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Application of pesticides in cereals using different types of field sprayers and very low spray volume

Fordeling af pesticider i kornafgrøder ved hjælp af forskellig type marksprøjte og meget lav væskevolumen

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Summary

The tested field sprayers were an air assisted hydraulic pressure sprayer, Minivariant (50 and 68 l/ha), one air-blast sprayer, Danfoil (45 l/ha), and 2 centrifugal sprayers, Girojet (41 l/ha), with vertical disk, and CDA-boom (30 l/ha) with horizontal placement of the distribution head. The different types of sprayer were compared with a hydraulic pressure sprayer at 150 l/ha. The investigations included biological effect using 1, ½ and ¼ of the normal dose, deposit on plants, measuring of droplet size spectra and number of droplets per cm^2 with and without additives.

No significant differences were found in effect on weeds among the 4 new types of field sprayer, using MCPA+dichlorprop or bromofenoxim for controlling dicotyledoneous weeds in spring barley.

The field sprayers were tested against mildew in spring barley. When using propiconazol+tridemorph (Tilt turbo) at ¼ of the normal dose Danfoil, and Girojet gave a significantly better effect compared to the hydraulic pressure sprayer. Minivariant 68 l/ha was tested in 2 of the experiments, but no significant differences in effect on mildew were found in these trials.

Using propiconazol+tridemorph (Tilt turbo) in winter wheat against mildew and yellow rust *(Puccinia striiformis),* a significantly better effect on mildew was recorded 3 weeks after application using Danfoil 45 l/ha as compared with all other sprayers.

No significant differences in yield increase were recorded using the different types of sprayer.

A significantly higher deposit on the upper sections of spring barley plants is registered using Danfoil and Minivariant for the application at g.s. 51 (Zadoks). On the lower part of the plants significantly less deposit was measured as compared to a hydraulic pressure sprayer.

When the spray volume from hydraulic pressure sprayer, Minivariant, Danfoil and Girojet is calibrated to 147, 72, 40 and 44 l/ha respectively, the per-

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centage of spray volume delivered in droplets <150 μm is 13, 37, 65 and 21%, and the number of droplets per cm^2 is 1078, 999, 1799 and 220, respectively.

Due to lack of significant differences in the biological effect between Danfoil and Girojet, no relations could be drawn between figures for the number of droplets per cm^2 determined under laboratory conditions and biological effect in the field.

The addition of a wetter or an oil to plain water in the normally recommended concentration had little influence on droplet size spectra using flat spray nozzle F 110/O.88/2.5 (Hardi - 14) or Girojet at 4200 r/min. When using F 110/0.40/2.5 (Hardi - 10) and assisting air, Minivariant, the size of droplets increased. The opposite was found after using Danfoil, where considerable decrease in droplet size was measured.

Key words: Types of fieldsprayer, application of herbicides and fungicides, spray volume, deposit, droplet size, additives.

Resumé

Forskellige typer af marksprøjter karakteriseret ved, at de kan fordele pesticider i betydelig lavere væskemængde end normalt anbefalet for almindelig hydraulisk marksprøjte blev undersøgt. Undersøgelserne omfattede biologisk effekt ved 1, ½ og ¼ normaldosering, afsætning på planter og additivers indflydelse på dråbestørrelsesfordelingen samt antal dråber pr. cm^2.

De nye typer af marksprøjter, som er prøvet i forsøgene omfatter Minivariant, der er en hydraulisk sprøjte med ledsageluft, Danfoil med pneumatiske dyser og 2 sprøjter med rotationsfordelere, Girojet, der har lodret monteret fordelerhoved og CDA-boom med vandret monteret fordelerhoved.

Herbicider: Virkningen på tokimbladet ukrudt i vårbyg er undersøgt i markforsøg ved sprøjtning med et systemisk herbicid MCPA+dichlorprop eller et kontaktvirkende herbicid bromofenoxim (Faneron). I forhold til almindelig hydraulisk marksprøjte og 150 l væske pr. ha er der ikke konstateret forøget bekæmpelseseffekt efter fordeling af midlerne med sprøjtetyperne Minivariant 30 l væske pr. ha, Danfoil 45 l væske pr. ha, Girojet 41 l/ha og CDA-boom 30 l/ha. Der blev heller ikke konstateret sikre forskelle i effekten mellem de nye sprøjtetyper indbyrdes. Effekten blev nedsat med reduceret dosering. Der blev ikke målt sikre forskelle i merudbyttets størrelse.

Fungicider: I vårbyg er propiconazol+tridemorph (Tilt turbo) anvendt mod meldug *(Erysiphe graminis)*. Ved bedømmelse af angreb på planterne 3 uger efter sprøjtningen er der ved ¼ normal dosering i gennemsnit af 3 forsøg målt signifikant bedre effekt af Danfoil 45 l/ha og Girojet 41 l/ha end med almindelig hydraulisk marksprøjte og 150 l væske pr. ha. I gennemsnit af 2 forsøg, hvor Minivariant 68 l/ha indgik i forsøgene, er forskellen mellem sprøjtetyperne ikke signifikant, men der er tendens til bedre effekt med Danfoil 45 l/ha og Girojet 41 l/ha. Effekten af Minivariant lå på linie med almindelig hydraulisk marksprøjte.

I forsøg med bekæmpelse af meldug *(Erysiphe graminis)* og gulrust *(Puccinia striiformis)* i vinterhvede er der i gennemsnit af 3 forsøg ved bedømmelse af meldugangreb, 3 uger efter sprøjtningen, konstateret signifikant bedre effekt med Danfoil 45 l/ha i forhold til de øvrige sprøjtetyper. Over for gulrust *(Puccinia striiformis)* er der i 2 forsøg fundet tendens til bedre virkning af Girojet 41 l/ha, Danfoil 45 l/ha og Minivariant 68 l/ha i forhold til almindelig marksprøjte, men forskellene er ikke signifikante. Der er målt et stort merudbytte ved behandlingen, men ikke signifikant forskel i merudbyttets størrelse mellem nye typer af marksprøjter og almindelig hydraulisk marksprøjte.

Afsætningen af sprøjtevæske på planter af vårbyg er undersøgt ved hjælp af sporstoffet Helios. Ved sprøjtning i stadium 51 (Zadoks) er der konstateret signifikant større afsætning på den øverste sektion af planterne med Danfoil og Minivariant. Derimod er der fundet signifikant mindre afsætning længere nede i plantebestanden end med almindelig hydraulisk marksprøjte.

Sammenholdt med en større effekt over for meldugangreb ved reduceret dosis med Danfoil konkluderes, at en høj effekt med reduceret dosis er mere

afhængig af en stor afsætning på planternes øverste sektioner end af en afsætning længere nede i plantebestanden. Resultaterne opnået med Girojet og Minivariant støtter denne konklusion.

Undersøgelser over dråbestørrelsesfordelingen og antal dråber pr. cm^2 er udført i laboratoriet ved opsamling af dråberne i petriskåle mellem 2 væskelag. Resultaterne viser meget stor forskel i den procentdel af væsken, der fordeles i form af små dråber <150 μm. En større andel små dråber <150 μm giver flere dråber pr. cm^2, men funktionsprincippet er afgørende for, hvor mange dråber der er pr. cm^2. Der blev anvendt væskemængder som i effektforsøgene. Disse var for almindelig hydraulisk marksprøjte Minivariant, Danfoil og Girojet henholdsvis 147, 72, 40 og 44 l væske pr. ha, heraf blev henholdsvis 13, 37, 65 og 21 pct. af væsken fordelt i form af dråber <150 μm, og det målte antal dråber afsat i petriskåle er ligeledes henholdsvis 1078, 999, 1799 og 220 pr. cm^2. Da der i forsøgene ikke blev konstateret signifikant forskel på den biologiske effekt over for bladsvampe på korn efter fordeling af fungicider med Danfoil og Girojet konkluderes det, at antal dråber pr. cm^2 over 220 har ringe betydning for effekten. Ved undersøgelsen er dråber >20 μm medregnet.

Tilsætning af et spredemiddel eller en penetreringsolie til vand i de normalt anbefalede doseringer medførte kun mindre ændringer i dråbestørrelsesfordelingen ved anvendelse af fladsprededyse 4110-14 ved 2,5 bar eller Girojet ved 4200 omdrejninger/min. Med fladsprededyse 4110-10 ved 2,5 bar og ledsageluft (Minivariant) blev dråbestørrelsen forøget, hvorimod der med Danfoil blev konstateret en betydelig nedsættelse af dråbestørrelsen. Dette medførte henholdsvis 28-35 pct. færre dråber pr. cm^2 for fladsprededyse 4110-10 og 40-90 pct. flere dråber pr. cm^2 for Danfoil. Tilsvarende resultat fandtes i højere eller lavere grad ved koncentrationer på 10 gange eller $1/10$ og $1/100$ af det normalt anbefalede af såvel spredemiddel som penetreringsolie.

Nøgleord: Typer af marksprøjter, virkning af herbicider og fungicider, væskemængde, afsætning, dråbestørrelse, additiver.

Introduction

An increased interest in low volume field sprayers has arisen in order to reduce the cost of application. It has also been argued that these sprayers make it possible to use reduced doses without loss of efficacy. The latter is of economical interest to the farmer, but could also help to fulfill the governmental demand of a 50% reduction in the use of pesticides by 1996.

Previous investigations indicated that the effect of herbicides was highly dependent on climatic conditions and the water status of the plants at the time of application. The dose could be reduced without loss in effect if the herbicide was applied at favourable climatic conditions (17). Furthermore, the dose could be reduced if the herbicide was highly effective on the dominating weed species, and if the herbicide was applied at the cotyledon stage of the weeds (2).

Application of reduced doses of fungicides for the control of fungal diseases in winter wheat has correspondingly indicated that the dose under certain conditions can be reduced without adverse effects on control or yield (2,8).

The recommended dose of a pesticide is selected to ensure a satisfactory effect even under unfavourable conditions. A satisfactory effect of a reduced dose depends on many factors other than the type of sprayer. In this study reduced doses of pesticides were applied using hydraulic pressure sprayers as well as new types of field sprayers. To investigate the relation between deposit and biological effect the deposits of spray liquid were measured.

The new types of sprayer deliver a low spray volume as many small droplets, which can be characterized as fog. Previous investigations on drift

from hydraulic pressure sprayers have shown that an increase in the greater % of the spray volume produced as droplets <100-150 μm increases the risk of drift (6,11). The droplet size spectra was in this investigation measured with and without addition of a wetter or an oil additive. The proportion of drift using new types of sprayer has previously been investigated (14).

The main objective of this investigation was to compare the biological effect between the new types of sprayer and a hydraulic pressure sprayer when using reduced dosages.

Material and methods

The biological effect was compared in field trials. Types of sprayer and configurations are shown in Table 1 and 2.

Specially designed equipment with a swath width of 5 m was used in the field trials. Plot size was 5×12.5 m gros and 2.5×10 m net and a split plot design was used.

Pesticides

A systemical herbicide MCPA + dichlorprop (DLG-D-propmix 67) or a contact herbicide bromophenoxim (Faneron 50 WP) was applied at the 2 leaf stage of the weeds. For the control of fungal diseases the systemic fungicide propiconazol + tridemorph (Tilt turbo) was applied as soon as infections were visible.

The biological effect of the herbicides was assessed by counting and weighing weed plants 3 weeks after application. In fungicide trials scores were given 1 and 3 weeks after application assessing percentage cover of fungus infection on the 3-4 upper leaves of the plant.

Deposit on plants

Deposits of the fungicides were measured by adding the tracer Helios (10 g/ha) to the spray solution. Samples of 5 plants from 2 sites, a total of 10 plants per plot, were collected and divided into sections containing 1 leaf with the appropriate piece of the stem, which was restricted to half way to the next leaf. The plant samples were washed with N-hexane (aromatic free) +5% pure acetone, and the washup was analysed on a flourometer. Deposit in horizontal level was measured by collection on artificial objects, each consisting of 5 metal rods placed horizontally just above the crop. Deposit per cm^2

Table 1. Configuration of sprayers by application of herbicides.
Indstilling af sprøjteudstyret ved sprøjtning med herbicider.

Type	Name	Spray volume l/ha at 7 km/h	Nozzle no.	Liquid pressure bar	Capacity l/min. per nozzle	Boom-hight cm	Nozzle space cm
Hydraulic pressure sprayer	Ordinary	150	4110-14	2.5	0.875	40	50
Air assisted hydraulic pressure sprayer	Mini-variant	50	4110-10	1.0	0.292	50	50
Air blast	Danfoil	45	Restrictor	0.4	0.084	60-80	16
Centrifugal sprayer vertical disc	Girojet*	41	do	3.0	0.6	60	125
Centrifugal sprayer horisontal disc	CDA-boom**	30	do	–	0.42	50	120

* Disc speed 4200 r./min.
** Disc speed 3500 r./min.

Table 2. Configuration of sprayers by application of fungicides.
Indstilling af sprøjteudstyret ved sprøjtning med fungicider.

Type	Name	Spray volume at 7 km/h	Nozzle no.	Liq-uid pres-sure	Capa-city l/min. per nozzle	Boom hight cm	Nozzle space cm
Hydraulic pressure sprayer	Ordinary	150	4110-14	2.5	0.875	40	50
Air assisted hydralic pressure sprayer	Mini-variant	68	4110-10	2.5	0.397	50	50
Air blast	Danfoil	45	Restrictor	0.4	0.084	40-60	16
Centrifugal sprayer vertical disc	Girojet*	41	do	3.0	0.6	60	125

* Disc speed 4200 r./min.

Table 3. Reproduction from determination of droplet size spectrum by means of scanning droplets collected in petri dishes.
Nozzle: F 110/0.49/3.0[1)]. Boom height: 1.0 m. Driving speed: 7 km/h. Spray liquid: Water. Scanned area: 317 mm^2.
Reproducerbarhed ved bestemmelse af dråbestørrelsesfordeling med scanning af dråber opfanget i petriskåle.

	Droplet size µm								Number of
10 repetitions	VMD	< 100	100-150	150-200	200-300	300-400	400-500	500-600	droplets/cm^2 per 100 l
Average	185.9	8.8	17.7	29.9	38.7	4.7	–	–	1066
s.	5.9	1.3	1.7	1.4	2.5	1.0	–	–	118
Variation koeff.	3.2	14.8	9.6	4.7	6.5	21.2	–	–	11

1) Flatspray, 110° spray angle/capacity l/min/pressure bar.

Table 4. Hydraulic pressure sprayer, nozzle no. 4110-10. Droplet size distribution at different boom height, with and without assisting air.
Hydraulisk sprøjte, dyse nr. 4110-10. Dråbestørrelsesfordeling ved forskellig bomhøjde med og uden ledsageluft.

	VMD	< 100	100 150	150 200	200 300	300 400	Number of droplets/cm^2 per 100 l
Pressure 3.0 bar Height of boom 1.0 m	186	9	18	30	39	5	1066
Pressure 2.5 bar Height of boom 0.5 m	190	8	16	30	41	5	747
Pressure 2.5 bar Height of boom 0.5 m + air 27 m/sec	166	15	22	31	30	2	1388

on the plants was calculated from cm^2 per g green weight of each section of the plants.

Investigations of droplet size were carried out by collecting droplets in petri dishes between 2 layers of liquid. The droplets were counted by means of electronic equipment according to *Tønnesen* (1981). The number of droplets per cm^2/100 l spray volume was calculated from the total collected spray volume during counting.

To illustrate the reproduction of the method a result of 10 replicated determinations of droplet size spectrum is shown in Table 3.

When testing the hydraulic pressure sprayer in the laboratory the height of the boom was 1 m, while only 0.5 m in the field experiments. This difference had only little influence on droplet size spectra measured, but air assistance increased the percentage of spray liquid produced as droplets <150 µm, Table 4.

The influence of additives on droplet size distribution and number of droplets per cm^2 was also examined. A wetter (Citowett) and an oil additive (Actipron) was added to plain water at concentrations of 1/100, 1/10, 1 and 10 times the normally recommended concentration. The surface tension of the spray liquid is shown in Table 5.

Table 5. Surface tension of aqueous solutions of the wetter and the oil. n = recommended concentration.
Sprøjtevæskens overfladespænding ved tilsætning af additiver. n = normalt anbefalet koncentration.

		m N/m
Water		70-71
Water + wetter		
1/100 n, Citowett	0.00025%	53
1/10 n, Citowett	0.0025%	36
1 n, Citowett	0.025%	26
10 n, Citowett	0.25%	31
Water + oil		
1/100 n, Actipron	0.01%	53
1/10 n, Actipron	0.1%	36
1 n, Actipron	1.0%	33
10 n, Actipron	10.0%	33

Results

Herbicides

3 doses of the systemic herbicide, MCPA + dichlorprop were applied in spring barley. The results are shown in Table 6.

On average of 3 doses a tendency to a lower effect on *Chenopodium album* was noticed using hydraulic pressure sprayer compared to the other sprayers. No significant differences were noticed between type of sprayer on the effect on *Polygonum convolvulus,* weeds in total, or yield increase.

Bromofenoxim is a contact herbicide. The results using bromofenoxim in spring barley are shown in Table 7.

At the reduced doses, 0.25 and 0.5 n, a lower effect was obtained compared to effect of the recommended dose, but the type of field sprayer had no significant influence on the number and weight of weeds or yield increase.

Table 6. Per cent effect on weight of weeds in spring barley using MCPA + dichlorprop. 1 exp. 1986.
Pct. effekt på vægt af ukrudt i vårbyg med MCPA+dichlorprop. Gns. 1 forsøg 1986.

	% effect Chenopodium album	Polygonum convolvulus	Weeds[1] in total	Yield[2] increase hkg/ha
Dose 1n				
Hydraulic	78.5	94.4	84.5	–1.9
Girojet	93.1	86.0	91.5	–0.3
Danfoil	70.0	83.2	74.5	1.6
CDA	82.0	94.4	81.0	0.4
Dose 0.5n				
Hydraulic	42.5	94.4	56.5	3.3
Girojet	77.7	91.6	81.0	–1.0
Danfoil	75.1	60.8	70.0	–0.6
CDA	63.9	80.4	66.5	1.3
Dose 0.25n				
Hydraulic	27.0	69.2	42.0	0.7
Girojet	69.1	88.8	74.0	–1.2
Danfoil	–	–	–	2.1
CDA	55.4	54.3	54.0	0.9
LSD_{95}	n.s.	n.s.	n.s.	n.s.
Dose. av.				
Hydraulic	49.4	86.0	61.0	0.7
Girojet	80.0	88.8	82.2	–0.8
Danfoil	72.6	72.0	72.3	1.0
CDA	67.1	76.4	67.2	0.9
LSD-untreated	n.s.	n.s.	n.s.	n.s.

1) Untreated per 10 m^2: Number 780. weight 499.
2) Yield. untreated: 72.6 hkg/ha.

Fungicides

The effect of propiconazol + tridemorph on mildew in spring barley is shown in Table 8.

At the lowest dose of 0.25 n a significantly greater effect was observed 3 weeks after spraying with Danfoil and Girojet compared to a hydraulic pressure sprayer.

Hardi Minivariant was included in 2 of the experiments. The results are shown in Table 9.

No significant differences were found between the type of sprayers tested. At 0.25 n a tendency to a greater effect with Minivariant than with the hydraulic pressure sprayer was noticed, 1 week after spraying. 3 weeks after spraying, this tendency was not found. Yields showed no significant differences between hydraulic pressure sprayer and the new types of sprayer investigated in these experiments.

In winter wheat experiments a significant better control of mildew was found with Danfoil compared to the other types of sprayer, when assessing biolocial efficacy 3 weeks after spraying, (Table 10).

The assessment of yellow rust showed a tendency towards a better effect using Girojet, Danfoil and Minivariant compared to the hydraulic pressure sprayer but the differences were not significant.

Fungicide treatments resulted in significant yield increases, but no significant differences were found between the types of sprayer.

Deposit on plants

Deposit at different heights in the plant canopy was measured by adding a tracer Helios to propiconazol. The results are shown in Table 11.

On the upper section of the stem, a significantly higher deposit was noticed when using Danfoil and Minivariant as compared to hydraulic pressure sprayer. On the contrary, significantly less deposit was measured further down in the plant canopy compared to hydraulic pressure sprayer. Less deposit was found on third section of the stem using Girojet, Danfoil and Minivariant, as well as on the fourth leaf using Minivariant, and on the third and fourth leaf using Danfoil.

Relations between deposit on plants and biological effect of fungicides

Compared to the hydraulic pressure sprayer, a significantly better effect was obtained, when the lowest dose was applied using Danfoil. Danfoil resulted in higher deposit on the upper parts, and less deposit on the lower parts of the plants. It can be concluded that a high efficiency at a low dose was more dependent on high deposit on the upper part, rather than the lower part of the plants.

This conclusion was supported by an almost identical deposit pattern with Girojet and Minivariant.

Droplet size spectra and number of droplets per cm²

Different ways of atomization and functions between sprayers are the reason for different spray clouds, which are characterized in terms of VMD, % spray

Table 7. Per cent effect of bromofenoxim in spring barley. Average of 2 exp. 1987.
Pct. effekt på vægt af ukrudt i vårbyg med bromofenoxim. Gns. 2 forsøg 1987.

	% effect		
	weeds in total[1]		yield[2] increase
	number	weight	hkg/ha
Dose 1n			
Hydraulic	70.1	82.3	2.5
Girojet	57.9	76.2	5.6
Danfoil	65.0	82.2	2.5
Minivariant	73.7	86.3	2.1
LSD_{95}	n.s.	n.s.	n.s.
Dose 0.5n			
Hydraulic	52.3	71.7	2.4
Girojet	33.3	57.0	2.1
Danfoil	59.1	73.6	2.8
Minivariant	59.6	76.4	2.1
LSD_{95}	n.s.	n.s.	n.s.
Dose 0.25n			
Hydraulic	34.2	57.4	2.9
Girojet	35.5	45.2	3.9
Danfoil	26.0	50.0	1.3
Minivariant	45.6	64.3	0.4
LSD_{95}	n.s.	n.s.	n.s.
Average			
Hydraulic	52.2	70.5	2.6
Girojet	42.2	59.5	3.9
Danfoil	50.0	68.6	2.2
Minivariant	59.5	75.6	1.5
LSD_{95}	n.s.	n.s.	n.s.

1) Untreated per 10 m²: Number 2205. weight g 2251.
2) Yield in untreated: Av. 51.1 hkg/ha.

Table 8. Per cent mildew *(Erysiphe graminis)* in spring barley after application of propiconazol + tridemorph. Average of 3 experiments (1986 and 1988).
Pct. meldug på vårbyg efter behandling med propiconazol + tridemorph. Gns. 3 forsøg 1986 og 1988.

	% infection of mildew		
	1 week after[1] spraying	3 weeks after[2] spraying	yield increase[3] hkg/ha
Dose 1n			
Hydraulic	2.5	3.5	3.9
Girojet	3.0	3.7	3.8
Danfoil	2.9	2.9	4.9
LSD_{95}	n.s.	n.s.	n.s.
Dose 0.5n			
Hydraulic	3.6	5.1	4.3
Girojet	3.8	4.4	1.2
Danfoil	3.7	3.2	2.7
LSD_{95}	n.s.	n.s.	n.s.
Dose 0.25n			
Hydraulic	7.5	14.3	0.6
Girojet	6.0	7.4	1.6
Danfoil	4.8	4.2	2.2
Sprayers LSD_{95}	n.s.	4.3	n.s.
Av. 3 doses			
Hydraulic	4.5	8.9	2.9
Girojet	4.3	6.9	2.2
Danfoil	3.8	5.0	3.3
LSD_{95}	n.s.	2.5	n.s.

1) Av. untr. mildew: 17.4%
2) Av. untr. mildew: 29.8%
3) Yield untr.: 46.7hkg

liquid delivered in droplets <150 μm and number of droplets per cm^2, (Table 12).

Without additives in the spray solution, the characterization of the spray cloud compared to that of hydraulic pressure sprayer can be described as follows:

Girojet (44 l/ha at 4200 rpm). A considerably bigger fraction of small droplets, but only 1/5 of the number of droplets per cm^2. This configuration was used for the application of herbicides as well as fungicides.

Danfoil (40 l/ha air pressure 60 cm water column). ⅔ of the spray volume is distributed in droplets <150 μm, and the VMD value was considerably lower. The number of droplets is almost 1.8 times greater than that measured from the hydraulic pressure sprayer. This configuration was used for the application of fungicides in cereals. Altering the air pressure to 40 cm water column, the fraction of small droplets is still higher than with the hydraulic pressure sprayer, but the number of droplets per cm^2 is halved. This configuration was used for the application of herbicides in cereals.

Minivariant (72 l/ha air velocity 27 m/sec, vertical nozzle position). The fraction of droplets <150 μm was high, but the number of droplets per cm^2 was almost equal. The configuration was used for the control of leaf fungus in cereals.

Altering the air velocity to 18 m/sec and nozzle position to 30° backwards, the VMD at a pressure of 1.1 bar making a spray volum of 47 l/ha was almost similar to the hydraulic pressure sprayer, but the number of droplets was reduced. This configuration was used for the application of herbicides.

Table 9. Per cent effect of propiconazol + tridemorph on mildew *(Erysiphe graminis)* infection in spring barley. Average of 2 exp. 1988.
Pct. meldug på vårbyg efter behandling med propiconazol + tridemorph. Gns. 2 forsøg 1988.

	% infection of mildew		
	1 week after[1] spraying	3 weeks after[2] spraying	yield increase[3] hkg/ha
Dose 1n			
Hydraulic	3.4	4.3	4.7
Girojet	3.9	4.7	6.3
Danfoil	4.0	4.0	5.1
Minivariant	4.1	4.4	4.1
LSD_{95}	n.s.	n.s.	n.s.
Dose 0.5n			
Hydraulic	4.6	4.5	5.1
Girojet	5.1	5.0	3.1
Danfoil	4.9	4.4	4.6
Minivariant	4.3	7.3	2.5
LSD_{95}	n.s.	n.s.	n.s.
Dose 0.25n			
Hydraulic	10.1	12.1	3.0
Girojet	7.5	6.4	2.6
Danfoil	6.5	4.9	3.6
Minivariant	6.5	12.7	2.5
Sprayers LSD_{95}	n.s.	n.s.	n.s.
Average 2 exp.			
Hydraulic	6.0	7.0	4.3
Girojet	5.5	5.3	4.0
Danfoil	5.1	4.5	4.5
Minivariant	5.0	8.1	3.1
LSD_{95}	n.s.	n.s.	n.s.

1) Av. untreated mildew: 23.2
2) Av. untreated mildew: 25.8
3) Av. untreated: 58.6 hkg/ha

Additives

The result of adding a wetter or an oil additive is given in Table 12 as % difference compared to plain water. The results vary between type of sprayer.

The recommended concentration of the wetter and oil additive is 0.025% and 1%. The dose was sometimes expressed as l/ha, and in case of very low spray volume the concentration becomes very high. Table 11 showns the results from adding Citowett or Actipron in concentrations which are $\frac{1}{100}$ – $\frac{1}{10}$ – 1 and 10 times the normal recommended dose.

Wetter. When taking the variation due to the method used into consideration, it can be concluded that adding a wetter only causes minor changes in droplet size spectra. With the hydraulic nozzle 4110-14 the wetter at the lowest concentration lead to an increased number of droplets <150 μm, and number per cm^2.

Minivariant fitted with a smaller hydraulic pressure nozzle. Air assistance resulted in a shift towards bigger droplets and less droplets per cm^2, when adding Citowett in concentrations 10 times the recommended dose.

Table 10. Per cent effect of propiconazol + tridemorph on mildew *(Erysiphe graminis)* and yellow rust *(Puccinia striiformis)* in winter wheat.
Virkning af propiconazol + tridemorph på meldug og gulrust i vinterhvede.

	% fungus infection			
	1 week after[1] spraying	3 weeks after[2] spraying		yield increase[3]
Experim. no.	Mildew 3	Mildew 3	Yellow rust 2	hkg/ha 3
Dose 1n				
Hydraulic	4.9	9.0	3.1	13.1
Girojet	5.1	9.2	1.2	13.6
Danfoil	5.2	7.1	2.2	13.8
Minivariant	5.0	9.2	1.6	12.7
LSD_{95}	n.s.	n.s.	n.s.	n.s.
Dose 0.5n				
Hydraulic	7.6	13.5	6.4	8.7
Girojet	7.8	13.3	4.9	9.1
Danfoil	6.5	11.3	3.0	11.2
Minivariant	7.0	11.8	2.6	12.8
LSD_{95}	n.s.	n.s.	n.s.	n.s.
Dose 0.25n				
Hydraulic	9.8	16.2	9.8	7.0
Girojet	8.9	15.3	6.0	8.8
Danfoil	8.2	15.0	7.8	9.3
Minivariant	9.4	16.2	6.5	7.8
LSD_{95}	n.s.	n.s.	n.s.	n.s.
Av. 3 doses excluc. untreated.				
Hydraulic	7.8	13.5	6.4	9.6
Girojet	7.7	13.3	4.0	10.6
Danfoil	7.0	11.7	4.3	11.5
Minivariant	7.4	13.0	3.6	11.1
Sprayers LSD_{95}	n.s.	0.7	n.s.	n.s.

1) Av. untr. mildew: 13.5
2) Av. untr. yellow rust: 25.9. mildew 22.0
3) Av. untr. hkg/ha = 47.6

No definite change in droplet size spectra was found when using the centrifugal sprayer, but with the blast sprayer, a definitely lower VMD value was found at all concentrations of Citowett. This increased the percentage of spray volume delivered in droplets <150 μm and number of droplets per cm^2. The increase was largest at the highest concentration.

Oil additive. Using Danfoil the addition of the oil additive at normal and 10 times the normal concentration caused a decrease in droplet size as compared to plain water. This resulted in almost a doubling of the number of droplets per cm^2.

The opposite reaction was seen when using Minivariant fitted with nozzle no. 4110-10 and air assistance. Adding the oil additive caused a shift towards bigger droplets and 30% fewer droplets per cm^2.

With the hydraulic pressure nozzle 4110-14 without air assistance or with the centrifugal sprayer Girojet, only small variations in droplet size were observed as a result of adding the oil additive at all concentrations tested.

Table 11. Deposit on spring barley plants at growth stage 51 (Zadoks) ng/cm^2.
Afsætning på planter af vårbyg i stadie 51 (Zadoks) ng/cm^2.

	Section	Hydraulic pressure sprayer	Giro-jet	Dan-foil	Mini-variant	LSD_{95}
Recorded over plants[1)]		72.3	84.2	61.8	58.8	
Leaves[2)]	1	22.40	25.24	33.14	21.37	n.s.
	2	18.02	17.96	15.06	19.77	n.s.
	3	12.20	10.70	5.78	8.97	4.26
	4	6.10	5.40	2.54	2.31	1.61
	Average	14.85	14.83	14.13	12.95	n.s.
Stems[3)]	1	7.96	10.58	14.25	13.08	3.31
	2	2.83	1.58	2.55	2.80	n.s.
	3	1.59	0.92	1.03	0.83	0.32
	4	1.02	0.67	0.80	0.49	n.s.
	Average	3.35	3.44	4.66	4.30	0.93

1) Recovered on rods. Sprayed 100 ng/cm^2.
2) Leaves from the top of plant.
3) Stem pieces in between leaves.

Discussion

There are many possible configurations with the new types of sprayer, and therefore the present results can only serve as an example.

Farmers prefer to use as low spray volume as possible, consequently a spray volume of only 150 l/ha was chosen as standard for the hydraulic pressure sprayer. Previous results pointed out that the spray volume could be reduced to 125 l/ha without lonering herbicide efficacy (10,12). When applying fungicides in cereals for the control of mildew or yellow rust the spray volume was reduced to 150 l/ha without any negative influence on the effect (13).

The centrifugal sprayer "CDA-boom" was excluded from the experiments after 1 year of trials, because of variable performance. The technical function of this system has also caused problems under practical conditions.

The centrifugal sprayer with vertical mounted spinning disk, Girojet, was tested in French experiments, in which it was concluded that the sprayer could apply herbicides as well as fungicides at a spray volume of 25-40 l/ha. Yield increases were comparable to the ones obtained with the hydraulic pressure sprayer (7). This conclusion is in agreement with the results found in the present experiments.

The Danfoil sprayer was tested in field experiments carried out by the Danish Agricultural Advisory Service. Compared to a hydraulic pressure sprayer (200 l/ha) the Danfoil sprayer, on an average of 12 trials over 3 years (1988-1990), sligtly increased the biological efficacy of fungicides on mildew and yellow rust at half of the normal dose No yield difference was found between the 2 types of sprayers. This conclusion is identical to the results presented in this report.

Minivariant is a prototype of the Twin sprayer, the latter possessing improved facilities for adjustment of air assistance.

According to Swedish results (1) no significant differences in biological effect were registrated between Hardi Twin at 50 l/ha and a hydraulic pressure sprayer at 200 l/ha. The result originate from 1 experiment with the herbicide bromofenoxim + terbuthylazin (Vegoran) in 1 and ½ the normal dose in spring barley. A tendency towards a better effect using hydraulic pressure sprayer at 200 l/ha

Table 12. Droplet size spectra and number of droplets per cm^2 at actual spray volume l/ha[1)] without and with additives.
Dråbestørrelsesfordeling og antal dråber/cm^2 ved aktuel væskemængde l/ha uden og med tilsætning af additiver.

	% difference to water, relatively								
		water + citowett konc.				water + actipron konc.			
	water	0.00025	0.0025	0.025	0.25	0.01	0.1	1.0	10.0
Hydraulic spray vol. 147 l/ha, nozzle 4110-14, height 1,0 m, space 0,5 cm, vertical position.									
VMD µm at									
3 bar	227	–8	–6	–2	–3	+1	–4	+4	–2
Pct. droplets									
<150 µm	13	+9	+4	–2	0	0	0	–1	0
Droplets/cm^2	1078	+30	+14	+6	+9	–3	+11	–10	+7
Girojet spray vol. 44 l/ha, height 0,6 m, space 1,25 m, vertical position, pressure 3 bar, 4200 r/min.									
VMD	193	+2	+8	+3	–2	+3	0	+6	+3
Pct. <150 µm	21	–1	–6	–3	+3	–2	+2	–5	+1
Droplets/cm^2	220	–6	–15	–8	+6	–10	0	–16	0
Danfoil spray vol. 40 l/ha, height 0,90 m, space 0,16 m, position 15° forward. Air pressure 60 cm water column. PTO 1000 r/min.									
WMD µm	126	–14	–10	–6	–22	–4	–5	–10	–11
pct <150 µm	65	+10	+4	+4	+15	+3	+4	+2	+9
Droplets/cm^2	1799	+57	+66	+40	+152	+57	+61	+90	+98
Air pressure 40 cm water column. PTO 800 r./min.									
VMD µm	205								
pct. <150 µm	20								
Droplets/cm^2	576	+14	+5	–18	+64	0	+15	+4	+22
Minivariant spray vol. 72 l/ha, nozzle 4110-10, height 0,50 m, space 0,50 m, vertical position. Pressure 2,5 bar, air speed 27 m/sec.									
VMD µm	166	+4	+2	+11	+10	+5	+10	+15	+13
pct. <150 µm	37	–5	–3	–9	–10	–6	–8	–14	–9
Droplets/cm^2	999	–13	–6	–28	–24	–15	–24	–35	–31
Minivariant spray vol. 47 l/ha, nozzle 4110-10, height 0,80 m, space 0,50 m, 30° backwards position. Pressure 1,1 bar, air speed 18 m/sec.									
VMD µm	224								
pct. <150 µm	10								
Droplets/cm^2	289	–5	+3	–37	–24	–1	–11	–38	–20

1) Velocity 7 km/hour

compared to Hardi Twin at 50 l/ha was however registered in the trial.

In this investigation, Minivariant did not produce significant improvements in effect against diseases compared to the hydraulic sprayer.

The spray deposit measurements indicated a higher deposit on the upper part of the plants using Danfoil and Minivariant compared to a hydraulic pressure sprayer. The air pressure from Danfoil and Minivariant can bend the straw of spring barley and form a compressed crop. This could be the reason for the higher deposit measured on the upper part of the plants.

An investigation of spray deposit on winter

wheat plants when using Hardi Twin at 100 l/ha revealed an increased deposit of 9% with air assistance compared to no air (16). This increased deposit was distributed in the plant canopy with +9% on the top, +20% in the middle and –8% on the base of the plants. In the above mentioned investigation, no distinction was made between deposits on leaves and stems. Other investigations, carried out with artificial collecting objects, indicate higher deposit of small droplets using air assistance, and an increased deposit on vertical contra horizontal placed objects (9, 15)

The higher deposits measured on the upper sections of the stems in the present investigation is in accordance with the bigger deposit on the vertically placed artificial objects. A higher deposit on the centre section of the wheat plants measured in the previous experiments was probably due to a greater strength of the straw in winter wheat compared to spring barley used in the present investigation.

Measurements of droplet size spectra showed great differences between the type of sprayer. The configuration of the sprayers during these investigations were identical to the configuration used in the field experiments except the boom height of the hydraulic pressure nozzle which was 1 m instead of 0.5 m in the field experiments. The reason for this is that 1 m is the standard height for testing hydraulic pressure nozzles (3). Apparently, the boom height only has a minor influence on droplet size distribution, as seen from Table 4, but air assistance increased the percentage of spray liquid produced in droplets <150 μm considerably.

Primarily the small droplets <150 μm are influenced by air assistance, as stated by *Young* (19). During field application, air assistance reduced drift very significantly (14,15,16).

Adding a wetter or an oil in normal recommended concentrations did not change the droplet size distribution when testing nozzle no. 4110-14, but with a smaller nozzle, 4110-10, and air assistance the droplet size was increased. The reverse results were found with the blast sprayer, Danfoil. This effect was enhanced when using concentrations 10 times the recommended dose. Adding a wetter increased the number of droplets per cm^2 more than adding an oil additive.

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