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The influence of wind on the efficacy of some foliage-applied herbicides

Vindpåvirkning af nogle bladherbiciders effekt

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Summary

In a series of three experiments wind was applied with differing speed, duration and timing relative to herbicide spraying of container grown plants to elucidate whether wind could influence herbicidal efficacy. Strong wind applied to white mustard before or after spraying with bentazone yielded a slight synergistic effect, whilst wind did not interfere with treatments with a mixture of MCPA and dichlorprop. With lower wind speeds a slight antagonistic effect with bentazone on white mustard was found if wind was applied before and after spraying, or if applied before spraying with a one day period of rest. With a mixture of ioxynil and bromoxynil applied to fat-hen no interference of wind was found.

Probably wind interacts by affecting the herbicide coverage and transport. Shifts in efficacy level found with some wind treatments are in all cases too low to be of practical significance in a herbicide strategy applying factor adjusted doses.

Key words: wind, herbicides, relative potency, factor-adjusted doses.

Resumé

Vindens mulige indflydelse på herbiciders virkning var temaet for tre forsøg udført med to plantearter, tre herbicider, og forskellige vindpåvirkninger som forsøgsvariable. Ved meget kraftig vindpåvirkning af gul sennep før eller efter sprøjtning viste der sig en svag, synergistisk effekt med bentazon. Med et systemisk hormonmiddel (MCPA + dichlorprop) udeblev denne virkning. Svagere vind på gul sennep før og efter sprøjtning eller før sprøjtning med et døgns hvile gav en svag, antagonistisk effekt med bentazon. Vind efter eller umiddelbart før sprøjtning gav imidlertid ingen effekt. Med hvidmelet gåsefod var der ingen signifikante vekselvirkninger med behandlinger med en ioxynil + bromoxynil blanding.

Vinden gør sig formentlig gældende ved at påvirke bladdækning og transport af det udsprøjtede herbicid. Forskydningen i herbicideffektiviteten var i alle tilfælde så beskeden, at den næppe har praktisk betydning i en faktorkorrigeret doseringsstrategi.

Nøgleord: Vindpåvirkning, herbicid, relativ styrke, faktorkorrigeret dosering.

Introduction

With the growing concern in resource and pollution issues in agriculture demands have emerged on environmental and economical grounds for a reduction in the use of pesticides. As a consequence, herbicide research in Denmark has shifted towards a search for ways to reduce doses to the minimum level adequate for the level of control desired (27). The concept of factor-adjusted doses was developed as a framework for a herbicide application strategy for the farmer to take any plant, soil, and weather factor of major importance into consideration when deciding upon the actual level to apply (16).

Much research in Denmark and elsewhere has been devoted to elucidate whether and to what extent differing climatic factors will influence the activity of herbicides, as discussed theoretically by *Legg* (17) and *Cole* (2), and reviewed by *McCann* and *Whitehouse* (18) and by *Kristensen* and *Kudsk* (15). Among the factors investigated so far, soil moisture, air humidity and air temperature seem to be of major importance.

A greater part of herbicidal spraying is carried out during the periods when strong winds prevail and the soil is void of crop canopy. The increasing risk of drift with increasing wind speeds during spraying was often investigated (e.g.1,3, 6, 28), and wind may also influence the deposition of pesticide on plants (19,23). No literature was found, though, concerned with the possible change in efficacy entailed by acute physiological interferences of wind during or close to a herbicide application. Only *Savory* and *Hibbitt* (22) from phytotron experiments noted as an unintentional result a reduced effect of an ioxynil salt, which they reckoned as being due to the ventilation air flow in the chambers.

In this series of experiments the question was pursued whether wind is another factor to take into consideration when adjusting the dose according to actual conditions.

Methods

A series of three experiments was carried out, covering differing wind conditions, herbicides and plant species.

In the **first** experiment white mustard (*Sinapis alba*) at the 3-4 leaf stage and with three plants in each 1-liter pot was treated for five days in three climate simulators with a diurnally oscillating temperature of 10-19°C and light intensity up to 480 $\mu E/s.m^2$, a daylength of 18 h with 3 h of dawn and dusk, and a constant vapour pressure of 1226 Pa.

Wind regimes were: Zero (only background ventilation at 0.3 m/s), Before Spraying and After Spraying (average wind speed of 6.9 m/s for 1 1/2days, before or after spraying, respectively). Two herbicides each in 6 doses were used: Bentazone (as Basagran 480) was applied at 0, 8, 16, 32, 64, and 128 mg/ha; a mixture of a MCPA Na-salt (167 g/l) and a dichlorprop K-salt (500 g/l) was applied as DLG D-Propmix 67 at 0, 10, 30, 90, 270, and 810 mg/ha. There were three replications.

In the **second** experiment white mustard with 2-3 leaves in 2-liter pots each with three plants was kept for five days in the climate simulators with temperatures oscillating between 7.5 and 16.5°C, a maximum light intensity of 400 $\mu E/s.m^2$, 16 h daylength with 3 h of dawn and dusk, and a constant vapour pressure of 1065 Pa.

The five wind regimes were: Zero (ventilation of 0.3 m/s), Before Spraying and After Spraying (wind speed 2.9 m/s for 1 day, before or after spraying, respectively), Before + After Spraying (do, before and after spraying for altogether 2 days), Before With Rest (do, for 1 day, but with 1 day rest before spraying).

Bentazone was used as the sole herbicide in six doses as mentioned above, and there were 5 replications (8 untreated).

In the **third** experiment fat-hen *(Chenopodium album)* with 2-5 leaves in 2-liter pots each with three plants were kept for five days in simulators under conditions similar to those in the second experiment. The five wind regimes also were copied from that experiment, albeit wind speed was reduced to 1.5 m/s. Plants were sprayed with a mixture of esters of ioxynil and of bromoxynil (200 + 200 g/l, as Oxitril), at 0, 4, 12, 36, 108, and 324 mg/ha, and there were 5 replications (8 untreated).

In all experiments plants were grown outdoors before being transferred to climate simulators, so as to obtain plants with natural leaf surfaces. Plants were subirrigated and shielded automatically in case of rain, wind speeds over 5 m/s or air temperatures under 5°C, measured at

5 m height. After the five days in simulators plants were placed outdoors for a continued growth until harvest 8-12 days later.

In all experiments plants were grown in a 1:2 (w/w) mixture of sphagnum and soil. Spraying was carried out in a pot sprayer fitted with a boom with two nozzles (13). Hardi 4110-14 flat fan nozzles were used with a pressure of 2.0 bar and a boom speed of 5.6 km/h, yielding 145 l/ha. Wind effects in climate simulators were produced by tangential blowers blowing air horizontally through the plant population moving slowly (0.3 cm/s) through the entire chamber.

Wind speeds were measured before the actual experiments with a three-probe non-directional hotwire anemometer logging air current values every second.

The three plants per pot were harvested together, and fresh and dry weights recorded.

Results

The relationship between dose *(z)* and effect *(U),* measured as biomass produced, in numerous herbicide investigations have proven to follow a logistic curve described by the equation

$$U=(D-C)/(1+\exp(-2(a+b.\log(z)))),$$

with D and C being upper (low dose) and lower (high dose) limits, respectively, and a and b identifying the horizontal position and slope halfway between these limits (5,25). This similarity in behaviour renders possible the comparison of herbicidal effect under differing conditions by measuring the displacement of the dose-response curve, or the relative potency, of the herbicide in question. The regression analyses carried out yielded the results shown in Tables 1, 2 and 3. In all cases parallelism of response curves was tested and accepted (cfr. figures for tests for lack of fit).

Table 1. 1st experiment (dry weight): Relative potency of bentazon and of dichlorprop+MCPA with three wind regimes: no wind ("zero"), wind of 6.9 m/s before spraying ("pre"), and after spraying ("post"). Relative potency with zero-wind was assigned a unity magnitude. The 95% confidence limits in ().

1.forsøg (if. tørvægte): Relativ styrke af bentazon samt af dichlorprop+MCPA under tre vindforhold: Ingen vind ("zero"), vind med 6.9 m/s før sprøjtning ("pre"), og efter sprøjtning ("post"). Relativ styrke er sat til 1 for ingen vind. 95 pct.konfidensgrænser i ().

	Bentazone	Dichlorprop + MCPA
Wind regime		
Zero	1	1
Pre	1.22 (1.09-1.35)	0.98 (0.85-1.12)
Post	1.21 (1.08-1.34)	0.99 (0.90-1.08)

Test for lack of fit:
$F_{47,130,0.95}$: 0.549 (bentazone), 0.778 (dichlorprop + MCPA)

Table 2. 2nd experiment (dry weight): Relative potency of bentazone with five wind regimes: no wind ("zero"), wind of 2.9 m/s before spraying ("pre"), after spraying ("post"), before and after spraying ("pre + post"), and before spraying with 1 day's rest ("pre/rest"). Relative potency with zero-wind was assigned a unity magnitude. Upper and lower 95% confidence limits in ().

2.forsøg (if. tørvægt): relativ styrke af bentazon under fem vindforhold: Ingen vind ("zero"), vind med 2.9 m/s før sprøjtning ("pre"), efter sprøjtning ("post"), før og efter sprøjtning ("pre + post"), og før sprøjtning med 1 døgns hvile ("pre/rest"). Relativ styrke er sat til 1 for ingen vind. 95 pct.-konfidensgrænser i ().

Wind regime	
Zero	1
Pre	0.91 (0.74-1.08)
Post	1.09 (0.89-1.30)
Pre + post	0.77 (0.63-0.92)
Pre/rest	0.78 (0.63-0.92)

Test for lack of fit: $F_{4,203,0.95}=1.083$

In the third experiment, the second lowest dose of 12 g/ha of ioxynil + bromoxynil with several of the wind regimes seemed to have stimulated growth, such that plant weights were larger than with untreated plants. A discussion of this phenomena is given by *Pestemer* and *Günther* (20). As pointed out by *Streibig* (24) records from such sublethal doses enhancing growth may be neglected, and this was done accordingly.

Table 3. 3rd experiment (dry weight): Relative potency of ioxynil + bromoxynil with five wind regimes: no wind ("zero"), wind of 1.5 m/s before spraying ("pre"), after ("post"), before and after spraying ("pre + post"), and before spraying with 1 day's rest ("pre/rest"). Relative potency with zero-wind was assigned a unity magnitude. The 95% confidence limits in ().
3.forsøg (if. tørvægt): relativ styrke af ioxynil + bromoxynil under fem vindforhold: Ingen vind ("zero"), vind med 1.5 m/s før sprøjtning ("pre"), efter sprøjtning ("post"), før og efter sprøjtning ("pre + post"), og før sprøjtning med 1 døgns hvile ("pre/rest"). Relativ styrke er sat til 1 for ingen vind. 95 pct. konfidensgrænser i ().

Wind regime	
Zero	1
Pre	0.92 (0.76-1.09)
Post	0.90 (0.74-1.06)
Pre + post	1.12 (0.92-1.32)
Pre/rest	1.07 (0.88-1.25)
Test for lack of fit:	$F_{4,203,0.95}$=0.220

In the first and the third experiment there was no significant difference between weights of non-sprayed plants from the different wind-regimes. In the second experiment, wind seems to have reduced plant weights (Table 4).

Table 4. Average weights (in g) of unsprayed plants with differing duration of wind in the second experiment. Values within a column with the same letter attached are not significantly different.
Usprøjtede planters vægt (i g) ved forskellig varighed af vinden i 2. forsøg. Talværdier med samme bogstavsmærke inden for en søjle er ikke signifikant forskellige.

	Fresh weight	Dry weight
Wind regime		
No wind	23.95a	1.94a
Wind for 24 h	21.48ab	1.75b
Wind for 48 h	19.27b	1.56c

Discussion

With the three experiments in this series indications of possible interactions between wind and herbicide differed greatly: With the strong wind of the **first** experiment no effect of wind on plant growth was found. The wind effect on the activity of bentazone on white mustard was synergistic, though, but this was not the case with dichlorprop + MCPA.

In the **second** experiment the weaker wind seems to have depressed growth of white mustard slightly. Effects of wind on the activity of bentazone were antagonistic in treatments with wind applied both before and after spraying, and with wind applied before with a one day's rest. In other cases interactions were not significant.

In the **third** experiment the weaker wind did not influence growth of fat-hen, neither were there any significant interactions between wind and the herbicidal effect of ioxynil + bromoxynil.

These differences in behaviour probably reflect conflicting mechanisms by which wind may affect plant physiology, as will be touched in the following.

Natural wind within plant stands or very close to the ground is difficult to characterize or to relate to prevailing wind at common measurement heights, as obviously it depend heavily on geometry, height and density of a heterogenous selection of obstacles in the form of soil and vegetation elements (7, 8, 11). Some practical measurements carried out in the context of spray deposition studies showed typical values of wind speed at 5-10 cm height in a 3 cm dense lane to be around 1-3 m/s at times of a wind speed at 2 m height of 5-6 m/s (*Nordbo,* unpublished results). Only seldom, for shorter periods or on especially exposed spots wind speeds at a height of weed plants in early spring will reach values of 7 m/s as applied in the first experiment.

One effect of wind is the abration of leaf surfaces, the more the stronger the wind. Primarily this is effected by the collisions of leaves in denser stands, but even wind itself produces a noteable wear (8,21). The outer wax layer is especially affected, but epicuticular cells may also be wounded, inflicting an increased conductance, by way of which the penetration of herbicide as well as transpiration rate may increase. On the other hand *Hunt* and *Baker* (10) working with chlormequat showed, that an improved liquid coverage of wheat and barley leaf surfaces was obtained by surface wounding, rather than an increase in inwards transport velocity.

Probably, the outcome of the first experiment can be ascribed to an increased abration of leaves which on one hand may have permitted an increased uptake of both herbicides. With the systemic hormone product, on the other hand, internal translocation may have been impeded by stress caused by an increased transpiration, such that an increase in herbicide uptake in effect was outbalanced.

While abration may explain the results from the strong wind treatments, other physical and physiological mechanisms may counter these effects at lower wind speeds. Wind applied after spraying may increase the evaporation rate and thus the drying out of spray droplets. It is generally believed, that the uptake of a herbicide, particularly of a water-soluble herbicide, is reduced, when it is no longer in solution. Furthermore, wind applied after and especially wind applied before spraying may inflict an acutely increased resistance to stomatal transport as a response to the potentially increased transpiration, and at the same time a reduced photosynthesis following the decline in leaf temperature. This is particularly the case with well watered plants, as opposed to plants already suffering from water stress, as discussed by *Grace* (8). Even vibrations (as also produced by wind) may reduce growth processes through some ethylene-mediated, yet unknown mechanism (12).

Analoguous to the effect on the efficacy of some foliage-applied herbicides of drought (14) or of lower air temperature or humidity (18, 26), wind stress thus theoretically may impede the penetration and translocation of herbicide. If such physiological restraint actually ocurred, it still evades explanation why, then, only those two out of four treatments with wind in the second experiment showed the antagonism, and why growth of the untreated plants of the first and the third experiment was not generally retarded.

With these observations it is demonstrated, that wind speed and durability, the type of herbicide and the plant species in question all act together to form the outcome of any acute wind influence on herbicidal efficacy. However, in this series of experiments herbicides were chosen which can be regarded as being among the more sensitive to climatic stress factors (15). Yet synergistic or antagonistic effects of wind in no case exceeded a magnitude of approx. 20% of the reference herbicidal efficacy with no wind. Such a small interference supposedly has little practical relevance, and hardly urges for further research in this context of factor-adjusted dosage.

The synergistic effect in the first experiment still points out possible incidences, where crop leaves recently damaged by a gale, hailstorm, tractor movements or even preceding pesticide applications, and then being sprayed, may fall victim to the damaging effect of a herbicide of little selectivity, as already noted by *Dewey et al.* (4). A range of studies quoted by *Pitcairn* and *Grace* (21), though, indicate a fair repairance of abraded leaf surface tissue to take place within few days, although *Hallam* (9) showed, that waxes regenerates at a significant rate only with younger and fast growing leaves.

Conclusion

The effect of wind on herbicidal efficacy varied with plant species, herbicide and wind conditions. Strong wind applied to white mustard before or after spraying with bentazone yielded a synergistic effect of approx. 20%, whilst with a dichlorprop + MCPA spraying no interference was observed. With lower windspeeds an approx. 20% antagonistic effect with bentazone on white mustard was found, if wind was applied before and after spraying, or if applied before spraying with a one day period of rest. With ioxynil + bromoxynil applied to fat-hen no interference of wind was found.

References

1. *Bache, D.H.; Lawson, T.J. & Uk, S.* 1988. Development of a criterion for defining spray drift. Atmos Envir. 22, 131-135.
2. *Cole, D.J.* 1983. The effects of environmental factors on the metabolism of herbicides in plants. In: Aspects of Applied Biology 4: Influence of Environmental Factors on Herbicide Performance and Crop and Weed Biology, 245-252.
3. *Cooke, B.K.; Hislop, E.C.; Herrington, P.J.; Western, N.M. & Humpherson-Jones, F.* 1990. Air-

assisted spraying of arable crops in relation to deposition, drift and pesticide performance. Crop Prot. 9, 303-311.

4. *Dewey, O.R.; Grefory, P. & Pfeiffer, R.K.* 1956. Factors affecting the susceptibility of peas to selective dinitro-herbicides. In: Proceedings of the 3rd British Weed Control Conference, 3, 313-326.
5. *Finney, D.J.* 1979. Bioassay and the practice of statistical inference. Int. Stat. Rev. 47, 1-12.
6. *Goering, C.E. & Butler, B.J.* 1975. Paired field studies of herbicide drift. Transaction ASAE 18, 27-34.
7. *Goudrian, J.* 1977. Crop micro meteorology: A simulation study. PUDOC, Wageningen. 249pp.
8. *Grace, J.* 1977. Plant response to wind. Academic Press, London. 204pp.
9. *Hallam, N.D.* 1970. Growth and regeneration of waxes on the leaves of Eucalyptus. Planta 93, 257-268.
10. *Hunt, G.M. & Baker, E.A.* 1983. Environmental factors affecting the retention and uptake of chlormequat into cereal leaves. In: Aspects of Applied Biology 4: Influence of Environmental Factors on Herbicide Performance and Crop and Weed Biology, 179-185.
11. *Johnstone, D.R.* 1985. Physics and meteorology. In: *Haskell, P.T.* (ed.) Pesticide application: Principles and practice. Oxford Univ. Press, 35-67.
12. *Jones, H.G.* 1983. Plants and microclimate. A qualitative approach to environmental plant physiology. Cambridge University Press, 323pp.
13. *Kristensen, J.L.* 1988. Pottesprøjte til brug ved pesticidundersøgelser i kar- og potteforsøg. Institut for Ukrudtsbekæmpelse, Slagelse, DK, 12pp.
14. *Kristensen, J.L.* 1990. Jordfugtighedens indflydelse på virkninger af bladherbicider. In: 7. Danske Planteværnskonference/Ukrudt, Planteværnscentret, Lyngby, 131-139.
15. *Kristensen, J.L. & Kudsk, P.* 1991. Klimafaktorernes indflydelse på bladherbicidernes virkning. In: 8. Danske Planteværnskonference/Ukrudt, 117-133.
16. *Kudsk, P.* 1989. Experiences with reduced herbicide doses in Denmark and the development of the concept of factor-adjusted doses. In: Brighton Crop Protection Conference - Weeds, 545-554.
17. *Legg, B.J.* 1983. Micrometeorology and the influence of local variations of environment on plant growth and herbicidal performance. In: Aspects of Applied Biology 4: Influence of Environmental Factors on Herbicide Performance and Crop and Weed Biology, 15-31.
18. *McCann, A.W. & Whitehouse, P.* 1983. A review of environment-formulation interactions in relation to the foliar persistence, uptake and translocation of herbicides. In: Aspects of Applied Biology 4: Influence of Environmental Factors on Herbicide Performance and Crop and Weed Biology, 329-344.
19. *Nordbo, E.; Taylor, W.A. & Kirknel, E.* 1991. Væskeafsætningens omfang og ensartethed ved konventionel og luftassisteret sprøjtning. In: 8. Danske PLanteværnskonference/Ukrudt. 177-187.
20. *Pestemer, W. & Günther, P.* 1991. No-Observable-Effect Level (NOEL). In: *Streibig, J.C. & Kudsk, P.* (eds): Herbicide bioassay. CRC Press, chap. 9 (in press).
21. *Pitcairn, C.E.R. & Grace, J.* 1985. Wind and surface damage. In: *Grace, J.* (ed.): Effects of shelter on the physiology of plants and animals. Progress in Biometeorolgy, vol. 2. Swets & Zeitlinger, Lisse, 115-126.
22. *Savory, B.M. & Hibbitt, C.J.* 1972. Artefacts in controlled environment studies. In: Proceedings of the 11th British Weed Control Conference, 2, 648-653.
23. *Schaeffer, G.W. & Allsop, K.* 1983. Spray droplet behaviour above and within the crop. In: 10th International Congress of Plant Protection, Brighton, UK, 1057-1065.
24. *Streibig, J.C.* 1980. Models for curve-fitting herbicide dose response data. Acta Agric. Scandi. 30, 59-64.
25. *Streibig, J.C.* 1988. Herbicide bioassay. Weed Res. 28, 479-484.
26. *Thonke, K.E.* 1984. Temperaturens og luftfugtighedens indflydelse på 3 forskellige herbiciders effekt. In: Klimatfaktorers inverkan på herbicidernas effekt. NJF seminar 58, SLU, Uppsala, sekt. II: Växtodling, 6.1-6.16.
27. *Thonke, K.E.* 1988. Research on pesticide use in Denmark to meet political needs. In: Aspects of Applied Biology 18: Weed Control in Cereals and the Impact of Legislation on Pesticide Application, 327-329.
28. *Threadgill, E.D. & Smith, D.B.* 1975. Effects of physical and meteorological parameters on the drift of controlled sized droplets. Transactions ASAE 18, 51-56.

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