Early season weed control in maize, new insights for a known phenomenon

Frühe Unkrautkontrolle in Mais, neue Erkenntnisse zu einem bekannten Phänomen

Willy Rueegg* & Albrecht Michel
Syngenta Crop Protection AG, Werk Rosental, Schwarzwaldallee 215, 4058 Basel, Switzerland
*Corresponding author, willy_t.rueegg@syngenta.com

DOI: 10.5073/jka.2012.434.046

Summary

The studies demonstrate the effect of early weed control on maize yields compared to late weed control with corresponding herbicide control strategies. Maize yield with a late weed control strategy was 10 % lower compared to a strategy controlling weeds early based on ten field trials. Interestingly the thousand-grain-weight (TGW) seems not to be affected significantly but the number of grains per cob were identified as major responsible factor for yield decrease. To explain these field effects, glasshouse test were undertaken to simulate the competitive weed effects. Specific methods allowed to grow maize plants to the yield stage even in the glasshouse under representative conditions. The field observations were confirmed clearly. The early yield parameters like number of grains per cob were mainly affected by the timing of weed control treatments (early vs. late), while the parameter grain rows per cob was more sensible than the number of grains per row. The TGW remained basically consistent. As a follow-up experiment, maize plants were grown under glasshouse conditions and as well grown to the yield stage. This time, subsamples were taken and the cob formation at very early stages was investigated destructively to follow the development of the cob formation. Ovules and rows were counted on 'mini cobs' (cobs with a size of 4 mm were harvested) under the binocular. Clearly, weed competition had an impact on the induction of the number of ovules early on and at the end impacted on the yield in ripe cobs.

Keywords: Herbicide, yield, yield parameter, *Zea mays* L.

Zusammenfassung

Die vorliegenden Studien belegen die Wirkung der frühen Unkrautbekämpfung in Mais auf den Ertrag im Vergleich zu später Unkrautbekämpfung mit entsprechenden Herbizid-Bekämpfungs-strategien. Der Maisertrag mit einer späten Unkrautbekämpfungsstrategie war 10 % niedriger im Vergleich zu einer frühen Unkrautbekämpfungsstrategie. Diese Angaben basieren auf zehn Feldversuchen. Interessanterweise scheint das Tausendkorngewicht (TKG) nicht erheblich betroffen zu sein, aber die Anzahl der Körner pro Kolben wurde als Faktor für die Ertragsminderung identifiziert. Um diese Effekte zu klären, wurden Gewächshaustests durchgeführt, welche kompetitiven Bedingungen simulierten. Dank spezifischer Methoden konnten Maispflanzen selbst im Gewächshaus unter repräsentativen Bedingungen bis zur Kornreife gehalten werden. Die Feldbeobachtungen wurden eindeutig bestätigt: Die frühen Ertragsparameter - wie Anzahl der Körner pro Kolben - wurden vor allem durch den Zeitpunkt der Unkrautbekämpfung (früh oder spät) betroffen, wovon die Parameter Reihen pro Kolben stärker reagierten als die Anzahl Körner pro Reihe. Das TKG blieb im Wesentlichen konstant. Als Nachfolge-Experiment wurden wiederum Pflanzen unter Gewächshausbedingungen angezogen und bis zur Ertragsreife angezogen Diesmal wurden destruktiv Stichproben entnommen und die Kolbenbildung in sehr frühen Stadien untersucht. 'Mini-Maiskolben' (4 mm Kolbengröße) wurden geerntet und Kornanlagen unter dem Binokular gezählt. Ganz klar konnte auch hier der Einfluss von früher oder später Unkrautkonkurrenz auf die Induktion der Zahl der Samenanlagen festgestellt werden.

Stichwörter: Ertrag, Ertragsparameter, Herbizid, *Zea mays* L.

1. Introduction

Many studies concerning ‚weed free' or 'critical periods' in maize were conducted in the 1980th, early 90th (HALL et al., 1992). They basically all concluded with the practical recommendation of complete weed free conditions between 3 and 6-8 leaves of maize plants in most regions of Europe. Nevertheless, these crop basics and the application for these findings have become dusty over time and are neglected in the agricultural practice. FERRERO et al. (2010) confirmed that still today a weed free period of 25 days after maize emergence is mandatory under northern Italian cropping conditions to avoid grain yield loss. It is hard to believe that weeds at such an early stage of maize growth can impact yield. Due to the limited biomass and ground cover it seems unlikely that small weeds can have such an effect on the maize yield. Publications of RAJEAN and SWANTON (2001) showed clearly that young maize plants react sensitively: From the very moment weeds appear, maize detects them by differences in light quality. Maize adopts a defense strategy, called shade avoidance and tries to grow away from the weeds (PAGE et al., 2009). Maize that is stressed grows smaller roots and elongated shoots, resulting in an imbalanced plant. This stress can impact the early yield parameters like rows per cob and number of ovules per row. Since drought stress as such has only limited impact on maize yield before 12 leaf stage (derived from RHOADS and BENNETT, 1990) we believe that this shade avoidance is important. Therefore it makes sense to understand if we can reduce this effect through early season weed control with herbicides, because former studies relied on manual removal of the weeds in most of the cases.

2. Materials and methods

2.1 Field trials to assess effects of weed control timings on yield and yield parameters under field conditions

In 2009, an European field trial program was conducted with 10 trials in Italy (4 trials), Spain (1), Hungary (2) and Poland (3). Besides of an untreated check, the following herbicide application timings were conducted with the aim to achieve commercially acceptable weed control at row closure (> 90 % weed control - biomass reduction): 1) pre-emergent herbicide followed by post-emergent foliar herbicide (PRE-PO), 2) early post timing with a residual herbicide (EPO), 3) post-emergent herbicide (PO) and pre-emergent herbicide (PRE). Per trial, three randomized replicates were set up.

Weed control after 40-50 and 80-90 DAP (days after planting) was assessed for each treatment (ANONYMOUS, 2006). At grain maturity, grain yields and TGW (1000-grain-weight) were assessed. The number of grains per cob was calculated assuming one cob/plant and plant densities according to the trial and using yield/ha and TGW as parameters for calculation. Yield data are expressed in % of the best treatment.

2.2 Greenhouse experiments to assess impact of weeds and water stress on yield and yield parameters under controlled conditions

In parallel to the field trials, glasshouse studies were conducted to understand the reaction of maize plants in competition with weeds and water stress in a more detailed way. The experiment was conducted in the greenhouses of the Institute de Biotechnologie des Plantes, France. The test plants were the maize variety DK315 and *Chenopodium album* L., (CHEAL) from Herbiseed (UK). CHEAL plants were used to induce the weed stress. Maize (1 grain) and weed (100 seeds) were sown in 20 cm diameter pots containing a mixture of perlite and loam. In February, 64 pots were sown, 32 pots with maize alone, the other 32 pots containing maize and *Chenopodium album*. The pots were arranged in blocks of four pots. One block contained all four test treatments: 1) no weed competition - no water stress (optimal); 2) no weed + water stress; 3) weed competition - no water stress; 4) weed competition + water stress. In order to keep realistic conditions, the pots were surrounded by additional borders of maize. Growing conditions were 18 °C / 15 °C (day / night) temperatures, photoperiod of 14 h. The plants were grown five weeks under these conditions until the weeds were removed. Several parameters were measured on the maize plants. The maize plants were then water stressed. Half of the control plants (16 plants grown without weed competition) and half the stressed plants (16 plants grown under weed competition) were deprived of watering during 16 days. The watering was resumed when the maize leaves began to scroll along their axis. At this time (end March), the temperature of the greenhouse was raised to 23 °C / 18 °C (day / night). At anthesis, the stems of maize plants (experimental plants as well as bordering plants) were gently shaken regularly to ensure a complete pollination. The plants were kept until complete ripening of the grains. End of July, the ears were collected and the aerial part and the roots weighed separately. For each ear, the kernels were counted and weighed. The Newman-Keuls test (NKT) was used to run the statistical analyis significance at the level of 0.05.

2.3 Greenhouse experiments to study the early cob formation depending on weed and water stress under controlled conditions

Growing conditions were the same as described under 2.2. Two levels of weed and water stress were applied to maize plants grown under glasshouse conditions and compared to no stress at all. The weed stress was applied from the germination to 3-4 leaf of maize, respectively 7-8 leaf of maize. The water stress started for both weed stress variants at 3-4 leaf of maize. The superimposed weed stress (weed removal at 7-8) was called HS = heavy stress the other one MS = mild stress. The ears of the maize plants not exposed to any stress (= control), HS or MS were dissected at different growth stages of the maize plants namely at 12 and 14 leaves, respectively. The stages of sampling were either before pollination (12 or 14 leaf stages) or after pollination (17 leaves and maturity of kernels) to understand the dynamics of ovule formation. Earlier sampling was not possible due to too small size of the mini-cobs. Several parameters were measured on the young ears: Length, number of spikelet along the ear axis, and number of rows per ear as shown in Figure 1. The Newman-Keuls test (NKT) was used to run the statistical analyis, significance at the level of 0.05.

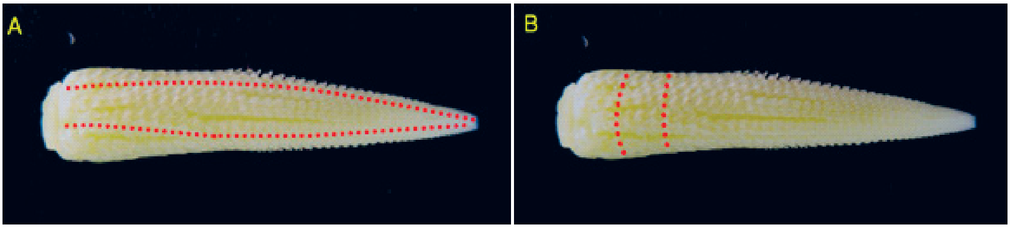

Fig. 1 Methods for counting the grains along the ear axis (A) and the number of rows round the ear (B) at very early grow stages; two measurements are carried out for each value. The length of the spikelet was 2-4 mm, earlier sampling stages were not useful as ovules on the mini-cob were not detectable.

Abb. 1 *Methoden zur Zählung der Körner entlang der Kolben-Achse (A) und die Anzahl der Kornreihen um die Kolben (B) in sehr frühen Wachstumsstadien; Zwei Messungen werden für jeden Wert durchgeführt. Die Länge der Ährchen lag bei 2-4 mm. Probenahme zu einem früheren Stadien waren nicht nützlich da die Ovulas auf den Minikolben nicht sichtbar waren.*

3. Results and discussion

3.1 Field trials to assess effects of weed control timings on yield and yield parameters under field conditions

All treatments were fully selective and no phytotoxicity was expected and observed. Table 1 shows a clear trend of inferior yield in late weed control programs - respectively long weed exposure. Though the level of weed control in the PRE-PO, EPO residual and PO treatments was comparable and commercially acceptable at row closure, the average yield across all sites of the post treatment was lower then those of the early weed control programs. The yield loss was 11 % compared to the best treatment. The pre-emergent treatment (PRE) achieved the lowest weed control efficacy at row closure, but still controlled early on weeds on a high enough level (see Table 1 rating at 40-50 DAP) to lose less yield then the post-emergent treatment.

The results shown in Table 1 are a strong indicator that the timing of the herbicide application can play an important role on maize yield formation, not only the level of control. To explain this model, trials were established in the glasshouse.

Tab. 1 Average of relative maize yield (in % of treatment with highest yield) depending on weed control timings (days after planting DAP) and control level (% weed control) based on 10 trials in HU, IT, FR and PL.

Tab. 1 *Durchschnitt des relativen Maisertrags (in % der Behandlung mit dem höchsten Ertrag) in Abhängigkeit des Anwendungszeitpunktes (Tage nach Saat DAP) und der Effizienz der Unkrautkontrolle (% Unkrautkontrolle) basierend auf 10 Feldversuchen in Ungarn, Italien, Frankreich und Polen.*

Timing of herbicide application	Pre followed by post	Early post residual	Post-emergent	Pre-emergent	No weed control
Relative yield	100 %	99 %	89 %	95 %	59 %
Weed control at 40-50 DAP	94 %	92 %	75 %	84 %	0 %
Weed control at 80-90 DAP	96 %	91 %	92 %	82 %	0 %

3.2 Greenhouse experiments to assess impact of weeds and water stress on yield and yield parameters under controlled conditions

Despite of weed competition, the number of leaves was only slightly affected under 'no weed' conditions. The average in the 'no weed' treatment was 6.00 leaves per plant and under weedy conditions 5.84 leaves just before the occurrence of water stress. This difference was not significant therefore we assume that the plants were morphologically in a comparable shape when the water stress kicked in. Interestingly, now the plants reacted heavily in their response on number of grains per cob, while the thousand grain weight was consistent. In Figure 2 and 3, we can clearly see that the early weed stress until five leaf stage significantly impacted on the number of grains. These effects became stronger under water stress and even stronger when weed and water stress were combined. Interestingly the TGW has not been impacted at all through the increasing stress conditions. The TGW is formed after the stress period in this experiment and the new watering after the stress conditions did therefore support the TGW formation. The model demonstrates a) the interaction of the two stress factors weed and water and b) the high sensitivity of the grain-number-per-cob as one of the most sensitive yield factor during the early development of maize. This model enables to understand potential interactions in the behaviour of the field experiment as described under 2.1 and 3.1.

Nevertheless, there was no over-compensation and as well no stress memory effect. What is still missing is the visualisation of the early cob formation as a proof of the reduction of grains through early stress occurrence. An experiment was conducted to clarify this question and is described under 2.3 and 3.3.

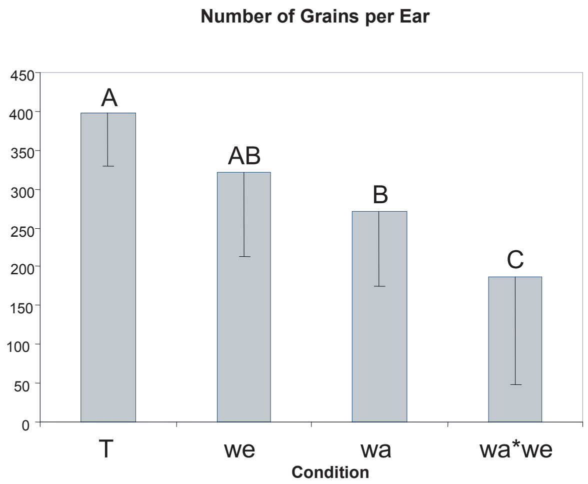

Fig. 2 Number of grains per ear of maize exposed to different growth conditions. T, Control; we, with weed stress only; wa, with water stress only; wa*we: with weed and water stress. Different letters in the bars stand for a significant difference between the conditions at the level of 0.05 (Newman-Keuls test).

Abb. 2 *Anzahl der Körner pro Kolben nach verschiedenen Wachstumsbedingungen. T, Kontrollbehandlung; we, mit Unkrautstress; wa, mit Trockenstress; wa*we, mit Unkraut- und Trockenstress. Unterschiedliche Buchstaben stehen für einen signifikanten Unterschied zwischen den Bedingungen (α = 0,05; Newman-Keuls-Test).*

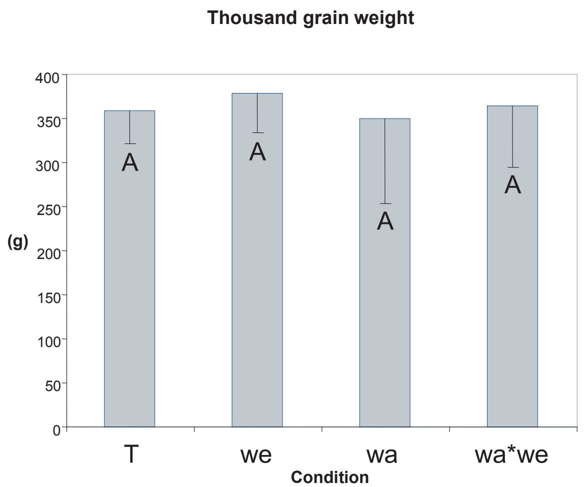

Fig. 3 TGW of maize grains exposed to different growth conditions. T, Control; we, with weed stress only; wa, with water stress only; wa*we: with weed and water stress. Different letters in the bars stand for a significant difference between the conditions at the level of 0.05 (Newman-Keuls test).

Abb. 3 *Tausendkorngewicht von Maiskörnern nach verschiedenen Wachstumsbedingungen. T, Kontrollbehandlung; we, mit Unkrautstress; wa, mit Trockenstress; wa*we, mit Unkraut- und Trockenstress. Unterschiedliche Buchstaben stehen für einen signifikanten Unterschied zwischen den Bedingungen (α = 0.05; Newman-Keuls-Test).*

3.3 Greenhouse experiments to study the early cob formation depending on weed and water stress under controlled conditions

Based on the experiments, independent of mild (MS) or heavy (HS) stress, the number of maize spikelet-rows per cob is significantly affected very early by weed stress (method see Fig. 1B). Figure 4 shows this clearly: Stressed plants either from MS (14.3 rows/cob) or HS (14.0 rows/cob) differed significantly from plants of the control treatment (15.9 rows/cob). Interestingly, the number of rows per ear did not change between the early sampling dates. The values obtained for 12-leaf sampling time (14.5 rows/ear) and for 14-leaf sampling time (14.9 rows) did not differ significantly, indicating that the formation process of this yield parameter has been terminated. The number of ovules per ear-row (method, see Fig. 1A tended to be decreased all above under HS but not under MS conditions (Fig. 5). This can be explained: Under MS, the (weed) stress stopped at the time when the parameter of number of ovules per row was initiated, while under HS the stress continued and therefore continued as well to impact the number of ovules per ear-row. The fact that the difference is not statistically significant could be linked to the difficulty to count ovules at the tip of the mini-cob precisely. As a control the number of grains per cob was counted on mature cobs (data not shown). They showed a significant difference of HS treatments compared to MS and control. Control and MS did not differ significantly. This indicates a certain compensation potential during this early cob formation process. Actually we would postulate that under MS conditions compensation is still possible but that under HS conditions, where the negative impact of stress is permanent negative, impacts can't be compensated anymore. The missing link is basically the confirmation of maize yield parameters in early crop stages under field conditions, depending on different weed control timings with herbicides. To cover this gap, field trials and corresponding mini-cob status investigations were conducted in the season 2011.

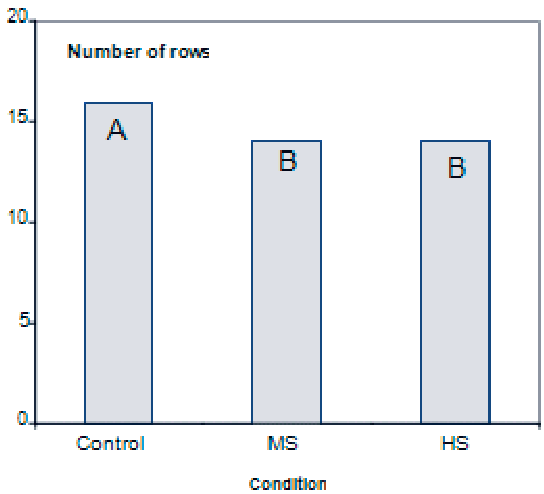

Fig. 4 Mean number of rows per ear, split by stress condition MS (medium stress) and HS (heavy stress) and unstressed control; the values include both sampling times (12 and 14 leaves). Different letters in the bars stand for a significant difference between the conditions at the level of 0.05 (Newman-Keuls-test).

Abb. 4 *Durchschnittliche Anzahl von Reihen pro Kolben nach verschiedenen Stressbedingungen MS (mässiger Stress) und HS (kräftiger Stress) und der nicht gestressten Kontrolle (Control). Unterschiedliche Buchstaben stehen für einen signifikanten Unterschied zwischen den Bedingungen (a = 0.05; Newman-Keuls-Test).*

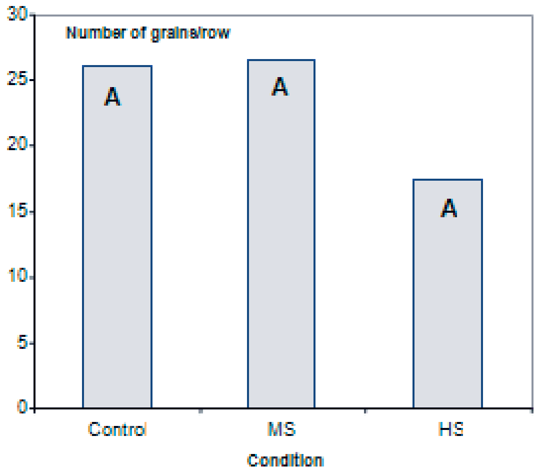

Fig. 5 Number of kernels per row, split by stress condition MS (medium stress) and HS (heavy stress) and unstressed control; each mean number gathers all the two sampling times Different letters in the bars stand for a significant difference between the conditions at the level of 0.05 (Newman-Keuls-test).

Abb. 5 *Durchschnittliche Anzahl von Körnern pro Kolbenreihe nach verschiedenen Stressbedingungen MS (mässiger Stress) und HS (kräftiger Stress) und der nicht gestressten Kontrolle (Control). Unterschiedliche Buchstaben stehen für einen signifikanten Unterschied zwischen den Bedingungen (α = 0.05; Newman-Keuls-Test).*

4. Discussion and conclusion

Basically the findings confirm the knowledge of maize growers and researchers generated since the 80s namely to control weeds in maize early to secure yield. This knowledge went dusty due to the fact that excellent post-emergent herbicides came to the market. These herbicides (mainly HPPD and ALS inhibitors) controlled weeds highly efficiently comparable to the popular residual herbicides. The fact early weed control was associated with environmental issues enforced this swap. But the reduction on efficiency as the main base for comparison is insufficient. The timing benefits of pre-emergent or early-post weed control on economic impact were probably not considered sufficiently. The fact that only timing differences of weed control measures at comparable weed control levels can cause a 10 % yield difference needs attention: At current average grain prices of USD 250/ton and the assumption of a grain yield of 12 t/ha, the cost of a late timing are significant and normally underestimated. Therefore a balanced view of weed control strategy is needed and early weed control strategies can lead to higher profits for the grower.

References

ANONYMOUS, 2006: EPPO GUIDELINE: WEEDS IN MAIZE PP 1/50 (3).

FERRERO, A., A. CRIVELLARI, F. TESIO AND F. VIDOTTO, 2010: CRITICAL PERIOD OF WEED COMPETITION IN MAIZE IN NORTH-WESTERN ITALY. IN: PROCEEDINGS 15TH EWRS SYMPOSIUM 2010, KAPOSVÁR. 192.

HALL, M.R., C.J. SWANTON AND G.W. ANDERSON, 1992. THE CRITICAL PERIOD OF WEED CONTROL IN GRAIN MAIZE (*ZEA MAYS*). WEED SCIENCE **40**, 441-447.

PAGE, E.R., M. TOLLENAAR, E.A. LEE, L. LUKENS AND C.J. SWANTON, 2009: DOES THE SHADE AVOIDANCE RESPONSE CONTRIBUTE TO THE CRITICAL PERIOD FOR WEED CONTROL IN MAIZE (*ZEA MAYS*)? WEED RESEARCH **49**, 563-571.

RAJEAN, I. AND C.J. SWANTON, 2001: UNDERSTANDING MAIZE-WEED COMPETITION: RESOURCE COMPETITION, LIGHT QUALITY AND THE WHOLE PLANT. FIELD CROPS RESEARCH **71**, 139-150.

RHOADS, F.M. AND J.M. BENNET, 1990: CORN. IN: STEWART, B.A. AND D.R. NIELSEN (EDS.): IRRIGATION OF AGRICULTURAL CROPS. AMERICAN SOCIETY OF AGRONOMY, MADISON, USA, 569-597.

SHAW, R.H. 1988: CLIMATE REQUIREMENT. IN: SPRAGUE, G.F. AND J.W. DUDLEY (EDS.): CORN AND CORN. IMPROVEMENT (3RD ED.). AGRONOMY SERIES: NO. **18**. ASA. MADISON, WISCONSIN, USA, 609-633.