FACTORS CONTRIBUTING TO IMPROVED EFFICIENCY OF THE SUGAR BEET CROP DURING THE AUTUMN IN THE UK

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ABSTRACT

Random samples from c. 500 fields in the UK have shown that in recent years the growth of the sugar beet crop through the autumn months has been 15% higher than previously. Typically, a healthy, unstressed crop converts intercepted radiation to stored sugar at the rate of 1g/MJ. In September and October the conversion rate has increased to 1.15 g sugar/MJ, which translates to a 5% increase in yield. We have begun investigating factors that may contribute to this faster autumn growth. One hypothesis is that increased use of triazole fungicides have produced a 'staygreen' effect similar to that observed in cereals. Field experiments tested the effect of triazole- (flusilazole) and strobilurin-type (trifloxystrobin) fungicides on yield and canopy physiology. Application of fungicides during the 2001 field season had a significant effect on disease control and hence on final root and sugar yield. During the autumn the senescence of the canopy was delayed by fungicide treatments, and the effect of the strobilurin helped maintain a greater percentage crop cover and top yield compared with other control measures. The 'stay-green' effect of the strobilurin was confirmed by measurements of chlorophyll content in September and October. Interestingly, however, there was only a small difference in net photosynthetic rate between untreated and triazole-treated leaves, presumably because the efficiency of the remaining canopy in untreated plots was not affected as much as the total leaf area. Preliminary results from pot experiments conducted in the glasshouse show that in the absence of disease the strobilurin and triazole fungicides had no effect on leaf expansion, net photosynthetic rate or leaf chlorophyll content within 40 d of treatment. The beneficial effects are most likely seen as the crop begins to age.

LES FACTEURS CONTRIBUANTS À AMÉLIORER L'EFFICACITÉ DES CULTURES DE BETTERAVE À SUCRE PENDANT LA PÉRIODE AUTOMNALE AU ROYAUME UNI.

Des échantillonnages aléatoires, effectués sur environ 500 champs au Royaume Uni ont montré que durant ces dernières années, la croissance des betteraves à sucre au cours de l'automne a été de 15% plus élevé qu'avant. Normalement, une plante en bonne santé et non stressée converti les radiations solaires interceptées en sucre stocké à raison de 1g de sucre pour 1MJ.

Pendant les mois de septembre et octobre, ce taux de conversion atteint 1.15g/ MJ, ce qui signifie une augmentation du rendement en sucre de 15%. Nous avons donc commencé à étudier les facteurs pouvant contribuer à cette croissance plus rapide en automne. L'une des hypothèses avancées est que l'utilisation de fongicides triaziques induit un effet "stay-green" similaire a celui observé dans les céréales. Les effets des fongicides triaziques (flusilazole) et de type strobilurique (tryfloxystobique) sur le rendement et la physiologie de la couverture foliaire furent investigués dans des champs expérimentaux. L'application de fongicides au cours de la saison 2001 eut un effet significatif sur la gestion des maladies et désormais sur les rendements finaux en racine et en sucre. Pendant l'automne, la sénescence de la couverture foliaire fut retardées par les traitements fongiques et les effets de la strobilurine aidèrent a maintenir un pourcentage de couverture des cultures plus important et un rendement optimal en comparaison d'autres mesures de contrôles. L'effet "stay-green" de la strobilurine fut confirmé par les mesures en chlorophylle contenue par plante en septembre et octobre. Quoi qu'il en soit, il y n'y avait qu'une petite différence entre les taux de photosynthèse nette entre les feuilles non traitées et celles traitées au triazole, probablement à cause du fait que l'efficacité de la couverture foliaire restante dans les plants non traites n'était pas autant affectées que l'aire totale occupée par les feuilles. Des résultats préliminaires, provenant d'expériences en pots conduites sous serre montrent qu'en l'absence de maladie, les fongicides strobiluriques et triazoliques n'eurent aucun effet sur les feuilles, le taux de photosynthèse nette ou la quantité de chlorophylle interne aux feuilles dans les 40 jours suivants le traitement. Les effets bénéfiques sont donc plus faciles à constater quand les cultures atteignent un certain âge.

FAKTOREN, DIE ZU EINER VERBESSERTEN ERTRAGSFÄHIGKEIT DER ZUCKERRÜBEN IM HERBST IN GROSSBRITANNIEN BEITRAGEN

Stichproben von ungefähr 500 Feldern in Großbritannien haben gezeigt, dass in den letzten Jahren das Wachstum der Zuckerrüben während der Herbstmonate 15 % höher als zuvor war. Normalerweise wandelt eine gesunde, nicht durch Stress belastete Frucht die aufgenommene Global-Strahlung mit einer Rate von 1 g/MJ in gespeicherten Zucker um. Im September und Oktober ist die Umwandlungsrate auf 1,15 g Zucker/MJ gestiegen, was einer Ertragssteigerung von 5 % entspricht. Es wurde begonnen die Faktoren zu untersuchen, die zu diesem erhöhten Wachstum im Herbst beitragen. Eine Hypothese besteht darin, dass die erhöhte Verwendung von Triazol-Fungiziden einen „Staygreen"-Effekt erzeugt hat, der dem bei Getreide beobachteten ähnelt. In Freilandexperimenten wurden die Auswirkungen von Triazol-Fungiziden (Flusilazol) und Fungiziden des Strobilurintyps (Trifloxystrobin) auf Ertrag und Physiologie der Kultur getestet. Die Anwendung von Fungiziden während der Anbausaison 2001 hatte signifikante Auswirkungen auf die Krankheitskontrolle und somit auf Rüben- und Zuckerertrag. Während des Herbstes wurde die Alterung der Kultur durch die Fungizidbehandlungen verzögert und die Wirkung des Strobilurins trug im Vergleich zu anderen Kontrollmaßnahmen zur Beibehaltung eines höheren Blattflächenanteils und zu einem Spitzenertrag bei. Der „Staygreen"-Effekt von Strobilurin wurde durch Messungen des

Chlorophyllgehalts im September und Oktober bestätigt. Interessanterweise bestand jedoch zwischen unbehandelten und mit Triazol behandelten Blättern nur eine geringe Differenz in der Netto-Photosyntheserate, vermutlich da die Leistungsfähigkeit der verbleibenden Blattfläche auf unbehandelten Parzellen im Vergleich zur gesamten Blattfläche in einem geringeren Ausmaße betroffen war. Vorläufige Ergebnisse von im Gewächshaus durchgeführten Gefäßversuchen zeigen, dass bei Abwesenheit der Krankheit die Fungizide Strobilurin und Triazol innerhalb von 40 Tagen nach der Behandlung keine Auswirkungen auf den Umfang der Blattfläche, die Netto-Photosyntheserate oder den Blattchlorophyllgehalt hatten. Die positiven Wirkungen werden mit zunehmenden Alter der Feldfrüchte am ehesten wahrnehmbar.

INTRODUCTION

Much is known about the growth and physiology of the sugar beet crop during the early phases of growth and during the summer when most of the sugar is produced. Considerably less is understood about the dynamics of dry matter production and the partitioning of carbon and nitrogen during the autumn months. Autumn conditions in the UK are characterised by shorter days and cooler temperatures; nevertheless, the crop produces on average 4 t/ha sugar during September and October (approximately 35% of the final yield). Thus, maintaining productivity during this period is critical to achieving profitable yields.

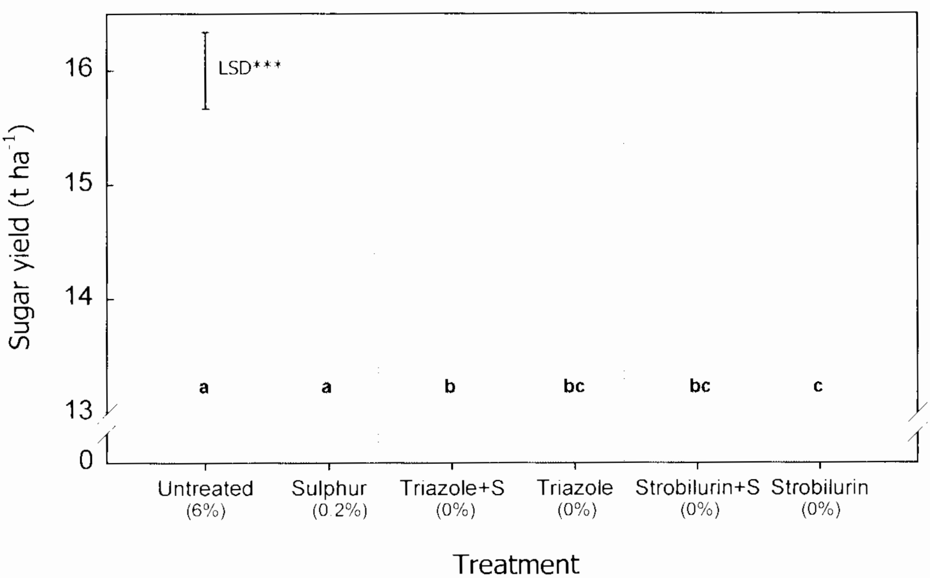
During the summer, healthy, unstressed crops convert solar energy to stored sugar at the rate of about 1g per megajoule of intercepted radiation (SCOTT, R. K. & JAGGARD, K.W., 1993). This rate continues, or in some cases improves during the autumn. The picture is complicated by the fact that the rate of canopy senescence increases during this period. Therefore, to maintain solar radiation conversion efficiency the remaining leaves must be more efficient and/or a greater proportion of carbon must be partitioned to sucrose storage than in previous months. This paper presents a few highlights of our ongoing study to determine what factors may contribute to maintenance of crop performance during the autumn.

An additional factor to consider is that triazole fungicides applied to the beet crop may cause a 'stay-green effect', delaying leaf senescence in addition to reducing diseases such as powdery mildew (HERMANN, O. & LEGRAND G., 1998). Strobilurin fungicides also appear to have this effect in wheat, and strobilurin-based fungicides soon may be available for beet. The physiological effects of these fungicides on canopy senescence and photosynthetic efficiency are not well characterised, and it is not known how to preserve any yield advantage should application of these products cease in the future due to regulatory restrictions. Therefore, we examined the effect of triazole (flusilazole+carbendazim), and strobilurin (trifloxystrobin [in 2001] or pyraclostrobin [in 2002]) on sugar beet in comparison with two controls: untreated plots and plots treated with sulphur to control diseases but without any 'stay-green effect.' A randomised complete block design was used with 4 replications of each treatment using standard husbandry for the sugar beet crop.

RESULTS AND DISCUSSION

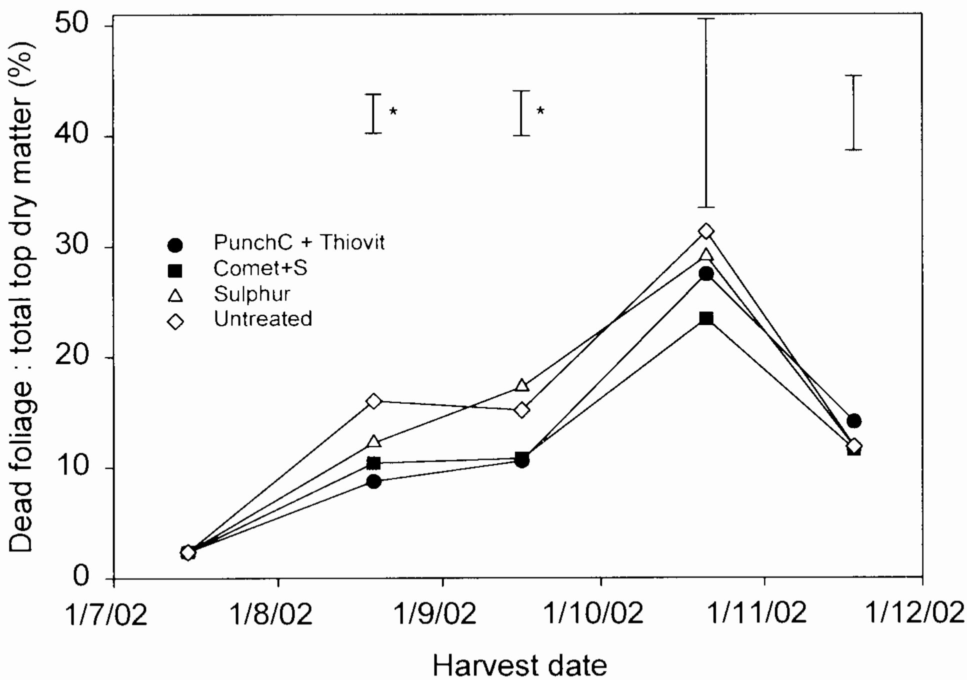
Application of fungicides had a significant effect on final root ($P < 0.01$) and sugar yield (Fig. 1). The yield increase was independent of disease effects since disease pressure was low and sugar yields were enhanced by the triazole and strobilurins compared to sulphur alone.

Fig.1. Sugar yield results from the field trial in 2002. The triazole treatment was PunchC (flusilazole+carbendazim), applied with or without sulphur (S). The strobilurin was Comet (pyraclostrobin), applied with or without sulphur. All fungicides were applied when signs of powdery mildew were first observed, on 19 July, 2002. Values in parentheses are the powdery mildew scores (as % of leaf area infected) on 6 September, 2002. Plots were harvested on 12 November, 2002. Bar represents LSD for treatment effect, P<0.001. Bars with the same letters are not significantly different using Fisher's LSD.



During the autumn the senescence of the canopy was delayed by fungicide treatments (Fig. 2), and the effect of triazole and strobilurin helped maintain a greater percentage green crop cover compared with untreated or sulphur-treated plots. The 'stay-green' effect was also evident from measurements of leaf chlorophyll content, with increasing effect with leaf age (Fig. 3). In newly expanded leaves, there were no treatment differences in chlorophyll content or the maximum (light-saturated) net photosynthetic rate (A_{max}) (Fig. 4). This indicates that the competence of the remaining upper canopy in untreated plants was not affected as much as the total leaf area. Results from a pot experiment conducted in the glasshouse showed that in the absence of disease the strobilurin and triazole fungicides had no effect on leaf expansion, A_{max} or leaf chlorophyll content within 40 d of treatment.

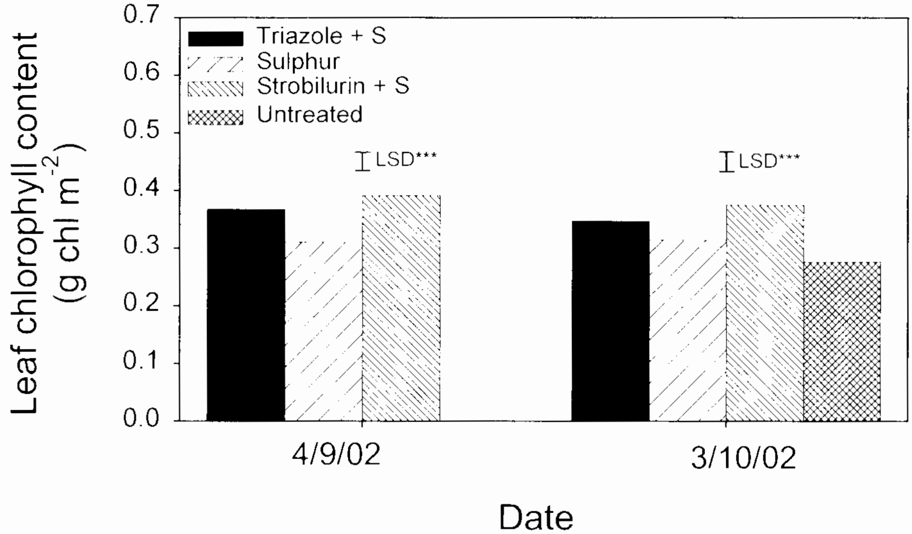
Fig. 2. The proportion of dead foliage to total top dry matter at each harvest. Dead foliage (in g m⁻²) was collected on wire mesh placed under the plants, which were re-visited at each harvest. Top weights (in g m⁻²) were determined on separate areas of the same plot. Treatments were the same as in Fig. 1. Bars represent LSD for the treatment effect, significant at P<0.05, where indicated).



Therefore, the effects are most likely seen as the crop begins to age. In the field, the most obvious effect of the systemic fungicides was on maintaining green leaf area lower in the canopy; however, these leaves were largely shaded by the canopy and showed minimal net photosynthesis under ambient light conditions, and therefore apparently contributed little to the carbon gain of the plant. If younger leaves at the top of the canopy showed little treatment effect, and lower leaves contribute little under any circumstance, where does the increased productivity in treated plants come from?

One possible answer is that leaves in *middle* regions of the canopy had greater output and photosynthetic efficiency in the treated plants. To test this, simultaneous measurements of A_{max} and chlorophyll fluorescence, and indicator of photosynthetic efficiency, were made in the field in 2002. Compared with the triazole and strobilurin treatments, sulphur-treated leaves showed lower A_{max} in middle-canopy positions (Fig. 4). Photosynthetic rates were not simply a function of leaf greenness, however. Sulphur-treated leaves also had lower A_{max} when expressed on the basis of leaf chlorophyll content, indicating that photosynthetic efficiency was decreased in this treatment. This was confirmed by measurements of ΦPS_{II}, which reflects the actual efficiency of photosystem II reaction centres in the light (Table 1). Since there were no differences in the intrinsic efficiency of photosystem II (indicated by the fluorescence parameter

Fig. 3. Leaf chlorophyll content measured with a SPAD meter on two separate dates. SPAD values were converted to chlorophyll content using an empirically-derived calibration curve (C. Malnou, personal communication). Values for each treatment are averaged across leaves sampled from top and middle positions within the canopy. Leaves at each position were sampled on one plant per plot, 3 plots per treatment. The value for each leaf was the average of five readings. Bar represents LSD for treatment effect, P< 0.001.



Fv/Fm), it is likely that the remaining photosynthetic apparatus in senescing leaves was fully intact. Therefore, the lower output of illuminated leaves in the sulphur-only treatment suggests that photosynthesis was biochemically down-regulated. Higher levels of non-photochemical quenching (qNP, thermal dissipation of excess light energy) measured in sulphur-treated leaves corroborate this possibility. There is evidence that as the requirement for photosynthetic products diminishes in a senescing leaf, photosynthetic output is regulated to match demand (LU, Q. *et al.*, 2002).

CONCLUSION

The mechanisms are not fully known by which triazole and strobilurins delay senescence and the concomitant changes in leaf physiology. However, these products provide a clear yield benefit that does not seem to be related to disease control. The data indicate the important role of canopy efficiency in maintaining sugar accumulation during the autumn. More information is needed on how disease and abiotic factors influence the performance of the sugar beet canopy, how canopy architecture could be manipulated to optimise use of solar radiation, and how the maximum photosynthetic efficiency can be achieved through the autumn months.

Fig. 4. Net photosynthesis measured under saturating light conditions (A_{max}) on leaves in different canopy positions in the field on 4 September, 2002. One leaf per block was measured (3 replications). Data were analyzed by ANOVA. Bar indicates the LSD for the Treatment x Position interaction term, significant at P<0.01.

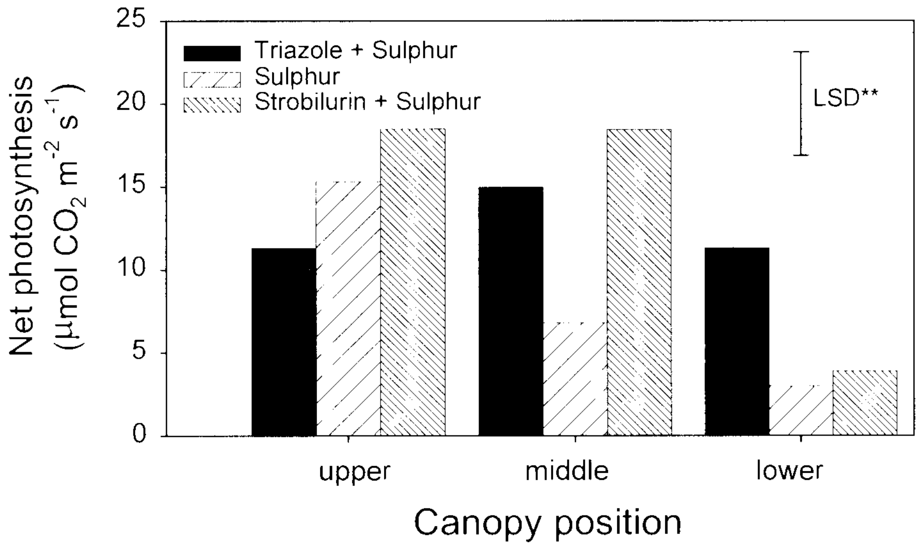


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Table 1. Chlorophyll fluorescence parameters measured on leaves at three canopy positions on 4/9/02. See Fig. 1 for treatments. Fv/Fm was measured on dark-adapted leaves, ΦPS_{II} was measured after 3 min at 1500 $\mu mol\ m^{-2}s^{-1}$ actinic light, followed by far red light to determine Fo' used in the calculation of qNP. LSD are shown for source of variation: treatment (T), canopy position (P) and the interaction term. ns = not significant as determined by ANOVA.

Treatment	ΦPS_{II}			Fv/Fm			qNP		
	top	middle	lower	top	middle	lower	top	middle	lower
Strobilurin+S	0.303	0.253	0.086	0.829	0.830	0.850	0.383	0.300	0.569
Triazole+S	0.192	0.261	0.146	0.823	0.830	0.853	0.473	0.244	0.545
Sulphur	0.184	0.092	0.043	0.835	0.846	0.848	0.618	0.567	0.697
LSD (T)		0.052 (P< 0.001)			0.016 (ns)			0.162 (P<0.05)	
LSD (P)		0.052 (P < 0.001)			0.016 (P < 0.05)			0.162 (P<0.05)	
LSD (TxP)		0.089 (P< 0.05)			0.028 (ns)			0.280 (ns)	