED 0.06) (Table 2.9). Again as at Rosemaund, variety had a highly significant effect (*P*<0.001), although here there were greater yields from Pronto than Apex (3.36 t ha^{-1} cf 3.02 t ha^{-1} SED 0.06). There was, however, a significant sowing date x variety (*P*=0.007) interaction, with Apex producing higher yields from late sowing cf. early sowings and the reverse for Pronto. In contrast to Rosemaund there was a significant (*P*=0.047) effect of seed rate, with the high seed rate yielding more than the low seed rate on average (3.25 t ha^{-1} cf 3.13 t ha^{-1} SED 0.06). PGR treatments again had significant effects (*P*=0.04), there was however a significant sowing date x variety x treatment (*P*=0.002) interaction. Yield responses to PGR treatment were greatest in early sown high seed rate plots of Apex reflecting the results at Rosemaund. The greatest yield responses in Pronto were however achieved in the late sown high seed rate plots, although these responses were not significant. There were yield decreases due to PGR use, however there was only one statistically significant decrease in late sown low seed rate Apex. There were positive yield responses in excess of 0.1 t/ha in 54% of the possible combinations.

Table 2.9: Yield, ADAS High Mowthorpe 2001.

Treatment	**Apex**				**Pronto**			
	Early		**Late**		**Early**		**Late**	
	120	**60**	**120**	**60**	**120**	**60**	**120**	**60**
Control	2.84	2.93	2.91	3.01	3.50	3.33	3.13	3.22
Full rate Folicur March	3.48	3.35	3.02	2.30	3.16	3.77	3.64	3.77
Full rate Caramba March	3.50	3.30	2.70	2.65	3.29	3.11	3.62	3.61
Full rate Folicur April	3.50	3.01	2.96	2.73	3.92	3.54	3.60	2.94
Full rate Caramba April	3.58	3.29	2.99	2.65	3.41	3.35	3.32	3.30
Half rate Folicur March	3.15	3.37	2.93	2.98	3.50	3.52	3.29	2.89
Half rate Caramba March	3.06	3.07	2.75	2.62	3.19	3.38	3.01	2.74
SED	Sow date x seed rate x variety x treatment (13 df) = 0.356, in the same level of sow date x seed rate x variety (161 df) = 0.262							
LSD (5%)	Sow date x seed rate x variety x treatment (13 df) = 0.770, in the same level of sow date x seed rate x variety (161 df) =0.517							

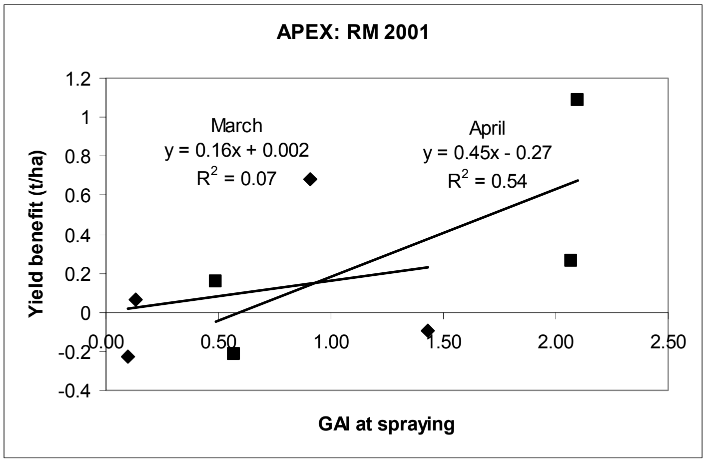
3.2.4. Relationship between GAI and yield benefit

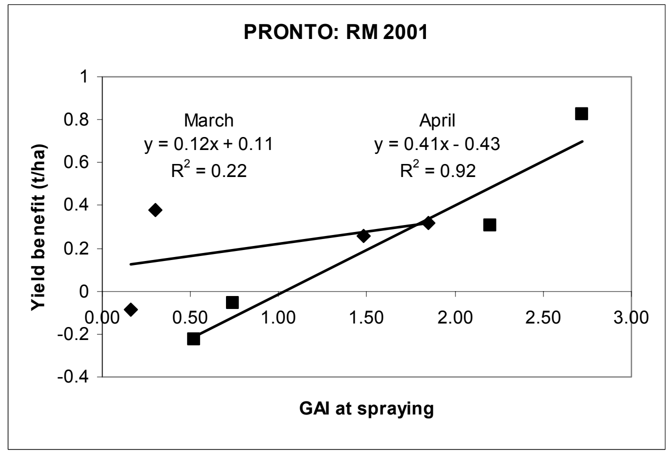
As in the previous year there was generally a positive relationship between canopy size at spraying and the yield response to PGR use (Figures 2.30-2.33).

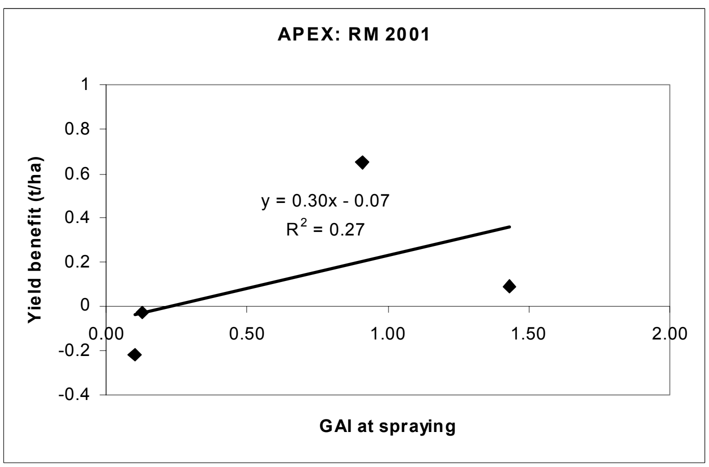
3.2.4.1. ADAS Rosemaund

At Rosemaund (Figures 2.30 and 2.31) the relationship between canopy size and yield response to treatment was generally best with April applications. This is perhaps not surprising as the closer the time of assessment is to the achievement of final canopy size, the less chance there is for weather to affect the relationship. For the April applications crops with in excess of 1.5 GAI at spraying would generally give economic responses although there was a tendency for Pronto to need larger crops in the order of 2 GAI. With the full rate applications in March the relationship between crop size at treatment and yield response was generally weaker, with the exception of Caramba applied to Pronto. The relationship between crop size at treatment and yield response was generally better with half rate treatments in March than with full rate, although yield responses tended to be lower.

Figure 2.30: Effect of full rate Folicur application in March or April and half rate in March, ADAS Rosemaund 2001







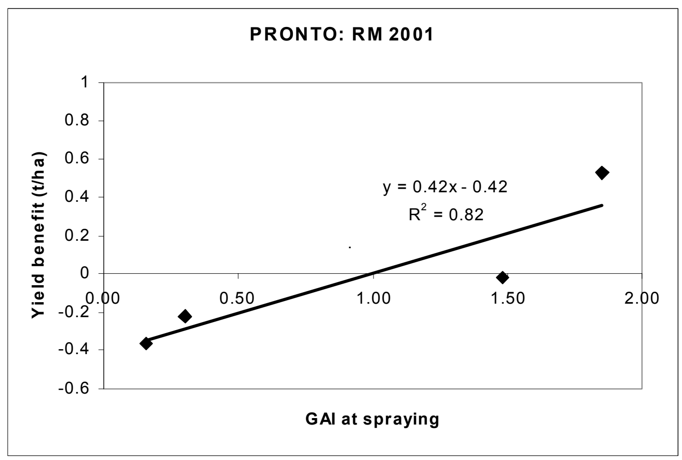
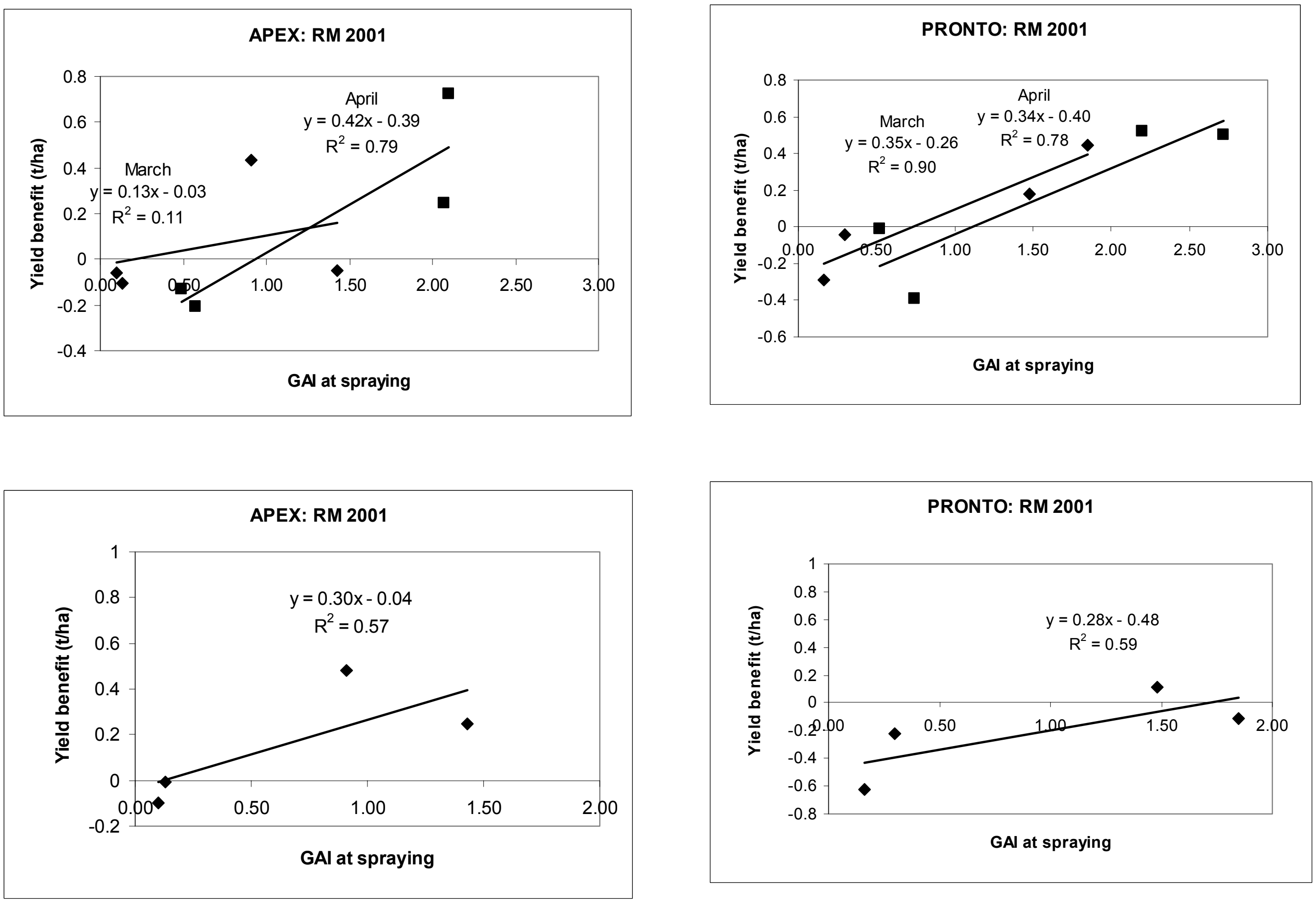


Figure 2.31: Effect of full rate Caramba application in March or April and half rate in March, ADAS Rosemaund 2001

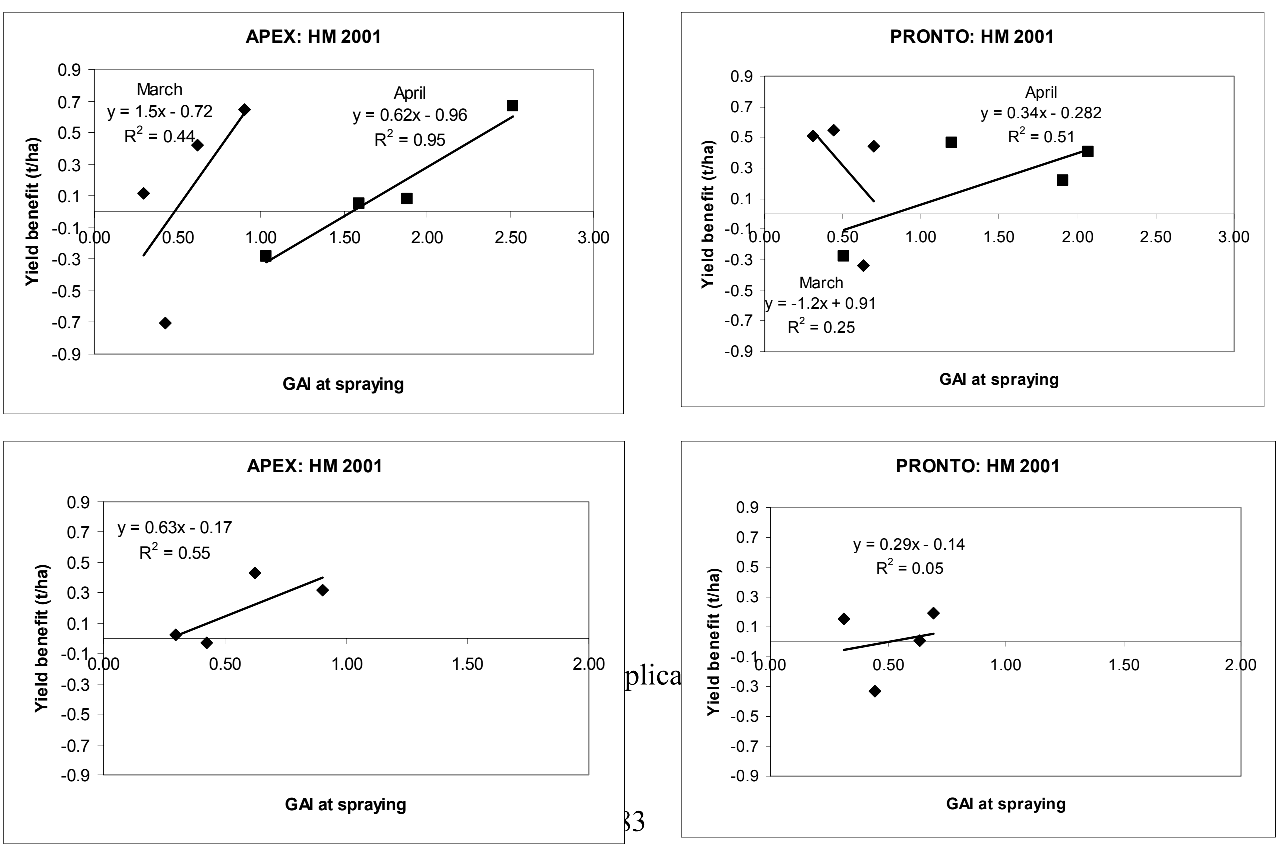


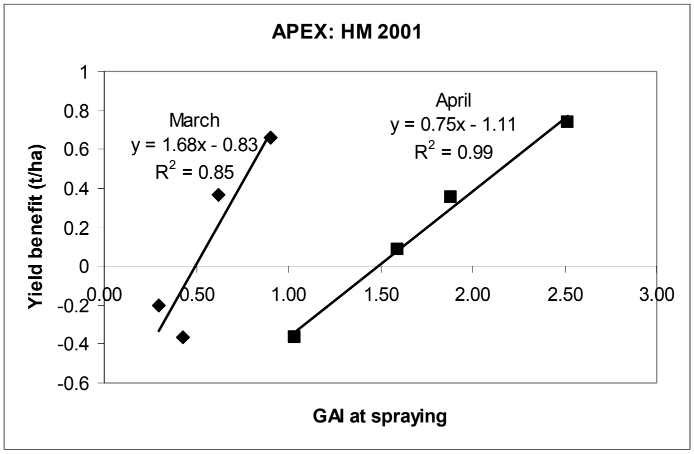
3.2.4.2. ADAS High Mowthorpe

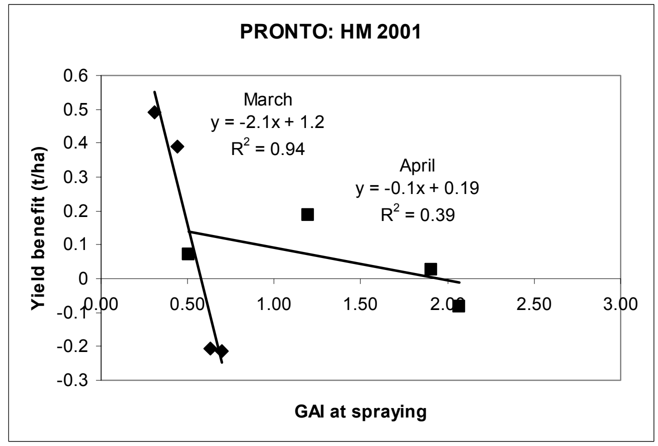
At High Mowthorpe there were generally strong positive relationships between crop size at spraying and yield response to treatment, across all timings, rates and products applied to Apex. For March applications with either product or rate, a canopy size in excess of 0.5 GAI was needed for a positive response to treatment. For April applications a canopy size in excess of 1.5 GAI was needed for a positive response and closer to 2 GAI was needed for an economic response.

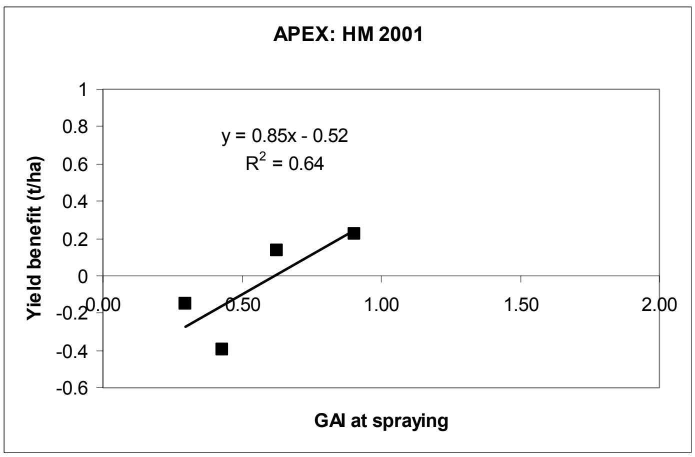
In contrast to the Apex at this site and results in the previous year there was no generally no positive effect of crop size at spraying on yield response found on Pronto. Full rate application of Folicur in April did give a positive relationship, but in all other cases there was either no relationship or a negative one. The small range in canopy sizes achieved in this variety in March may go some way to explain the lack of any correlation, for the early treatments. In addition yield responses to April applications were generally small which would reduce the chances of identifying a correlation especially given the relatively low number of comparisons for each treatment.

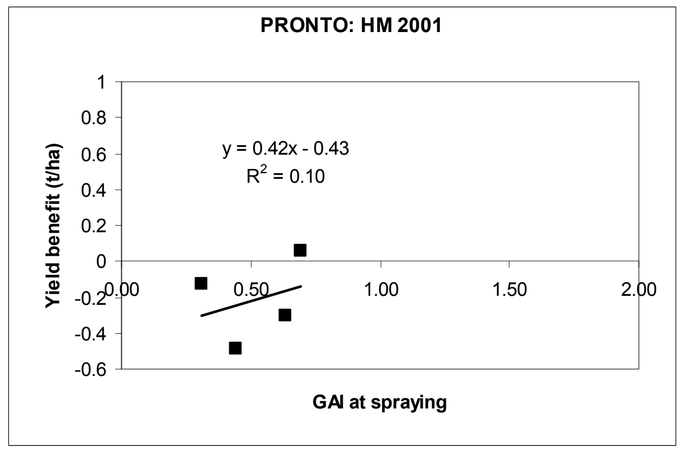
Figure 2.32: Effect of full rate Folicur application in March or April and half rate in March, ADAS High Mowthorpe 2001











3.2.5. Mechanism of PGR action (effects on yield components and growth analysis parameters)

3.2.5.1. ADAS Rosemaund

As was seen in the 2000 season, the variation in yield of Apex was well explained by variation in the number of seeds per square metre (Figure 2.34). Variation in thousand seed weight (data not shown) did not significantly affect yield. The increased seed numbers per square metre were not related to final pod numbers, which did not vary significantly (P>0.1) and which did not affect yield. Therefore, the increased seed numbers per square metre were due largely to increased seed numbers per pod (Figure 2.34).

Figure 2.33: Relationship of seed numbers per square metre to yield (Apex RM 2001)

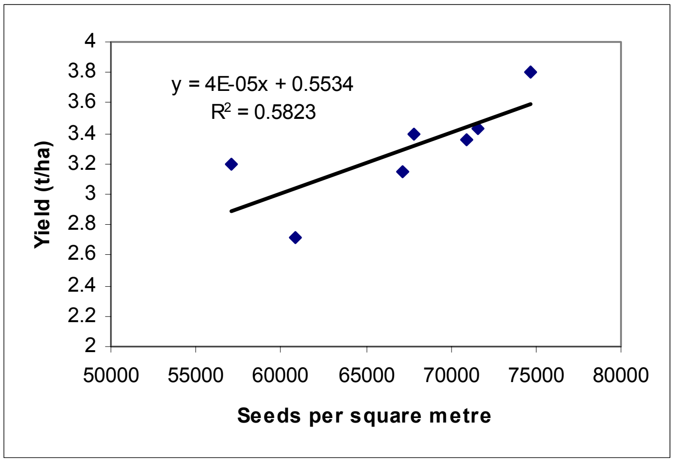
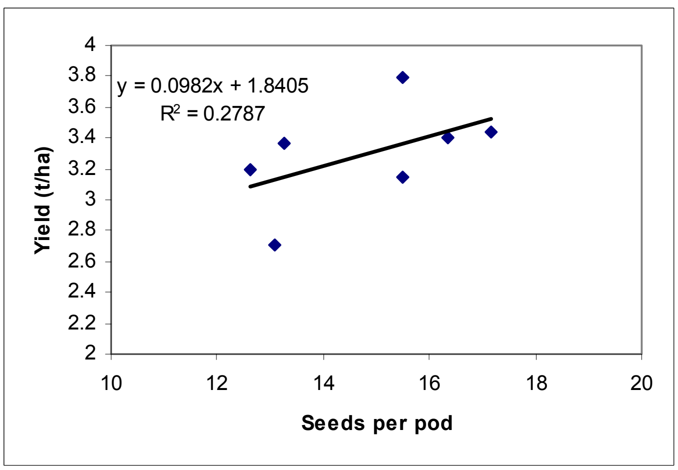


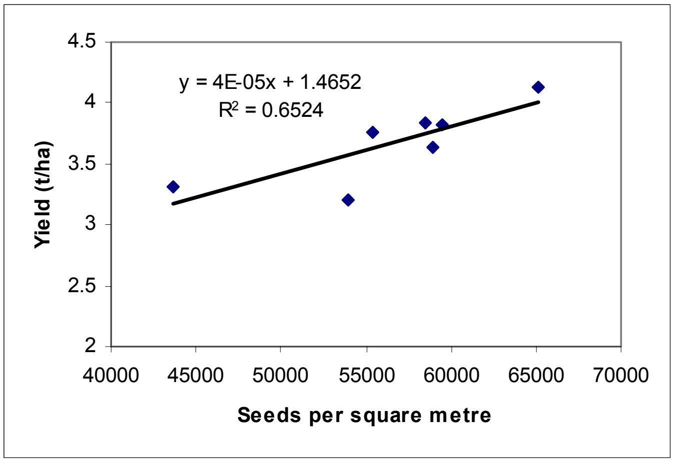
Figure 2.34: Relationship of seed numbers per pod to yield, Apex RM 2001



Unfortunately, as was also found in 2000, due to the inherent variability in the crop neither the light interception data nor the growth analysis data could be used to determine whether the greater seed numbers per square metre in the sprayed treatments were due to better light interception, enhanced assimilate supply and seed survival or better combine recovery of seed. ANOVAs showed no significant differences (P>0.1) between growth analysis parameters and significant regression relationships of post flowering crop parameters to yield could not be identified.

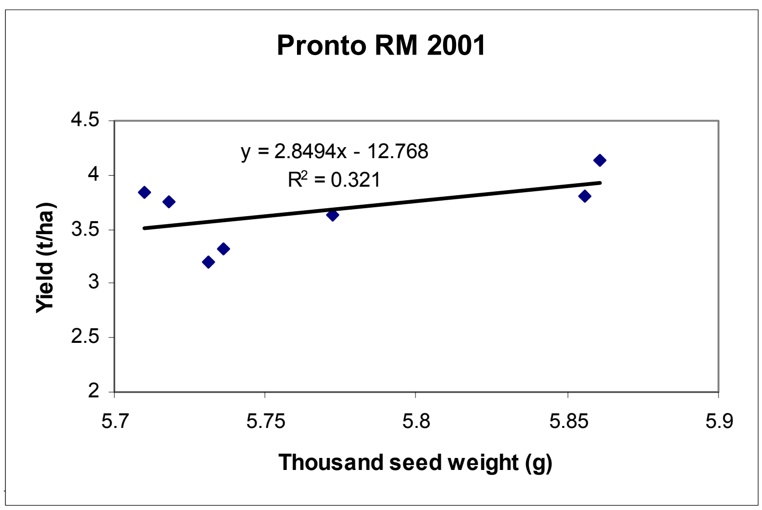
A similar picture emerged for Pronto, with increased yields best explained by increased numbers of seeds per square metre (Figure 2.35).

Figure 2.35: Relationship of yield to seed numbers per square metre, Pronto RM 2001



As for Apex, pod numbers per square metre did not significantly affect yield, indicating that increased seed numbers were due to increased seed number per pod. However, unlike Apex there was a proportion of the yield increase due to increased thousand seed weight (Figure 2.36).

Figure 2.36: Relationship between thousand seed weight and yield



3.2.5.2.

At High Mowthorpe, higher numbers of seeds per square metre were also strongly associated with higher yields, for Apex and Pronto (Figure 2.37 and 2.38 respectively). Again, there was no association between final pod numbers (at the pre-harvest assessment) and yield. However, a greater proportion of higher yield at this site was was explained by enhanced thousand seed weight.

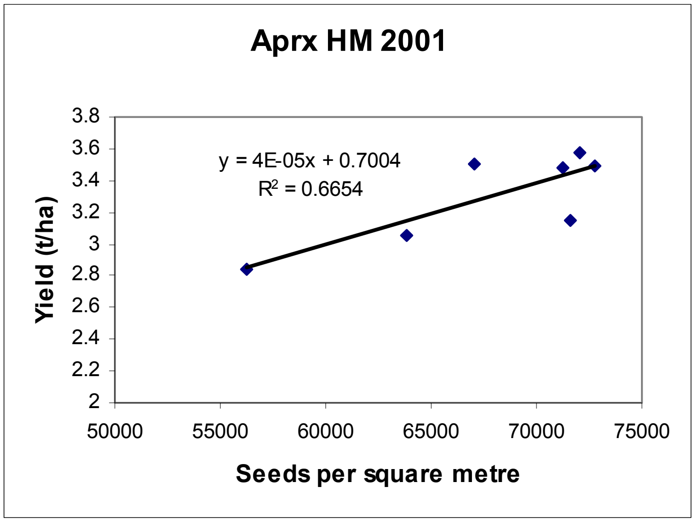


Figure 2.37: Relationship between seed numbers per square metre and yield, Apex HM 2001

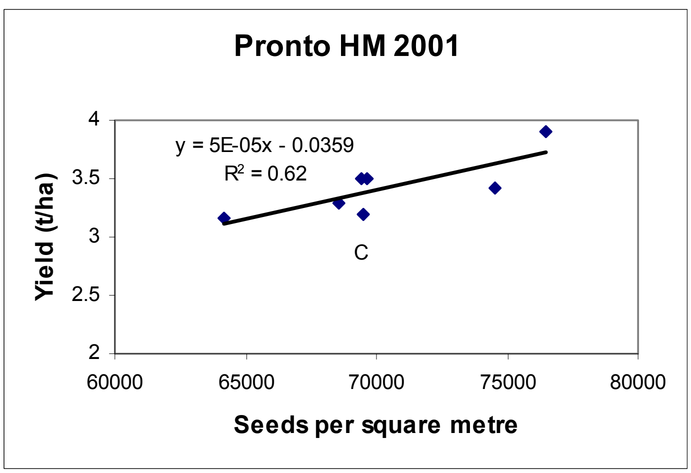


Figure 2.38: Relationship between seed numbers per square metre and yield, Pronto HM 2001

4. Conclusion

In conclusion, this work confirms that the fungicides Folicur and Caramba, do have PGR activity, which can be used to control plant height, reduce lodging and benefit yield, with increases of up to 1 t ha^{-1} recorded However, the effects of PGRs on height, lodging and yield were still occasionally inconsistent and ambiguous, as has been found with many studies using other PGR chemicals. Application of the PGR could reduce as well as increase yield. In general, a linear association was found between crop size at spraying and yield benefit, with small crops (<GAI 0.5-1) showing no benefit or reduction in yield, and large (> GAI 1-2) crops showing the greatest increase in yield, the lower and higher figure in both cases relating to march and April applications respectively. These significant linear relationships were found for 66% of the 32 full rate applications and 75% of the eight half-rate applications over the 2000 and 2001 seasons. Application in April (green/yellow bud) gave more consistent and greater yield increases than application in March (stem extension). Half rate applications in March usually gave small benefits that were usually not economically beneficial. Reduction in yield by inappropriate PGR application was possibly due to 'over-remediation' and reduction in total crop and pod layer dry matter. The higher yields in some treatments were generally associated with more seeds per square metre, with occasional small effects of increased thousand seed weight. In no instance was there a significant difference in the number of pods per square metre due to treatment (although occasionally there was due to variety). Increased seed numbers per unit area in conjunction with stable pod numbers indicates that there must be an increase in seed number per pod. Growth analysis in some cases supported this where significant increases in the numbers of seeds per pod could be demonstrated, however, in other cases this could not be demonstrated, most probably due to masking by inherent crop variability. Three hypotheses can be postulated to explain greater numbers of seeds per square metre: Better assimilate supply during the critical phase of seed abortion post-flowering, due to altered canopy structure or better light interception. Increased retention of early formed, higher yield potential pods. Better seed recovery at combine harvest (due to reduced pre-harvest pod shatter or a better canopy structure). No evidence could be found to support the last hypothesis through the collection of shed seed in trays under the crop. The presence of yield improvements in hand harvested yields also tends to rule out combine recovery as the primary cause of yield improvement due to PGR activity. Evidence for the first or second hypothesis was also scarce, since no differences in light interception could be demonstrated. However, growth analysis data in some cases showed association of greater crop dry matter, pod dry matter, pod green area and pod specific weight with greater yield. The increased thousand seed weight responsible for some of the variation in yield also implies better assimilate supply or partitioning due to PGR action. However, the exact mechanisms by which yield improvements are effected by PGR treatment are uncertain and more work is required before the physiological processes can be fully understood and manipulated.

APPENDIX III: Identification of canopies requiring spring remediation.

1. Introduction

The previous two Appendices have demonstrated the importance of canopy size in relation to the response to plant growth regulation with both tebuconazole (Folicur) and metconazole (Caramba). In most of the combinations of site, cultivar and chemical tested there was a positive relationship between canopy green area index (GAI) and the yield benefit from PGR application. Small crops did not benefit or suffered small yield losses whereas the larger canopies that were sprayed produced positive yield responses compared to untreated controls, with benefits of up to 1.0 t ha^{-1}. In most of the cases where there was no correlation between crop size and response this appeared to be due to insufficient range in canopy size. Therefore it is important to be able to identify which canopies will be suitable for remediation in order to target the use of either product, to just those situations where a response is likely. The potential methodologies assessed included crop knowledge/visual information, crop height and crop dry or fresh mass.

2. Materials and Methods

Data from the three years of trials collected using the methods described in Appendices I and II were used. Regression analyses between parameters such as crop height and GAI were performed using Genstat 5 for Windows statistical software.

3. Results

3.1. Crop knowledge and visual observation

In most of the studies, early-sown (late August/early September) high seed (120 seeds m^{-2}) rate crops had large canopies that benefited from chemical remediation whereas late-sown (late September/early October) low seed rate (60 seeds m^{-2}) showed no benefit or a small yield decrease. These criteria could therefore be used to identify broad classes of crops suitable or not suitable for remediation. However, there is no detailed information on the transition point from unsuitable to suitable crops in terms of sowing date or seed rate. In any case, in certain seasons, conditions could allow even relatively late-sown or low seed rate crops to reach a size suitable for remediation or vive-versa so this method is still likely to cause some inaccurate applications.

Direct observation of the crop may allow a slightly greater refinement. Gross differences in crop canopy size (e.g. GAI < 0.5 compared to GAI > 1) due to sowing date are easily detectable and could be distinguished by reference photographs (Figure 3.1). However, the difference between GAI values of 1 and 2 (which may still result in differential benefit from chemical remediation) is far more difficult to discern by visual observation (Figure 3.2). Thus a visual observation and decision on whether a crop is backward or forward (e.g. comparing to reference photographs) is also likely to result in a substantial degree of error.

3.2. Relationship between crop height and GAI

In 1999, a relatively good relationship between crop height and GAI was found (Figure 3.3), with crops greater than 25 cm in height having GAIs above 2, which were though probably suited to remediation in March/April. In the absence of additional information, this was used as a crude recommendation for PGR application to crops after the first year trials.

However, in subsequent years a poorer relationship was found, with a great degree of scatter, due to both site and year variation leading to less accurate identification of crops suitable for remediation. There is a possibility that the relationship could be improved by taking account of plant population, but although crop height is a feasible measurement to gauge crop size it is still rather crude and likely to cause more inaccurate applications than the other methods discussed here.

Figure 3.1: Comparison of (a) GAI <1 with (b) GAI > 1

(a) GAI = 0.2

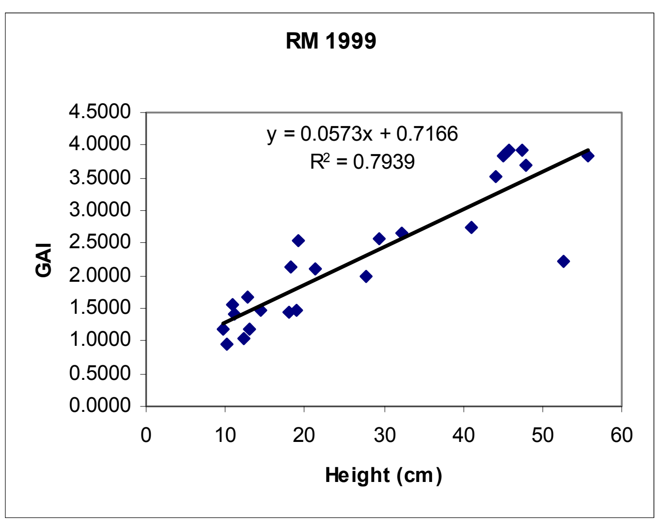
(b) GAI = 1.0

Figure 3.2: Comparison of (a) GAI = 1.0 with (b) GAI = 2.0

(a)

(b)

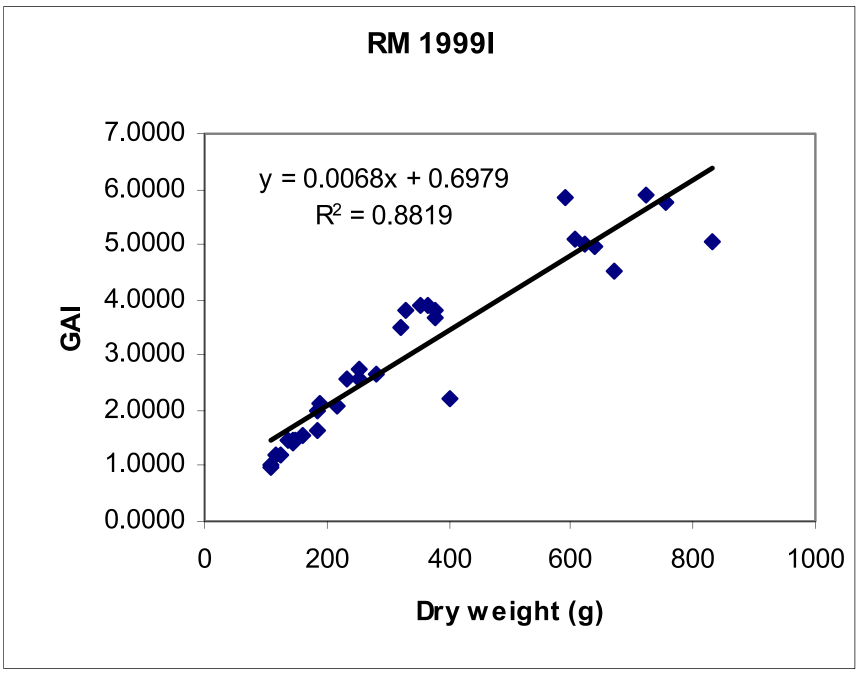
Figure 3.3: Relationship between crop height and GAI, Rosemaund 1999



3.3. Relationship between crop dry matter and GAI

Further investigation demonstrated a much closer correlation between GAI and dry matter than between GAI and height (Figure 3.5). Thus the dry matter in a given area (e.g. from a metre square quadrat) could be used to give a relatively accurate assessment of crop canopy size. However, this method requires significantly more effort and equipment than the previous methods.

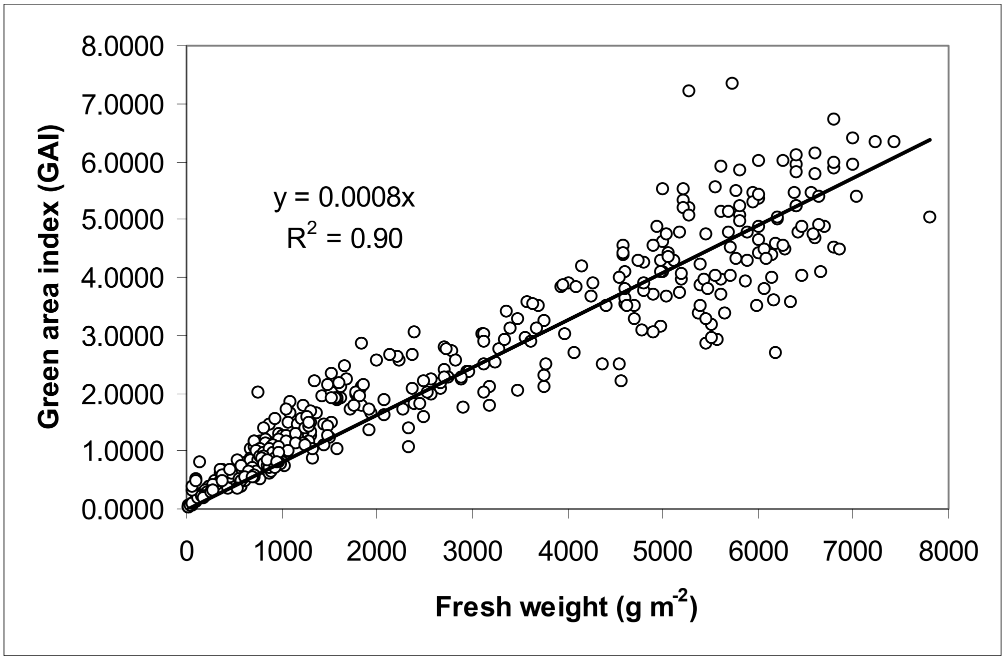
Figure 3.5: Relationship between crop dry weight and green area index, Rosemaund Apex 1999



3.4. Relationship between crop fresh weight (biomass) and GAI

Since determination of dry matter requires time- and space-consuming oven drying, this may be an unsuitable test for farmers and agronomists to determine which crops may benefit from remediation. Consequently, the fresh weight/GAI relationship was investigated. As for dry matter, fresh weight showed a very well-defined and consistent relationship to GAI before flowering. Post-flowering, when leaves started to senesce, the relationship started to break down, although this was deemed to be of lmited importance as PGRs would not be applied at this late stage and assessment of crop size would need to be performed earlier in the season. Thus crop GAI could be accurately estimated by sampling and weighing all the plant material in a defined (e.g. metre squared quadrat) area representative of the crop. The overall relationship is shown in Figure 3.6 (all pre-flowering data from 2 cultivars x 2 sites x 3 years), where green area index is given by the equation GAI = 0.0008*FW (where fresh weight is in g). If FW is taken in kg, then GAI = 0.8*FW. The effects of cultivar, site and year were studied by linear regression analysis with groups using Genstat 5 software. Fresh weight accounted for 90.9% of the variance in green area index. Including cultivar as a group did not significantly (P=0.382) increase the amount of variance accounted for, nor did including year (P=0.689). Including site as a group, did significantly (P<0.001) increase the amount of variance accounted for, but only from 90.9 to 91.6%. There was no GAI x site interaction so the lines for each site were parallel. The lines were very close together and for practical purposes they can be considered coincident, so that the single relationship could be used to predict GAI from FW across all cultivars, sites and seasons in the study.

Figure 3.6: Relationship between fresh weight and green area index



3.5. Guidelines for growers

PGR applications can be used to limit crop height, reduce lodging and enhance yield. The maximal effects for height and lodging reduction comes from application at around GS 2 (stem extension in March). However, these effects were not associated with the greatest benefits for yield, which come around GS 3-4 (green-yellow bud) in mid April to early May. This timing is also later than the optimal timing for spring phoma and light leaf spot control (although these are not the primary targets of Folicur and Caramba); use of these chemicals this early on all but the most forward crops runs the risk of yield reduction due to over-remediation. However, with PGR application in April, some useful control of *Sclerotinia* and *Alternaria* may be gained. Even at the later applications, in the majority of cases (66-75%) positive yield responses have been found with applications to the largest crops. Thus a compromise between chemical choice and timing is required, between disease control, height and lodging reduction and yield benefit, depending on the priorities in the particular crop. The following key sets out a decision scheme.

1. January/February

Monitor crops for phoma leaf spot and light leaf spot infection. If disease levels reach threshold levels, spray with a non-PGR fungicide (e.g. flusilazole, difenconazole) since most crops are likely to be too small to benefit from PGR application at this stage. Exceptionally forward crops (GAI > 1) may benefit from PGR fungicide application (tebuconazole or metconazole) which may also give some disease control.

2. March

If control of plant height and lodging is a priority to optimise combine harvest, application of full rate tebuconazole or metconazole by mid March gives the likelihood of the greatest benefit. Crops of GAI < 0.5 may suffer slight yield depression, crops of GAI > 1 are more likely to show yield benefit and crops of GAI > 2 are most likely to benefit. This timing is probably too late for effective phoma and light leaf spot control, but may provide some control of alternaria. A half rate application lowers the risk of yield depression on small crops but is also likely to give smaller yield benefits on large crops.

3. April

If crops are large, yield may be increased by up to 1 t ha^{-1} by full rate tebuconazole or metconazole around mid April. This timing may also give some control of alternaria and sclerotinia. Canopies of GAI < 1 are unlikely to benefit, those of GAI > 1.5-2 are likely to produce an economic response.

Assessment of canopy size: Harvest all the above ground material (biomass) from an area of one square metre and weigh the biomass fresh weight (FW) in kilograms. Green area index (GAI) = 0.8 x FW.

Note of caution: Yield benefit depends on optimising canopy structure in relation to environmental conditions. However, the extent of remediation can vary due to spray conditions, persistence of the chemical on the crop, temperature *etc*. which will affect chemical uptake. Additionally, the extent of remediation required depends on the amount of growth that would have been made post-remediation, which depends on weather conditions that cannot be predicted accurately at the time of application. Thus crops appearing to need remediation may in some extreme conditions not produce a yield response; for example in dull post-spray conditions there may be insufficient growth to reach optimum canopy size. In these trials, remediation of large crops was successful in about 66-75% of cases.